CRC Report No. A-100

Improvement of Default Inputs for MOVES and SMOKE-MOVES

Final Report

February 2017

COORDINATING RESEARCH COUNCIL, INC.
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Eastern Research Group, Inc.

Improvement of Default Inputs for MOVES and SMOKE-MOVES: CRC Project A-100

Final Report

Prepared for:

The Coordinating Research Council

Prepared by:

Eastern Research Group, Inc.

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Executive Summary

The Coordinating Research Council (CRC) sponsored the A-100 project to develop improved inputs of vehicle speeds and vehicle-miles traveled (VMT) distributions for EPA's Motor Vehicle Emission Simulator (MOVES) and the Sparse Matrix Operator Kernel Emissions (SMOKE) modeling systems. The MOVES and SMOKE input files developed under this project are planned for use in Version 2 of the 2014 U.S. National Emissions Inventory (NEI). The products of the A-100 project provide local inputs for areas of the country where the alternative default data source is a nationwide average applied to all vehicle classes. Because the data for this study originated from millions of vehicles operating in counties across the U.S., the A-100 products may also represent an improvement over local data developed by some state/local air quality or transportation agencies if the data relied on modeling or other estimation methods rather than direct observation data.

Under contract with CRC, Eastern Research Group, Inc. (ERG) identified vendors of vehicle telematics data suitable to build inputs for MOVES and SMOKE. ERG selected StreetLight Data and purchased their analytics reflecting a sample of millions of vehicles operating over a consecutive 12-month period. The purchased telematics data included a high degree of temporal resolution – travel by 24 hours of day, seven day types, and twelve months, enabling profiles useable in either MOVES as a standalone inventory model or in the SMOKE model, which allows more day types than MOVES. The main products of this work are a National Database and MOVES Tool script. The National Database contains speed and VMT distribution input files for MOVES and SMOKE for all counties in the lower 48 states, and the MOVES Tool is a script that facilitates use of the National Database's MOVES tables by porting them into any number of individual county databases (CDBs) for a specific analysis. The SMOKE tables in the National Database can be exported by modelers and manually incorporated into their SMOKE modeling setups.

In the core counties in Atlanta, Chicago, and Las Vegas, there were several interesting findings. First, peak hour heavy-duty commercial truck speeds were higher than those of light and medium duty vehicles. This result is different than other datasets, which traditionally show trucks travel at slightly slower speeds than the rest of traffic, and is likely due to differences in travel between cars and commercial trucks within the broad MOVES road categories. VMT patterns in the three cities show clear differences between LD, MD, and HD. LD travel is highest during commute times, MD travel tends to also begin with the morning peak but remains elevated through the end of business hours, and HD truck travel peaks during midday. The distribution of VMT by month was also analyzed, but the results appear to be been affected by a shift in sample size or method in the telematics data. For this reason, we do not recommend using these data to update monthly VMT distribution. An emissions impact analysis of use of the A-100 data in core counties of three urban cities revealed differences in the input speeds and travel patterns by city and by vehicle class. ERG compared the emissions inventories for baseline vs. telematics data scenarios in the three counties Fulton, Georgia (representing Atlanta); Cook, Illinois (Chicago); and Clark, Nevada (Las Vegas). In these cities, the impact on the annual average day emissions ranged from -2 to 9 percent for VOC, 1 to 5 percent for NO_X,

and -9 to 14 percent for $PM_{2.5}$. The changes in hourly emissions were much larger than the daily totals (as much as doubling the emissions in some individual hours), underscoring the importance of good local data for hourly speeds and VMT distributions. While the large changes in hourly emissions may not impact the daily total much in some cases, the hourly result is nonetheless important because it could impact air quality modeling where the timing of emissions is important.

A technical challenge for this project was accessing the large body of telematics data at the nationwide scope with a fine level of detail. Resource constraints resulted in building the National Database from processing a 1/16th sample size of available data (with the exception of 50 counties which received a full draw). As a result of sample size, some counties needed to be grouped into a larger area, such as averages for non-core counties inside MSAs or US census region-average for counties outside MSAs. Future work with telematics data would benefit from assessing how the full sample of available data can be applied for the desired analysis.

1.0 Introduction

The Coordinating Research Council (CRC) has sponsored three projects aimed at improving the on-road portion of the U.S. National Emissions Inventory (NEI). CRC contracted with Eastern Research Group, Inc. (ERG) to undertake each of these. The first, CRC project A-84, analyzed MOVES input data submitted by 30 states for over 1,400 counties in Version 1 of the 2011 NEI (ERG, 2013). The study found a high degree of variability in the state-supplied data, reported best practices for the input data, and conducted an emissions sensitivity analysis of five key inputs. The work highlighted the importance of good local data for use in developing emission inventories in MOVES, and one of the conclusions noted was that for speed inputs in particular, good local data are scarce. Many states rely on nationwide averages for their NEI submittals. The second study, CRC project A-88, built upon A-84 by developing improved default data that was applied at the local level for Version 2 of the 2011 NEI (ERG, 2014). The A-88 study resulted in light-duty vehicle age distributions and populations, as well as long-haul truck VMT allocations for each county in the US.

CRC sponsored project A-100 to further improve default NEI data, focusing on speed and relative distributions of VMT for use in both MOVES and SMOKE. The products of this work include a National Database containing MOVES tables filled with data specific to each county and SMOKE-formatted speed and VMT temporal profiles that can be applied to counties or broader areas. These products will benefit the NEI by providing a better source of default data than a nationwide average, and the products will also benefit the modeling community who use MOVES and SMOKE to prepare air emissions inventories for air quality planning. Furthermore, state and local agencies who already produce this input data (e.g., using a travel demand model) may choose to incorporate speed and VMT profiles from this study into their inventories because the data are based on direct observations rather than modeling estimates.

This report begins with an overview of the NEI on-road modeling with background on MOVES and SMOKE. After the NEI overview, Section 3.0 describes the vehicle telematics data source and the methodology to transform the data into MOVES and SMOKE inputs. Section 4.0 presents the telematics-based speed and VMT distribution data for the three counties (representing Atlanta, Chicago, and Las Vegas), and an emission inventory impacts analysis for these areas of the country. Section 5.0 closes with conclusions, summary, and challenges of this work.

2.0 Overview of NEI On-road Modeling

Developed every three years, the NEI provides the official accounting of all emissions in the U.S. at a detailed level and serves as the foundation for trends analysis, air quality planning, regulation development, and health exposure analysis. Beginning with Version 1 of the 2011 NEI, US EPA has relied solely on MOVES as the basis for on-road mobile source emissions, fully replacing the MOBILE model. EPA also uses the Sparse Matrix Operator Kernel Emissions (SMOKE) processing system to prepare the inventory for air quality modeling. This study will benefit Version 2 of the 2014 NEI by providing improved input data for both MOVES and SMOKE models at the county level for vehicle speeds and relative distributions of VMT by road type, hour, day, and month. Version 2 of the 2014 NEI will be developed and published by the end of 2017.

MOVES can be run using either of the two calculations modes "inventory" or "emission rates." MOVES inventory calculation mode produces mass emissions over an area (e.g., county) for a specific time period (e.g., annual total). Some state and local agencies also run MOVES in inventory mode for state implementation plan (SIP) or conformity analyses. For these official purposes, MOVES must also be run in the County Domain/Scale, where local data is provided to the model through county-specific databases called CDBs. The emissions impact analysis in Section 4.0 relies on MOVES inventory runs using CDBs from Version 1 of the 2014 NEI.

The on-road NEI is currently generated using MOVES run at the County Domain/Scale in emission rate calculation mode. In this configuration, MOVES uses the same input CDBs required for inventory mode runs, but the outputs populate lookup tables of emission rates in units of grams of pollutant per unit distance, vehicle-hour, start, or idling-hour, rather than mass emissions. Emission rate mode MOVES requires careful post-processing of the results to ensure that all emission processes (e.g., running, starts, etc.) are included in the inventory and that none are double-counted. The SMOKE-MOVES integration tools are used for the NEI to build the inventory inside SMOKE, combining MOVES rate lookup tables with SMOKE activity files for VMT and population, as well as SMOKE hourly speeds and VMT temporal profiles. This study provides inputs for both MOVES and SMOKE formats to allow maximum flexibility to the modeling community who can choose whether to run MOVES standalone or SMOKE-MOVES.

State agencies provide local data in the form of CDBs for the NEI, but they often contain a mix of local data and MOVES defaults (often national averages) where local data are not available. Figure 2-1 shows the areas of the country where agencies submitted a CDB with at least 1 local input table during Version 1 of the 2014 NEI (EPA, 2016); the dark blue shading covers 1,815 counties in 33 states where at least some local data was provided. The light blue areas in the figure signify that the state or local agency did not submit local data for this round of NEI. California (shaded in light blue) is an exception; the Air Resources Board (ARB) submits county total emissions developed by running the Emissions FACtor (EMFAC) model rather than MOVES (EPA, 2016).

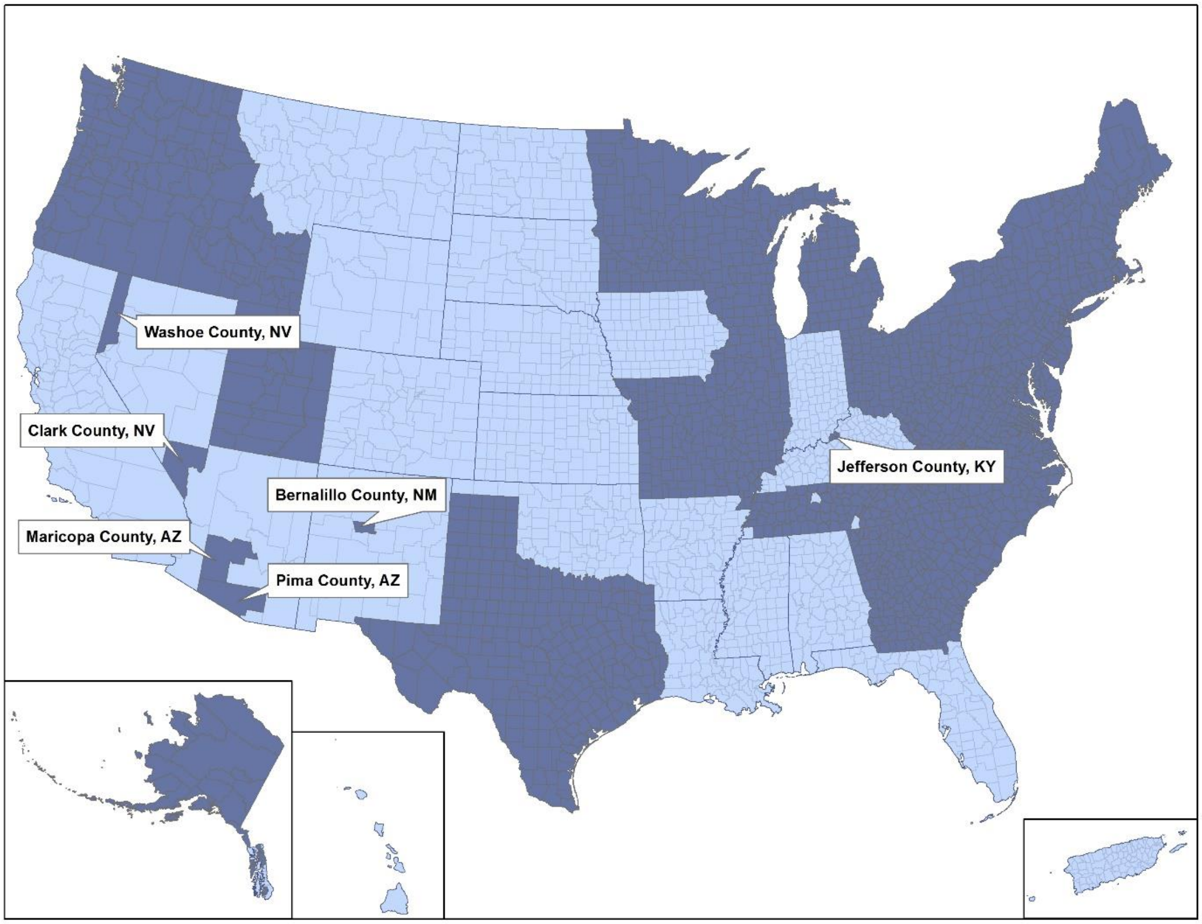


Figure 2-1. Dark blue indicates counties with local data for at least 1 CDB table (EPA, 2016)

3.0 Methods

3.1 Evaluation of Potential Data Sources

At the outset of the project, potential sources of vehicle telematics data were evaluated for suitability for county-level speed and VMT distributions. The detailed consideration factors are outlined in the technical memorandum appended to this report. In summary, two vendors were seriously considered, and StreetLight Data was selected for their willingness to develop a highly customized pull of their data at a high spatial and temporal resolution for this work, the fact that their data originated from three unique types of vehicles (the other vendor did not have this distinction), and a lower bid. StreetLight Data's analytics included personal vehicles, medium-duty commercial trucks (Class 6 and lower), and heavy-duty commercial trucks (Class 7 and 8).

StreetLight Data (http://www.streetlightdata.com/) is a mobility analytics firm that compiles and processes raw telematics data for use in transportation analysis. Their data products are derived from billions of trips created from archival, anonymous, location data from hundreds of millions of mobile devices. The devices include smart phone applications, in-dashboard car navigation systems, and commercial fleet management systems. The navigation-GPS data used for this project have a spatial precision of approximately 5 meters, a high frequency sampling rate, and separate data on commercial and personal vehicle trips.

3.2 StreetLight Vehicle Telematics Data

For this study, StreetLight Data performed a custom pull of their navigation-GPS data from vehicles over the 12-month period of September 2015 through August 2016. The source data included latitude and longitude coordinates and time stamps reported by millions of individual vehicles as they "ping" or send information about their instantaneous position and time to a central server. StreetLight Data overlaid the coordinates onto their roadway network to determine route and therefore distance traveled between consecutive pings. With travel distance and known elapsed time between pings, the vehicle telematics data provide a large sample of average speeds classified by month, day of week, and hour of day. The personal vehicle dataset was available at two resolutions – a high resolution of 1 ping per second (1 Hz), and the second, lower resolution of 1 ping every 10 or 30 seconds. The commercial dataset (medium and heavy trucks) resolution was 1 ping every 60 or 180 seconds.

3.3 Data Processing for the National Database

ERG developed a geographic information system (GIS) shapefile for StreetLight Data to map the location data onto the four MOVES road types. StreetLight Data used this shapefile, and another defining county boundaries, to define their analytics by county and road type. The MOVES model uses the four road types listed in Table 3-1, differentiating based on whether the road is located within an urban or rural area, and whether it has restricted access points (i.e., by ramps), or unrestricted access, such as entry points at multiple intersections.

Table 3-1. MOVES Road Types

MOVES Road Type ID	MOVES Road Type Name
2	Rural Restricted Access Roads
3	Rural Unrestricted Access Roads
4	Urban Restricted Access Roads
5	Urban Unrestricted Access Roads

The definitions of urban, rural, restricted, and unrestricted applied for this study were taken from the U.S. Census Bureau for consistency with EPA's modeling platform for the NEI and regulatory impact analyses (EPA, 2015). The U.S. Census Bureau defines "urban" as densely populated areas over more than 50,000 people, urban clusters having over 2,500 people, and all other areas are considered rural. Figure 3-1 (Upper Panel) highlights the urban land area across the US, and also shows the three cities evaluated in the emissions impacts analysis (Section 4.0). Figure 3-1 (Lower Panel) shows the U.S. Census Bureau Topologically Integrated Geographic Encoding and Referencing (TIGER)/Line roadway network, made up of nearly 19 million road segments. Consistent with EPA modeling platform convention, primary roads were assigned to "Restricted Access" and secondary roads to "Unrestricted Access." All other roads lesser than the secondary roads were also assigned to the "Unrestricted Access" category. This study's definition of urban and rural is not the same as MOVES definitions (which come from the federal highway administration, FHWA). The MOVES approach wasn't adaptable for this study because this study required geospatially resolved definitions of urban and rural areas in order to categorize the raw mobility data.

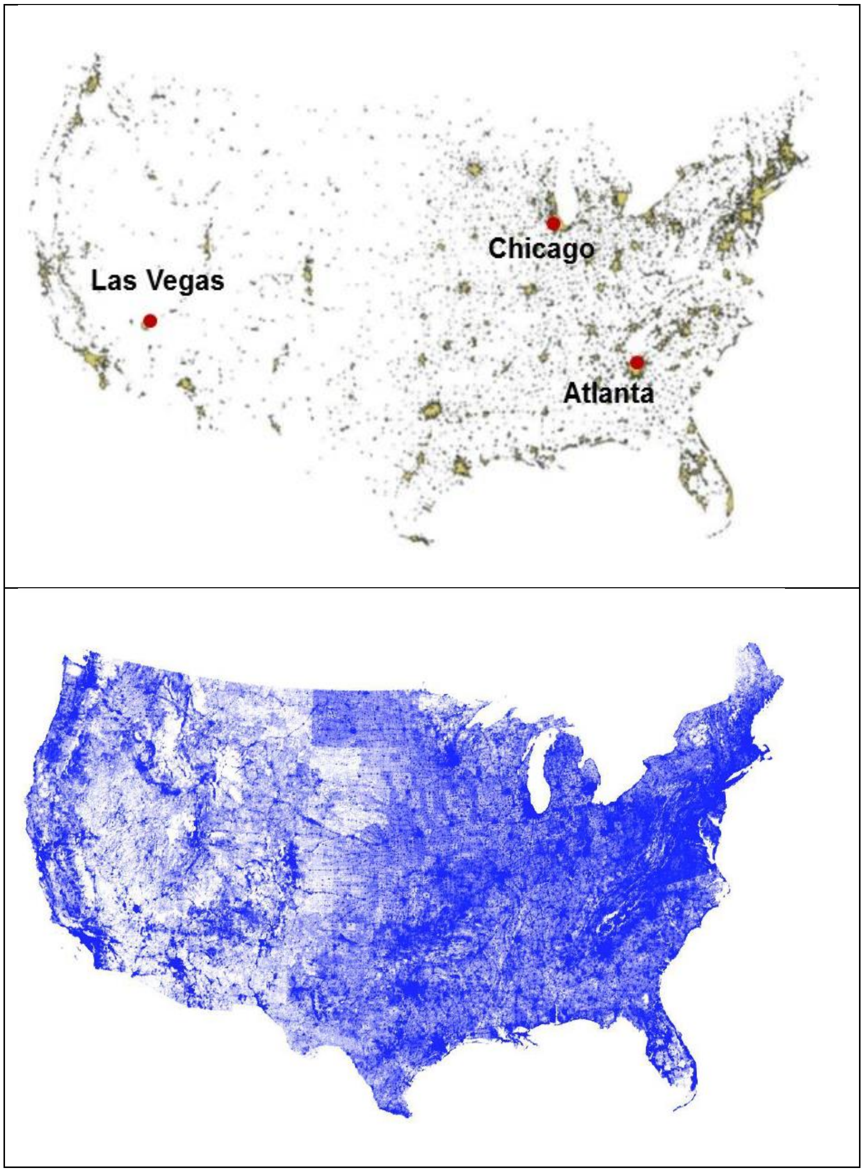


Figure 3-1. U.S. Census Bureau Urban Areas (Upper Panel) and TIGER/Line Roads (Lower Panel)

StreetLight Data also categorized the distance and travel time data by 21 speed bins, including the MOVES bins listed below in Table 3-2 and 5 additional bins at the high end. The extra high-speed bins are not currently useable for NEI model inputs, but they were included nonetheless in the raw data in case of future utility in emissions modeling. To date, MOVES considers all speeds greater than 72.5 mph as the last bin.

Table 3-2. MOVES Speed Bins

MOVES Speed Bin ID Code	"Midpoint" Speed (mph)	Speed Range
1	2.5	speed < 2.5mph
2	5	2.5mph <= speed < 7.5mph
3	10	7.5mph <= speed < 12.5mph
4	15	12.5mph <= speed < 17.5mph
5	20	17.5mph <= speed <22.5mph
6	25	22.5mph <= speed < 27.5mph
7	30	27.5mph <= speed < 32.5mph
8	35	32.5mph <= speed < 37.5mph
9	40	37.5mph <= speed < 42.5mph
10	45	42.5mph <= speed < 47.5mph
11	50	47.5mph <= speed < 52.5mph
12	55	52.5mph <= speed < 57.5mph
13	60	57.5mph <= speed < 62.5mph
14	65	62.5mph <= speed < 67.5mph
15	70	67.5mph <= speed < 72.5mph
16	75	72.5mph <= speed

After StreetLight Data classified the data by county and MOVES road type, they aggregated distance, time, and count records over speed bin and provided ERG with the sum of (1) distance traveled in feet, (2) travel time in seconds, and (3) the count of observations, categorized by the following parameters:

- 3,109 counties in the mainland US,
- 4 MOVES road types (see Table 3-1),
- 21 speed bins: 16 from MOVES (see Table 3-2) plus 5 additional at the high end,
- 7 days of the week,
- 24 hours of day,
- 12 months of year, and
- 3 vehicle categories: personal passenger vehicles, medium-duty trucks (under 26,000 lbs gross vehicle weight rating), and heavy-duty trucks (over 26,000 gross vehicle weight rating).

Table 3-3 shows a fictitious sample of raw vehicle telematics data in order to illustrate how StreetLight Data performed the aggregation. The columns are labeled A through O, and the basic procedure follows:

- Columns A through G show categories of the raw data. The example here is limited to a single county (48453), vehicle type (Personal vehicle, or LD), data resolution (low resolution, meaning a ping rate of 10 or 30 seconds), MOVES road type (urban unrestricted), month (April), day of week (Monday), and hour (2 PM).

- Columns H through K represent sample (not real) raw vehicle telematics data sample for unique observations (data point IDs in Column H) that correspond to a set of two consecutive “pings” each having a latitude and longitude coordinate. Each row corresponds to 1 observation that begins and ends with a vehicle ping reporting the time and position. The Column I “segment length” is the over-the-road distance traveled between two pings, and the Column J “time in segment” is the time between pings, which for the low resolution personal vehicle dataset was 10 or 30 seconds. Column K is the travel distance divided by travel time, converted to units of mph.

- Column L shows the midpoint speed (Table 3-2) based on which bin the Column K speeds fell within.

- Columns L through O show the unique speed bins and aggregated travel distance, time, and counts. The sample rows of raw data condense to the sample 4 records provided to ERG. This method was applied for all counties, vehicle classes, road types, and time periods.

StreetLight Data applied this procedure on a representative data sample of 1/16th of their total repository for 12 consecutive months of data. The use of a subset of full data was pursued out of necessity; StreetLight Data concluded that performing the aggregation on the full dataset across all counties, months, days and hours was not feasible under the timing and resource constraints of the project. Selection of 1/16th and the implication of this on coverage across these dimensions is discussed in Section 3.4.

After these processing steps, StreetLight Data delivered the data to ERG, where it was further analyzed and processed for input to MOVES and SMOKE. The aggregated dataset delivered to ERG totaled 250 million records.

Table 3-3. Example of Source Data Detail and Speed Bin Calculation

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
County FIPS (~3000 levels)	**Vehicle Category (3 levels)**	**Ping Resolution**	**Road Type (4 levels)**	**Month (12 levels)**	**Day of Week (7 levels)**	**Hour (24 levels)**	**Data Point ID**	**Segment Length (feet)**	**Time in Segment (s)**	**Average Speed in Segment (mph)**	**Average "Midpoint" Speed of the Bin (21 levels)**	**Total of Segment Lengths for this Speed Bin (feet)**	**Total of Segment Times for this Speed Bin (s)**	**Counts**
48453	Personal	Low	Urban Unrestricted	April	Monday	14:00:00 to 14:59:59	5	200.0	10	13.64	15	550	27	2
							16	208.3	10	14.20				
							1	900.0	30	20.45	20	1800	60	7
							11	312.5	10	21.31				
							12	277.8	10	18.94				
							15	937.5	30	21.31				
							18	937.5	30	21.31				
							20	833.3	30	18.94				
							21	937.5	30	21.31				
							2	1000.0	30	22.73	25	1650	47	6
							3	1125.0	30	25.57				
							4	333.3	10	22.73				
							13	357.1	10	24.35				
							14	1071.4	30	24.35				
							19	357.1	10	24.35				
							17	416.7	10	28.41	30	250	6	1

After the data handoff, ERG imported the 250 million records into the computer software MySQL (My Structured Query Language, a database management system) and SAS (Statistical Analytical Software) to develop the National Database. The National Database contains the final model-ready speed and VMT distributions listed below in Table 3-4. The structure of each table generally follows the format requirements of MOVES or SMOKE, but with an extra, leading field to identify the county FIPS code, and in some cases also the day of week and month.

Table 3-4. List of Tables in the National Database

No.	Model	MySQL Table Name	Description
1	MOVES	avgSpeedDistribution	Distribution of 16 speeds by hour
2		dayVMTFraction	Fraction of VMT by day type
3		hourVMTFraction	Fraction of VMT by hour of day
4		monthVMTFraction	Fraction of VMT by month of year
5		roadTypeDistribution	Fraction of VMT by road type
6	SMOKE	spdpro	Average speed by hour
7		mtpro_weekly	Fraction of VMT by day type
8		mtpro_hourly	Fraction of VMT by hour of day
9		mtpro_monthly	Fraction of VMT by month of year

Table 3-5 shows the map of MOVES source type to the three vehicle types in the telematics data. The telematics data applies to 8 of the 13 MOVES sources types, excluding the buses (source types 41-43), refuse trucks (51), and motor homes (54) because they have traditionally had driving patterns and speeds that differ significantly from those of commercial trucks. However, the eight source types that are applicable to the telematics data make up the vast majority of emissions in the on-road inventory.

Table 3-5. Map of MOVES Source Types to Telematics Data Vehicle Types

MOVES Source Type ID	MOVES Source Type Name	Telematics Vehicle Type
11	Motorcycle	Personal
21	Passenger Car	Personal
31	Passenger Truck	Personal
32	Light Commercial Truck	Medium-Duty Commercial
41	Intercity Bus	N/A
42	Transit Bus	N/A
43	School Bus	N/A
51	Refuse Truck	N/A
52	Single Unit Short-haul Truck	Medium-Duty Commercial
53	Single Unit Long-haul Truck	Heavy-Duty Commercial
54	Motor Home	N/A
61	Combination Unit Short-haul Truck	Heavy-Duty Commercial
62	Combination Unit Long-haul Truck	Heavy-Duty Commercial

Speed Tables in the National Database

The National Database provides the MOVES average speed distribution separately for each county, stored in a single table. Following EPA guidance, the speed distributions were calculated as the fraction of time vehicles spend in each of the 16 speed bins within each hour, by day type, road type, source type, and county. The fractions sum to one (1) for each hour, and Equation 1 shows the calculation.

$$avgSpeedFraction_{C,S,R,H,DT,B} = \frac{SegmentTime_{C,S,R,H,DT,B}}{\sum_B (SegmentTime_{C,S,R,H,DT})} \qquad \text{Eqn. 1}$$

Where *avgSpeedFraction* = A decimal value between 0 and 1 representing the fraction of time in the hour spent in a speed bin *B*
SegmentTime = the travel time in seconds
C = County
S = MOVES source type ID (11, 21, 31, 32, 52, 53, 61, and 62)
R = MOVES road type ID (2, 3, 4, 5)
H = MOVES hour ID (1 to 24)
DT = MOVES day type ID (5 = weekday, 2 = weekend)
B = MOVES speed bin (1 to 16)

The National Database also provides the corresponding SMOKE input speed file (file name "spdpro," or speed profiles) providing hourly average speeds by county and source category code (SCC). In SMOKE, the spdpro input data represent a single average speed in each hour of day, as opposed to a distribution of 16 speeds that MOVES allows. Equation 2 shows how the average hourly speeds for SMOKE spdpro were calculated.

$$avgSpeed_{DOW,M,C,SCC,H} = \sum_B (avgSpeedFraction_{DOW,M,C,SCC,H,B} \times MidSpeed_B) \qquad \text{Eqn. 2}$$

Where *avgSpeed* = the average speed in units of mph
avgSpeedFraction = A decimal value between 0 and 1 representing the fraction of time in the hour spent in speed bin *B* (see Eqn. 1 above)
MidSpeed = The midpoint speed of bin *B* in mph (see previous Table 3-2)
DOW = day of the week (1-7)
M = month of year (1 to 12)
C = County
SCC = SMOKE source category code, a 10-digit code that includes MOVES source and road type
H = Hour of day (1 to 24)
B = MOVES speed bin (1 to 16)

VMT Distribution Tables in the National Database

Road Type Distribution

The road type distribution is a MOVES input table describing the allocation of county total VMT to the four MOVES road types. There is no SMOKE equivalent of this distribution table because the VMT is provided to SMOKE directly as a total magnitude of activity by SCC, which includes road type. Equation 3 describes how MOVES road type distribution fractions were calculated for the National Database table listing the distributions for each county.

$$roadTypeVMTFraction_{C,S,R} = \frac{SegmentDistance_{C,S,R}}{\sum_R SegmentDistance_{C,S}} \qquad \text{Eqn. 3}$$

Where *roadTypeVMTFraction* = A decimal value between 0 and 1 representing the fraction of distance traveled on road type *R*
C = County
S = MOVES source type ID (11, 21, 31, 32, 52, 53, 61, and 62)
R = MOVES road type ID (2, 3, 4, 5)
SegmentDistance = the distance traveled in feet

Hour VMT Distributions

Hourly VMT distributions describe how models allocate day total VMT to 24 hours. The equations used to populate the MOVES and SMOKE tables in the National Database are shown in Equations 4 and 5, respectively.

$$hourVMTFraction_{C,S,R,DT,H} = \frac{SegmentDistance_{C,S,R,DT,H}}{\sum_H SegmentDistance_{C,S,R,DT}} \qquad \text{Eqn. 4}$$

Where *hourVMTFraction* = A decimal value between 0 and 1 representing the fraction of distance traveled in hour *H*
C = County
S = MOVES source type ID (11, 21, 31, 32, 52, 53, 61, and 62)
R = MOVES road type ID (2, 3, 4, 5)
SegmentDistance = the total distance traveled in feet
DT = MOVES day type ID (5 = weekday, 2 = weekend)
H = MOVES hour ID (1 to 24)

The SMOKE mobile source temporal profile allocating VMT to hours of the day is calculated similarly to the MOVES version. The main difference is these SMOKE profiles are available by seven days of the week and are listed by profile ID.

$$hourWeight_{DOW,P,H} = \frac{SegmentDistance_{DOW,P,H}}{\sum_H SegmentDistance_{DOW,P}} \qquad \text{Eqn. 5}$$

Where *hourWeight =* An integer representing the relative proportion of VMT in hour *H*
DOW = day of the week (1-7, corresponding to Monday through Sunday)
P = Profile code, an integer to identify the temporal profile for assignment to regions and SCCs
H = Hour of day (1 to 24)

Day VMT Distributions

MOVES day type VMT distributions represent the portion of week total VMT that is allocated to the block of five weekdays and block of two weekend days. The day VMT fractions vary by source type, month, and road type. In SMOKE, the temporal profile allocates week total VMT into 7 days of the week, Monday through Sunday. These calculations are shown in Equations 6 and 7, respectively.

$$dayVMTFraction_{C,S,M,R,DT} = \frac{SegmentDistance_{C,S,M,R}}{\sum_R SegmentDistance_{C,S,M,R,DT}} \qquad \text{Eqn. 6}$$

Where *dayVMTFraction =* A decimal value between 0 and 1 representing the fraction of week VMT allocated to the day type *DT*
C = County
M = Month (1 to 12)
S = MOVES source type ID (11, 21, 31, 32, 52, 53, 61, and 62)
R = MOVES road type ID (2, 3, 4, 5)
DT = MOVES day type ID (5 = weekday, 2 = weekend)
SegmentDistance = the total distance traveled in feet

$$dayWeight_{P,DOW} = \frac{SegmentDistance_{P,DOW}}{\sum_{DOW} SegmentDistance_{P}} \qquad \text{Eqn. 7}$$

Where *dayWeight =* An integer representing the relative proportion of VMT in day of the week *DOW*
DOW = day of the week (1-7, corresponding to Monday through Sunday)
P = Profile code, an integer to identify the temporal profile for assignment to region and SCC
SegmentDistance = the total distance traveled in feet

Month VMT Distributions

Month VMT fractions in both MOVES and SMOKE distribute annual VMT to the twelve months of year. The traditional source of local data for this input is continuous traffic monitors, with several years of data used to develop a seasonal trend. The telematics data are from 12 consecutive months, representing only one year rather than multiple years and so we recommend not using month VMT fractions from the study. The average trip distance of personal vehicle and medium-duty commercial fleets in particular appear unstable over the period of September 2015 through August 2016, and discussion surrounding Figure 4-18 in the next section explains this further. The calculations to develop the distributions for MOVES and SMOKE are Equations 8 and 9, respectively.

$$monthVMTFraction_{C,S,M} = \frac{SegmentDistance_{C,S,M}}{\sum_M SegmentDistance_{C,S}} \qquad \text{Eqn. 8}$$

Where *dayVMTFraction =* A decimal value between 0 and 1 representing the fraction of week VMT allocated to the day type *DT*
C = County
M = Month (1 to 12)
S = MOVES source type ID (11, 21, 31, 32, 52, 53, 61, and 62)
SegmentDistance = the total distance traveled in feet

$$monthWeight_{P,M} = \frac{SegmentDistance_{P,M}}{\sum_{DOW} SegmentDistance_{P}} \qquad \text{Eqn. 9}$$

Where *monthWeight =* An integer representing the relative proportion of VMT in day of the month *M*
M = Month (1 to 12)
P = Profile code, an integer to identify the temporal profile for assignment to region and SCC
SegmentDistance = the total distance traveled in feet

3.4 1/16th Sample Size and Grouping

The granularity of the data required for the NEI and the large size of StreetLight Data's repository resulted in a major computational challenge for this work.

At the outset, StreetLight Data determined that processing their full repository would not be doable on the timeframe of CRC project A-100 or the next NEI, at least not without adding significant cloud hardware that had prohibitive costs for the project. Instead, StreetLight Data pulled a representative 1/16th sample of their telematics repository for processing. Figure 3-2 shows the number of observations in the raw telematics data by county in the July data.

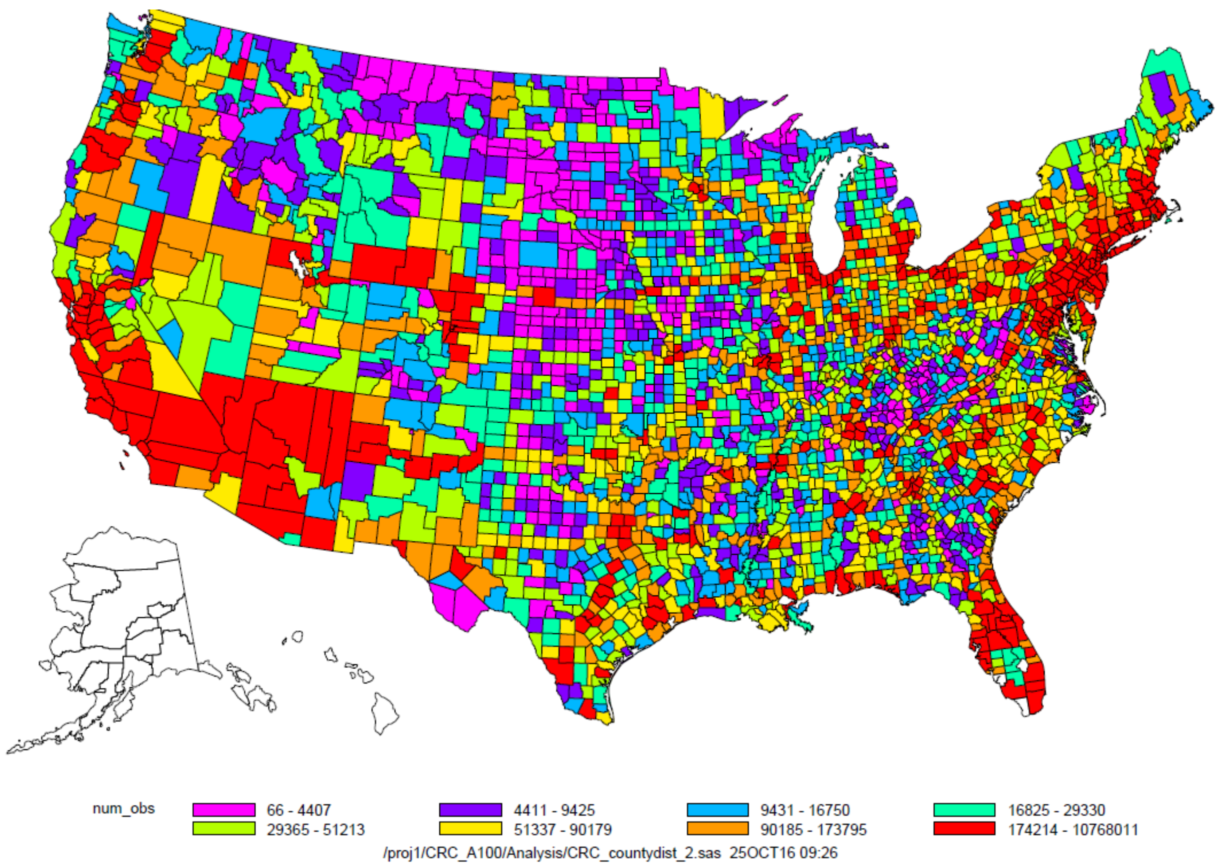


Figure 3-2. Number of Observations by County in the July Vehicle Telematics Data

ERG's assessment of county coverage focused on the 374 metropolitan statistical areas (MSAs) as defined by the U.S. government, which are multi-county regions grouped around urban centers but including surrounding (e.g. suburban, exurban) counties as well. The coverage of MOVES speed bins by county and temporal dimensions based on 1/16th of StreetLight Data's repository is adequate for the core counties in the larger MSAs, but is an issue in other locations of the country where some hours of the day may not have any observations for combinations of road types and hours. To deal with these cases of data gaps, we grouped counties according to their MSA or non-MSA status. The hierarchy of county specificity of the MOVES and SMOKE data is the following:

1. Counties inside MSAs that could stand alone (no gaps) remained individual.
2. Counties inside MSAs with gaps in their profiles required grouping:
    a. Single-county MSA counties were grouped together by region
    b. Core counties of MSAs were grouped by region
    c. Non-core counties of MSAs were grouped by region
3. All counties outside of MSAs were automatically grouped with the other non-MSA counties in the region.

The regional averages for rural counties are separated for the four census regions *West*, *Midwest*, *Northeast*, and *South*, shown in Figure 3-3. In the National Database, any area outside an MSA is populated by the set of profiles reflecting the regional average of one of these four based on state. The division of rural counties into the four census regions was not based on new analysis of the StreetLight data. In the A-88 project, statistical analysis of long-haul vs short-haul VMT showed meaningful differences between these regions, and for A-100 these regions were chosen with the presumption that regional differences exist.

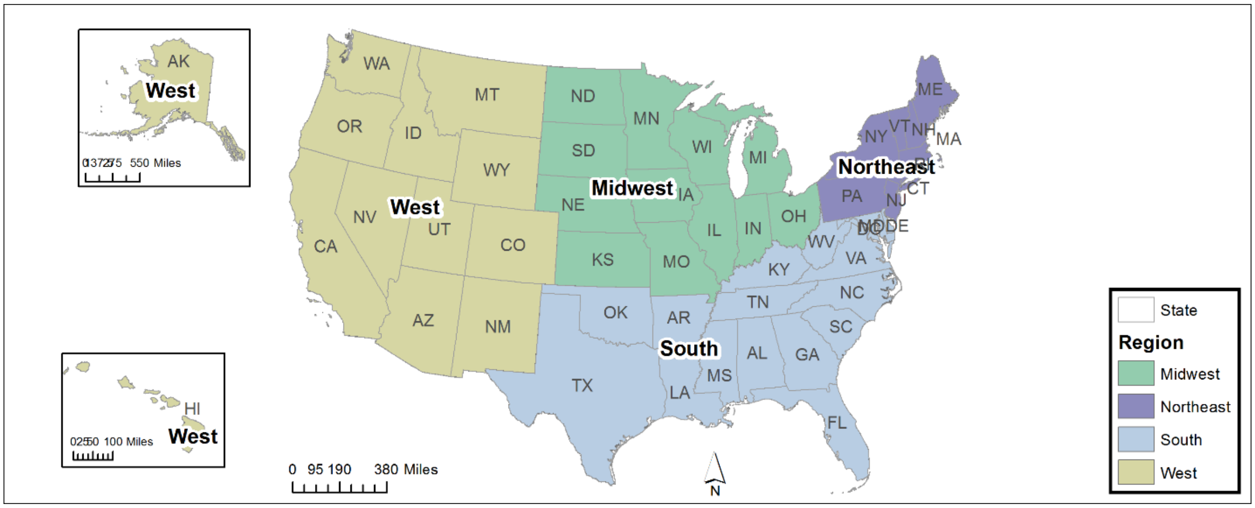


Figure 3-3. U.S. Census Regions[1]

To ensure that all MSAs had at least one county where data could adequately populate average speed bins by month, day and hour by itself, StreetLight Data provided a full data draw for 50 additional counties belonging to unique MSAs that did not already meet this criterion. Thus, for these 50 counties the effect of sample size on model input development could be examined. Any county inside an MSA with adequate data coverage retained its individuality for the MOVES and SMOKE profiles. However, some counties had certain road types with poor coverage where one or more hours of the day had no observations. For these cases, the MSA county was grouped with similar MSA counties in the same census region. The grouping of counties was restricted to whether the county was (1) the county of a single-county MSA, (2) the core county of an MSA, defined as the highest VMT county, or (3) a non-core county of an MSA, defined as not the highest VMT county and excluding the single-county MSAs.

Figure 3-4 shows annual average weekday hourly speeds on urban restricted roads in Pinal County, Arizona. The full dataset results in a smoother profile with less variability hour to hour than the 1/16th profile. Other combinations (not shown) of county, road type, and hour sometimes had instances of zero data available for the particular combination, but did have observations when moving to the full data repository draw. Clearly, having more data improves the final profiles. This limitation of server power resulting in a 1/16th sample size for the rest of

[1] Accessed February 2017. https://www.census.gov/geo/reference/webatlas/regions.html

the nation is significant for this work because it results in aggregating data over counties that may not have otherwise needed grouping.

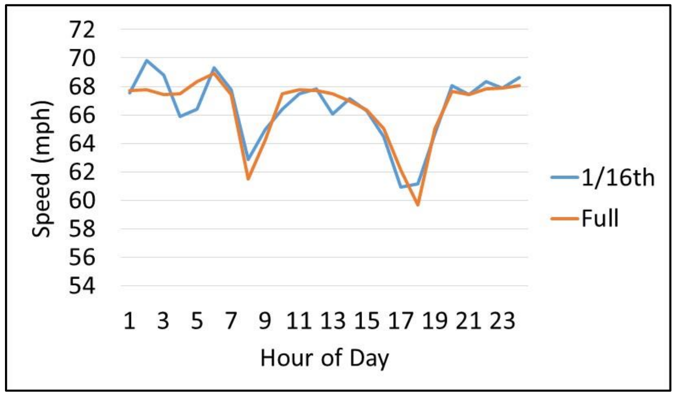


Figure 3-4. Sample Size Effect on Annual Average Weekday Diurnal Speed Profiles

4.0 New Model Inputs and Emissions Impacts Analysis

This section presents a preview of the telematics data based MOVES speed and distributions of VMT and the emissions inventory impacts of using these inputs focusing on three counties: Fulton County in Georgia, Cook County in Illinois, and Clark County in Nevada.

4.1 Vehicle Speeds

The MOVES input of average speed distributions includes a fraction in each of 16 speed bins that sums to one (1) for each hour of the day, and these vary by hour, weekday/weekend, road type, and source type. Due to the large volume of information, this section presents the average speeds for each hour as summary. In order to look at the speed bin detail on a manageable sample, distributions for two sample hours are also included. The National Database includes the full distributions for all hours. The hourly speeds presented here are for MOVES and therefore represent an annual average (data come from all twelve months) because MOVES does not differentiate speeds by month, though month detail is provided in the SMOKE speed profile table of the National Database.

The following figures illustrate the variation in hourly speed derived from vehicle telematics data, showing some significant differences among cities and vehicle types. The city-specific profiles are also compared to a “national default” that is often used by modelers due to a general unavailability of local data on vehicle speed. The national default is a single set of average speed distributions contained in the MOVES database that vary by road type, but there is no distinction by county or for most vehicle types. While most vehicle types share the same speed distributions in the MOVES database, the exception is combination-unit trucks operating on restricted access roads; these are lower speed because freeway speed limits are lower for heavy trucks. Interestingly, the telematics data from heavy-duty (HD) vehicles show just the opposite – that HD trucks travel at faster speeds on average than medium-duty (MD) trucks or personal passenger vehicles, which are referred to in this analysis as light-duty (LD) vehicles.

Figures 4-1 and 4-2 compare the hourly average speeds among the three cities and the national default for the LD fleet, on weekdays and weekends, respectively. Because the three counties Fulton (Atlanta), Cook (Chicago), and Clark (Las Vegas) are mostly urban, only the two urban road types are shown here. Weekday traffic (Figure 4-1) in Atlanta and Chicago has slower speeds compared to Las Vegas and the national default, particularly in morning and evening peak commute hours.

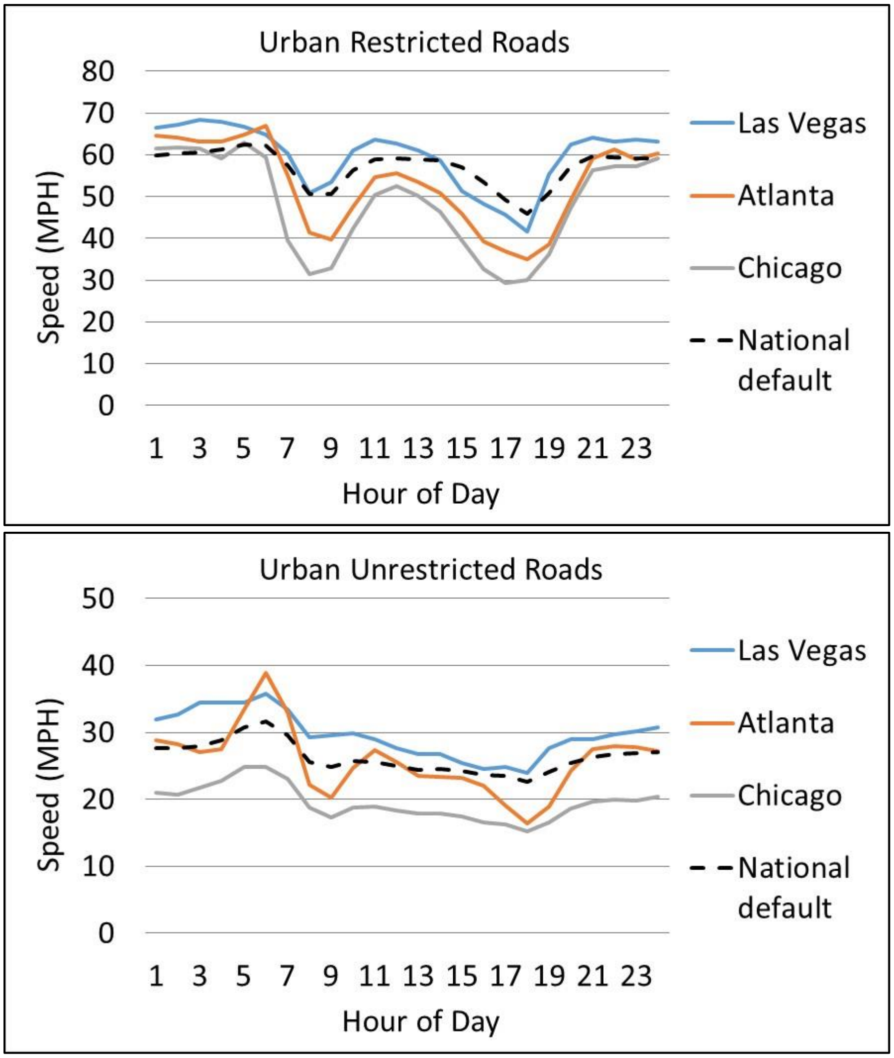


Figure 4-1. Weekday Comparison of Three County LD Vehicle Average Hourly Speeds

On weekends (Figure 4-2), Atlanta and Chicago exhibit an afternoon period of relatively low speeds on urban restricted roads (Figure 4-2, Upper Panel) that doesn't appear in Las Vegas or the national default. The low speed period is less pronounced on the urban unrestricted roads (Figure 4-2, Lower Panel), and it is notable that Chicago LD speeds in all hours are nearly 10 miles per hour (mph) slower than the national default. By contrast, Las Vegas experiences hourly average speeds that are typically higher than the national default and the other two cities.

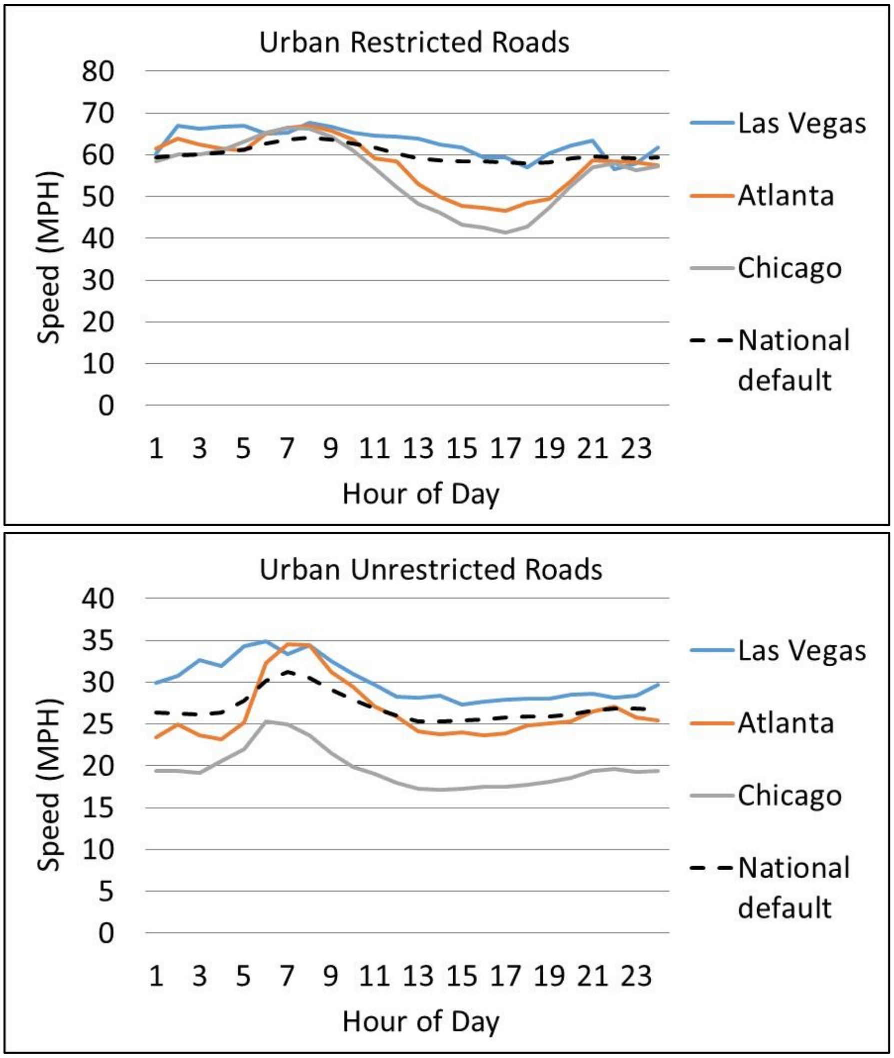


Figure 4-2. Weekend Comparison of Three County LD Vehicle Average Hourly Speeds

The next set of figures show the hourly average speeds by vehicle type, allowing comparisons among heavy, medium, and light vehicles on roads in the same area. Figure 4-3 shows that in Atlanta during weekday peak hours, HD vehicles travel at the fastest speeds. This is a counterintuitive result because trucks are often subject to lower speed limits on freeways and, anecdotally, drivers of passenger vehicles are accustomed to passing 18-wheelers on the freeway. A similar result appears in Chicago (Figure 4-5) but not in Las Vegas (Figure 4-7).

There are several plausible hypotheses for why the data would show higher speeds from HD vehicles than MD and LD. One element to consider is that MOVES road types are aggregations of several sub-types as defined by U.S. DOT. On a specific roadway, past research has shown that trucks travel at lower speeds than passenger vehicles; the differences observed within the broad MOVES road categories likely reflect a different mix of sub road-types. On restricted access roads (Figure 4-3, Upper Panel), HD trucks could be more likely to be pass-through traffic, as opposed to maneuvering between lanes to enter or exit the freeway. HD truck drivers also may be more likely to avoid the most congested freeways in the county, thereby raising the vehicle class-average speed. The unrestricted access road type (Figure 4-3, Lower Panel) could have a different explanation; the broad MOVES road type of "unrestricted" includes many types of roads –larger arterials, collectors, and small local roads. The HD data on urban unrestricted roads may represent a different mix of road types than travel by MD or LD because HD are less likely to travel on the local roads (residential neighborhood roads, for example).

Further work could evaluate this hypothesis by comparing car and heavy truck speeds on the same set of roadway links. Isolating specific links may reveal a different trend than that shown on the more aggregated MOVES road types.

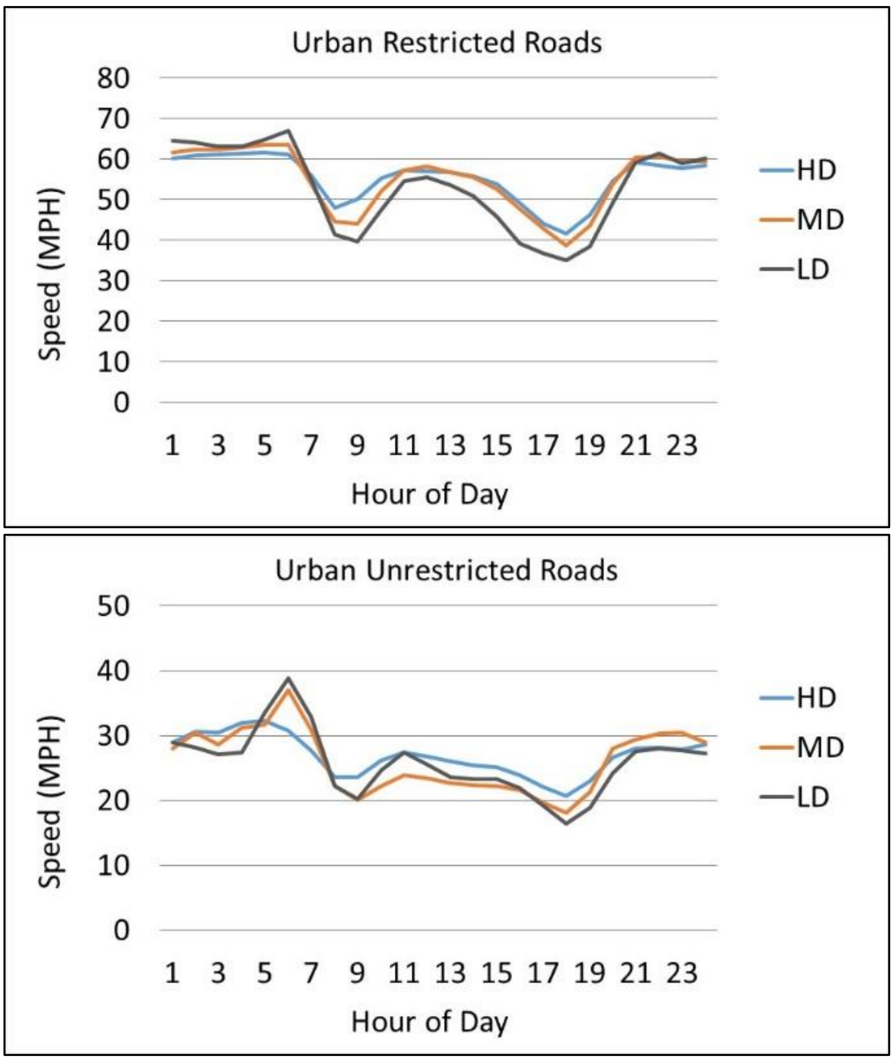


Figure 4-3. Weekday Average Hourly Speeds by Vehicle Class in Atlanta

Figure 4-4 below shows the distribution of speeds by 16 MOVES bins for each vehicle type in Atlanta on restricted access roads in two sample hours – a morning peak hour of 8:00 to 8:59 AM (Figure 4-4, Upper Panel) and a midday hour of 12:00 to 12:59 PM (Figure 4-4,Lower Panel).

These correspond to the average shown previously as hour 9 and 13 in the Upper Panel of Figure 4-3 above. The most notable difference between the two sample hours' speed distributions is that the morning peak hour profile is bimodal with a congested, low-speed mode and a higher speed mode that may represent free flow traffic, while the midday sample hour does not have a congested mode. Comparing vehicle classes to each other in Atlanta, the LD vehicles seem to experience a higher fraction of low speeds, followed by MD and then HD in the morning peak. The LD vehicle speed distributions on both road types exhibit a "tail" or upturn in the highest speed bin (> 72.5) that does not appear for other two vehicle types.

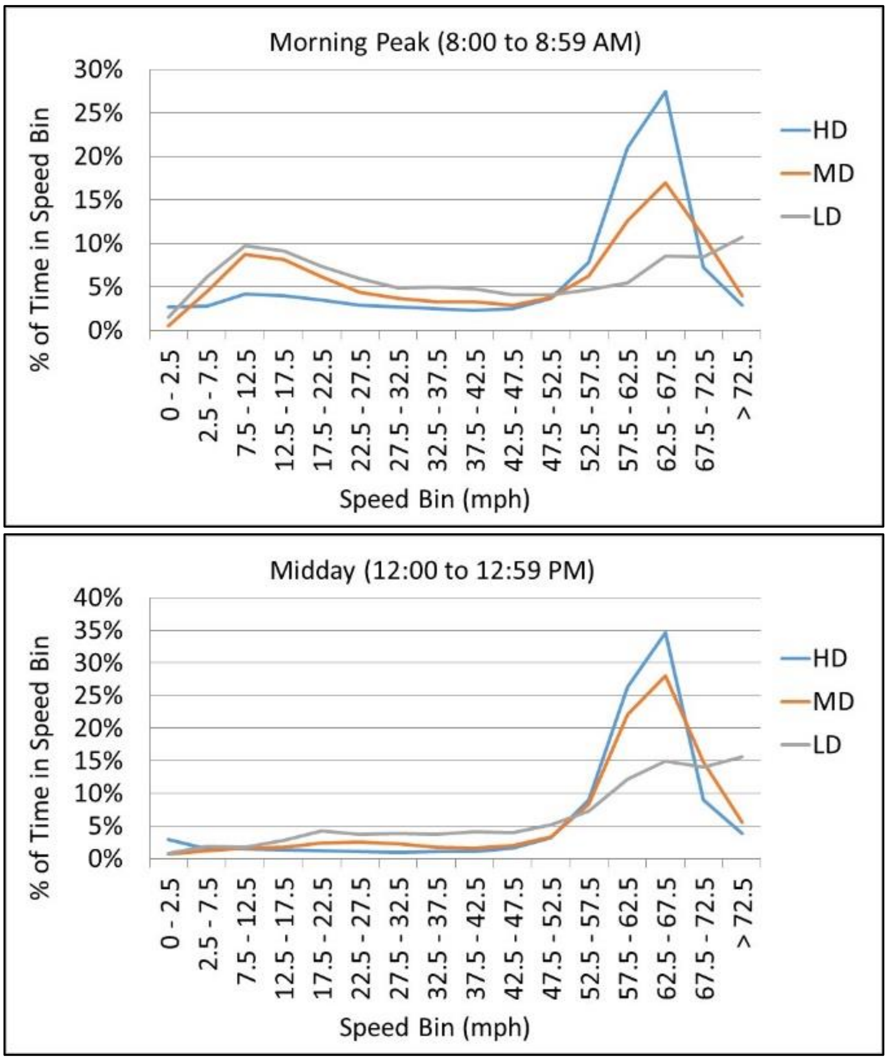


Figure 4-4. Weekday Speed Distributions for Selected Hours on Urban Restricted Roads in Atlanta

The next set of figures below in are the Chicago version of Figure 4-3 Atlanta hourly average speeds. A similar pattern in Chicago of HD traveling at higher speeds than MD and LD vehicles can be seen on both restricted and unrestricted access roads. On Chicago's restricted roads, up to 10 mph difference in speed by vehicle type occurs, and on unrestricted roads there is a maximum difference of 5 mph. MOVES emissions are sensitive particularly to low speeds such as 15 and 20 mph, as shown in Figure 4-5 (Lower Panel), so distinction between vehicles operating in the county can improve the emission inventory.

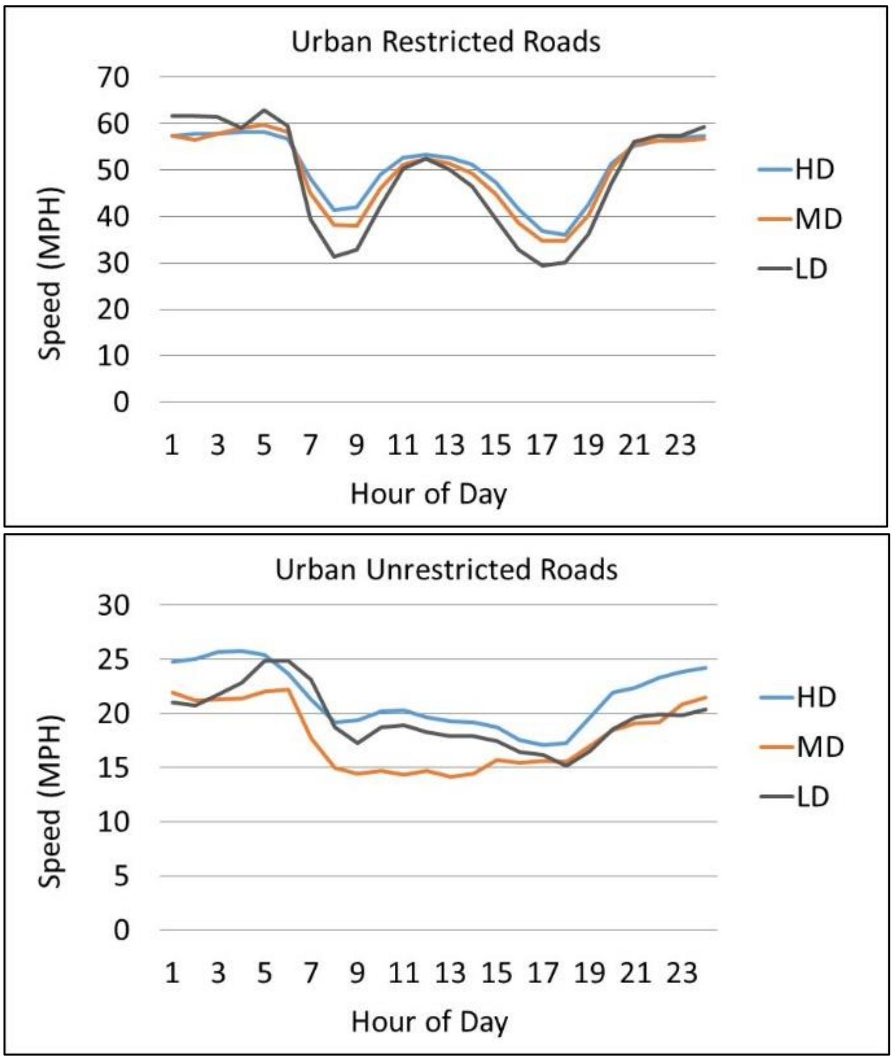


Figure 4-5. Weekday Average Hourly Speeds by Vehicle Class in Chicago

Figure 4-6 shows the distribution of speeds by bin in Chicago for each vehicle class for the sample hours in the morning peak and midday periods. Similar to Atlanta, in Chicago during the morning peak the average speed distribution is bimodal with peaks in a relatively low speed (7.5 to 12.5 mph) bin and higher speeds (57.5 to 62.5 mph). Chicago appears more congested, however, because the low speed peak makes up a larger percent of travel in the hour than

Atlanta's low speed peak. Similar to Atlanta, in Chicago a low speed peak is not visible in the midday period.

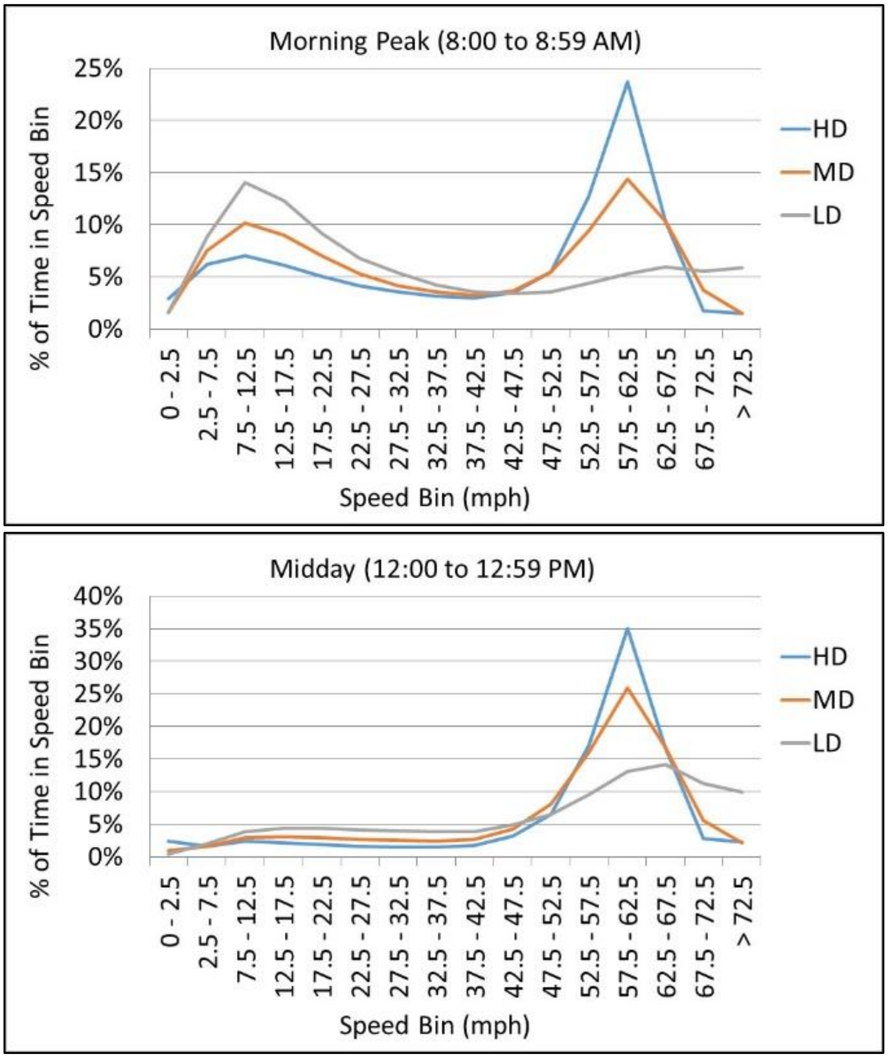


Figure 4-6. Weekday Speed Distributions for Selected Hours on Urban Restricted Roads in Chicago

Figure 4-7 and Figure 4-8 show the hourly average speeds and sample hour distributions by speed bin for Las Vegas. This city differs from Atlanta and Chicago in that HD trucks do not consistently travel at higher speeds during peak hours (Figure 4-7). The unrestricted access road average speed profiles (Figure 4-7, Lower Panel) do not show prominent depressions in speed in the peak hours like the other cities, indicating that Las Vegas is less congested. Earlier graphs comparing the three cities (Figure 4-1 and Figure 4-2) showed that Las Vegas consistently had the highest speeds and the profiles there were closest of any city to the national default for the urban restricted and urban unrestricted road types. Las Vegas does not have the low speed mode in the morning peak (Figure 4-8, Upper Panel) that was present in Atlanta and Chicago.

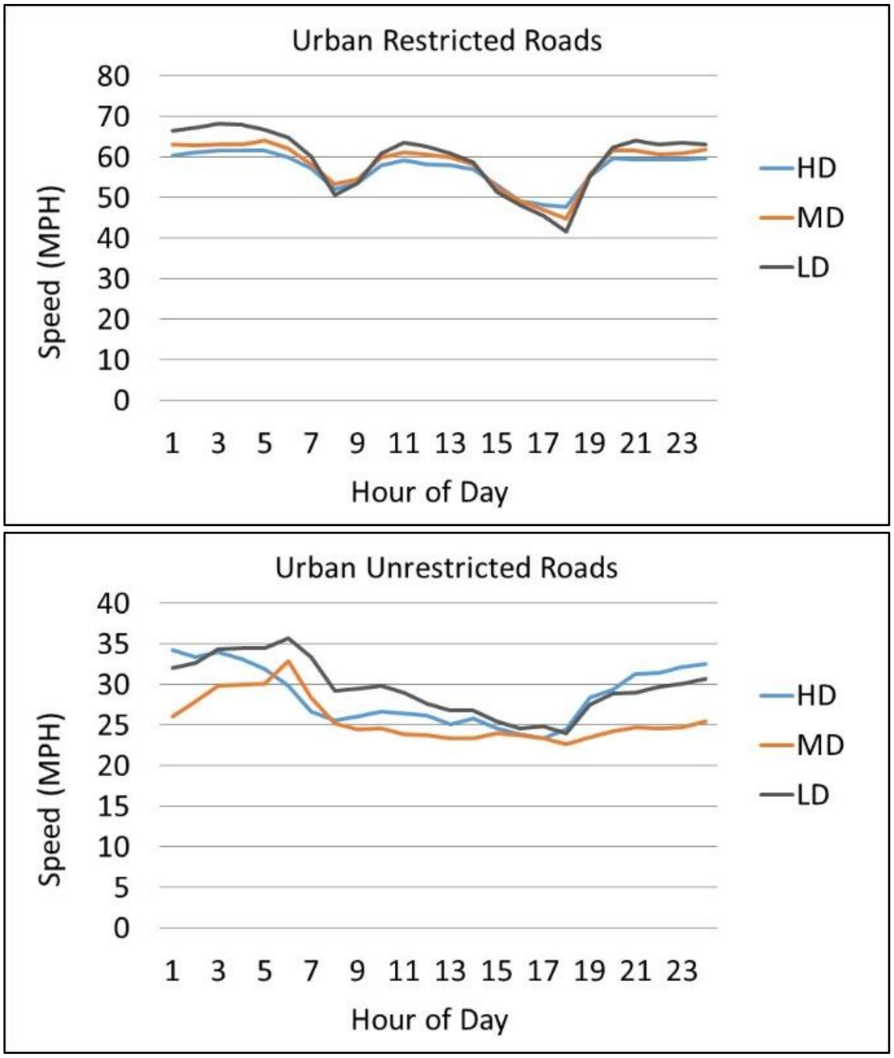
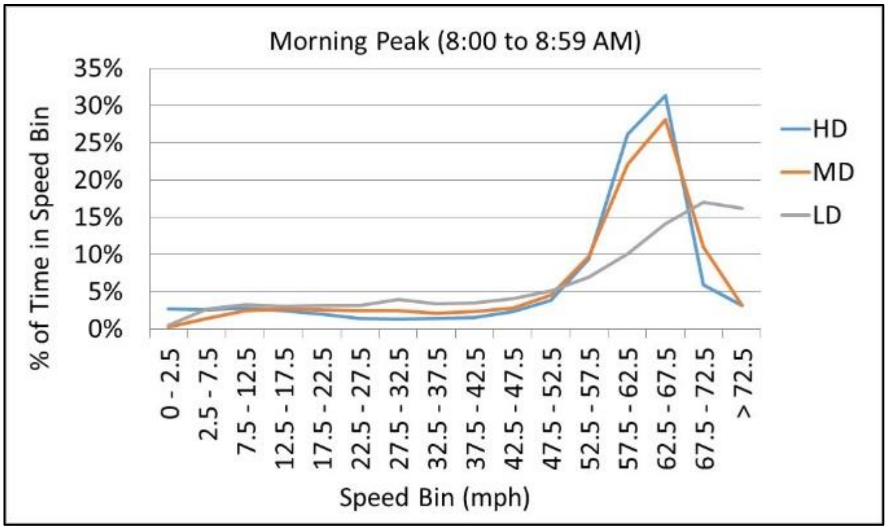


Figure 4-7. Weekday Average Hourly Speeds by Vehicle Class in Las Vegas



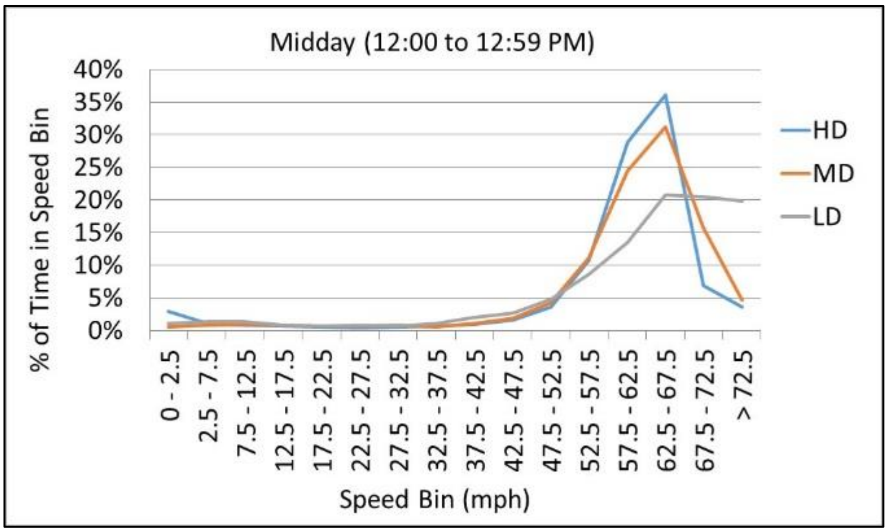


Figure 4-8. Weekday Speed Distributions for Selected Hours on Urban Restricted Roads in Las Vegas

4.2 VMT Distributions

The VMT distributions presented here focus on the resolution for MOVES county databases (CDB), but additional resolution (by seven days of week) is present for SMOKE tables in the National Database. The VMT distributions used in the emissions impact analysis include the MOVES tables:

- Hour VMT Fraction
- Day VMT Fraction
- Month VMT Fraction
- Road Type Distribution

Hourly VMT Distributions

The following graphs illustrate how MOVES distributes daily total VMT to 24 hours on weekdays and weekends (the area under each curve sums to 1). The MOVES input format does not allow variation by month, and so the data presented here are annual (underlying telematics data came from all twelve months). Figure 4-9 and Figure 4-10 compare the LD vehicle hourly VMT distributions among cities and to the national default, which is the MOVES database nationwide average. Unlike speed data, state/local agencies frequently have local data on these VMT distributions. Some local sources of data include under-road sensors that count vehicle volumes, or data may be estimated using travel demand models. Figure 4-9 compares weekday light-duty VMT among the three counties and shows that on unrestricted access roads, the three cities have relatively larger portions of their daily VMT in peak hours of the day compared to the national average. Weekend travel on the urban unrestricted roads (Figure 4-10, Lower Panel) shows that Atlanta and Chicago have a higher relative percent of VMT in the middle of the day than Las Vegas or the national average.

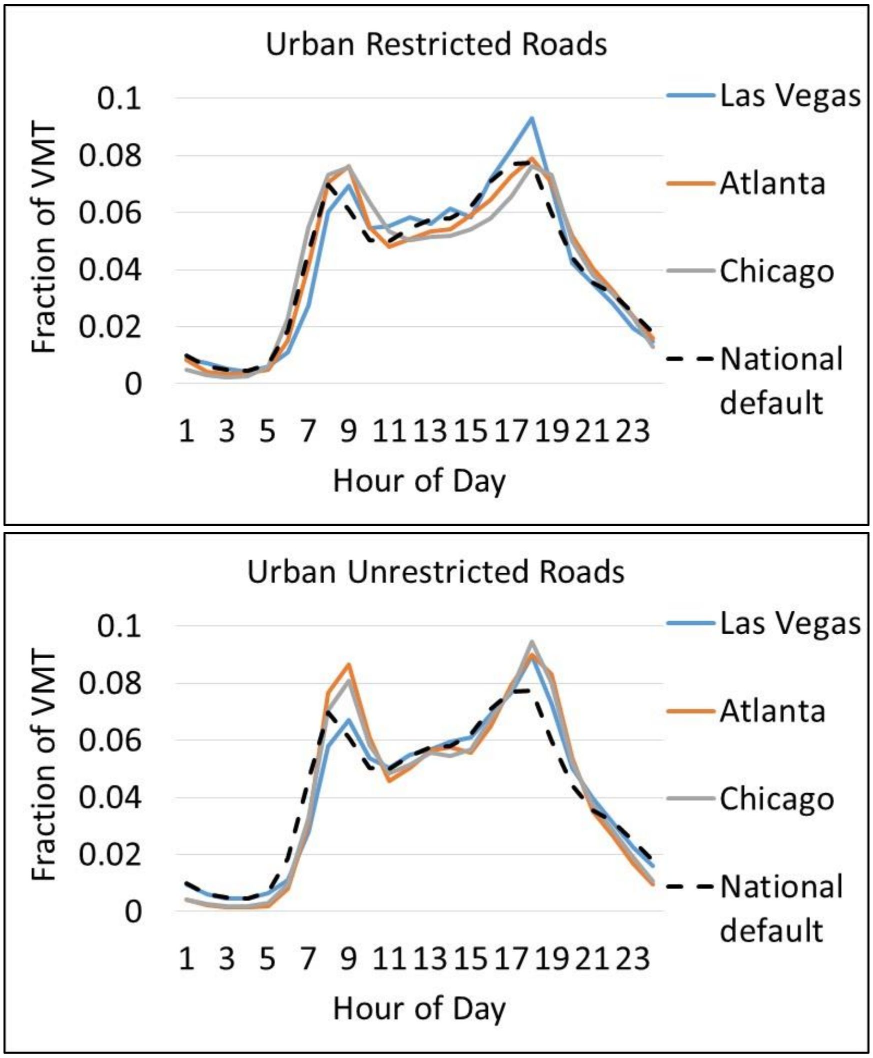


Figure 4-9. Weekday Comparison of Three County LD Vehicle Hourly VMT Distributions

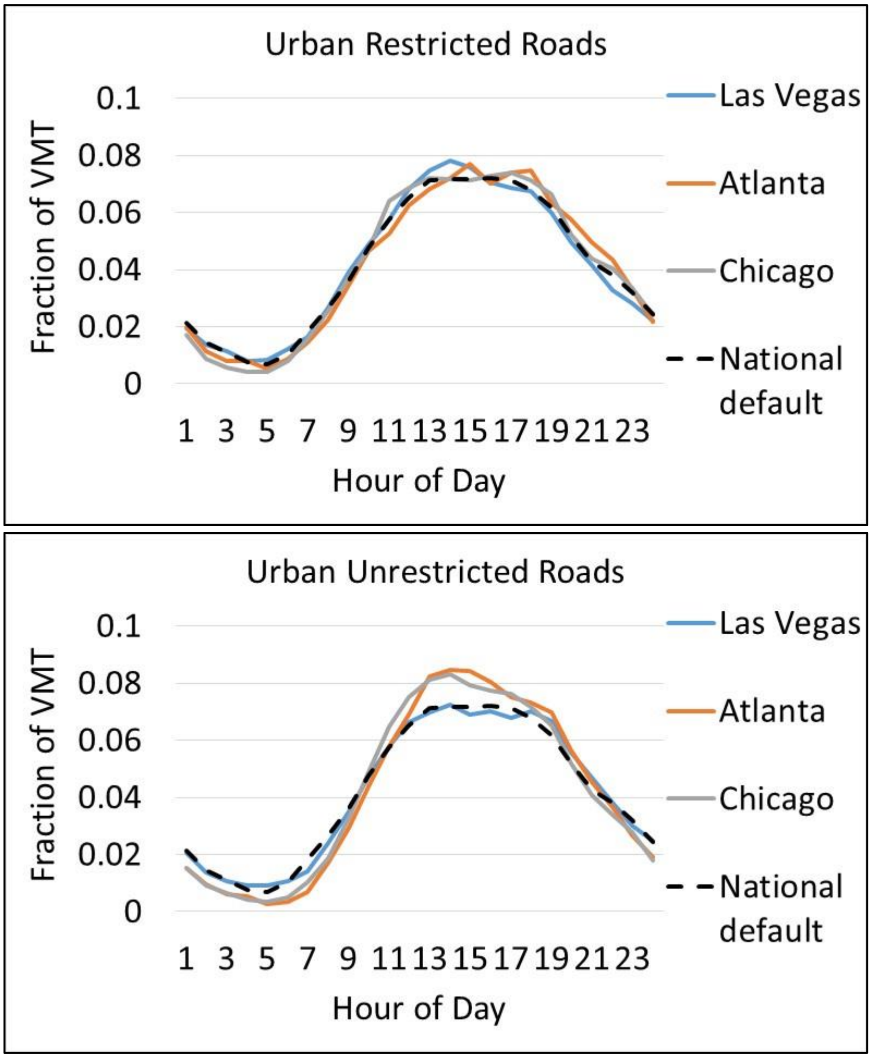


Figure 4-10. Weekend Comparison of Three County LD Vehicle Hourly VMT Distributions

The next three figures show weekday hourly VMT distributions by vehicle type. While not displayed here, the "national default" hour VMT fraction does not vary by MOVES vehicle type. The vehicle telematics data fills that gap by showing distinct patterns by HD, MD, and LD vehicles, that are apparent consistently by city (Atlanta in Figure 4-11, Chicago in Figure 4-12, and Las Vegas in Figure 4-13. The LD vehicles tend to show what is commonly thought of as a typical weekday pattern of peaks in the morning and evening commute hours, with lower VMT fraction between peaks midday, and even lower VMT fractions overnight. By contrast, the MD vehicle VMT tends to rise also at the morning peak but stays high through the midday and into the afternoon peak period. The HD vehicles' weekday VMT patterns consistently show the maximum daily VMT occurring during midday period with no distinguishable morning or evening peaks. HD vehicles also have a higher relative VMT fraction in the early morning hours compared to LD and MD.

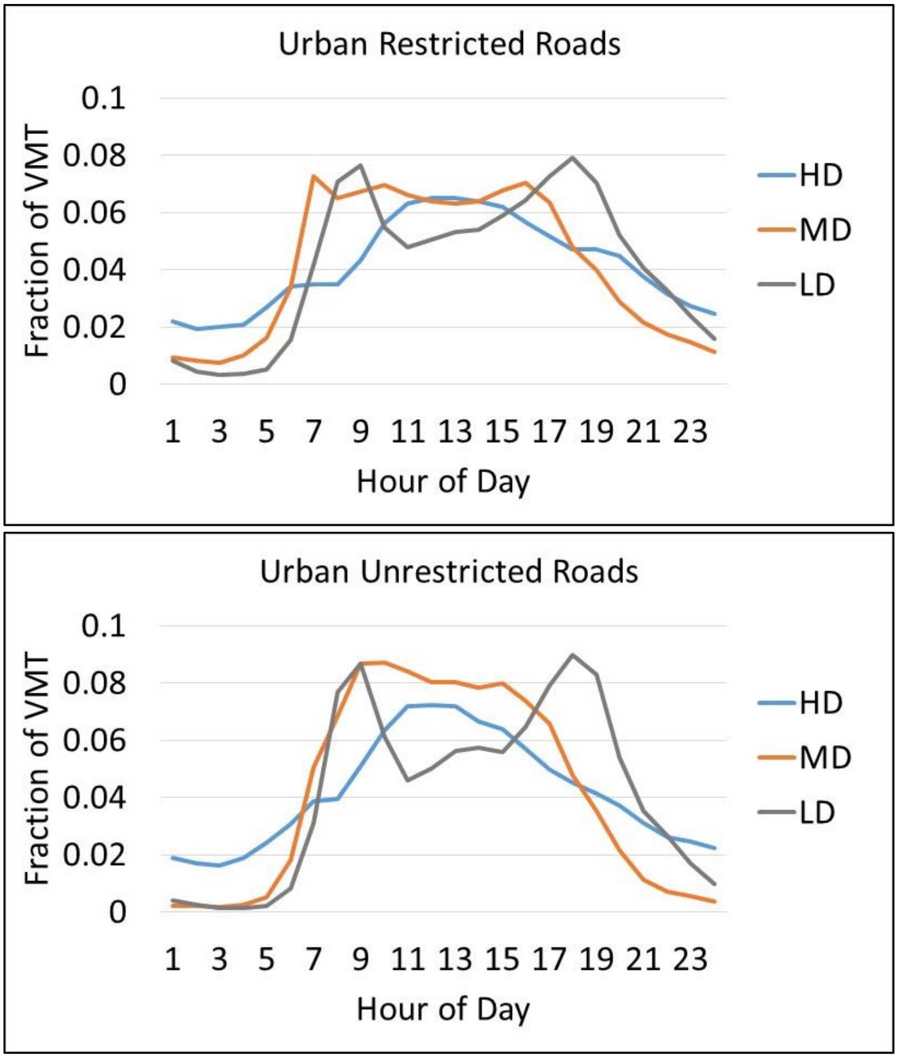


Figure 4-11. Atlanta Weekday Hourly VMT Distributions by Vehicle Class

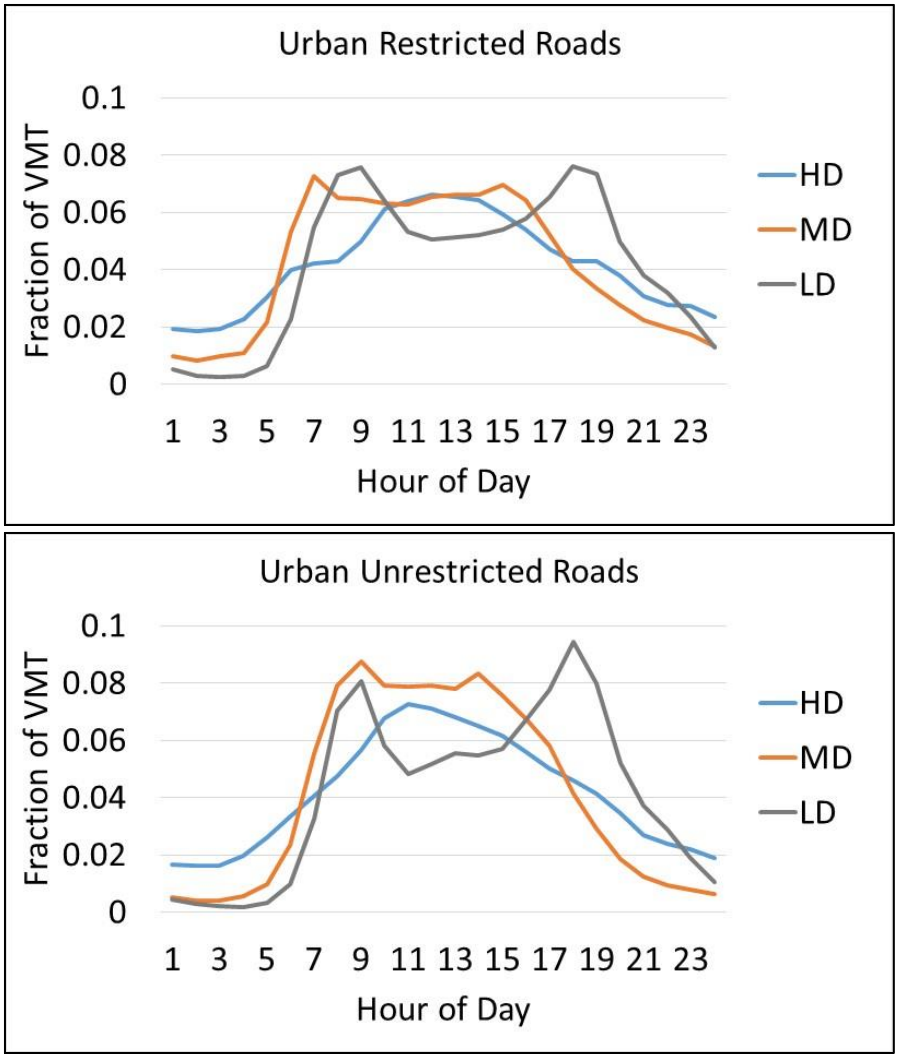


Figure 4-12. Chicago Weekday Hourly VMT Distributions by Vehicle Class

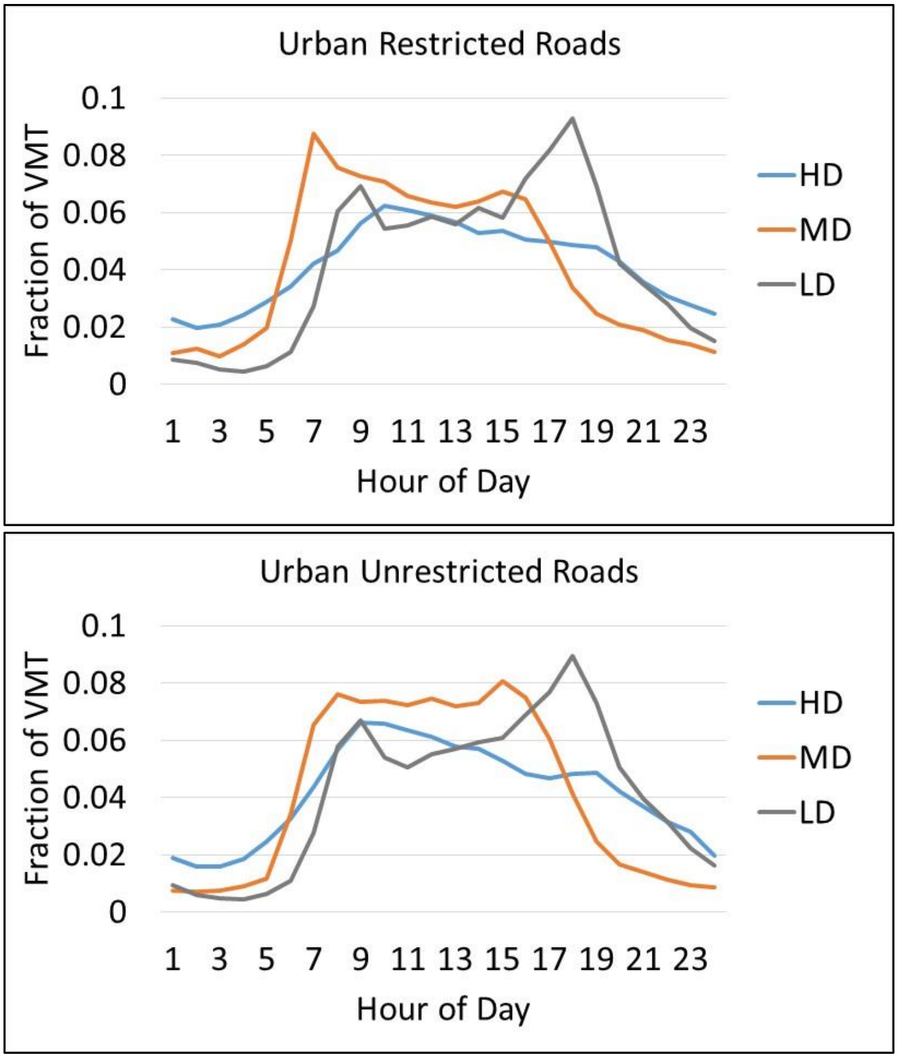


Figure 4-13. Las Vegas Weekday Hourly VMT Distributions by Vehicle Class

Figures 4-14 through 4-16 show the hourly VMT distributions by 7 days of the week for each city and vehicle type. The data for these figures are in Appendix B. The LD vehicle VMT patterns on Fridays look different from Monday through Thursday – midday period VMT appears to ramp up earlier in the afternoon on Fridays, flattening out the evening commute peak on that day. For the MD vehicles, the Sunday profile looks strikingly different than other days, with a gentle slope lasting late morning until midnight, rather than a sharp rise at the morning peak as observed on Monday through Saturday.

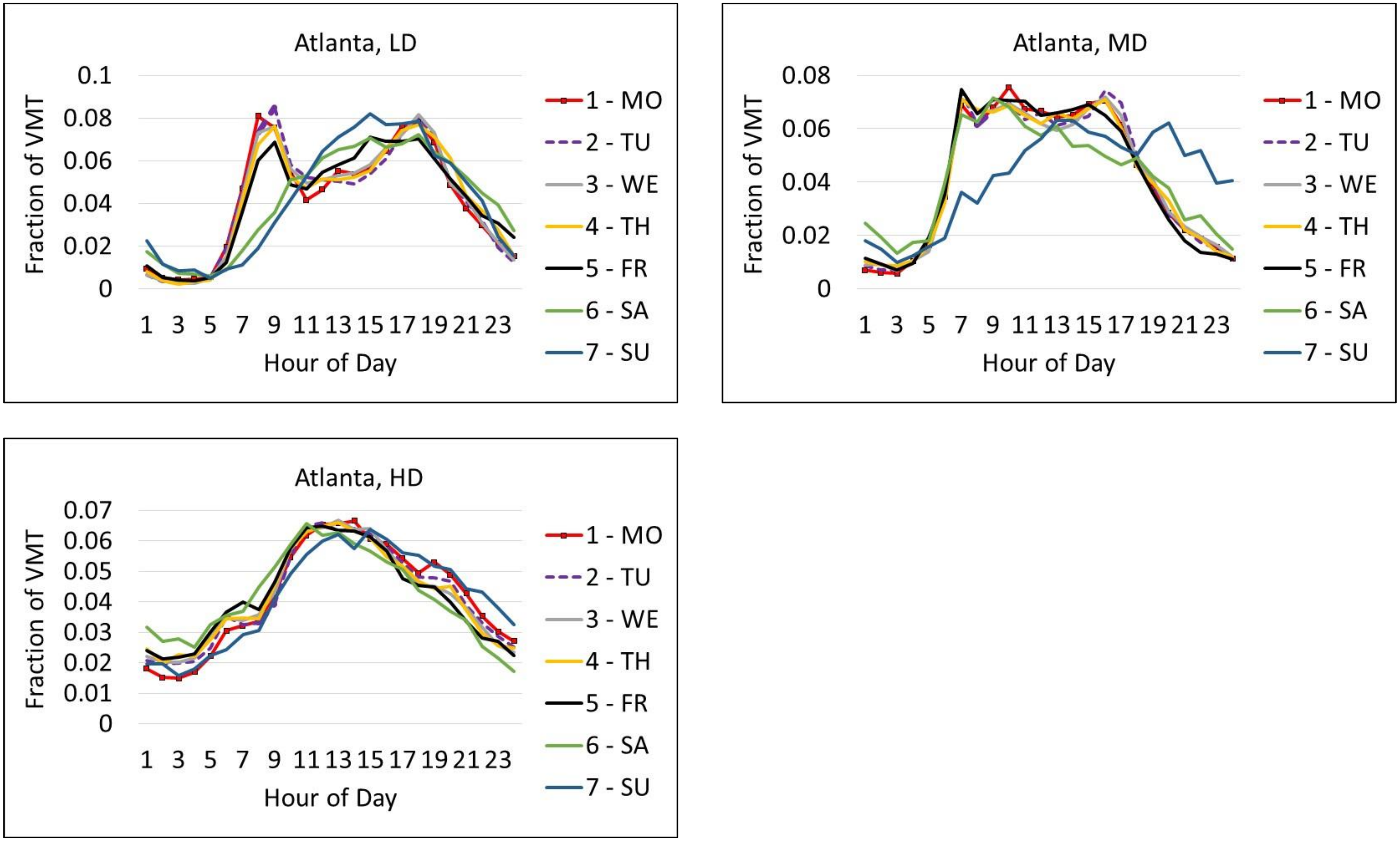


Figure 4-14. Atlanta Differences in Hourly VMT Distributions by Day of Week on Urban Restricted Roads

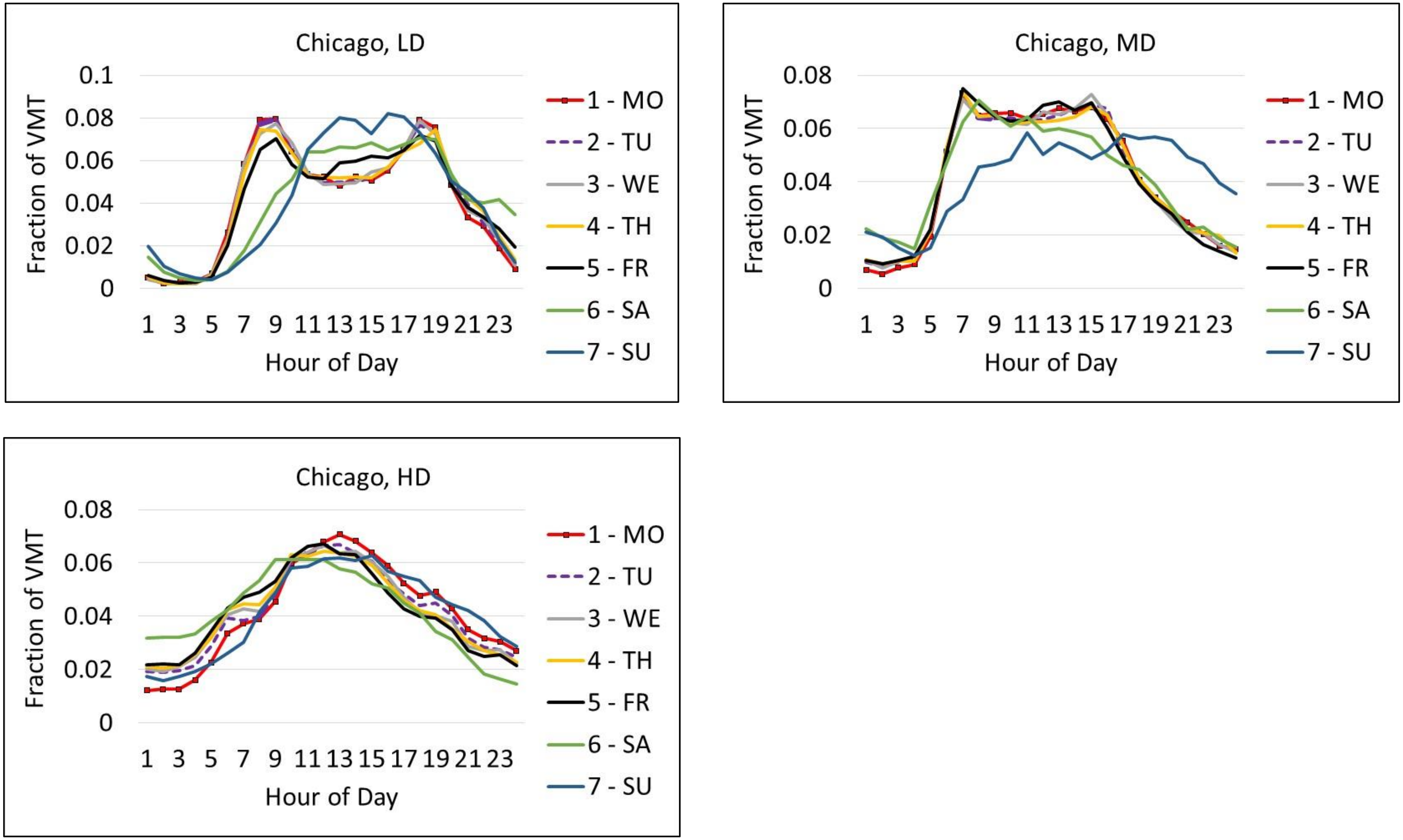


Figure 4-15. Chicago Differences in Hourly VMT Distributions by Day of Week on Urban Restricted Roads

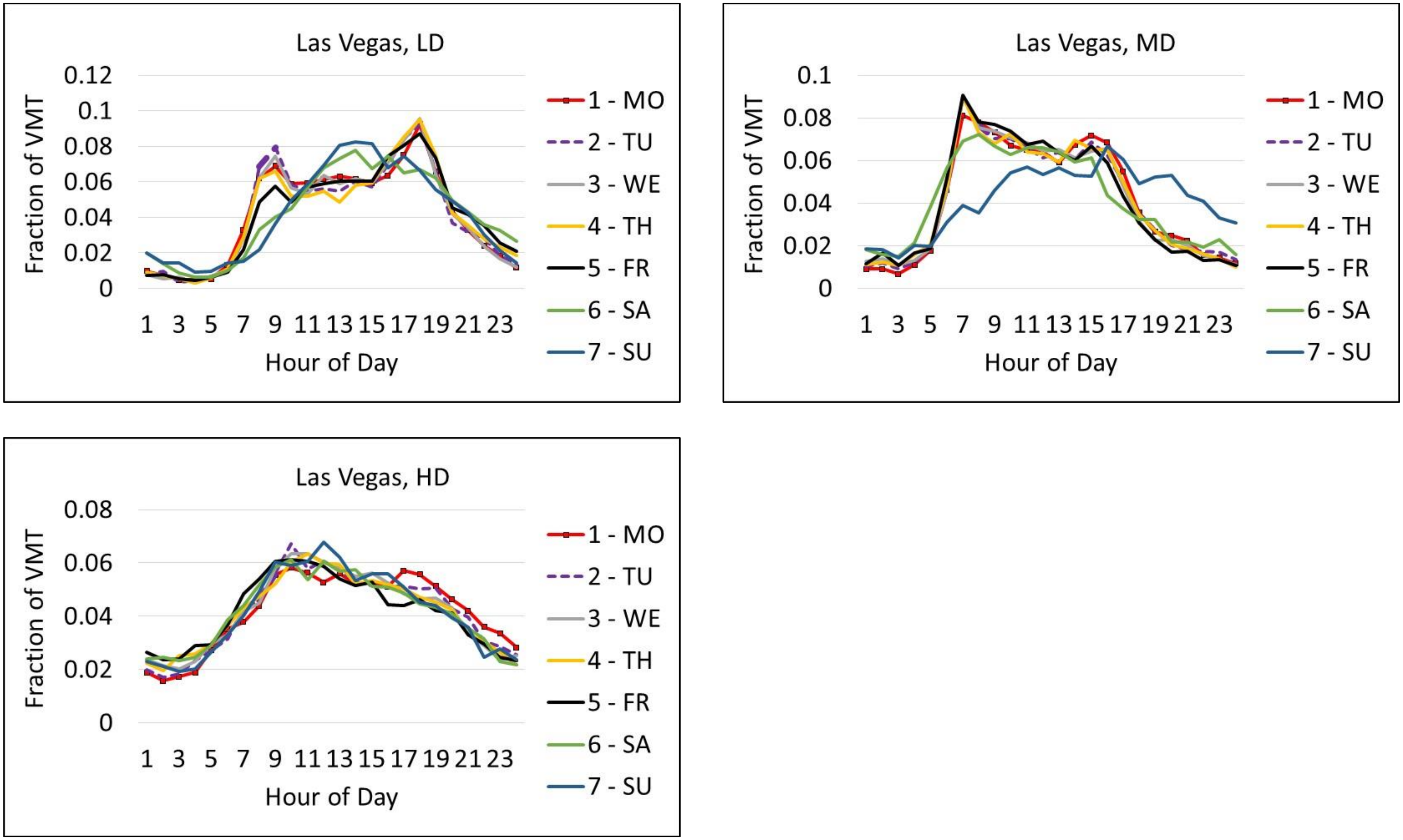


Figure 4-16. Las Vegas Differences in Hourly VMT Distributions by Day of Week on Urban Restricted Roads

Day Type VMT Distributions

Figure 4-17 illustrates how MOVES distributes week total VMT into blocks of weekday (five-day) and weekend (two-day) periods with vehicle telematics data from the month of July, for the three cities and three vehicle types. MOVES input formats allow differences in day type VMT fractions by month of the year, and only July is shown here though the National Database contains data for all twelve months. In MOVES, the day type VMT fraction input is allowed to vary not only by month but also by road and vehicle type. The default road type VMT fractions in MOVES are a national average and do not vary by vehicle class. Figure 4-17 shows that of the three vehicle types, MD has the highest fraction of VMT occurring during weekdays, while LD shows the lowest weekday fraction.

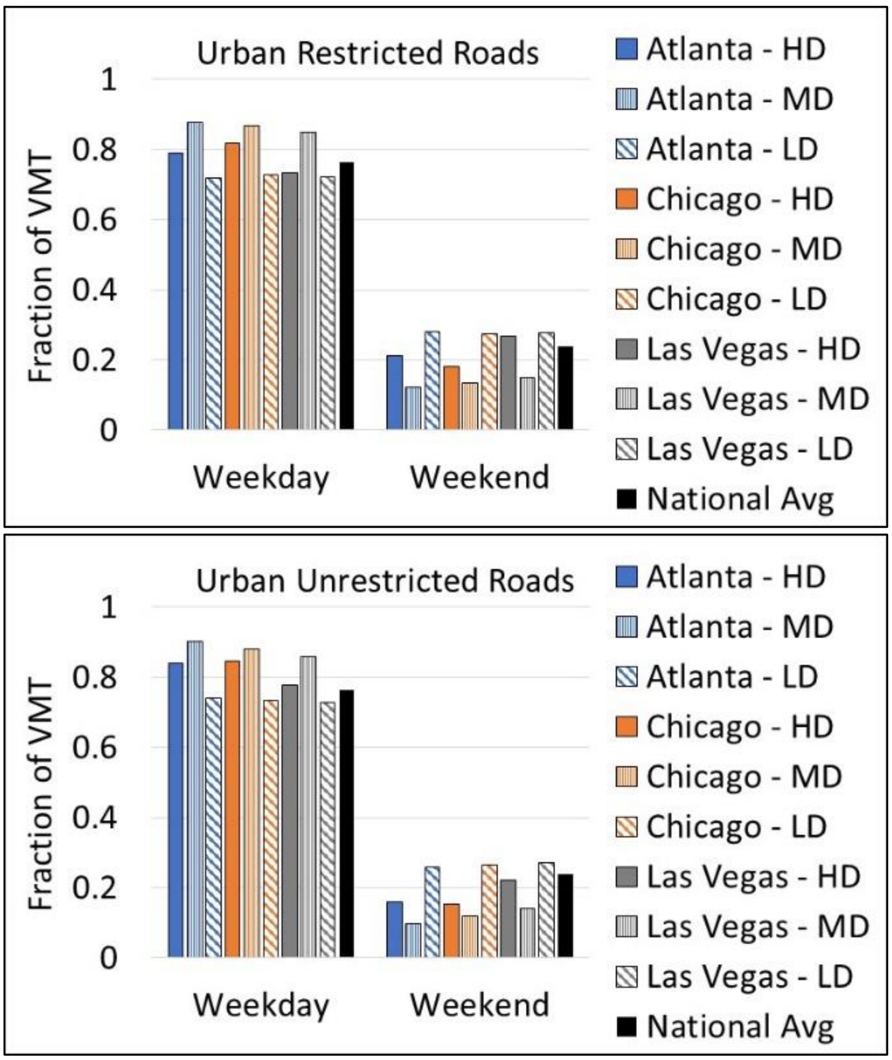


Figure 4-17. Comparison of Day Type VMT Distributions by Vehicle Class in July

Month VMT Distributions

The next three figures show the fraction of annual VMT that MOVES allocates to the twelve months of year, separately for 3 vehicle types. The "National default" shown in each figure is a nationwide average in the MOVES default database that does not vary by vehicle type except for motorcycles. Figure 4-18 shows LD vehicle month VMT fractions for the three cities and the default national average. The most striking feature of the profiles is that there is a relatively large drop in VMT fraction between August (month 8) and September (month 9). Coincidentally, the source telematics data was provided for the continuous 12-month period of September to December 2015 followed by January to August 2016. The relative VMT by month appears to show a difference in the 2015 data compared to 2016 that was unrelated to the sample size; the count of observations by month did not follow this pattern of VMT. Because the average trip length appears to be different in the 2015 and 2016 data, modelers should evaluate the data in their area and proceed with caution on using the month VMT fractions in the National Database. It is worth noting that month VMT fractions for LD (and to a lesser degree the MD vehicles in Figure 4-19) show a step down in VMT fractions for the September – December period in these particular three cities, but the effect is not present in all counties across the U.S. in the National Database, and the HD trucks (Figure 4-20) do not show this trend. The total VMT by month in the personal vehicles dataset reflects a shift in sampling method of the raw mobility data, and not true differences in typical travel month by month. StreetLight explained that the ping rate in their personal vehicles set changed between 2015 and 2016. The speed, hour and day VMT profiles are relative measures that are internally consistent regardless of the shift in sampling technique.

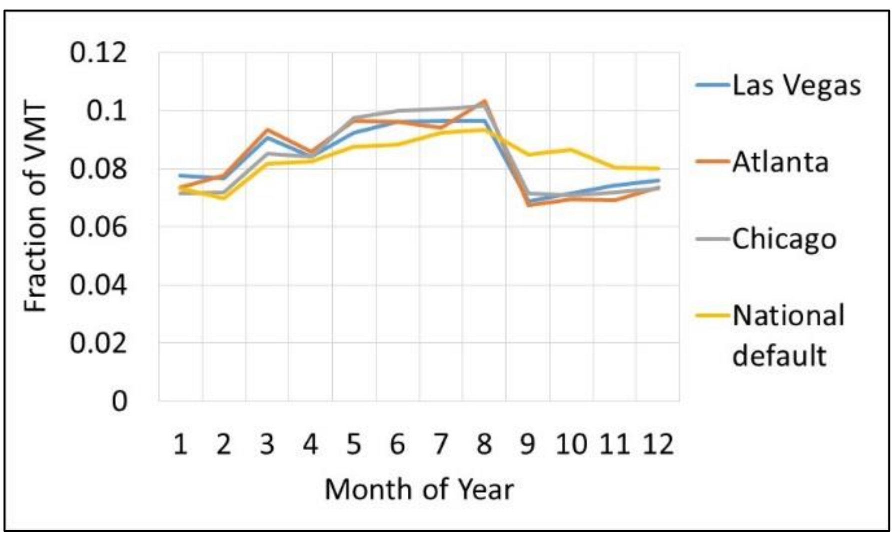


Figure 4-18. LD Comparison of Three County Monthly VMT Distributions

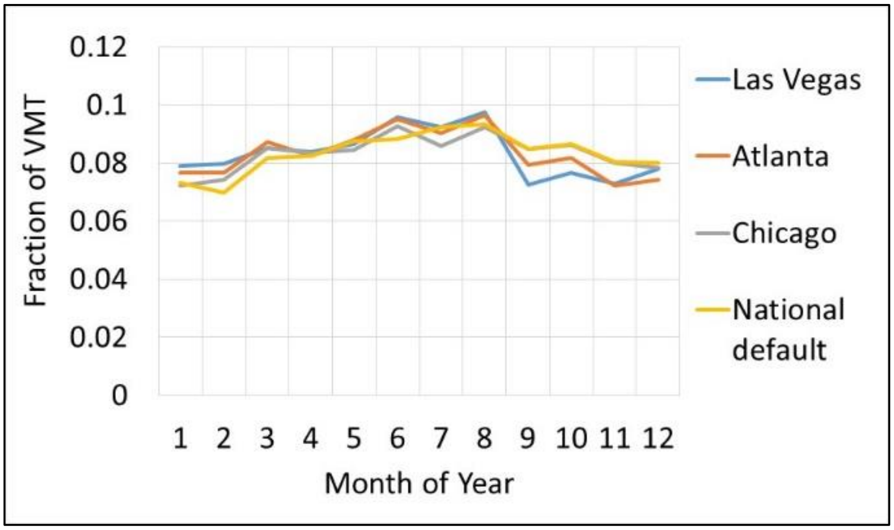


Figure 4-19. MD Comparison of Three County Monthly VMT Distributions

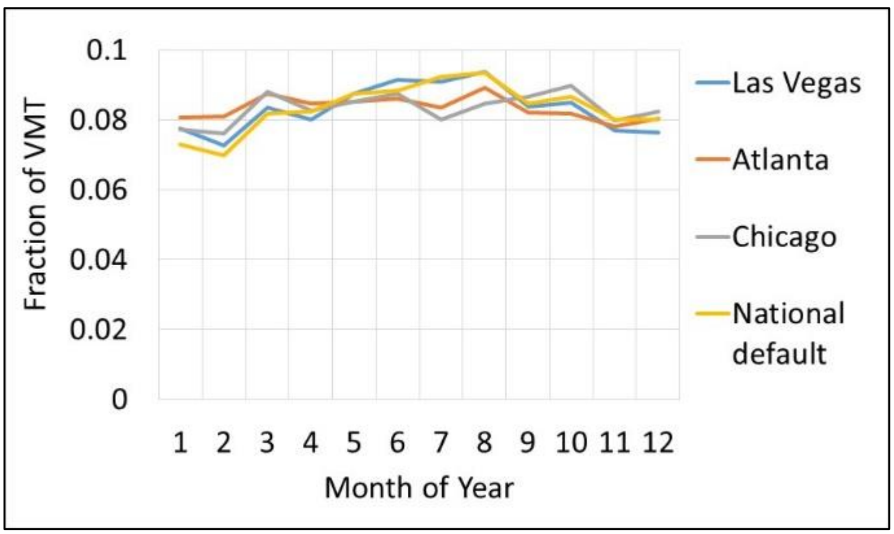


Figure 4-20. HD Comparison of Three County Monthly VMT Distributions

Road Type VMT Distributions

MOVES run in the County Scale (as required for the NEI and other official modeling purposes) allocates total VMT to the four road types of rural restricted, rural unrestricted, urban restricted, and urban unrestricted access using the 'RoadTypeDistribution' table. EPA requires that users provide local information for this table, and the MOVES default database national average RoadTypeDistribution table is not considered a suitable default to fall back to in the absence of local data. A better available default in MOVES can be calculated from outputs of a National Scale MOVES run; in this scale, MOVES uses additional allocation tables (such as 'ZoneRoadType') to accomplish the VMT allocation to roads with factors specific to each county in the US.

The next three tables show the road type VMT fractions separately for LD, MD, and HD vehicles, respectively, listing side-by-side the NEI defaults and A-100 VMT fractions by road. The percent VMT by road type sums to 100 percent over the four road types and varies by vehicle type. In MOVES, the national average road type VMT distribution differs for each of the 13 vehicle types; however, the vehicle telematics data distinguishes three types (LD, MD, and HD). The telematics data represent a spatial improvement in the default data because it updates the RoadTypeDistribution and ZoneRoadType tables. EPA's expectation for County Scale MOVES runs (required for NEI) is that counties input their own values and not rely on national average RoadTypeDistribution from the model database. Of the three case-study counties, only Cook County's database ("baseline" in following tables) was populated with the national average for this input; Fulton County and Clark County were populated with local data. The distribution of VMT to road types is important to the inventory because each road type has an associated speed distribution that differs for urban/rural and restricted/unrestricted access. For the LD vehicles (Table 4-1), Atlanta and Chicago data show that approximately 99 percent of the VMT is urban, which tracks with Atlanta's baseline (local) data where 93% of the VMT from LD vehicles (personal vehicles in Table 3-5) is classified as urban. The effect on Chicago's RoadTypeDistribution was a large shift from 9 and 25 percent of VMT on rural restricted and rural unrestricted access roads to less than 0.5 percent each in the A-100 National Database RoadTypeDistribution table. Las Vegas has a distribution that includes 16 percent of VMT on rural roads, an increase from the baseline of 6 percent rural.

Table 4-1. LD Vehicle Comparison of Three County Road Type VMT Distributions

	Atlanta (Fulton County)		Chicago (Cook County)		Las Vegas (Clark County)	
Road Type	**Baseline**	**CRC A-100**	**Baseline**	**CRC A-100**	**Baseline**	**CRC A-100**
Rural Restricted Access	2%	0%	9%	0%	3%	12%
Rural Unrestricted Access	4%	0%	25%	0%	3%	4%
Urban Restricted Access	44%	22%	23%	47%	24%	18%
Urban Unrestricted Access	49%	77%	43%	53%	70%	67%
Total	***100%***	***100%***	***100%***	***100%***	***100%***	***100%***

* The "LD" vehicles include the MOVES source types *Motorcycle*, *Passenger Car*, and *Light Passenger Truck*.

In Las Vegas, the rural VMT fraction is much higher for MD (Table 4-2) and HD (Table 4-3) relative to LD vehicles (Table 4-1). Table 4-3 shows that in Atlanta and Chicago the HD VMT occurs mostly (80% and 84%, respectively) on urban restricted access roads. For Chicago, this A-100 distribution differs greatly from the MOVES national average of approximately 24% for heavy-duty vehicle types (including single-unit long haul and combination unit trucks).

Table 4-2. MD Vehicle Comparison of Three County Road Type VMT Distributions

Road Type	Atlanta (Fulton County)		Chicago (Cook County)		Las Vegas (Clark County)	
	Baseline	CRC A-100	Baseline	CRC A-100	Baseline	CRC A-100
Rural Restricted Access	3%	0%	11%	0%	5%	24%
Rural Unrestricted Access	4%	2%	28%	1%	4%	7%
Urban Restricted Access	44%	44%	22%	46%	25%	24%
Urban Unrestricted Access	49%	55%	39%	53%	66%	45%
Total	***100%***	***100%***	***100%***	***100%***	***100%***	***100%***

* The "MD" vehicles include the MOVES source types *Light Commercial Truck* and *Single Unit Short-haul Truck*.

Table 4-3. HD Vehicle Comparison of Three County Road Type VMT Distributions

Road Type	Atlanta (Fulton County)		Chicago (Cook County)		Las Vegas (Clark County)	
	Baseline	CRC A-100	Baseline	CRC A-100	Baseline	CRC A-100
Rural Restricted Access	9%	1%	24%	0%	32%	64%
Rural Unrestricted Access	5%	1%	27%	0%	11%	10%
Urban Restricted Access	72%	80%	25%	84%	25%	21%
Urban Unrestricted Access	14%	18%	23%	15%	32%	5%
Total	***100%***	***100%***	***100%***	***100%***	***100%***	***100%***

* The "HD" vehicles include the MOVES source types *Single Unit Long-haul*, *Combination Unit Short-haul*, and *Combination Unit Long-haul* trucks.

4.3 Emissions Impacts Analysis

Baseline and Scenario Descriptions

In order to evaluate emissions inventory impacts, MOVES was run at the County Domain/Scale in inventory calculation mode at the hourly level for the year 2014. The pollutants included volatile organic compounds (VOC), carbon monoxide (CO), oxides of nitrogen (NO_X), and fine particulate matter ($PM_{2.5}$). The inputs for the model runs include the ambient meteorology, vehicle fleet descriptions, fuel parameters, inspection & maintenance programs, and activity (VMT, population, and speeds), which were included in the CDBs that EPA publicly released for Version 1 of the 2014 NEI[2]. The version 1 CDBs served as the baseline case, and for two scenarios a subset of input tables was replaced with the National Database data illustrated above in Sections 4.1 and 4.2.

The three CDBs were downloaded from EPA's website, and were run directly as-is to produce the 2014 annual baseline emissions estimates. The responsible agencies provided

[2] MOVES County Databases developed by US EPA as part of the Version 1 2014 NEI. Accessible as of January 2017. ftp://ftp.epa.gov/EmisInventory/2014/doc/onroad/2014v1_supportingdata/2014v1_CDBs/unseeded/

some local and some default data to EPA in their CDB submittals. Table 4-4 indicates which inputs of speed and VMT distributions were default (marked with an 'X'). The Fulton, Georgia CDB contained local data for all five inputs of interest to this study; the Cook, Illinois CDB contained defaults, and the Clark, Nevada CDB had default speeds but local VMT distributions.

Table 4-4. MOVES Default Data Usage by County in the Baseline

CDB Table Name	Fulton, GA	Cook, IL	Clark, NV
Average Speed Distribution		X	X
Road Type Distribution		X	
Hour VMT Fraction		X	
Day VMT Fraction		X	
Month VMT Fraction		X	

The scenario data for the emissions analysis replaced the above listed MOVES CDB tables with ones developed from the vehicle telematics data specific to each county. All other inputs (e.g., age distribution, fuels, etc.) were the same between baseline and scenario. The analysis included two scenarios, representing likeliness of end-use of the National Database data. In the first scenario, only the average speed distribution data from telematics was input; the VMT distributions are the same as the baseline. This scenario represents a likely case where a modeler has good estimates of VMT distributions but insufficient information on vehicle speeds. In the second scenario, all five tables are based on the vehicle telematics data.

Results

The annual average day impact of the speed-only data in Fulton County, Georgia is a change in VOC, NO_X, and $PM_{2.5}$ emissions of 4%, 5% and -1%, relative to the baseline. When including VMT distributions with the speed data from A-100, the cumulative impacts on emissions are increases of 9%, 5%, and 2% from the baseline VOC, NO_X, and $PM_{2.5}$.

Table 4-5. Atlanta Annual Average Day Emissions

Pollutant	Baseline Emissions (TPD)	CRC A-100 Speeds		CRC A-100 Speeds and VMT Distributions	
		Emissions (TPD)	Change from Baseline	Emissions (TPD)	Change from Baseline
VOC	11.4	11.9	4%	12.4	9%
CO	145.5	155.2	7%	152.8	5%
NO_X	30.2	31.8	5%	31.7	5%
$PM_{2.5}$	1.1	1.1	-1%	1.2	2%

Figure 4-21 and Figure 4-22 break out Atlanta's daily total emissions by road type and vehicle class. Approximately half of the Fulton County on-road VOC inventory is from starts and evaporative emissions occurring "off-network," and these emissions are constant across the baseline and two scenarios in Figure 4-21 (Upper Left Panel). In the speed-only scenario, the relative emissions on different road types does not change much because it uses the same road type VMT distribution as the baseline. The third scenario shows a shift in the emissions from urban restricted towards urban unrestricted due to a corresponding shift in the road type VMT distribution. Although total VMT is the same, it was allocated to different road types and thus combined with different average speed distributions. The effect of road type VMT fractions is more pronounced in the other two cities. Figure 4-22 shows that most of the VOC and CO emissions are from LD vehicles and HD makes up a relatively larger portion of the NO_X and $PM_{2.5}$ inventory. The vehicle category “Other” includes buses, refuse trucks, and motorhomes and their emissions do not change by scenario.

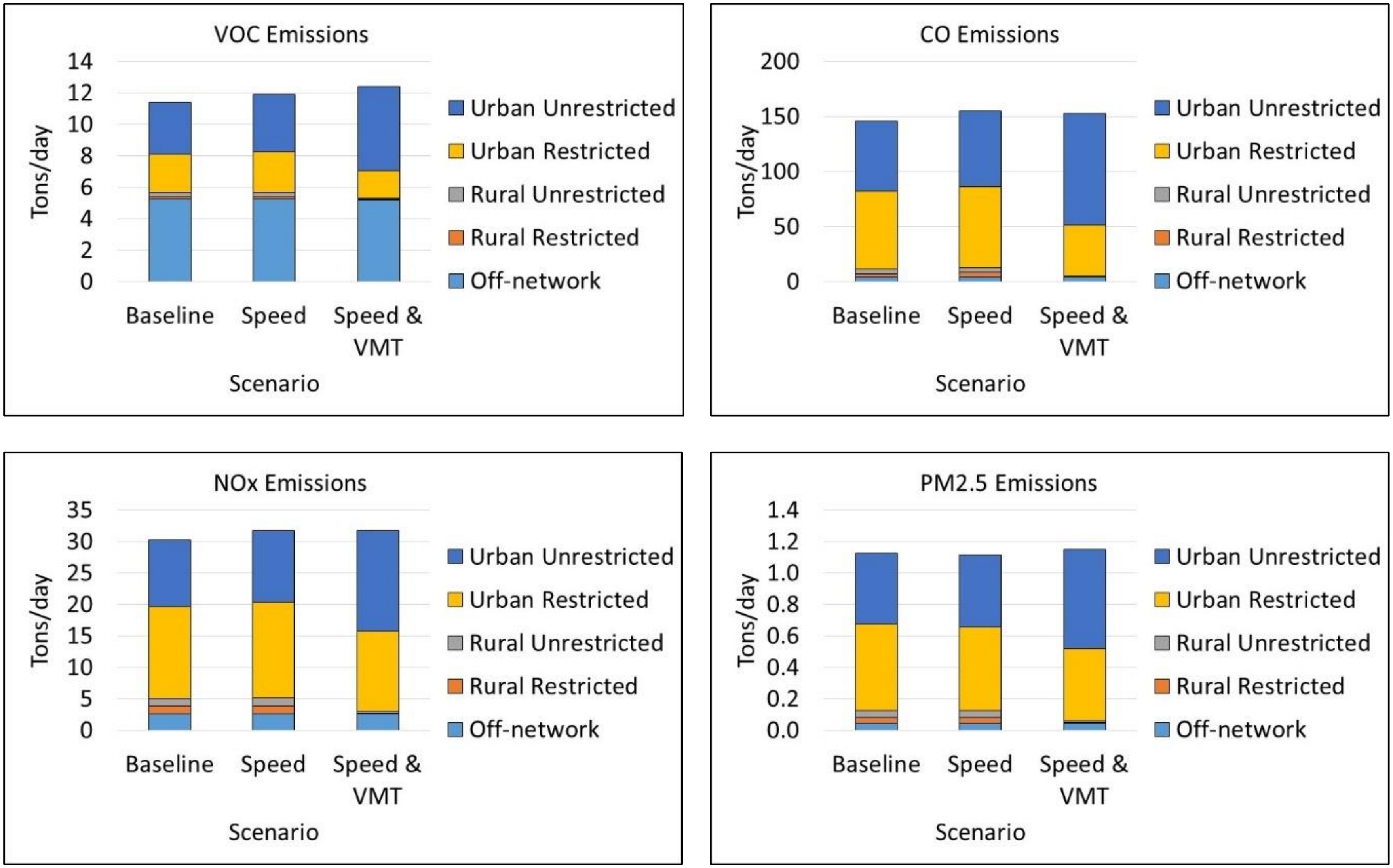


Figure 4-21. Atlanta Annual Average Day Emissions by Road Type and Scenario

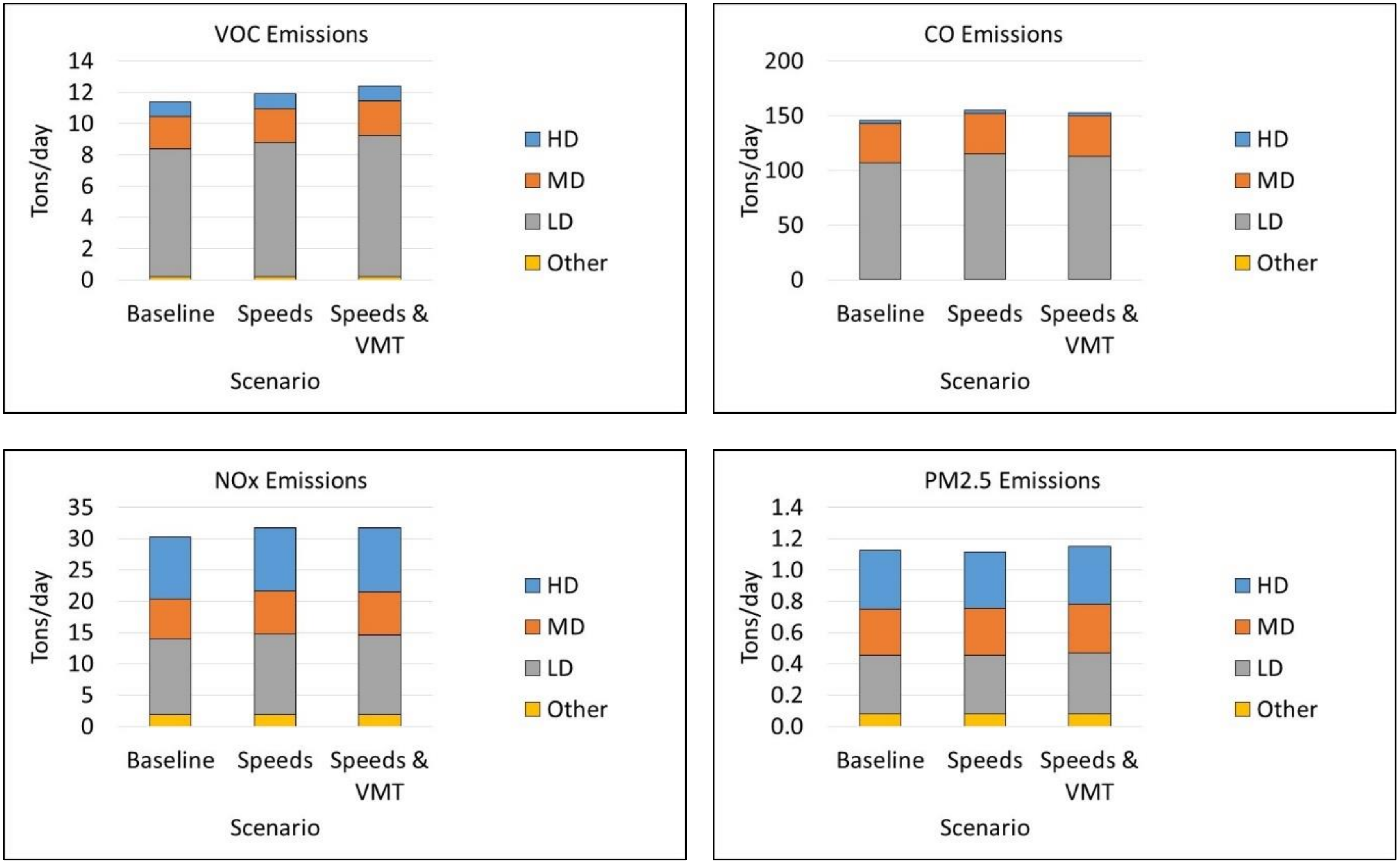


Figure 4-22. Atlanta Annual Average Day Emissions by Vehicle Type and Scenario

The daily total emissions impact in Chicago is larger than in Atlanta because there is more congestion in Chicago and the baseline for this city was MOVES national average data; therefore, the difference in the vehicle telematics data speeds and VMT distributions was larger change than for Atlanta, where the baseline already used local data. In Chicago, emissions of VOC, NO_X, and $PM_{2.5}$ changed by 5, 3, and 14 percent, respectively, in the speed-only scenario and similar results for the full telematics scenario (6, 4, and 13 percent changes).

Table 4-6. Chicago Annual Average Day Emissions

Pollutant	Baseline Emissions (TPD)	CRC A-100 Speeds		CRC A-100 Speeds and VMT Distributions	
		Emissions (TPD)	Change from Baseline	Emissions (TPD)	Change from Baseline
VOC	68.8	72.5	5%	73.3	6%
CO	651.9	677.9	4%	698.5	7%
NO_X	135.2	139.4	3%	140.2	4%
$PM_{2.5}$	4.6	5.3	14%	5.2	13%

The difference in Chicago emissions by road type is strikingly different between the Speed & VMT scenario and baseline, particularly for CO, NO_X, and $PM_{2.5}$. The changes in emissions appear to be driven by the LD vehicles for VOC and CO emissions; and MD and HD for NO_X and PM.

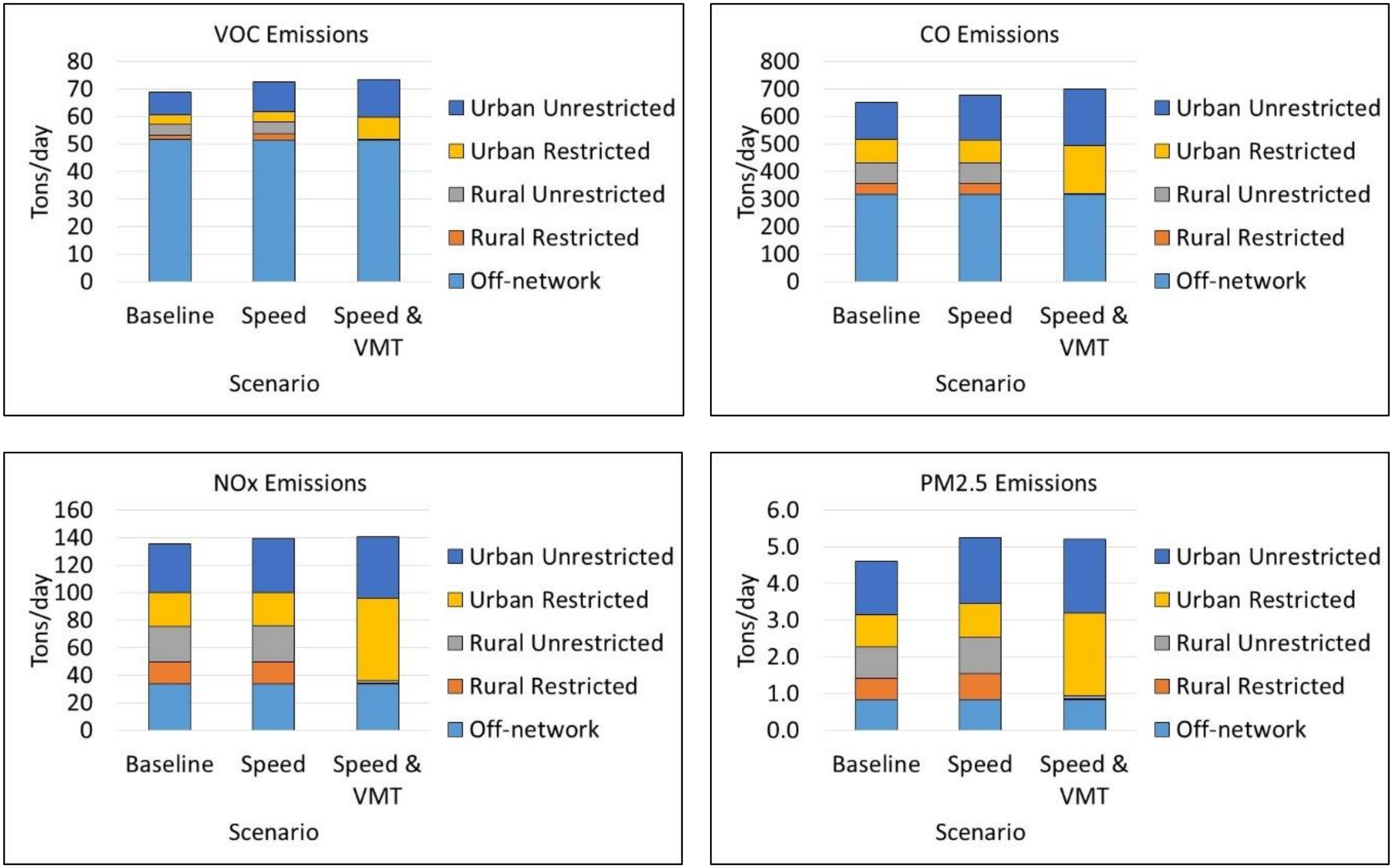


Figure 4-23. Chicago Annual Average Day Emissions by Road Type and Scenario

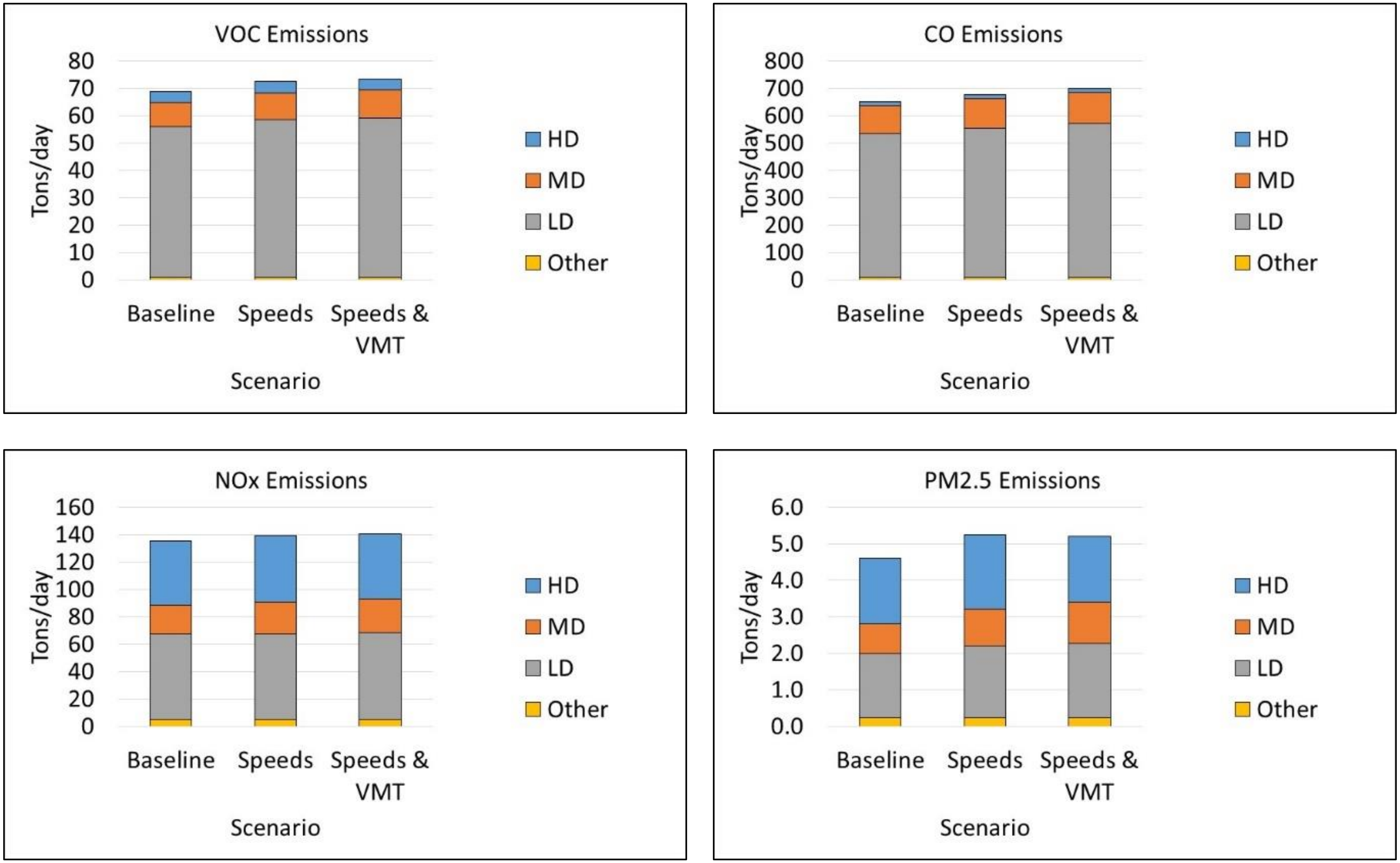


Figure 4-24. Chicago Annual Average Day Emissions by Vehicle Type and Scenario

The telematics data in Las Vegas decreased the annual daily on-road emission inventory of VOC and $PM_{2.5}$ between 1 and 9 percent depending on scenario, and increased NO_X by 1 to 2 percent.

Table 4-7. Las Vegas Annual Average Day Emissions

Pollutant	Baseline Emissions (TPD)	CRC A-100 Speeds		CRC A-100 Speeds and VMT Distributions	
		Emissions (TPD)	Change from Baseline	Emissions (TPD)	Change from Baseline
VOC	29.7	29.5	-1%	29.2	-2%
CO	329.3	336.4	2%	341.9	4%
NO_X	68.3	69.4	2%	69.2	1%
$PM_{2.5}$	1.7	1.6	-3%	1.5	-9%

Figure 4-25 shows that Las Vegas on-road emissions in the full scenario (Speed & VMT) have more emissions on rural restricted access roads and lower emissions on urban unrestricted roads. The largest change in daily total emissions in Las Vegas from a vehicle class (Figure 4-26) appears to be the decrease in HD vehicle $PM_{2.5}$ in the Speeds & VMT scenario.

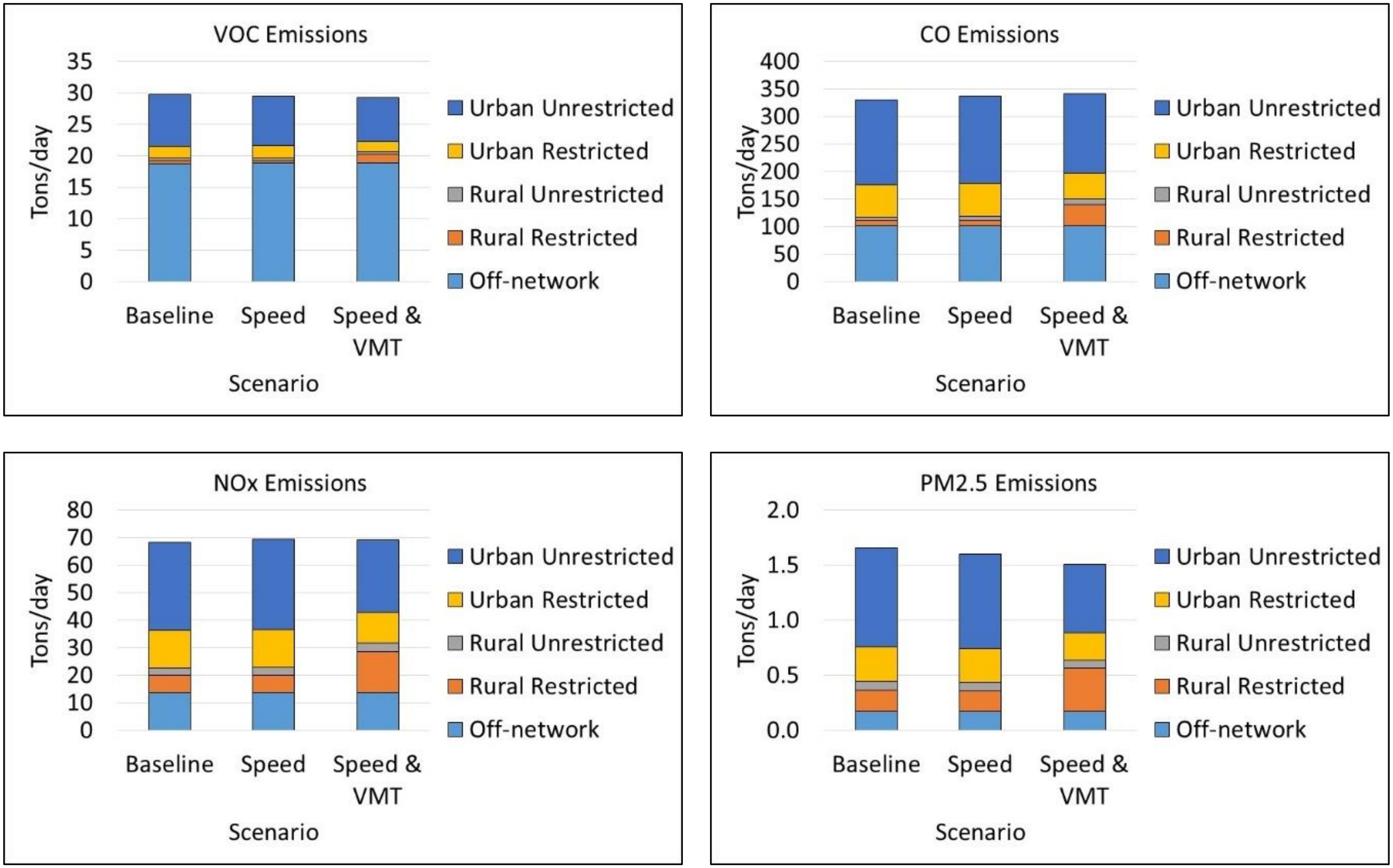


Figure 4-25. Las Vegas Annual Average Day Emissions by Road Type and Scenario

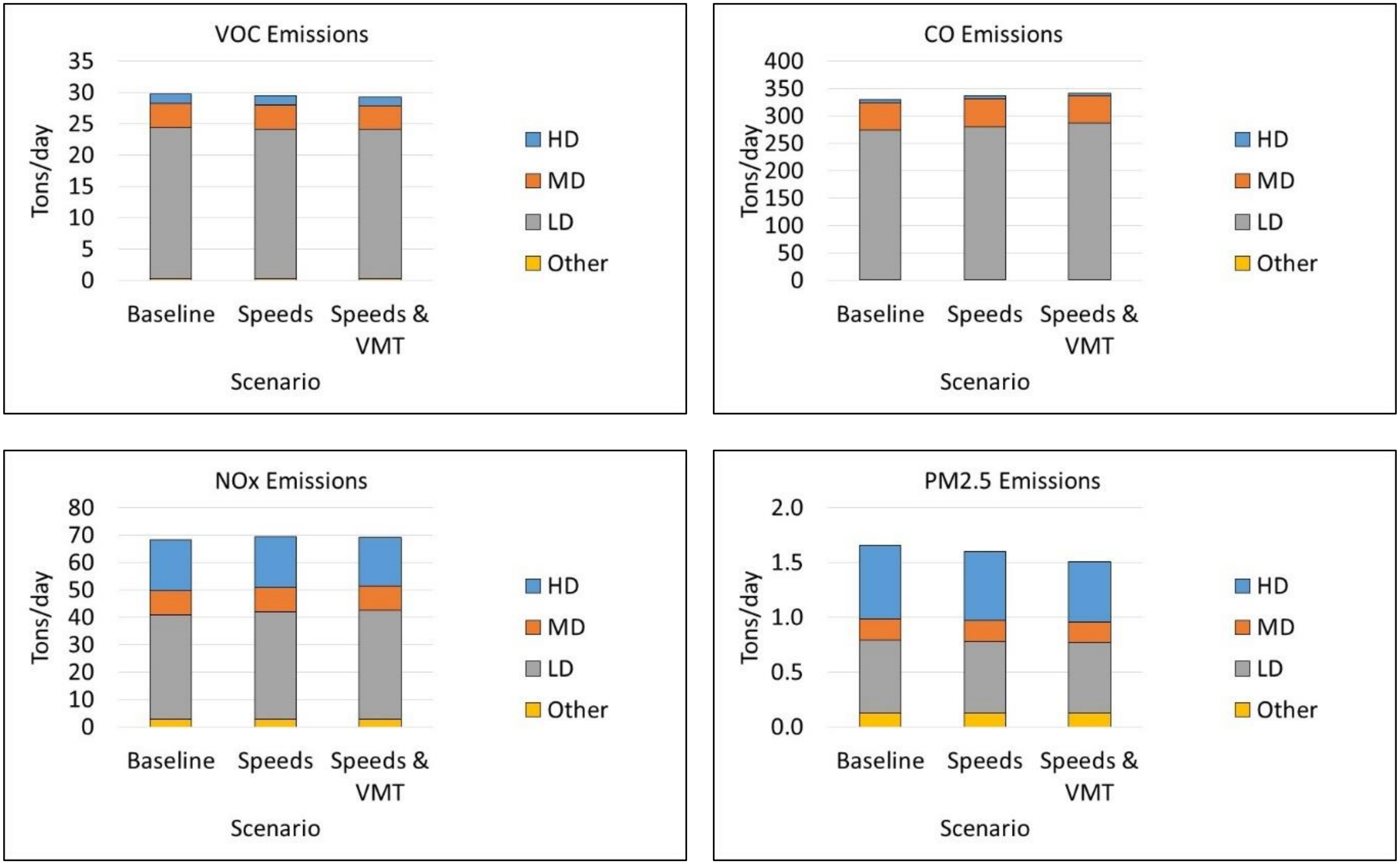


Figure 4-26. Las Vegas Annual Average Day Emissions by Vehicle Type and Scenario

The next three figures show the hourly changes in emissions between the speeds-only scenario and baseline for a July weekday. The hourly impact on the emissions inventory in Atlanta (Figure 4-27) shows increases of up to 10 percent for each of the four pollutants. Chicago (Figure 4-28) had similar magnitude of hourly changes as Atlanta, except for $PM_{2.5}$ emissions. Chicago's $PM_{2.5}$ emissions increased between 10 to 20 percent in most hours of the day. The emission inventory impacts in Las Vegas (Figure 4-29) from the speeds-only scenario are the smallest of the three cities.

The final set of three figures shows the percent emissions changes due to the speed and VMT distributions data. The percent changes in emissions by hour from this full scenario dwarf the speeds-only changes (which more easily viewed on their own above). The changes in hourly emissions are large: up to 50 percent change in Atlanta (Figure 4-30), 110 percent change in Chicago (Figure 4-31), and 35 percent in Las Vegas (Figure 4-32) in an individual hour on a summer weekday. Such large changes in hourly emissions can be important in predicting ozone and particulate matter concentrations using air quality models, though such an evaluation was outside the scope of this study.

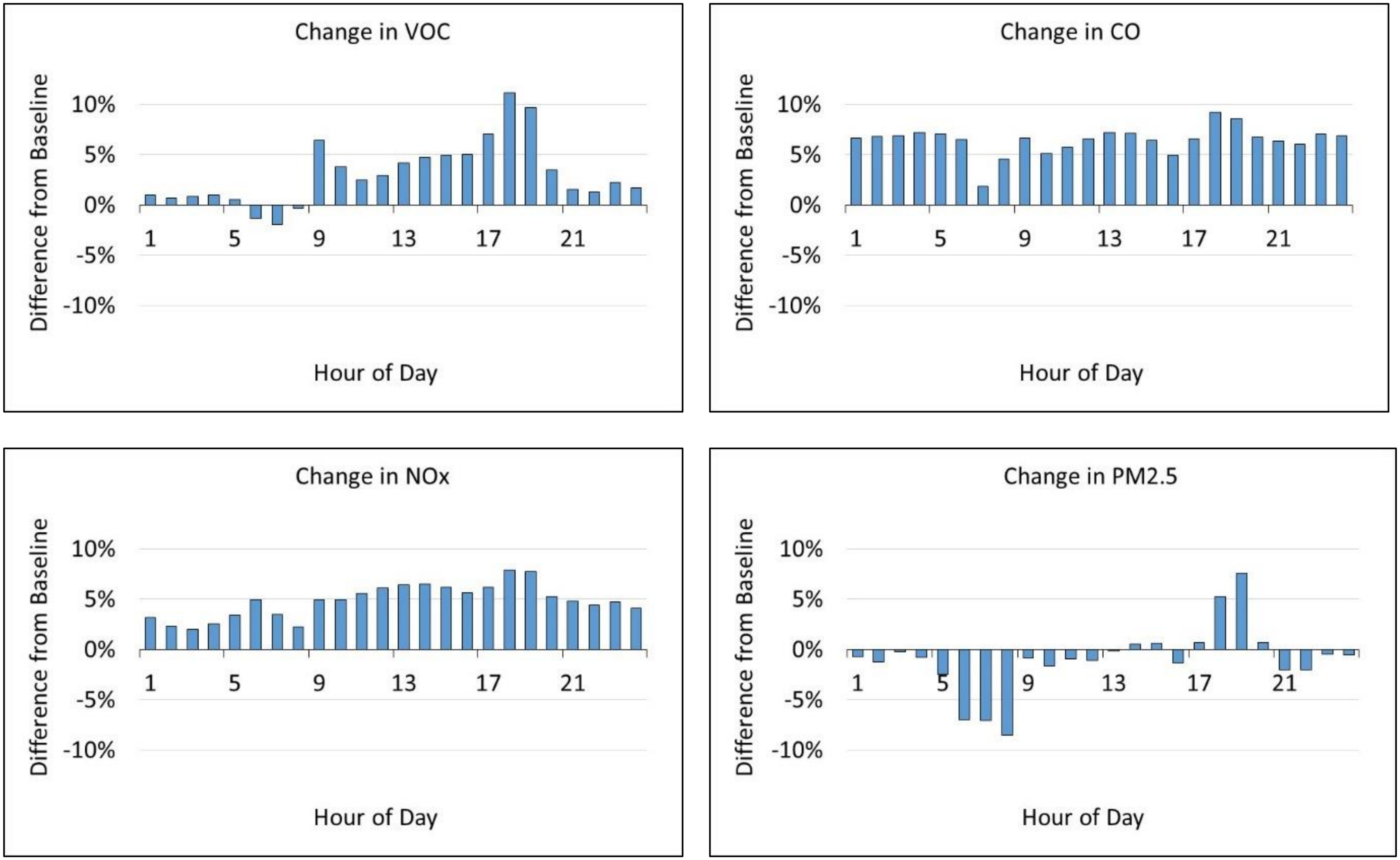


Figure 4-27. Atlanta July Weekday Hourly Impacts of Speed Data

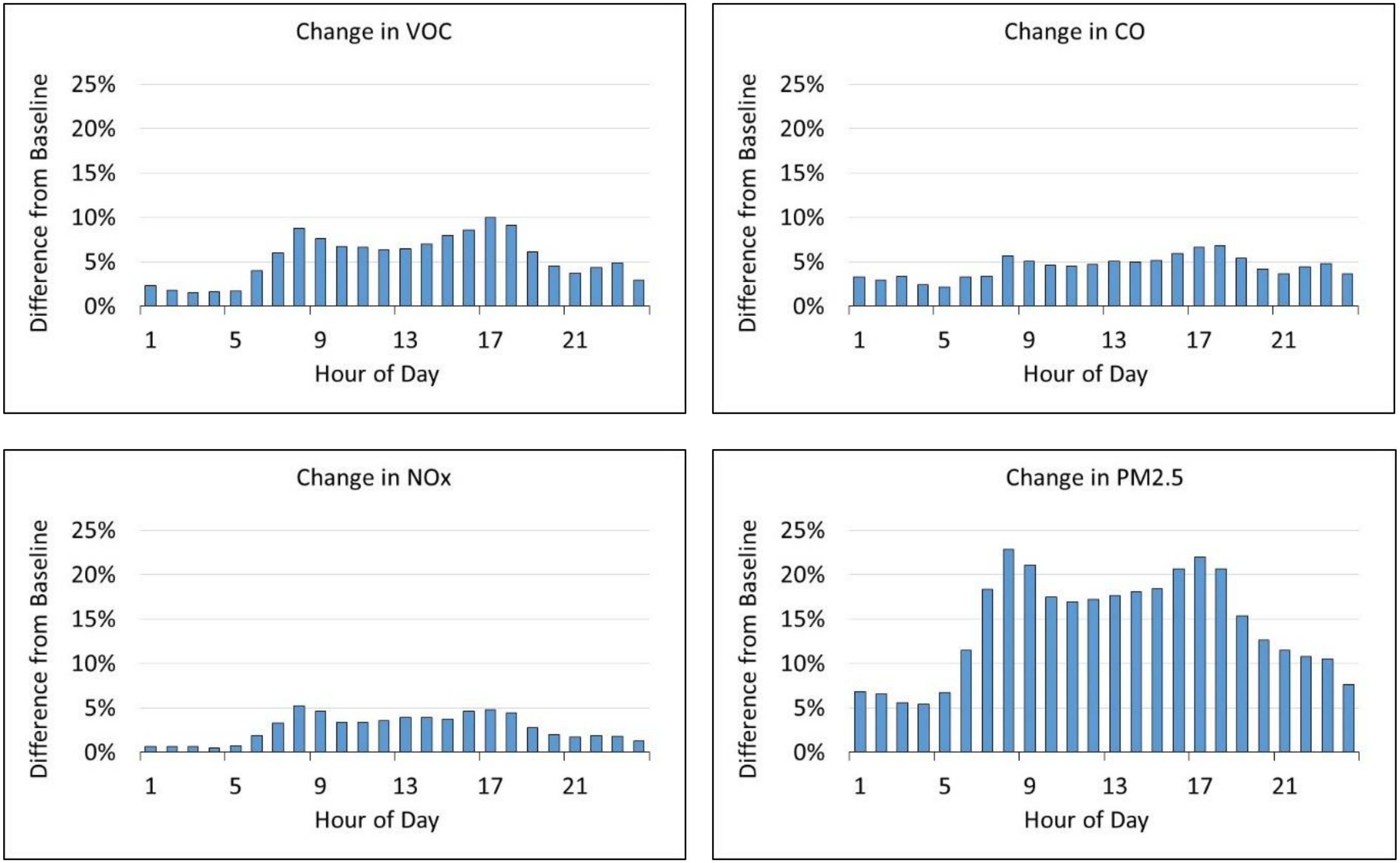


Figure 4-28. Chicago July Weekday Hourly Impacts of Speed Data

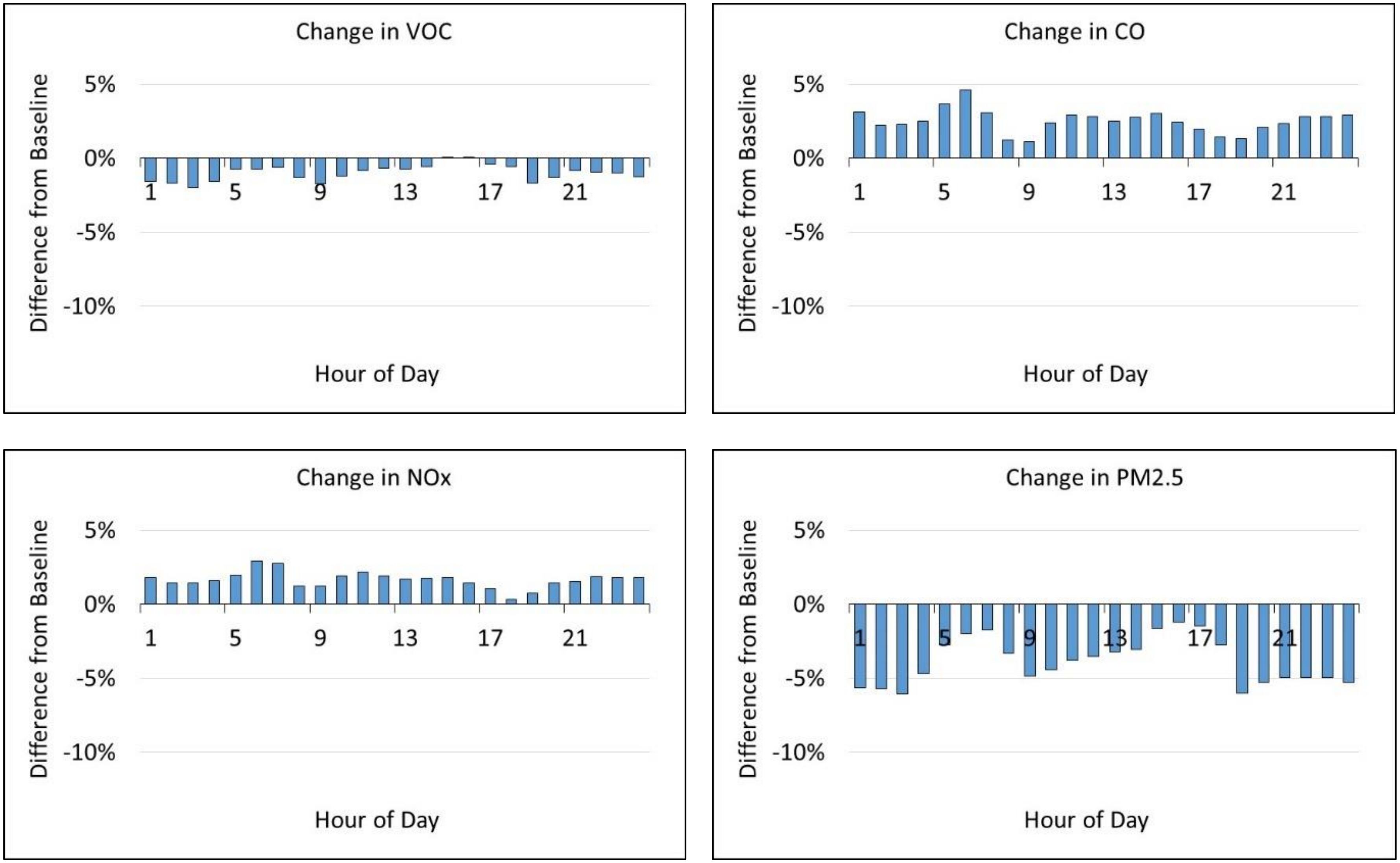


Figure 4-29. Las Vegas July Weekday Hourly Impacts of Speed Data

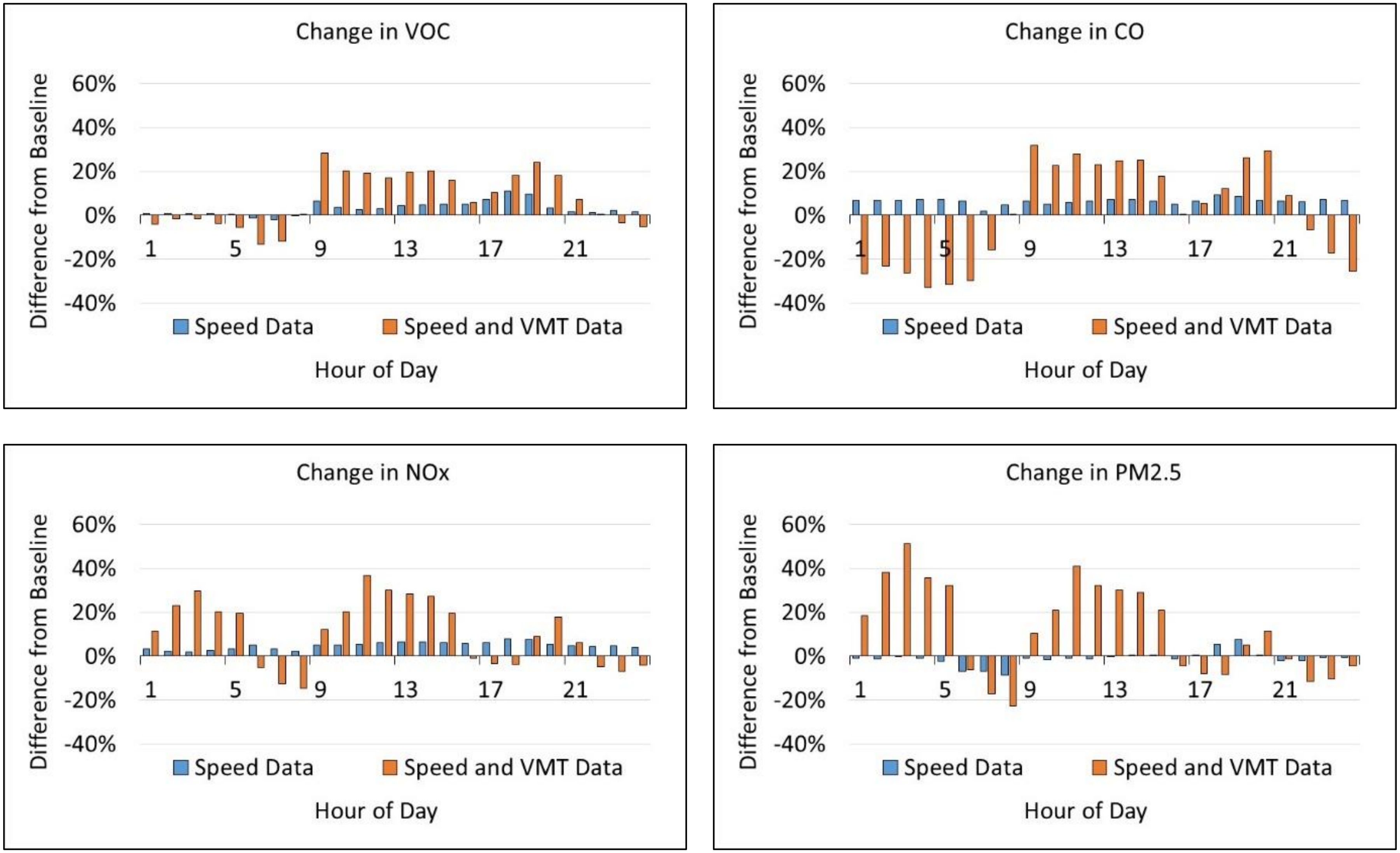


Figure 4-30. Atlanta July Weekday Hourly Impacts of Speed and VMT Distributions

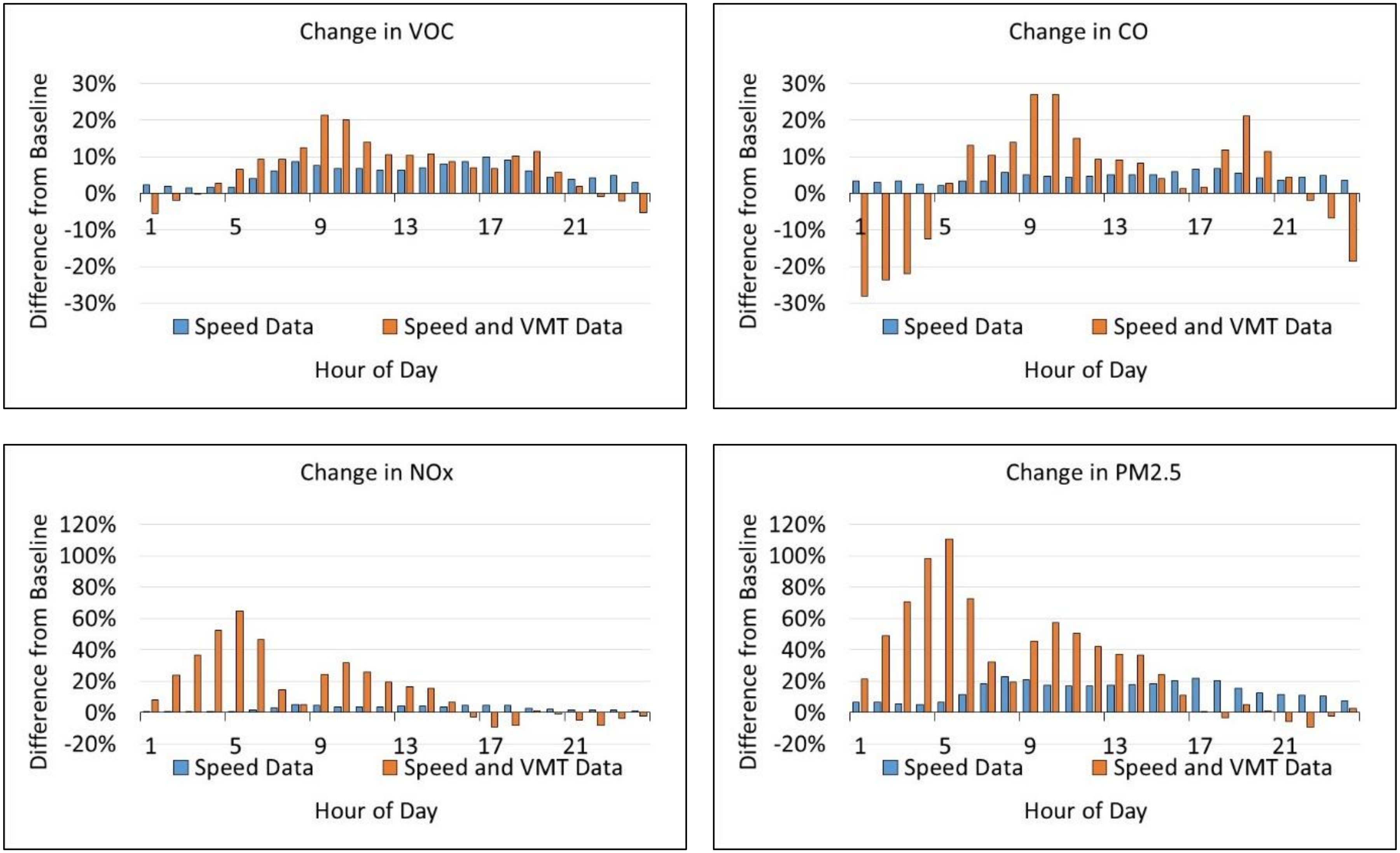


Figure 4-31. Chicago July Weekday Hourly Impacts of Speed and VMT Distributions

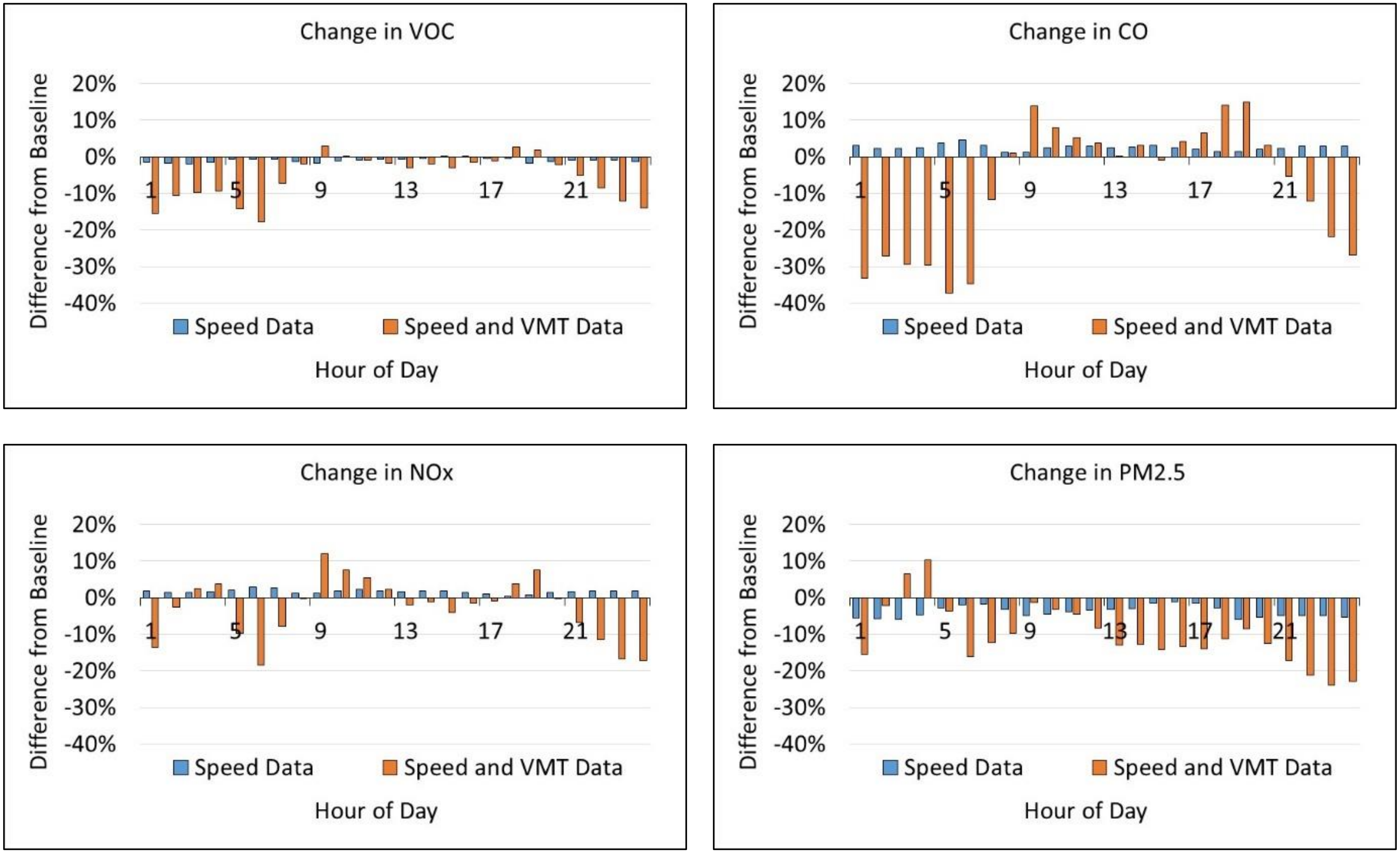


Figure 4-32. Las Vegas July Weekday Hourly Impacts of Speed and VMT Distributions

5.0 Conclusions

CRC sponsored the A-100 project to improve NEI inputs of speeds and VMT distributions for MOVES and SMOKE. ERG selected StreetLight Data to provide vehicle telematics data for the project. The National Database provided with this study provides speeds and VMT distributions for MOVES and SMOKE covering each county in the continental U.S. (excluding Alaska and Hawaii), with data that are unique by city and by vehicle type. In the core counties in Atlanta, Chicago, and Las Vegas, there were several interesting findings. First, peak hour heavy-duty commercial truck speeds were higher than those of light and medium duty vehicles. This result is different than other datasets, which traditionally show trucks travel at slightly slower speeds than the rest of traffic, and is likely due to differences in travel between cars and commercial trucks within the broad MOVES road categories.

This project also demonstrated how telematics data can help improve temporal VMT distributions, particularly by hour of the day, and day of the week. VMT patterns in the three cities show clear differences between LD, MD, and HD. LD travel is highest during commute times, MD travel tends to also begin with the morning peak but remains elevated through the end of business hours, and HD truck travel peaks during midday. The distribution of VMT by month was also analyzed, but the results appear to be been affected by a shift in sample size or method in the telematics data; unexpected drops in VMT were observed between July and August, which do not correspond with typical VMT patterns observed from traffic count data. For this reason, we do not recommend using these data to update monthly VMT distribution.

An emissions sensitivity analysis was performed for three cities, running MOVES with information used in the Version 1 NEI vs. telematics data for average speed and hourly VMT distribution. In the three cities, the impact of using telematics-based model inputs on daily total emissions ranged from -2 to 9 percent for VOC, 1 to 5 percent for NO_X, and -9 to 14 percent for $PM_{2.5}$. To some degree, these totals reflect offsetting effects of speed and VMT distribution over the course of a day. The emission changes were much larger in magnitude for individual hours of the day

A technical challenge for this project was accessing the large body of telematics data at the nationwide scope with a fine level of detail. Resource constraints resulted in building the National Database from processing a 1/16th sample size of available data (with the exception of 50 counties which received a full draw). As a result of sample size, some counties needed to be grouped into a larger area, such as averages for non-core counties inside MSAs or US census region-average for counties outside MSAs. Nonetheless, the use of telematics data is a substantial improvement to the NEI over national average default data, providing the ability to improve our understanding of emissions trends and potentially better predict air pollutant concentrations.

6.0 Acknowledgements

The authors gratefully acknowledge the CRC Atmospheric Impacts Committee for devising project objectives and providing funding, and project leaders Dan Baker (Shell), Mark Janssen (LADCO), and Susan Collet (Toyota) who provided technical guidance; Laura Schewel, Catherine Manzo, and Neal Bowman of StreetLight Data, Inc. for their vehicle telematics data; EPA’s Office of Air Quality Planning and Standards (OAQPS) and Office of Transportation & Air Quality (OTAQ) for NEI coordination; and Doug Jackson, Rebecca Bayham, and Anita White of ERG for script development, GIS support, formatting and editing.

7.0 References

1. Eastern Research Group, Inc., 2013. "Study of MOVES Information for the National Emission Inventory: CRC Project A-84", CRC Final Report, October.

2. Eastern Research Group, Inc., 2014. "MOVES Input Improvements for the 2011 NEI: CRC Project A-88", CRC Final Report, October.

3. U.S. EPA, 2016. "2014 National Emissions Inventory, version 1 Technical Support Document," Office of Air Quality Planning and Standards, December.

4. U.S. EPA, 2015. "Technical Support Document, Preparation of Emissions Inventories for the Version 6.2, 2011 Emissions Modeling Platform," Office of Air Quality Planning and Standards, August.

Appendix A

Note: The following is a summary of data suorces identified for CRC project A-100. The text has been adapted from a memorandum to remove confidential business information (CBI).

The US EPA, States, and practitioners develop on-road mobile source emission inventories for input to air quality models (AQMs) using primarily two modeling systems – the Motor Vehicle Emissions Simulator (MOVES) model in combination with the Sparse Matrix Operator Kernel Emissions (SMOKE) processor. In addition, many states and local agencies use MOVES standalone for official purposes such as State Implementation Plans (SIPs) and transportation conformity analyses. This broad community of on-road emissions modelers often rely on existing or "off-the-shelf" input datasets for MOVES and/or SMOKE that US EPA develops every three years for the National Emissions Inventory (NEI). The datasets are a combination of state-submitted data and national defaults. The NEI modeling platform is the basis for other on-road rulemaking analyses and therefore must be as accurate as possible.

The CRC A-100 project is intended to improve the default estimates of two important inputs that determine the magnitude as well as spatial and temporal variability of on-road emissions estimated by MOVES and SMOKE: (1) vehicle speeds and (2) profiles of vehicle-miles traveled (VMT) including VMT mix. Currently, national average defaults are used for these inputs when states do not provide custom data. For speeds in particular, local data are not often available, so most states do not provide their own data; when they do, it is often based on travel demand models instead of directly measured data. The objective of A-100 is to identify sources for, and obtain new inputs for speed and VMT temporal patterns that cover each US county at an hourly level. This memorandum discusses the purchasing options for large-scale datasets that can be formatted into the level of detail required by MOVES and SMOKE, and recommends a course of action for CRC given timing, budget, and project objectives.

Data Sources Evaluated

Under Task 1, ERG sought and evaluated sources of data required to generate nationwide, county-level inputs of speed and VMT profiles for MOVES and SMOKE for the 2014 NEI. Hereafter, "SMOKE" refers to the "SMOKE-MOVES Integration Tools" that EPA currently uses to develop the on-road emissions for the NEI.

Telematics Data Vendors

Data Detail Requested by ERG

ERG requested cost estimates from vendors of vehicle speed data at a level of detail matching the input requirements/capabilities of both MOVES and SMOKE. The specific data we would receive from a vendor would be results of their in-house data processing of high resolution speed data from a large number of vehicle trips, reported to ERG as the total distance, time, and number of observations by the following details:

- 20 speed bins
- 4 road types
- 7 days of the week
- 24 hours of the day
- 12 months of the year
- All U.S. counties

Why ERG Requested this Detail

Rather than direct speeds (miles per hour), we requested the distance and time separately to have flexibility in calculating the speeds ourselves. One benefit of having the data in these terms is that it allows us to evaluate grouping together counties which may have sparse or missing data for some categories, and to properly estimate the average speed within these groupings. Furthermore, it enables us to potentially use the distance data records to compute profiles of vehicle miles travelled (VMT) to supplement the Vehicle Travel Information System (VTRIS) data source for VMT temporal profiles and mix.

The same speed dataset would feed both MOVES and SMOKE, but ERG will need to pre-process the data (as part of the tool development under Task 2) in order to fit each modeling system. Table 1 shows that the two models allow the same level of detail for speed data on many parameters, with two differences noted.

Table 1. Speed Input Detail Capabilities of MOVES and SMOKE

Parameter	**Difference Exists?**	**MOVES Input**	**SMOKE Input**
Months		12 Months of Year	Same
Day types	Yes	2 day types (weekday/end)	All 7 days of week
Hours		24 Hours of Day	Same
Sub-hour	Yes	16 MOVES speed bins*	One average speed for the full hour
Vehicle types		13 MOVES source types*	Same (via the Source Category Code; SCC)
Road types		4 MOVES road types*	Same (via the SCC)

* Tables 2, 3, and 4 define the MOVES speed bins, source types, and road types, respectively.

The first of two differences between models is that MOVES allows detail at the sub-hour level whereas SMOKE does not. Within each hour, MOVES requires fractions of VMT that belong to each of 16 MOVES speed bins (defined in Table 2), whereas SMOKE allows a single, average speed in a given hour. The second difference is SMOKE allows more day types in the speed profiles (each of 7 days of the week); MOVES only distinguishes between weekday and weekend day types.

Tables 2 through 4 define categories of MOVES speed bins, source types, and road types that will be used for this work.

Table 2. MOVES Speed Bins

MOVES Speed Bin ID Code	"Midpoint" Speed (mph)	Speed Range
1	2.5	speed < 2.5mph
2	5	2.5mph <= speed < 7.5mph
3	10	7.5mph <= speed < 12.5mph
4	15	12.5mph <= speed < 17.5mph
5	20	17.5mph <= speed <22.5mph
6	25	22.5mph <= speed < 27.5mph
7	30	27.5mph <= speed < 32.5mph
8	35	32.5mph <= speed < 37.5mph
9	40	37.5mph <= speed < 42.5mph
10	45	42.5mph <= speed < 47.5mph
11	50	47.5mph <= speed < 52.5mph
12	55	52.5mph <= speed < 57.5mph
13	60	57.5mph <= speed < 62.5mph
14	65	62.5mph <= speed < 67.5mph
15	70	67.5mph <= speed < 72.5mph
16	75	72.5mph <= speed

Table 3. MOVES Source Use Types (Vehicles)

MOVES Source Type ID Code	Source Type Name
11	Motorcycles
21	Passenger Car
31	Passenger Truck
32	Light Commercial Truck
41	Intercity Bus
42	Transit Bus
43	School Bus
51	Refuse Truck
52	Single Unit Short-haul Truck
53	Single Unit Long-haul Truck
54	Motor Home

MOVES Source Type ID Code	Source Type Name
61	Combination Short-haul Truck
62	Combination Long-haul Truck

Table 4. MOVES (On-network) Road Types used in the NEI

MOVES Road Type ID Code	Road Type Name
2	Rural Restricted Access
3	Rural Unrestricted Access
4	Urban Restricted Access
5	Urban Unrestricted Access

Cost of New Data

ERG requested quotations for the data purchase outlined above from three different vendors known to compile vehicle trip and speed information from some combination of personal navigation devices, on-board GPS systems, mobile devices: TomTom, StreetLight, and Inrix. The mobile traffic app Waze was also contacted, though it is unclear if they compile speed data in a similar manner to the other three. Waze did respond to our inquiry, but declined to provide a quote for this work or any information on what data they might have available. A follow-up email seeking their reason for declining (i.e. lack of data, lack of interest, or COI) was not returned. Inrix did not respond to two requests ERG sent through their general business development web contact form (a contact ERG had worked with in the past is no longer with the company). However, in 2012 ERG received a quote from Inrix for a similar pull of data needed to update speed distributions for MOVES2014, but at the national rather than county level; the quote at that time was **REDACTED**. Unless their pricing structure has changed significantly, we assume the quote for county level data would far exceed the A-100 project budget.

ERG did have substantial discussions with both TomTom and StreetLight, which led to the quotations shown in Table 5, summarized to provide a high-level comparison between the two. Additional discussion on each is presented below. The costs are CBI and should not be shared with any individuals outside the CRC project A-100 panel.

Table 5. Summary of Data Sources for Vehicle Speed Distributions for all US Counties

Vendor	Vehicle Types Available	Road Types Available	Direct Cost (CBI)
TomTom	LD	Urban and Rural, Restricted and Unrestricted Access	**REDACTED**
StreetLight	LD, MD, HD	Urban and Rural, Restricted and Unrestricted Access	**REDACTED**

Both vendors can provide the temporal level of detail required for this work and for each U.S. county.

TomTom: Background

Vehicle in-use data is collected by TomTom, which manufactures and sells portable GPS units as well as an iPhone application. Some users of TomTom units give permission to TomTom to collect and store users' personal (anonymous) data on TomTom servers. The data is collected while the GPS unit is on, either in map or navigation mode. As long as the device is turned on, it is gathering data. A unit's GPS tracks are delivered to TomTom servers when data is collected either over the cell network as a "live" feed or as a "non-live" stream of data when the user connects to receive software or map updates.

Data collection began in January 2008. The data has been collected continuously, and the database currently has over 1 trillion data points. Since all U.S. drivers do not use a TomTom GPS unit or app and users who "opt in" are self-selective, biases could exist in the data that is collected. Anecdotally, drivers that own GPS units are less likely to use them when they drive in familiar areas in comparison with unfamiliar areas. TomTom data is obtained from units on all road types but at this time the data does not distinguish source types. Since these are portable devices, they are not able to capture vehicle information. TomTom suspects that "virtually all" of their vehicles are light-duty cars, trucks, and vans. TomTom data is obtained from all areas of North America where vehicles with TomTom GPS units drive. There are some areas where their data counts are low, but for any reasonably sized city TomTom states that they have an "excellent quantity of data."

Because TomTom units are not in all vehicles or even in a random fraction of all vehicles, the data cannot be used to determine absolute VMT. However, the TomTom data can be used to estimate light-duty relative VMT distributions as well as vehicle speed distributions since some vehicles in traffic will be sending their speed data to TomTom.

TomTom: ERG Working History

The ERG project team has a positive working history with TomTom; in the past we purchased a nationally-aggregated dataset to develop the national average speed distribution for the MOVES model database for EPA. TomTom's cost quote for county-level speed data takes into account our past work together because the query was already developed under the previous effort. Therefore, minimal additional TomTom staff labor time is needed to modify the query to add additional data fields for this work. The additional data fields we requested from them for this work include just (1) county and (2) day of the week. However, the addition of these parameters increases the database size delivery substantially. With approximately 3,143 counties, 20 speed bins, 4 road types, 24 hours, 7 days of the week, and 12 months of the year, the total number of aggregate distance and time records could reach up to 510 million. Not all counties in the U.S. necessarily have all 4 of the road types (urban and rural), so the 510 million is an upper limit estimate.

TomTom: New Discussions for A-100 Work

ERG held a conference call with TomTom staff on June 20, 2016, with numerous email exchanges before and after that date. During our call with TomTom, we discussed that while the NEI was specific to 2014, we felt that calendar year was less important than having a robust speed dataset. The TomTom dataset that would be drawn on for this work therefore includes data points over the years 2010 through 2014, when they were receiving relatively high amounts data from participants who opted into TomTom's program of sharing personal GPS device data. Starting around 2014, the amount of data supplied to program declined because users began switching to mobile phone apps for navigation. Including data pre-2014 increases the robustness of the speed dataset and we do not expect older years to bias speeds.

TomTom staff provided their final price quote (in Table 5) on July 25th.

TomTom: Limitations

From a technical standpoint, the TomTom data is limited in that it includes only light-duty (LD) vehicles. While these are excellent tracers for the speed of overall traffic, sometimes heavy-duty trucks are subject to lower speed limits on highways or may elect to drive slower due to safety concerns of stopping ability while carrying a heavy load. The TomTom data has no way of providing us with any speeds for the non-LD vehicles.

From a practical standpoint, TomTom's price quote exceeds by a wide margin what the A-100 project's data budget can afford (our initial estimate was based on the cost of data purchase for EPA's national average default speeds in 2012). However, given the scope and volume of data, we consider this quote to be fair – compared to the 2012 quote from Inrix, for example. should CRC choose to pursue this data source perhaps additional funds could be added to the project, either exclusively or in combination with cutting ERG's scope of work (e.g., no VMT temporal profiles).

StreetLight: Background

StreetLight Data (http://www.streetlightdata.com/) is a firm based in San Francisco specializing in "Big Data analytics to help companies and governments make smarter decisions." Their data are derived from billions of trips created from archival, anonymous, trace data from millions of GPS devices. The devices include smart phone applications, in-dashboard car navigation systems and commercial fleet management systems. The data have a spatial precision of approximately 5 meters, a high frequency sampling rate, and the ability to separate commercial and personal trips.

StreetLight: ERG Working History

ERG does not have a past history working with StreetLight. However, StreetLight appears to be very enthused to cooperate on this project. The initial meeting included a presentation from their CEO that reflected background research on MOVES, and they have been very responsive and resourceful in addressing several rounds of questions from ERG. StreetLight also offered to sit in on a call with the CRC project panel to answer questions when appropriate.

StreetLight: Discussions for A-100 Work

ERG held a conference call with StreetLight staff on July 15, 2016, and they provided us the price quote via email on two separate dates: July 20th (for Unrestricted Access Roads) and July 26th (for Restricted Access Roads), totaling the value shown in Table 5. The data would be specific to a 12-month period of our choosing (e.g., 2013 or 2014, etc.); while we weren't able to receive exact sample sizes from either StreetLight or TomTom, it appears that StreetLight draws from a larger pool of data, especially for the most recent years.

The LD vehicle raw data that StreetLight would process for ERG is mostly recorded at 1 Hz (one per second) resolution, but some coarser data are also available that pings once every 10 seconds or 30 seconds. For their commercial dataset (MD and HD vehicles), the resolution is mostly one ping per 60 seconds, with some additional coarser data available at 1 per 3 minutes. StreetLight would be able to filter out the coarser data if we direct them to. The end product of their data draw would be distance and time by 20 speed bins, county, etc., according to the details already mentioned above.

While the primary focus of our discussion with StreetLight was on vehicle speed, their records of distance categorized by hour, day type, and month could be useful for improving county level VMT temporal distributions separately for LD, MD, and HD vehicles.

StreetLight: Limitations

StreetLight recommended against providing the 7 days of the week detail due to reducing the sample size from the weekday/weekend classification. Adding day type of the week would increase the cost above what is listed in Table 5 due to labor of mining an additional data source.

StreetLight initially provided only a quote for unrestricted roads, because they have a separate database for trips that don't enter freeways; we then worked with them to develop a quote for restricted roads, which they said would be possible if ERG could provide a GIS shapefile of restricted roads in the U.S. This is possible, but will require some additional labor hours on ERG's part. Finally, the StreetLight data would cover only the continental US, excluding Alaska and Hawaii.

The Vehicle Travel Information Survey (VTRIS)

For providing data on VMT temporal distribution, as part of A-88 ERG had discussed the potential use of the Vehicle Travel Information System (VTRIS). VTRIS is a database maintained by the Federal Highway Administration (FHWA) consisting of traffic count data provided by individual State Departments of Transportation. The traffic counts are collected across a network of permanent count locations on arterials and highways that generally count, classify, and weigh trucks. In 2012, 27 states provided classification information to VTRIS. Most years it is the case that only a subset of states provide data. ERG teamed with Cambridge Systematics for a project to produce tools for improving MOVES defaults, National Cooperative Highway Research Program (NCHRP) 25-38. One outcome of the work was a spreadsheet tool that compiled VTRIS data for all available states, and reports temporal patterns of VMT (daily and hourly) by MOVES source type and road type in each available state. This tool is available online as part of "MOVES tools" at http://www.trb.org/Main/Blurbs/172040.aspx. This is based on 2012 VMT, and for the 2014 NEI could conceivably be updated based on 2014 VMT; however, ERG is not recommending this for A-100 so that project resources can be focused on the much greater need of purchasing speed data, and filling out VMT distribution for states without VTRIS data.

Because complete coverage of the U.S. is desired for the A-100 project, ERG proposes to fill in states not included in the VTRIS data-based NCHRP MOVES tool with distributions derived from the TomTom or StreetLight data, which can be used to varying degrees for VMT temporal distribution as discussed earlier in this memo. The TomTom data would provide a means to temporalize the VMT for LD vehicles only, whereas the StreetLight data provides the data for three groups of vehicles, LD, MD, and HD. Where there is geographic overlap between VTRIS and the speed dataset, we propose to compare the relative hourly distributions of VMT to assess how well the TomTom or StreetLight collected distributions of VMT compare with the continuous monitors of VTRIS.

Conclusion

ERG has identified two promising telematics data vendors who can provide vehicle speed distribution data at the needed level for each U.S. county. This would be a huge improvement over the national average default speeds currently used in MOVES2014, and the NEI for states that do not submit custom data. Of the two, StreetLight is offering the data for a price within the A-100 budget, and can provide separate data for LD, MD and HD vehicles – though the resolution of MD and HD vehicles would need to be evaluated for mapping to the MOVES vehicle types.

Appendix B

Table B1. Data for Figure 4-14 (Atlanta, LD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.009409236	0.006593195	0.006341238	0.00805365	0.010905943	0.017259641	0.022618577
2	0.005124658	0.003220387	0.003795248	0.003640352	0.005402671	0.011708155	0.011704309
3	0.004137616	0.003333124	0.002630459	0.002027078	0.00397037	0.007071609	0.008578853
4	0.004512733	0.003538307	0.002448707	0.003189782	0.003793201	0.006713511	0.008812181
5	0.005290502	0.005310542	0.004696	0.004231001	0.005405885	0.006082283	0.004796127
6	0.019474456	0.01905641	0.015109921	0.01229947	0.012220877	0.008757108	0.009227045
7	0.046969239	0.046059318	0.042717654	0.040866309	0.035804312	0.017969487	0.010994358
8	0.081053903	0.073375636	0.073017304	0.067525598	0.060108998	0.027492598	0.01912898
9	0.075559163	0.084834133	0.07635482	0.076009827	0.068664939	0.035906094	0.031214338
10	0.054427678	0.05819349	0.056191657	0.0520966	0.048880015	0.05122794	0.04172353
11	0.041663474	0.052163382	0.049683666	0.047319266	0.046759019	0.053050656	0.052811505
12	0.04659129	0.051117778	0.051228853	0.051590669	0.054715548	0.061192487	0.06446509
13	0.055277828	0.05012704	0.053031523	0.051293178	0.058195631	0.065090702	0.071029953
14	0.053648492	0.049039949	0.054376317	0.052355366	0.061318301	0.06681136	0.075765924
15	0.056456992	0.053958615	0.058166176	0.055590303	0.07096492	0.070615493	0.081896168
16	0.064736472	0.06104034	0.06578842	0.065325729	0.069098919	0.066462866	0.077057505
17	0.076219866	0.072791053	0.072330926	0.07403084	0.068921191	0.068094487	0.077279086
18	0.078235018	0.080369425	0.081589087	0.076939208	0.070160954	0.072140499	0.078559453
19	0.06865443	0.071539065	0.072863222	0.070941573	0.060882505	0.06389075	0.062466229
20	0.048601564	0.049785971	0.049024231	0.061425072	0.051398383	0.058779888	0.058744194
21	0.037633798	0.0407366	0.04260901	0.04371638	0.043293608	0.052242169	0.049804937
22	0.029602299	0.032066629	0.030608105	0.036542482	0.034427621	0.044999651	0.041378255
23	0.021486461	0.019391918	0.021878744	0.027544213	0.030822067	0.039347898	0.024633456
24	0.015232833	0.012357693	0.013518713	0.015446054	0.023884119	0.027092668	0.015309947
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table B2. Data for Figure 4-14 (Atlanta, MD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.007008449	0.008726911	0.008997099	0.010226411	0.011401792	0.024721098	0.018109047
2	0.006078122	0.00699022	0.009104514	0.008944255	0.009228707	0.019202039	0.014910209
3	0.00577135	0.007191629	0.006662828	0.008553483	0.007050561	0.013240726	0.009784127
4	0.010380103	0.010927259	0.010438035	0.010339781	0.009511689	0.017282522	0.01223202
5	0.016341408	0.015019524	0.014074635	0.015890424	0.019318353	0.017865125	0.015825439
6	0.034594543	0.034421047	0.034549215	0.032025652	0.035206045	0.039599446	0.018919552
7	0.069051682	0.073784362	0.071132485	0.071081462	0.074613249	0.065344505	0.036176899
8	0.061957923	0.061467346	0.066145696	0.06723157	0.065539785	0.062523759	0.032125865
9	0.067856668	0.066719763	0.066747198	0.066386904	0.070994008	0.071589207	0.042349739
10	0.075535763	0.069589725	0.069378467	0.06875666	0.070771759	0.068048194	0.043466479
11	0.067363693	0.063282964	0.065898993	0.064940404	0.070337604	0.06101305	0.051738788
12	0.066573729	0.065954952	0.062012961	0.061997052	0.065097709	0.057393202	0.056164055
13	0.06423773	0.061311817	0.059265309	0.065849852	0.066036985	0.060959299	0.063161296
14	0.065034406	0.062954422	0.061577356	0.063696661	0.067241748	0.053446068	0.063044659
15	0.069347762	0.064739419	0.067733035	0.067482914	0.0691302	0.053775145	0.058821895
16	0.070550624	0.074507133	0.071810308	0.070818699	0.065141279	0.049794267	0.057117502
17	0.061551737	0.069679869	0.064977294	0.060341255	0.058892793	0.046610999	0.05324862
18	0.046448906	0.049719087	0.047872824	0.04548756	0.046900501	0.049062653	0.050208111
19	0.037973932	0.039257204	0.04102821	0.039775686	0.035876092	0.042041246	0.058632296
20	0.028497312	0.027618088	0.029052157	0.033160282	0.025830016	0.037810126	0.062236635
21	0.021949874	0.022488862	0.023419418	0.022044045	0.018113369	0.025782088	0.050012557
22	0.018896709	0.017407436	0.019539526	0.018875511	0.013567286	0.027472565	0.05178991
23	0.01579941	0.015343719	0.016570612	0.013927221	0.012966774	0.020444588	0.039497339
24	0.011198163	0.010897244	0.012011825	0.012166255	0.011231695	0.014978086	0.040426961
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table B3. Data for Figure 4-14 (Atlanta, HD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.018024888	0.020665176	0.021981297	0.024465079	0.02395237	0.031688185	0.019680278
2	0.015075749	0.019657729	0.020129069	0.019862984	0.021297018	0.027009506	0.019611667
3	0.01489371	0.019974783	0.020128299	0.022521846	0.021881001	0.027898769	0.015681754
4	0.016897192	0.020335599	0.021531198	0.021950098	0.022749203	0.025083999	0.017849639
5	0.022078949	0.024813868	0.029050339	0.027632521	0.02989354	0.032437839	0.02220175
6	0.030493519	0.035276979	0.034797149	0.034427069	0.036603224	0.035581217	0.024300532
7	0.032141195	0.032611016	0.033785818	0.03474738	0.039922288	0.036934337	0.029171013
8	0.033708411	0.033163146	0.035717763	0.034528729	0.037328013	0.044867065	0.030506709
9	0.042751874	0.039205937	0.043101644	0.045358388	0.046462434	0.051476246	0.041057614
10	0.054594534	0.05489552	0.057773526	0.057375083	0.057671232	0.058870915	0.049231948
11	0.061677144	0.064878128	0.063855998	0.062878387	0.064355744	0.065608129	0.055608028
12	0.065311427	0.065946159	0.064307274	0.064821385	0.064763319	0.061939692	0.059784822
13	0.065713172	0.063088836	0.066628795	0.065893175	0.063489498	0.062632662	0.061955857
14	0.066590447	0.064002013	0.063633642	0.063109209	0.063294135	0.058986423	0.057489263
15	0.060450736	0.062441696	0.0639416	0.061092102	0.061226326	0.056693223	0.063609998
16	0.058884898	0.058047716	0.056915246	0.054627724	0.056572416	0.053170341	0.060403107
17	0.054163783	0.052752343	0.051144625	0.051678508	0.047495059	0.050443569	0.05604568
18	0.049374616	0.048055773	0.045236389	0.046829835	0.04538874	0.043742426	0.055326104
19	0.052954028	0.047804708	0.044974605	0.044295183	0.044863978	0.040630284	0.051749679
20	0.048924508	0.046845274	0.04267608	0.044965099	0.03981904	0.0367363	0.050686064
21	0.042718787	0.038833845	0.037856221	0.037029558	0.033689177	0.03375124	0.044315299
22	0.035321509	0.03302308	0.031776238	0.029640194	0.028051081	0.025253496	0.043230224
23	0.030173116	0.028548462	0.025664931	0.025560834	0.026970366	0.021555091	0.03801974
24	0.027081809	0.025132216	0.023392254	0.024709628	0.022260796	0.017009045	0.032483232
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table B4. Data for Figure 4-15 (Chicago, LD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.004907044	0.004445349	0.004263876	0.005292489	0.006187115	0.014566502	0.019764506
2	0.00231758	0.00238116	0.002679965	0.00252189	0.003700655	0.007495487	0.010429031
3	0.003110463	0.002058327	0.001994892	0.002179667	0.002636424	0.004808958	0.006670718
4	0.003453465	0.00217972	0.002153875	0.002415301	0.003026991	0.0035858	0.004924793
5	0.007017937	0.006565567	0.006660066	0.005869809	0.005098955	0.004295224	0.00410392
6	0.026259027	0.022875087	0.023278202	0.021514104	0.020288061	0.007875253	0.007584383
7	0.058362585	0.057735194	0.058793423	0.054338878	0.046846457	0.017845215	0.014222676
8	0.079115008	0.077098265	0.072489437	0.074611429	0.065057865	0.031073365	0.020581947
9	0.07954963	0.079435468	0.077418078	0.073905222	0.070102024	0.044511742	0.030925172
10	0.064130381	0.064252217	0.068222521	0.063754593	0.057951472	0.05094101	0.043546764
11	0.053549665	0.053362885	0.0540976	0.052558471	0.052257513	0.063920255	0.065209425
12	0.05243946	0.049444166	0.048603287	0.05211446	0.051585423	0.064082089	0.073123667
13	0.047982905	0.050066006	0.049213836	0.051935958	0.059002855	0.066194657	0.079969955
14	0.052370913	0.049896101	0.049582259	0.052094499	0.059582314	0.065840419	0.079075147
15	0.050693628	0.051847274	0.05449708	0.05172739	0.062182026	0.06824152	0.072796997
16	0.055404947	0.056122845	0.056706425	0.057031722	0.061260018	0.064826101	0.081883171
17	0.065323986	0.065590565	0.065680855	0.064561262	0.064778397	0.06769141	0.080459716
18	0.079282144	0.076610655	0.078864034	0.067829467	0.071865551	0.070833746	0.073081592
19	0.075407861	0.073337475	0.072268245	0.074536453	0.069100522	0.069912488	0.063158555
20	0.048506814	0.051313285	0.049232827	0.05210969	0.048523294	0.053293681	0.050492708
21	0.033379411	0.039601215	0.036787402	0.042754139	0.038265835	0.041840882	0.044893861
22	0.029356735	0.030546122	0.033024357	0.036127562	0.033311383	0.040128643	0.037762657
23	0.018943797	0.021515939	0.022545587	0.024659392	0.028130428	0.041667397	0.023001077
24	0.009134615	0.01171911	0.010941868	0.013556154	0.019258422	0.034528157	0.012337563
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table B5. Data for Figure 4-15 (Chicago, MD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.007026027	0.010001116	0.010394991	0.010932864	0.010567314	0.022298251	0.021218874
2	0.005450449	0.00841364	0.007801493	0.009311712	0.009372378	0.018894404	0.01932547
3	0.007758008	0.010019215	0.010253903	0.010123567	0.010338488	0.017380811	0.01522698
4	0.009003527	0.011265746	0.012119217	0.010250266	0.011923502	0.014859601	0.012337008
5	0.019322124	0.020969109	0.021009545	0.021085275	0.021945455	0.031385598	0.015229062
6	0.051341399	0.051572591	0.052753588	0.053380161	0.051515789	0.047562437	0.028863907
7	0.073250378	0.072070112	0.070910809	0.073863547	0.075167242	0.062383964	0.033404206
8	0.064921434	0.06430735	0.064322382	0.064571436	0.069288443	0.070765609	0.045641484
9	0.065737732	0.063742097	0.064992797	0.064961434	0.064653441	0.065376194	0.046522498
10	0.065903183	0.064103431	0.062101719	0.061599802	0.062921528	0.060840957	0.048417777
11	0.0636841	0.062726062	0.061657892	0.062409352	0.063339781	0.064509347	0.058265813
12	0.065408651	0.063428997	0.06618135	0.062392967	0.068912533	0.059089053	0.050145243
13	0.067634178	0.065090795	0.065273689	0.063120289	0.070117483	0.059986653	0.054540007
14	0.066450463	0.067413166	0.067415609	0.064366232	0.066946879	0.058699338	0.052250911
15	0.0680007	0.069179079	0.072881219	0.068135716	0.069821871	0.05679845	0.048738098
16	0.063536349	0.067360134	0.064938057	0.065060606	0.060433933	0.049826045	0.051929757
17	0.055393657	0.050536385	0.053757601	0.05349792	0.049447419	0.046127285	0.057664104
18	0.040852429	0.039800958	0.040337929	0.041121582	0.039389089	0.044664245	0.056178883
19	0.034218427	0.03332095	0.032893939	0.034161533	0.0328635	0.039071664	0.057004827
20	0.029097113	0.028287275	0.026114649	0.028866169	0.02791977	0.030407522	0.055608717
21	0.024883427	0.023682045	0.021291551	0.022641064	0.021159914	0.022029633	0.049323046
22	0.020428186	0.020220669	0.020701211	0.020686616	0.016466563	0.02303445	0.046869261
23	0.016117323	0.018958303	0.016308595	0.020032331	0.013932445	0.018614962	0.039730164
24	0.014580736	0.013530774	0.013586265	0.01342756	0.01155524	0.015393525	0.035563903
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table B6. Data for Figure 4-15 (Chicago, HD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.01214304	0.01941778	0.020294609	0.021282524	0.021721956	0.031782718	0.017396283
2	0.012547039	0.019098228	0.019373824	0.020475157	0.022051179	0.032239385	0.015685595
3	0.012594451	0.01966335	0.021247	0.021377729	0.021773397	0.032028263	0.017483896
4	0.015984656	0.021576781	0.024460318	0.02547863	0.026148111	0.033402302	0.019155565
5	0.022691904	0.028716206	0.032147513	0.031857528	0.034334472	0.037948444	0.021997971
6	0.033533749	0.03937835	0.040584004	0.042316837	0.043011682	0.042412651	0.026220399
7	0.037243073	0.038242592	0.042792447	0.044581521	0.047117849	0.048783843	0.030107122
8	0.038847993	0.04003563	0.041927489	0.044300133	0.049033701	0.053507266	0.041597021
9	0.045561917	0.049249725	0.049396226	0.050831459	0.053036481	0.06118123	0.048720151
10	0.059690033	0.060443842	0.061583281	0.06302006	0.061836882	0.061322118	0.058132516
11	0.06339965	0.063168595	0.063951857	0.062503743	0.066249347	0.061318692	0.058579433
12	0.067859808	0.066498332	0.066644374	0.064516646	0.067085868	0.061138727	0.061501613
13	0.070711056	0.066807697	0.063802375	0.063597172	0.063385345	0.057809318	0.061718526
14	0.068184085	0.063898046	0.064511724	0.06260071	0.06307461	0.056430333	0.06079779
15	0.063832668	0.060672174	0.060250272	0.058897272	0.055839465	0.052202491	0.062653115
16	0.05894027	0.05323941	0.054946922	0.052599328	0.048680327	0.05064435	0.056962881
17	0.052416541	0.048553118	0.047117848	0.04595693	0.042643013	0.045101938	0.054850142
18	0.047657972	0.044011295	0.04118388	0.041992067	0.040015904	0.041171387	0.053517356
19	0.049162014	0.045033228	0.040108381	0.040642084	0.039182955	0.034421132	0.047208666
20	0.042886616	0.040399215	0.038078418	0.035298257	0.034921005	0.031109338	0.044285088
21	0.034938314	0.031664052	0.028812486	0.030647894	0.027065328	0.024556081	0.041981957
22	0.031737992	0.028436935	0.026938382	0.02717142	0.024751426	0.018429464	0.038347649
23	0.030409392	0.027269158	0.027414209	0.025398038	0.025649795	0.016388961	0.03250672
24	0.027025766	0.024526261	0.022432161	0.022656863	0.021389902	0.014669568	0.028592545
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table B7. Data for Figure 4-16 (Las Vegas, LD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.009684501	0.008030144	0.007665591	0.009244862	0.007078869	0.019976964	0.019935109
2	0.007410186	0.009531503	0.005440872	0.007428386	0.007926806	0.013814641	0.014463109
3	0.00477631	0.003319379	0.006181329	0.005564594	0.005458816	0.008650973	0.014452619
4	0.005130894	0.004553187	0.003170521	0.003214543	0.004384781	0.006524832	0.008969768
5	0.005317829	0.006917759	0.006676894	0.005969313	0.006485395	0.00628284	0.009788325
6	0.013017281	0.009660457	0.010531897	0.011104488	0.009187666	0.010216409	0.014139375
7	0.033100739	0.027746359	0.028012656	0.028767216	0.02184781	0.016923135	0.015454204
8	0.061970418	0.068584336	0.062453969	0.061810471	0.048554416	0.033129884	0.021718717
9	0.06888232	0.079433708	0.074491118	0.06598027	0.057707717	0.040334659	0.03621221
10	0.058884603	0.058429452	0.05651236	0.051850803	0.048577053	0.044678047	0.049398109
11	0.059297351	0.054873856	0.053133757	0.051820448	0.057092697	0.056937801	0.059115177
12	0.061358604	0.055921764	0.063638883	0.05488471	0.059150219	0.067931333	0.069493818
13	0.063146144	0.054654513	0.059049811	0.048516629	0.060424716	0.073280091	0.080597696
14	0.061751757	0.060342984	0.061864097	0.057797797	0.060283984	0.077900635	0.082607737
15	0.059339652	0.056860603	0.059264587	0.059359538	0.060486081	0.067267693	0.081477382
16	0.063572578	0.069909437	0.070590179	0.07360685	0.074641638	0.074316468	0.067725401
17	0.074947263	0.084469872	0.083197426	0.08543775	0.080735929	0.064865675	0.074414929
18	0.092469007	0.09214057	0.095719796	0.095031087	0.087361512	0.066946422	0.066588898
19	0.065745184	0.066014581	0.064005766	0.074857314	0.073494509	0.062243722	0.055695177
20	0.043489742	0.036885273	0.042184173	0.042532139	0.045311855	0.049497427	0.049181081
21	0.032862794	0.031556851	0.033944226	0.035413839	0.041762465	0.042829382	0.042487937
22	0.024042047	0.028625541	0.023497813	0.028074431	0.035653992	0.036063197	0.030275047
23	0.018241798	0.018360383	0.016809358	0.023021689	0.025375653	0.032656449	0.021327343
24	0.011560997	0.013177487	0.011962921	0.018710832	0.021015419	0.026731321	0.014480833
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table B8. Data for Figure 4-16 (Las Vegas, MD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.009178696	0.010212729	0.012785944	0.011233204	0.011414183	0.018161163	0.01875445
2	0.009050912	0.011931894	0.013775046	0.01228446	0.016520156	0.015836631	0.018388238
3	0.006679317	0.009124372	0.010978362	0.010741893	0.010603564	0.015230478	0.014221841
4	0.011005755	0.012405001	0.013158994	0.015996638	0.016592566	0.021382504	0.020072056
5	0.017743963	0.018617622	0.01849732	0.020742301	0.018486809	0.038074776	0.019580718
6	0.046069508	0.049105508	0.045610899	0.047725186	0.051872034	0.056512754	0.031290315
7	0.081085019	0.089614736	0.090440029	0.090148594	0.090456809	0.069101783	0.039077838
8	0.077783599	0.076740857	0.075273404	0.073181744	0.078174214	0.072142484	0.035375272
9	0.073349544	0.070146669	0.073920318	0.068038528	0.076976347	0.066949018	0.045934999
10	0.067054064	0.070422497	0.07049376	0.072586104	0.073976974	0.062870261	0.054094126
11	0.064896573	0.066160006	0.06838655	0.063859704	0.067618196	0.066010332	0.057101482
12	0.063843642	0.061160664	0.064509656	0.063113162	0.069297227	0.065941839	0.053462559
13	0.058937334	0.064004138	0.065333338	0.059236141	0.063508317	0.063953032	0.056643044
14	0.067475495	0.06056913	0.061332641	0.069366309	0.059920258	0.059498803	0.053209609
15	0.071676569	0.068581731	0.064471608	0.065744518	0.06685193	0.061123136	0.05266164
16	0.068466469	0.062520468	0.065530267	0.064700616	0.058817481	0.043685949	0.066740556
17	0.054852105	0.05001426	0.048065001	0.049960214	0.043376918	0.037318505	0.060360711
18	0.035481472	0.035371066	0.031565207	0.034793917	0.03088331	0.032490575	0.048976873
19	0.026498163	0.02742085	0.022617959	0.027238575	0.022816437	0.032198855	0.052116907
20	0.024812603	0.020223798	0.022989374	0.020701856	0.016839531	0.021630927	0.052997648
21	0.02249764	0.018025181	0.02028677	0.01847602	0.01737076	0.021786369	0.043840204
22	0.015492731	0.017329117	0.015506383	0.016255852	0.013021644	0.019345788	0.040932086
23	0.01438462	0.016926402	0.013474377	0.013787194	0.01365569	0.022893273	0.033277781
24	0.011684207	0.013371305	0.010996792	0.010087272	0.010948644	0.015860764	0.030889047
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**

Table B9. Data for Figure 4-16 (Las Vegas, HD, Urban Restricted Roads)

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1	0.018840756	0.020031619	0.023674577	0.022381581	0.026519152	0.024069352	0.022875409
2	0.015778544	0.016959407	0.021431858	0.019720029	0.023582166	0.024743822	0.021029461
3	0.017245058	0.0182033	0.020117294	0.02528081	0.023873397	0.023224466	0.019181391
4	0.018831237	0.023417289	0.023110322	0.025741792	0.029088787	0.024619489	0.020322409
5	0.027194867	0.027052805	0.029582553	0.029501131	0.029280921	0.028827281	0.026515801
6	0.035186505	0.031477992	0.033114279	0.036604435	0.036840121	0.038802066	0.032907769
7	0.037895763	0.042960023	0.041814105	0.043176028	0.048357874	0.043977478	0.040365359
8	0.043894628	0.045996204	0.044987207	0.047406221	0.05407129	0.051718753	0.0492544
9	0.055595612	0.056123271	0.05800881	0.052158376	0.060603707	0.058293827	0.06024991
10	0.058167374	0.067252087	0.063297313	0.060411826	0.06126074	0.061137159	0.059131899
11	0.056325394	0.057652792	0.063487234	0.063358039	0.060543515	0.053773204	0.060735908
12	0.052684796	0.060566474	0.060162078	0.059865244	0.058740444	0.060504135	0.067965366
13	0.055920463	0.057486434	0.058180561	0.059466118	0.05410935	0.056926328	0.062093555
14	0.052603658	0.052833888	0.0550159	0.052073653	0.051434979	0.057611198	0.05343194
15	0.052458004	0.051650376	0.056178761	0.05355332	0.052758632	0.05120078	0.056057503
16	0.051170688	0.051262249	0.05237798	0.051822855	0.04443301	0.050907789	0.055779637
17	0.057076631	0.051186463	0.048277309	0.050309323	0.044003775	0.048608513	0.050972387
18	0.055612685	0.050372317	0.046564261	0.047095567	0.046300785	0.044666668	0.045379858
19	0.0513381	0.050442264	0.046729212	0.045420585	0.042248349	0.04351711	0.044102739
20	0.04628931	0.042882124	0.04303746	0.04245875	0.041228192	0.040961967	0.039436192
21	0.042086644	0.039574726	0.03311123	0.033320575	0.033109365	0.035421238	0.035932254
22	0.035952398	0.030499973	0.028968472	0.030599541	0.02962868	0.031509637	0.024694631
23	0.033569049	0.0286683	0.023629324	0.026481314	0.02464574	0.023117895	0.027792743
24	0.028281834	0.025447622	0.025141899	0.021792888	0.023337029	0.021859845	0.02379148
Grand Total	**1**	**1**	**1**	**1**	**1**	**1**	**1**