Eastern Research Group, Inc.

Clark County On-road Vehicle Classification Study

Final Report

Prepared for:

Clark County Department of Air Quality

Prepared by:

Eastern Research Group, Inc.

June 29, 2018

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Prepared for:

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Executive Summary

The Clark County Department of Air Quality (CCDAQ) sponsored the On-Road Vehicle Classification Study to support CCDAQ's periodic updates of emission inventories for State Implementation Plans and Maintenance Plans. CCDAQ contracted with Eastern Research Group, Inc. (ERG) and its subcontractor, the University of California at Riverside's College of Engineering-Center for Environmental Research & Technology (CE-CERT) to conduct the study.

Vehicle classification is a crucial component for developing on-road emission inventories. Reliable data on vehicle type mix is as important as accurate data concerning total vehicle vehicle-miles traveled (VMT) and emission rates. The temporal distribution of VMT and variation in fleet mix are important for accurate air quality modeling because photochemical models are sensitive to the timing of emissions released into the atmosphere. Studies have shown that the vehicle type mix and temporal traffic patterns can vary significantly from area to area.

This study produces new VMT temporal distribution and VMT mix profiles based primarily on two recent data sources: traffic monitor data from the Nevada Department of Transportation (NDOT) and a license plate survey that CE-CERT conducted to capture license plates on high-resolution video. ERG worked with data firm IHS Markit to match the license plates to vehicle identification number (VIN) and decode into vehicle attributes. ERG used the decoded vehicle information to classify cars vs. light-duty trucks consistently with the definition of how vehicle emissions are certified and U.S. EPA's MOVES guidance. The profiles developed in this study will support various CCDAQ on-road modeling efforts for the next several years. In addition to the profiles, ERG delivered a Python-based tool so that CCDAQ can conduct their own updates of modeling profiles in the future when new data become available.

1.0 Introduction

The Clark County Department of Air Quality (CCDAQ) and the Regional Transportation Commission (RTC) of Southern Nevada have conducted three vehicle classification studies over the past 15 years. The earliest was an Orth-Rodgers & Associates 2003 study which used NDOT monitor data from 1999 to 2002 and used national splits to estimate the relative portion of cars out of cars and light-duty trucks. CCDAQ and RTC directed a second project to characterize fleet mix and temporal distributions in 2013, conducted by Parsons. The Parsons 2013 study updated traffic data profiles based on 2010-2012 NDOT monitor data and added a field study component to improve the estimate of cars and light-duty trucks, based on visual observation of vehicle body styles. This current study uses 2014-2016 NDOT monitor data and included a license plate survey conducted by ERG's subcontractor CE-CERT in September 2017. The surveyors recorded vehicles on high-resolution video at five different sites around the central Las Vegas valley; later the surveyors played back video and manually recorded the license plate number and state of the plate, a process called tag-editing. The data firm IHS Markit matched the license plates to VINs and decoded the VINs into vehicle attributes that allowed ERG to classify cars vs. light trucks consistently with MOVES source type definitions and EPA emissions certification definitions of car vs. light-duty truck, which vary by make and model. Although a significant portion of the project resources were dedicated to collecting new data for the car vs. light truck splits, the foundational data source of this work is the traffic volume counts from NDOT traffic monitors.

Under-road traffic monitors sense vehicles driving past and are a rich source of information because they record every vehicle at a given point, along with a date and time stamp. NDOT provided traffic monitor data for years 2014 through 2016 at all sites in Clark County. There are over 1,000 traffic monitors on roadways in Clark County, most of which are used for reporting for the Highway Performance Monitoring System (HPMS). Some of the traffic monitors classify the vehicles according to the number and spacing of axles, a vehicle classification system used by the Federal Highway Administration (FHWA). A big challenge for vehicle classification monitors is distinguishing between FHWA class 2 (passenger cars) and class 3 (pickups, panels, vans) vehicles, due to similar chassis.

The portion of cars vs. light-duty trucks is important to pinpoint because these vehicles make up a large portion of the Clark County on-road mobile source emissions inventory. In EPA's version 2 of the 2014 National Emissions Inventory (NEI), the county's cars and light trucks together comprised 95% of the VMT[1] and 89%, 95%, and 63% of the on-road emissions[2] of volatile organic compounds, carbon monoxide, and nitrogen oxides, respectively. These vehicles are dominant sources of activity and emissions, are difficult to distinguish based on axles, and they emit very differently. On a per-vehicle basis, light-duty trucks emit 1.3 to 1.7

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[1] ftp://newftp.epa.gov/air/nei/2014/doc/2014v2_supportingdata/onroad/2014v2_onroad_activity_final.zip. Accessed May 9, 2018.

[2] ftp://newftp.epa.gov/air/nei/2014/data_summaries/2014v2/2014neiv2_onroad_byregions.zip. Accessed May 9, 2018

times more cars (for a 2014 fleet average age). For these reasons, it is important to understand the proportion of cars vs. light-duty trucks.

This report begins with an overview of on-road emissions modeling, providing background on the MOVES, SMOKE, and CONCEPT models. After the overview, Section 3.0 describes the existing data sources, new data collection, and methodology to transform the data into modeling profiles. Section 4.0 presents example results of the traffic profiles, and Section 5.0 closes with a summary and challenges of this work.

2.0 Overview of On-road Modeling

This study produces VMT temporal and VMT mix profiles formatted for three different models: (1) the Motor Vehicle Emission Simulator (MOVES), (2) the Sparse Matrix Operator Kernel Emissions (SMOKE), and (3) the Consolidated Community Emissions Processing Tool (CONCEPT).

MOVES

MOVES is U.S. EPA's state-of-the-science emission modeling system that estimates emissions for mobile sources at the national, county, and project level for many pollutants. Data contained in MOVES is based on analysis of millions of emission test results as well as many instrumented vehicle and telematics activity studies that produced second-by-second driving schedules, hourly speed distributions, temporal patterns of VMT, and more. The vehicle activity data in MOVES is representative of the nation, and the model design reflects the intention of US EPA to allow users to easily update certain activity types with local data, such as the VMT fractions and vehicle mix developed under this study.

MOVES can generate either an emissions inventory or lookup tables of emission factors for creating inventories outside the model (with SMOKE or CONCEPT being two examples). In emission-factor mode, the factors vary by vehicle, fuel, road type, hour, day, month, speed bin, temperature, and other parameters.

CCDAQ is an active participant in U.S. EPA's NEI process and submits MOVES county database (CDB) inputs regularly to EPA for this purpose. Table A-1 of Appendix A lists the data structure and purpose of each of the CDB tables developed for Clark County in this study, including the tables *Month VMT Fraction*, *Day VMT Fraction*, *Hour VMT Fraction*, and annual VMT mix for *Source Type Year VMT*. 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. In addition to CDBs, EPA also uses the SMOKE processing system to prepare the NEI for air quality modeling.

SMOKE

SMOKE is an emissions processor that requires MOVES emission factor lookup tables as well as temporal profiles, VMT, and other activity to calculate on-road emissions in a different level of detail than MOVES inventory mode produces. SMOKE prepares emission inventories that are hourly, gridded, and speciated into the chemical compounds needed for air quality modeling. SMOKE calculates the emission inventory in a detailed way by assigning county VMT and population to the modeling grid using spatial surrogates, then looking up the appropriate emission factors for the temperatures in the grid cell. SMOKE uses temporal profiles (monthly, weekly, and diurnal) to allocate annual VMT into specific day type and hourly values. Like MOVES, SMOKE also requires annual VMT input. Table A-2 in Appendix A describes the structure and purpose of all SMOKE profiles prepared in this study.

CONCEPT

CONCEPT is like SMOKE in that it is an emissions processor that prepares inventories for air quality modeling. CONCEPT also requires MOVES emission factor lookup tables and uses temporal profiles to redistribute VMT to specific time periods. CONCEPT has more spatial detail than SMOKE because it directly uses VMT and speeds specific to individual roadway segments or "links" with known start and end node coordinates. Therefore, the location of best estimates of vehicle activity are known throughout the modeling grid, which is superior to placing county VMT in grid cells using spatial surrogates. CONCEPT requires more inputs and takes more computation time than SMOKE, and it is not as widely used.

VMT temporal and fleet mix profiles operate differently in CONCEPT than they do in MOVES and SMOKE due to differences in the VMT input detail for CONCEPT. MOVES and SMOKE intake annual VMT, while CONCEPT intakes day-specific VMT that must be adjusted to other day types in other months. The day-specific VMT input to CONCEPT is also often already subdivided into time periods (e.g., AM peak, midday, PM peak, and overnight) which CONCEPT preserves and further disaggregates into 24 hours using hourly total volume profiles. Lastly, fleet mix in CONCEPT varies by 24 hours of day, 7 days of week, and can vary by 12 months of year. Table A-3 in Appendix A describes the structure and purpose of all CONCEPT profiles prepared in this study.

3.0 Methods

3.1 Existing Data Collection

The existing data for this study includes monitor data from the NDOT, the plate-to-VIN matching capability from all 50 states' department of motor vehicles (DMV) or equivalent agency vehicle registration records through the data firm IHS Markit, long-haul truck allocation factors from the Freight Analysis Framework (FAF), EPA emissions certifications lists, the publicly available 2014 NEI version 2, and annual transit bus VMT from the National Transit Database[3].

Nevada Department of Transportation (NDOT)

The NDOT dataset is by far the largest source of existing traffic volume data in Clark County. ERG received traffic monitor data from NDOT for the years 2014, 2015, and 2016. NDOT has three different types of monitors: (1) those which are part of the Highway Performance Monitoring System (HPMS), (2) continuous total volume traffic counters, and (3) vehicle classification monitors.

[3] https://www.transit.dot.gov/ntd/transit-agency-profiles/regional-transportation-commission-southern-nevada-rtc. Accessed June 29, 2018.

HPMS Monitors

The HPMS dataset reports hourly traffic volumes for seven consecutive days in each of the three years. There were approximately 1000 monitoring sites in Clark County, located on roads representing all twelve types of the HPMS functional classes (see Table 3-1). Most of the sites are located on urban roads (90% in 2016, vs. 10% rural). There are fewer sites on urban and rural local system roads compared to the higher HPMS functional classes.

Table 3-1. Number of HPMS Sites in Clark County, Years 2014-2016

HPMS Functional Class ID	HPMS Functional Class Name	2014	2015	2016
11	Rural Principal Arterial - Interstate	63	54	61
13	Rural Principal Arterial - Other	16	17	15
15	Rural Minor Arterial	8	7	6
17	Rural Major Collector	27	23	19
19	Rural Minor Collector	12	15	3
21	Rural Local System	5	5	5
23	Urban Principal Arterial - Interstate	174	176	175
25	Urban Principal Arterial - Other Freeways	78	101	101
27	Urban Principal Arterial - Other	97	103	115
29	Urban Minor Arterial	334	246	349
31	Urban Collector	198	143	202
33	Urban Local System	66	36	34
Total Count of Sites		***1078***	***926***	***1085***

Continuous Volume Sites

There were 33 continuous volume counter sites operating in Clark County as of 2016. The continuous sites are located only on the higher functional classes; there are no monitors on Rural Minor Collector, Rural Local, Urban Collector, or Urban Local roads as shown in Table 3-2. The monitors are intended to record data 24 hours of 365 days per year; however, only about half of the sites had full data for a year.

Table 3-2. Number of Continuous Volume Sites in Clark County, Years 2014-2016

HPMS Functional Class ID	HPMS Functional Class Name	2014	2015	2016
11	Rural Principal Arterial - Interstate	4	4	4
13	Rural Principal Arterial - Other	3	3	3
15	Rural Minor Arterial	2	2	2
17	Rural Major Collector	5	5	5
19	Rural Minor Collector	-	-	-
21	Rural Local System	-	-	-
23	Urban Principal Arterial - Interstate	5	5	5
25	Urban Principal Arterial - Other Freeways	4	3	4
27	Urban Principal Arterial - Other	7	7	7
29	Urban Minor Arterial	3	3	3
31	Urban Collector	-	-	-
33	Urban Local System	-	-	-
Total Count of Sites		***33***	***32***	***33***

Vehicle Classification Monitors

There are 47 vehicle classification sites as of 2016, and as shown in Table 3-3, they cover all HPMS road types except the local system roads. These monitors provide hourly volumes classified into the 13 FHWA vehicle types shown in Figure 3-1 and cover 24 hours of 7 consecutive days of each year. The FHWA vehicle classes do not directly correspond to all 13 source types in MOVES. For example, FHWA Class 5, 6, and 7 are Single Unit 2-Axle Trucks, Single Unit 3-Axle Trucks, and Single Unit 4-or-more Axle Trucks, respectively. In MOVES, Single Unit trucks are divided into usage patterns, including Short-haul and Long-haul operations, Refuse Trucks, and Motor Homes. The MOVES categories aren't defined by number of axles, but as a group, the FHWA Single Unit Trucks corresponds to multiple MOVES categories; therefore, the monitors still help provide fleet mix information that is useful in MOVES.

Table 3-3. Number of Vehicle Classification Sites in Clark County, Years 2014-2016

HPMS Functional Class ID	HPMS Functional Class Name	2014	2015	2016
11	Rural Principal Arterial - Interstate	3	2	2
13	Rural Principal Arterial - Other	5	5	4
15	Rural Minor Arterial	3	2	1
17	Rural Major Collector	6	4	1
19	Rural Minor Collector	1	1	1
21	Rural Local System	-	-	-
23	Urban Principal Arterial - Interstate	2	4	2
25	Urban Principal Arterial - Other Freeways	1	2	4
27	Urban Principal Arterial - Other	13	8	7
29	Urban Minor Arterial	22	17	19
31	Urban Collector	7	5	6
33	Urban Local System	-	-	-
Total Count of Sites		***63***	***50***	***47***

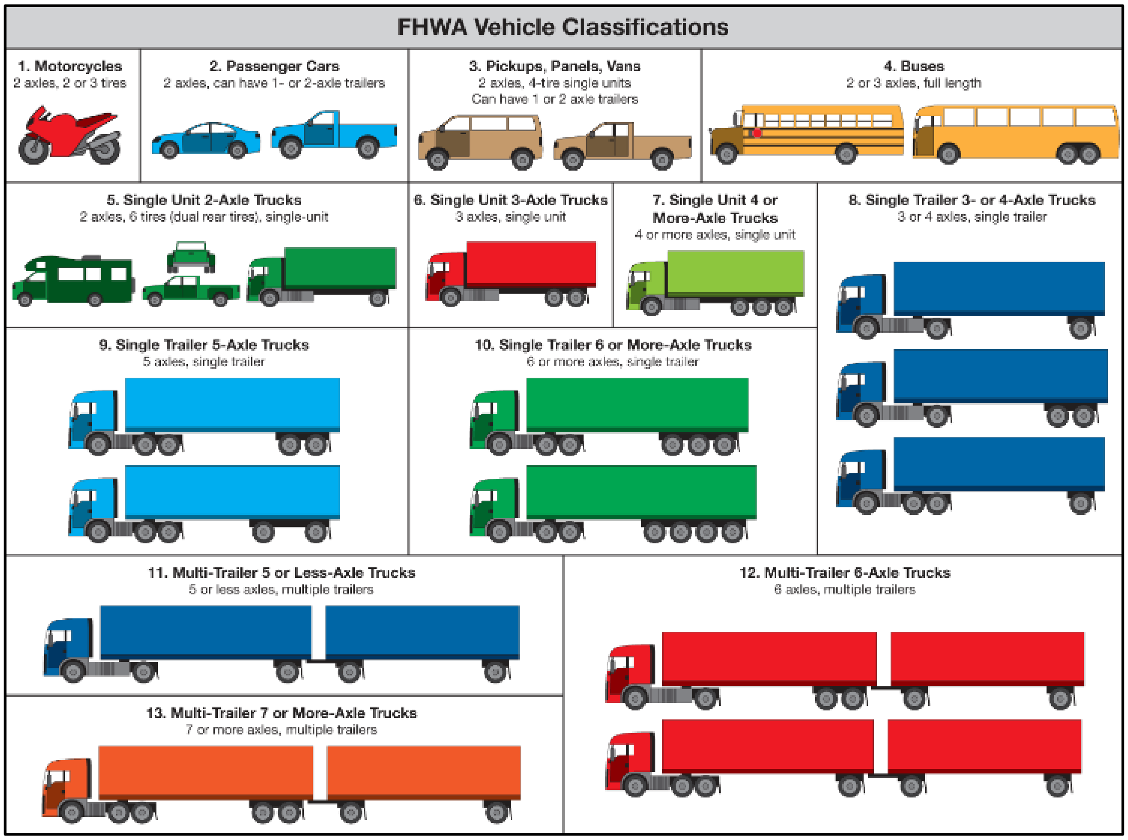


Figure 3-1. FHWA Vehicle Classifications

IHS Markit

For this study, IHS Markit (IHS) provided plate-to-VIN matching services using current registration data from every state DMV and vehicle attributes from their continuously maintained VIN decoder. IHS can match any vehicle's license plate to a VIN so long as the state registration record included the plate. Surprisingly, the plate number is not a required entry by all DMVs; therefore, there is a wide variation in license plate coverage from state to state[4]. Section 3.2.9 provides more details on plate matching in the context of this study. IHS also provided key VIN-decoded attributes of the matched vehicles, useful to determine whether a light-duty vehicle is a car or truck.

ERG and CE-CERT anticipated that the license plates collected in the new 2017 survey could be registered in Nevada, California, Arizona, Utah, and perhaps several non-neighboring states. Because IHS has all registration records from all states, their product represents an improvement over registration data from a single DMV (Nevada). Furthermore, Nevada DMV declined to agree to provide vehicle-level information to ERG as a contractor to the CCDAQ, because ERG is not law enforcement or an insurance company[5].

[4] Personal communication with IHS Markit product team members by teleconference on May 14, 2018.
[5] Personal communication with Jackie Cobb of the Nevada DMV on April 18, 2017.

Freight Analysis Framework (FAF)

The FAF is a free and publicly available dataset maintained by FHWA that provides traffic volume estimates that allow the calculation of short-haul vs. long-haul truck VMT allocations. The FAF network contains validated, modeled estimates of both long-haul VMT and total truck VMT. From these parameters, ERG calculated the long-haul fraction of truck VMT with geographic specificity, separately for single unit and combination trucks, and by road type. The approach mirrored that of the Coordinating Research Council (CRC) project A-88[6], which used 2007 FAF data, and the results of which U.S. EPA incorporated into the 2011 NEI. The extent of the national FAF network is shown below in Figure 3-2.

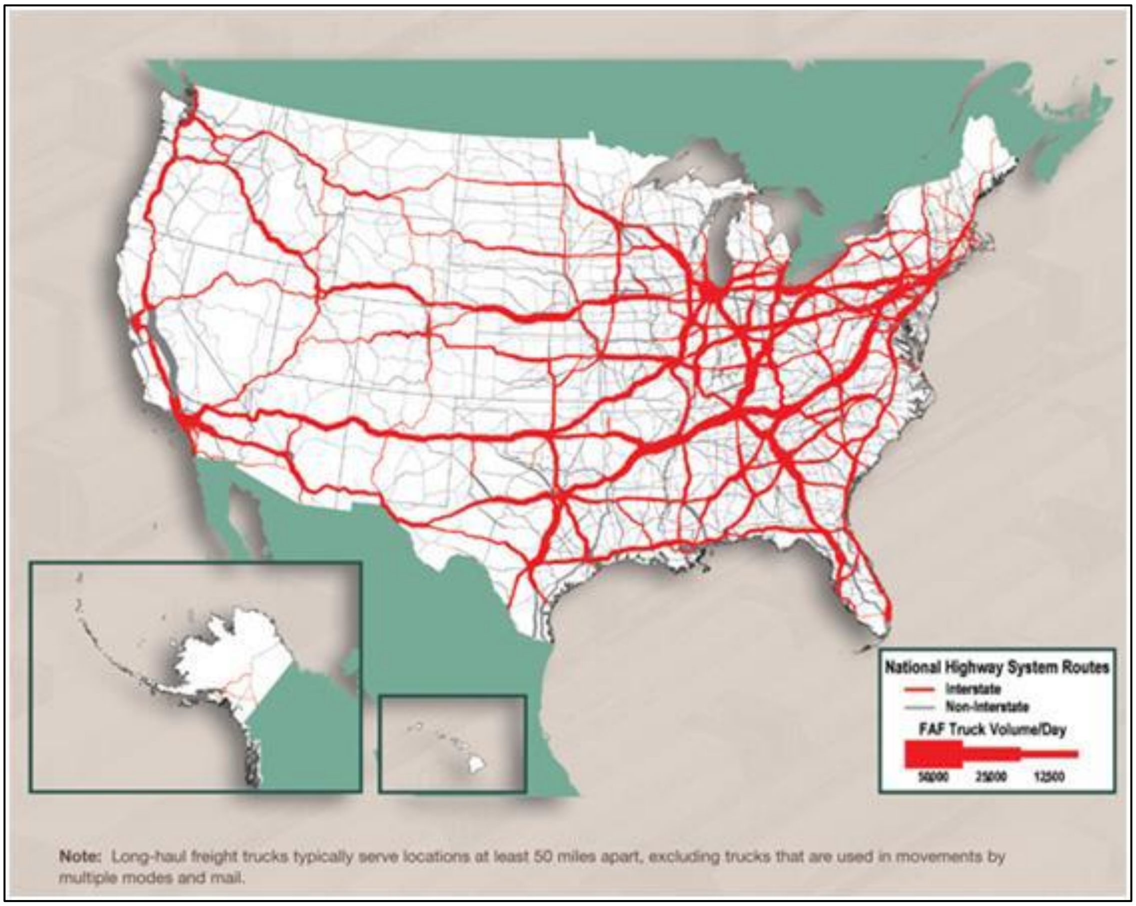


Figure 3-2. FAF Average Daily Long-haul Freight Traffic (Source: FHWA)

In the CRC A-88 study, ERG used 2007 FAF combined with 2011 HPMS estimates to calculate long-haul fractions separately for single-unit and combination trucks in the four census regions of the country shown below in Figure 3-3 (West, South, Midwest, and Northeast). The long-haul fractions were calculated separately for the four MOVES roadway types (Urban Restricted, Urban Unrestricted, Rural Restricted, and Rural Unrestricted). Analysis of the FAF dataset

6 http://www.crcao.org/reports/recentstudies2014/A-88/CRC%20A88%20Final%20Report%20102114.pdf

showed that there are meaningful differences in long-haul truck VMT fractions by the four road types and census region. The data represented an improvement over previous estimates that were a static 59% across all geographic areas, with varying long-haul fractions from 28 to 84 percent for combination trucks operating on rural interstates in the West region. In the CRC A-88 study, the long-haul fractions for the single-unit trucks varied from 3 percent on Urban Unrestricted Access roads to 38 percent on the same road type, compared to a static default value of 12 percent that would have otherwise been used.

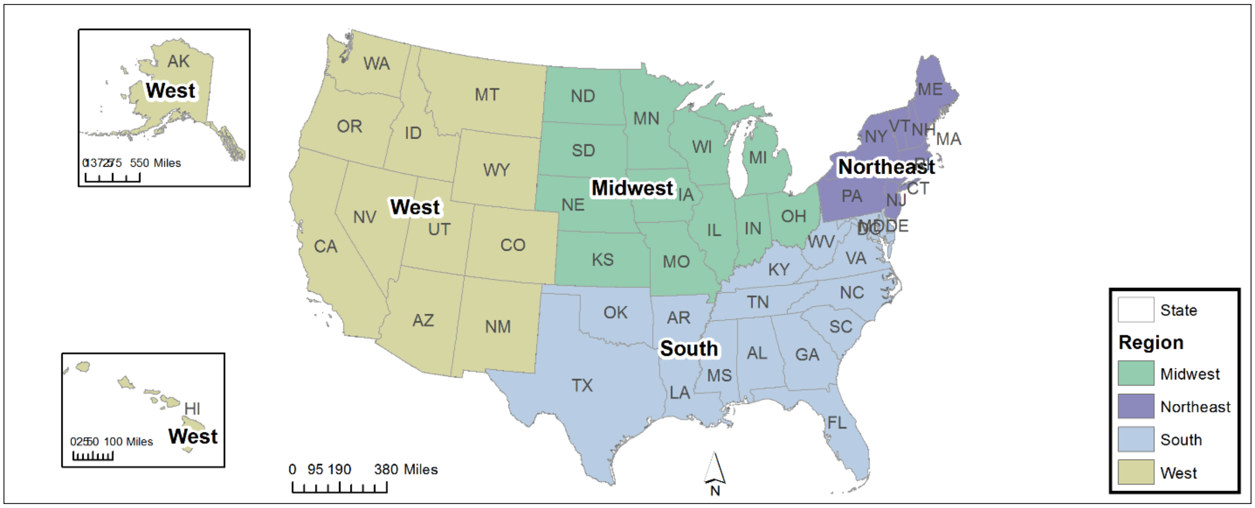


Figure 3-3. U.S. Census Regions (Source: Census Bureau) used in the CRC A-88 Study

The Clark County Vehicle Classification Study uses the more recently released 2012 FAF data and produced new long-haul fractions following similar methods of the CRC A-88 study. As one update to the previous methods, ERG used the HPMS road type classifications to provide additional detail in the long-haul fractions for use in CONCEPT's VMT mix profiles. It should be noted that the FAF documentation warns that their database is not meant to pinpoint with accuracy the truck volumes for individual links. Part of ERG's work in the previous CRC study was determining the best regional aggregation to remove the "noise" of the dataset.

3.2 New Data Collection

New data collection refers exclusively to the "2017 License Plate Survey" conducted by CE-CERT. The objective of the survey was to improve the estimated split of cars vs. light-duty trucks that operate in Clark County. These vehicle categories aren't reliably distinguished by vehicle classification monitors, yet their pollutant emission rates are so different that it is important to correctly categorize them in Clark County's on-road emissions inventory.

The scope of CE-CERT's work in the 2017 License Plate Survey included videotaping vehicles in traffic streams and transcribing the license plate numbers from the videos into a list (a process termed 'tag-editing'). CE-CERT previously conducted similar license plate surveys at three locations in Clark County, Nevada, in the summer of 2010. As part of the current study, the license plate numbers were matched to vehicle identification number (VIN) and decoded into the relevant vehicle information available and needed to classify the vehicles consistently with the U.S. EPA's MOVES model definitions.

The primary goal of the 2017 License Plate Survey was to improve the relative split of cars vs. light-duty trucks. The secondary goals of the data collection were (1) to determine whether there are temporal differences in the car vs. light truck split by time period and day of the week, and (2) to cross check the new data against existing sources of data where possible.

3.2.1 Survey Sites

There are two aspects to the selection of license plate survey sites—the general area where the survey should be conducted and the specific location of the camera set up for videotaping. The general area where the survey was conducted was selected to represent typical traffic in Clark County. High volume roadways were preferred for two reasons. First, having high volume of traffic means a higher number of license plates can be captured within the same amount of time. Second, vehicles on a roadway with high volume of traffic are more likely to travel at a slower speed, which makes it easier to read the license plate numbers.

The survey sites for the 2017 License Plate Survey were selected by CCDAQ. Figure 3-4 shows the locations of the NDOT vehicle classification monitors within the boundaries of Clark County. Because most of the stations are concentrated in the center of the county, the figure also shows an enlarged view of the Las Vegas Valley to the Right. The survey sites selected for the 2017 License Plate Survey are marked by the five large red circles. The five survey sites, number of cameras and lanes, and the preferred direction of traffic flow to survey are listed in Table 3-4.

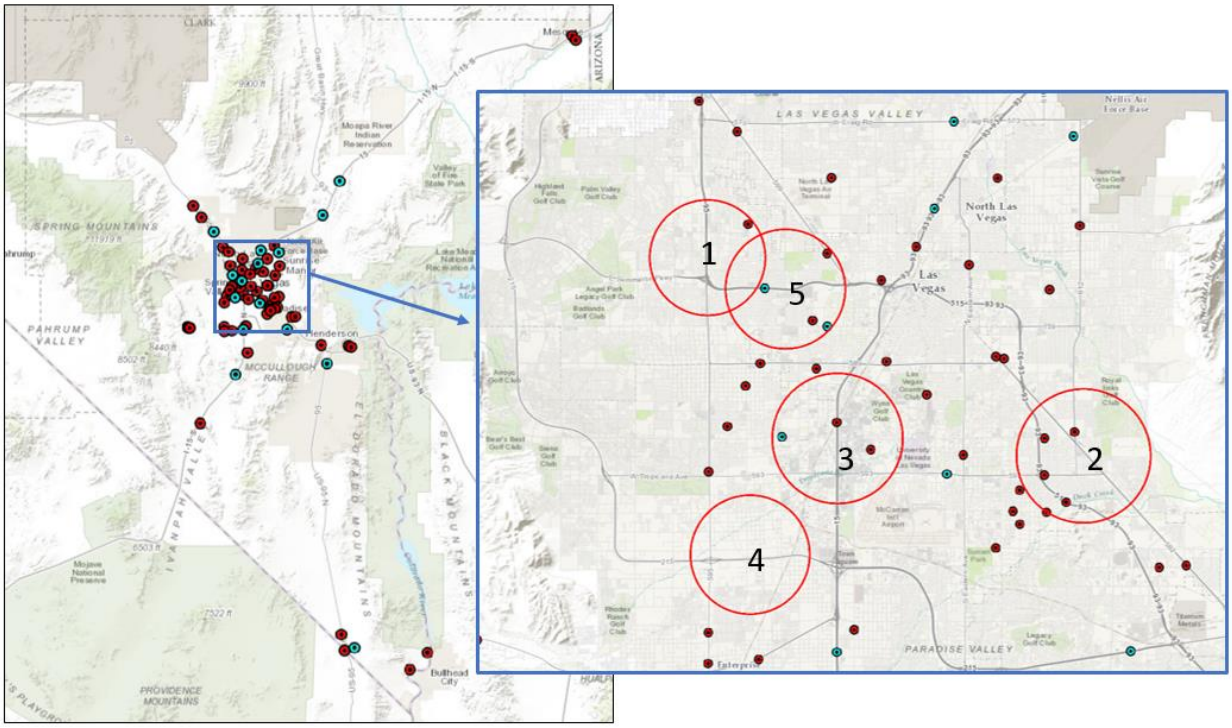


Figure 3-4. Locations of NDOT vehicle classification monitors and license plate survey sites

Table 3-4. Details of survey sites

Site No.	Location	No. of Cameras	No. of Lanes	Preferred Traffic Direction	
				AM & MD	PM
1	I-95 at W. Washington Ave	2	6	SB	NB
2	S. Boulder Hwy at E. Harmon Ave	2	4	NB	SB
3	I-15 at W. Flamingo Road	2	7 NB, 6 SB	NB	SB
4	IR-215 at S. Jones Blvd	3	3	EB	WB
5	I-95 at Decatur Blvd	3	5	EB	WB

NB = Northbound, SB = Southbound, EB = Eastbound, and WB = Westbound.

The location of the camera set up for videotaping was either on the roadside or on a bridge overcrossing the roadway, depending on site. Where available and suitable, the latter is preferred for two reasons. First, it is safer. Second, unlike a roadside location from which the view of the traffic in the inner lanes may be occluded, a location on a bridge allows for the traffic in any of the lanes to be captured. In the case of a bridge, overpasses with a wide shoulder lane or sidewalk that provides enough working space for setting up video cameras and other equipment were preferred. Also, normally there are fences on either or both sides of the bridge. These fences may be made of wire mesh, steel bar, etc. A bridge without fences or with ones that have large opening spaces is preferred. In the case of roadside, the surveyors found a safe spot away from traffic. In general, this can be a section of the roadway with a sidewalk, an elevated bank, or a wide median. Figure 3-5 through Figure 3-9 shows the map view of the five survey sites in the 2017 License Plate Survey and the street view of each survey site.

3.2.2 Survey Dates and Times

The 2017 License Plan Survey included two Thursday through Sunday periods during the second half of September 2017. Surveys at sites 4 and 5 occurred between September 14 and 17. Surveys at the remaining sites 1, 2, and 3, occurred between September 21 and 24. The time periods of survey by date type (weekday vs. weekend) are listed in Table 3-5.

Table 3-5. Survey periods

Day Type	Primary Video			Backup Video
	AM Period	Midday	PM Period	
Thursday and Friday	7:00 – 8:00 AM	10:00 – 11:00 AM	5:00 – 7:00 PM	6:30 – 7 AM and 11–11:30 AM
Saturday and Sunday	9:00 – 10:00 AM	12:00 – 2:00 PM	5:00 – 6:00 PM	4:00 – 5:00 PM

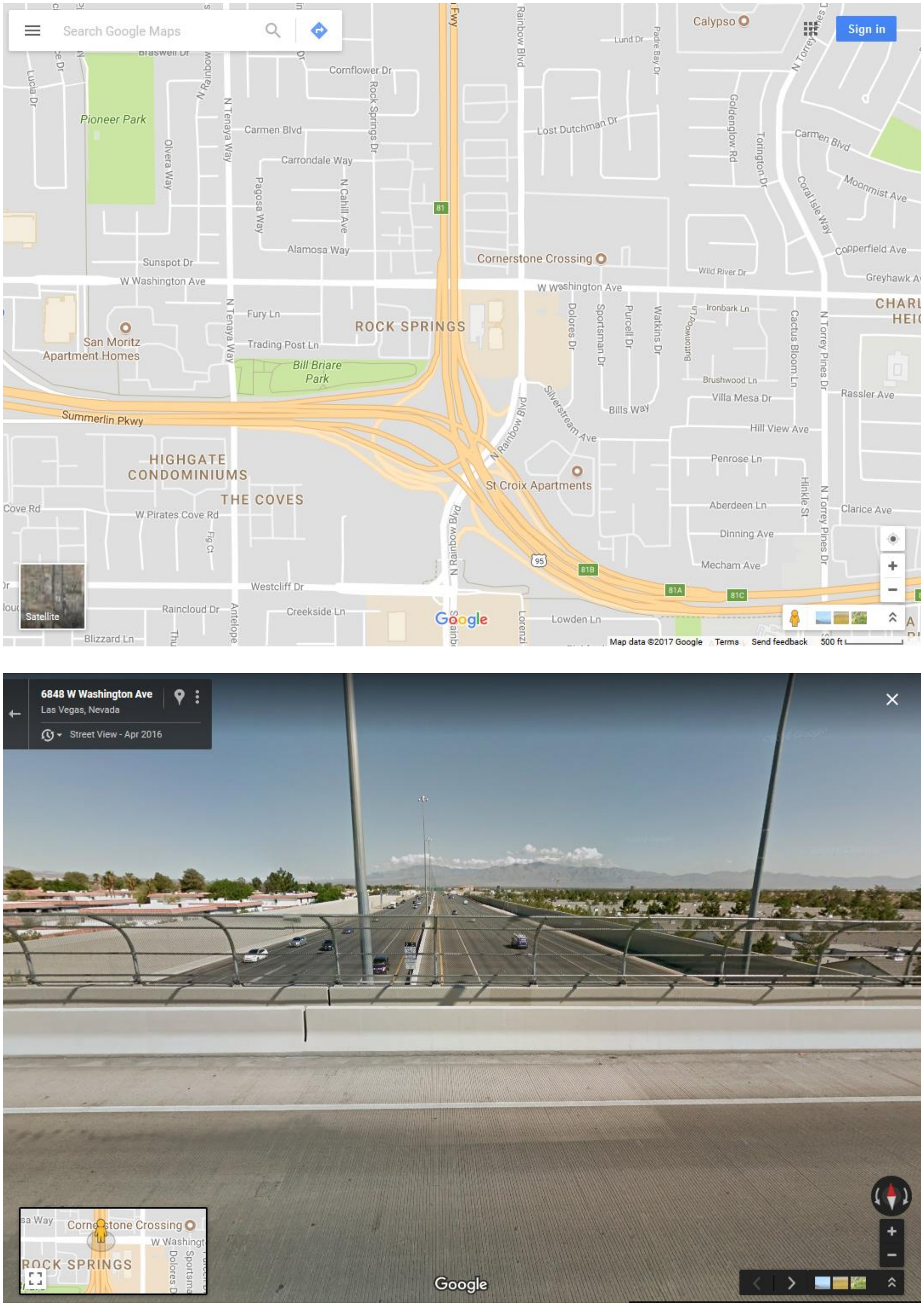


Figure 3-5. Site 1: I-95 at W. Washington Ave

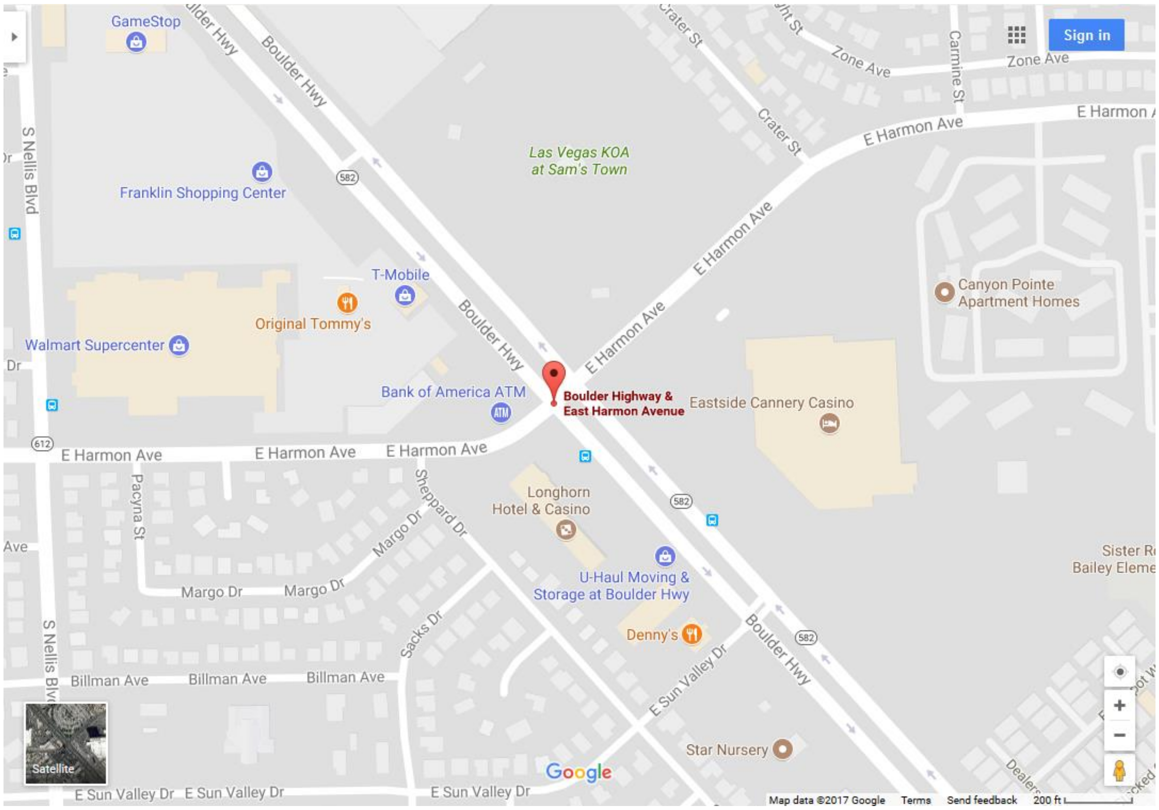


Figure 3-6. Site 2: S. Boulder Hwy at E. Harmon Ave

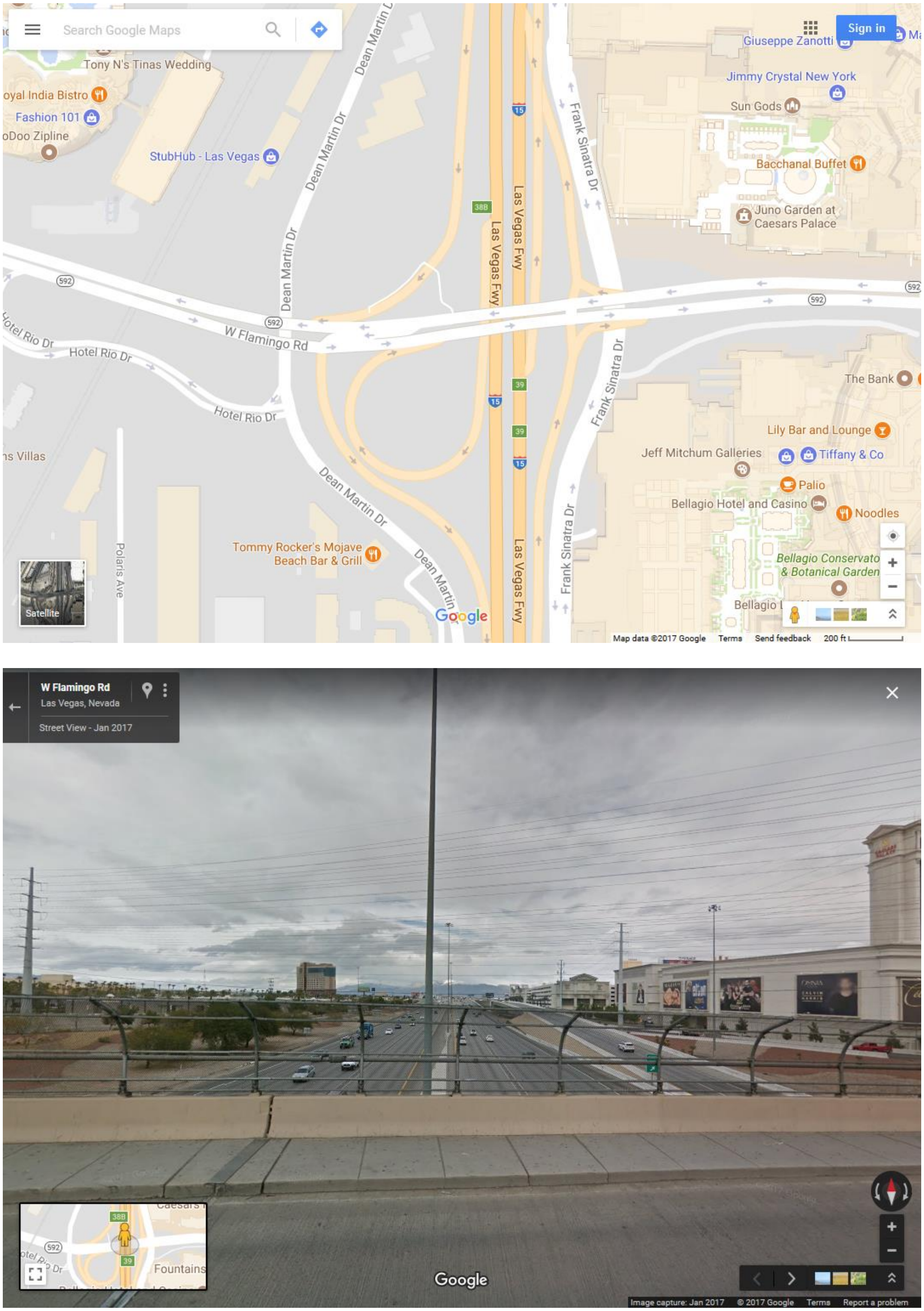
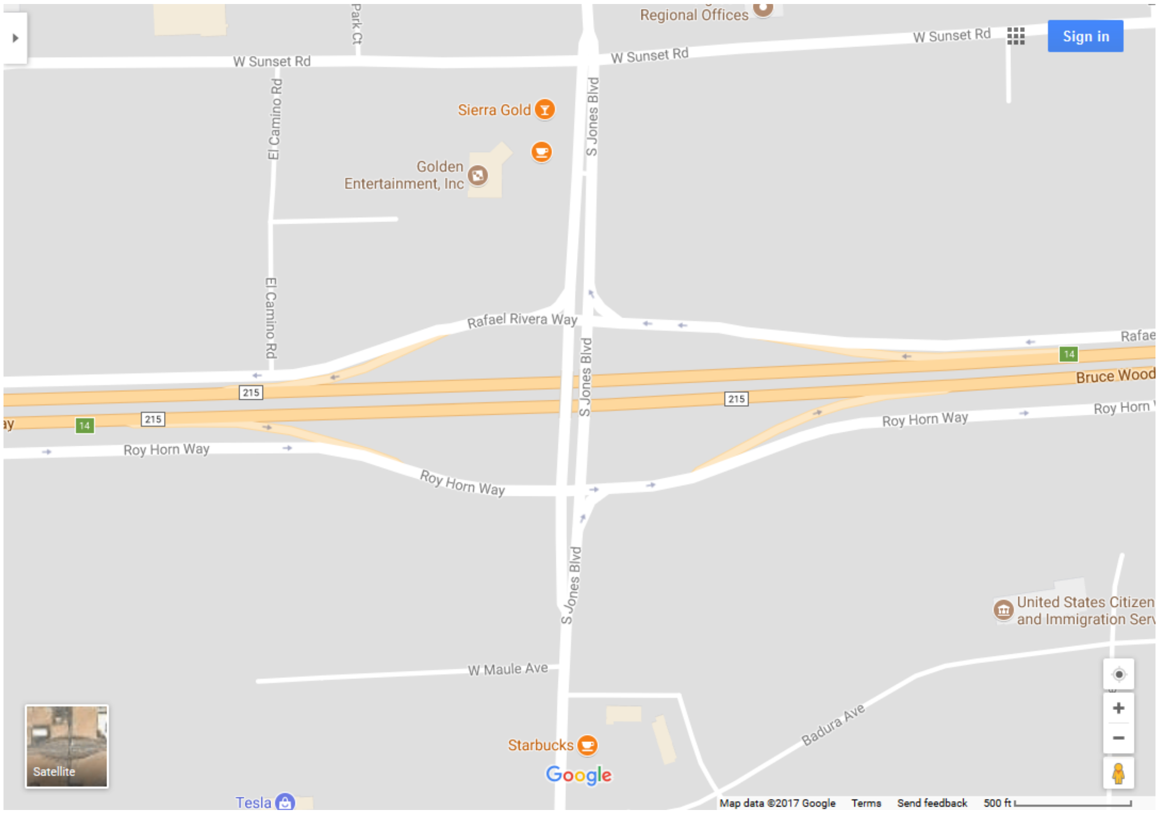


Figure 3-7. Site 3: I-15 at W. Flamingo Road



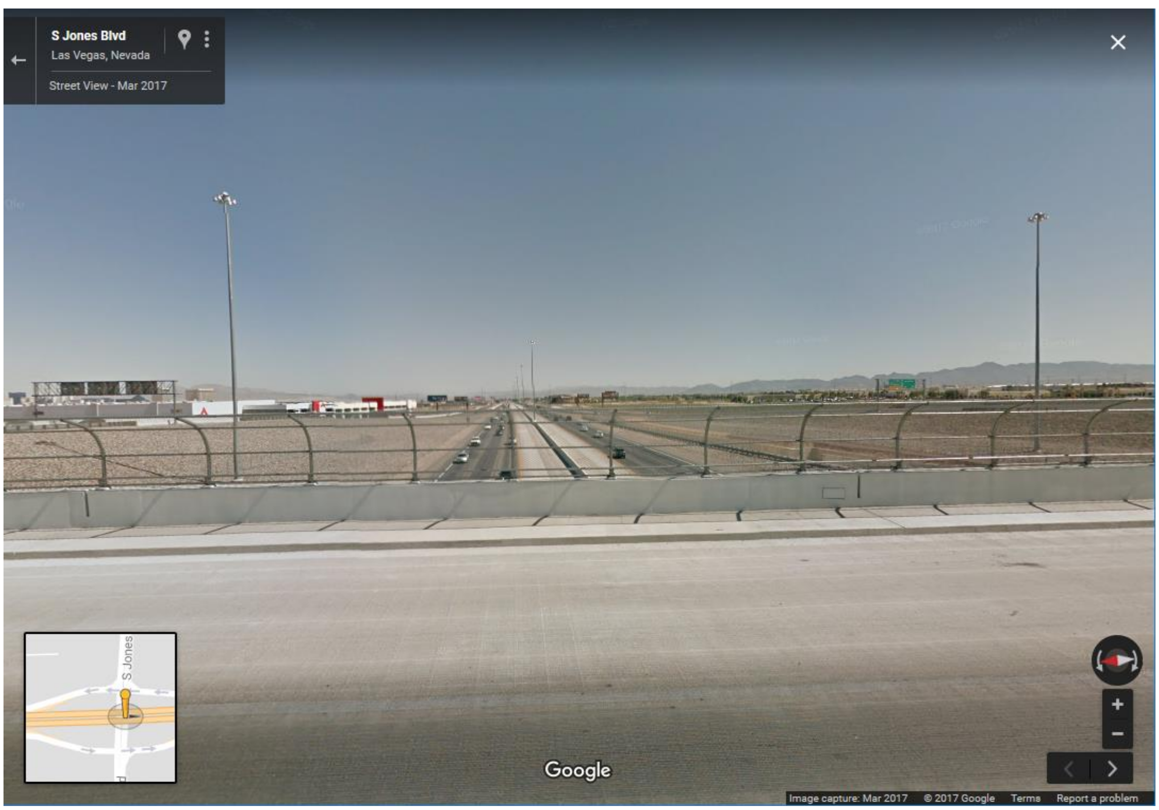
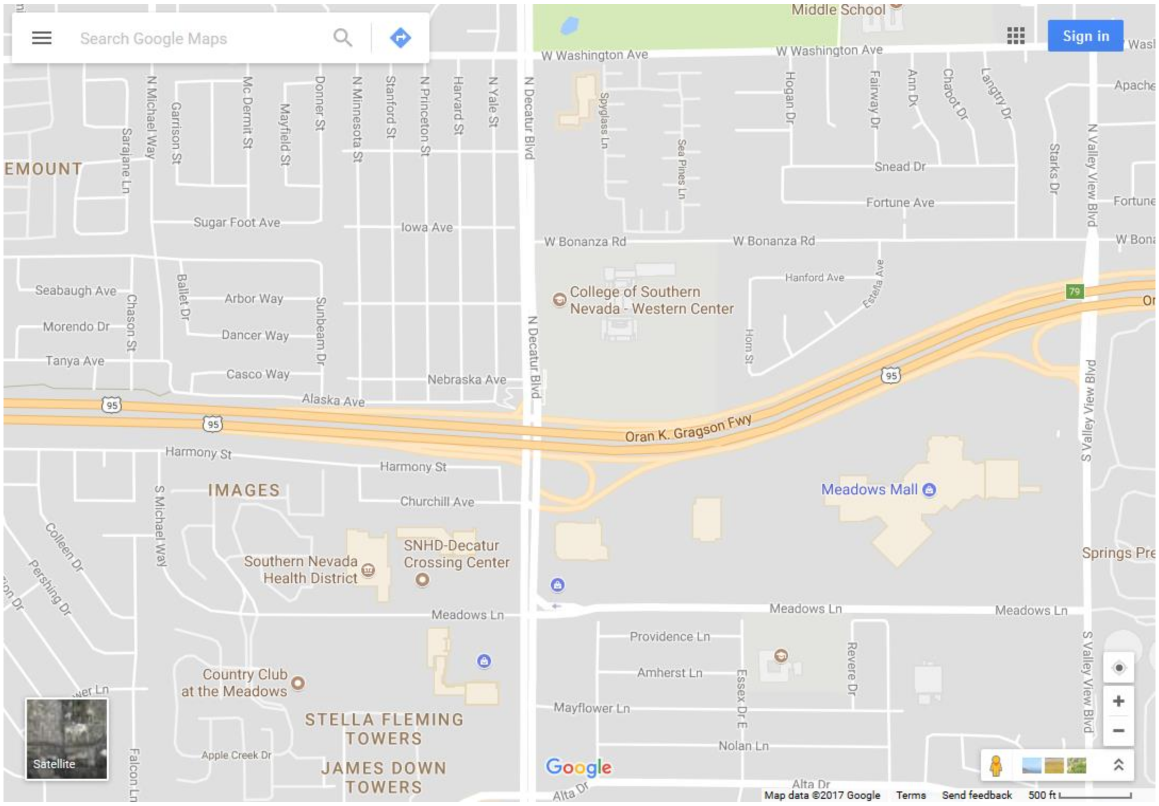


Figure 3-8. Site 4: IR-215 at S. Jones Blvd



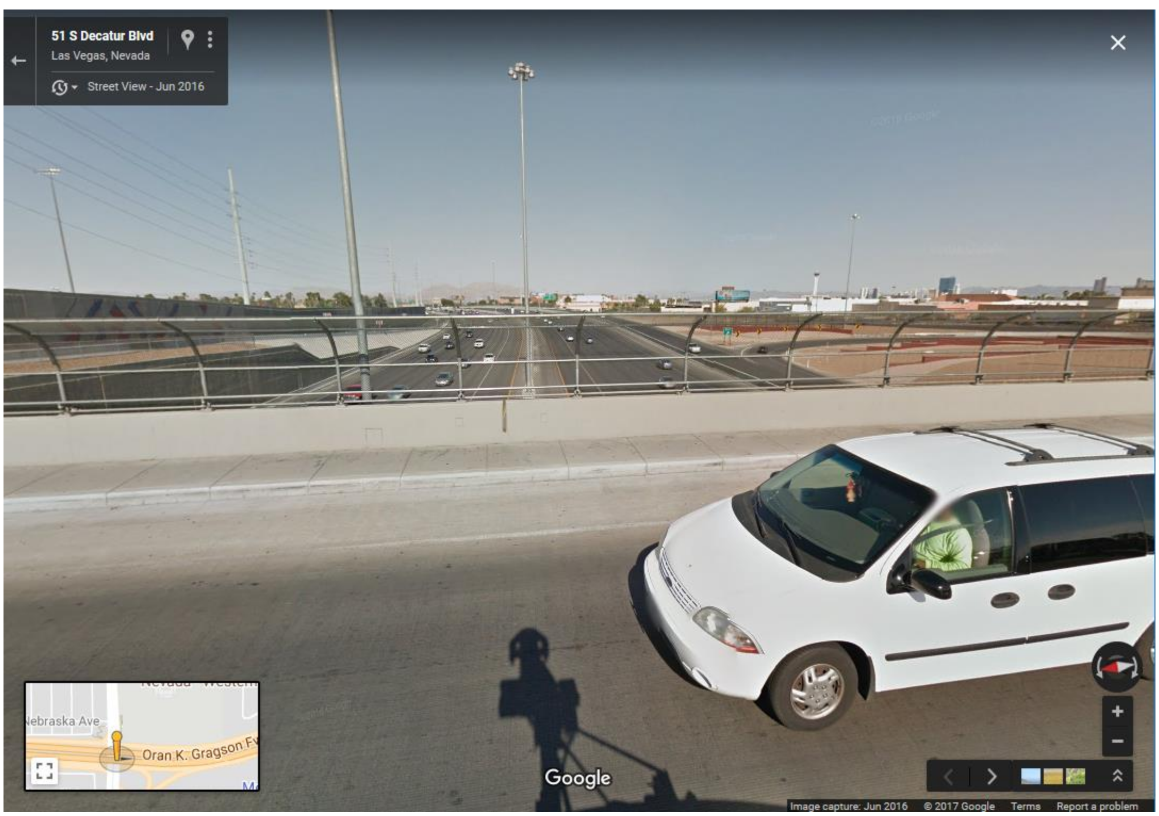


Figure 3-9. Site 5: I-95 at Decatur Blvd

3.2.3 Permits

Depending on the survey site, a permit can be required to occupy the site and videotape the traffic. The permit may be acquired from the responsible agency such as the City (for city streets), the County (for county roads), and the state department of transportation (for highways). In addition to the permit, some agencies may also require a traffic control plan that details how the impact on vehicular or pedestrian traffic will be mitigated. The permit application and approval process may take days or weeks. Therefore, the surveyor should apply for it as soon as the survey location has been identified.

Four of the five sites (Sites 1, 2, 3, and 5) in the 2017 License Plate Survey are in the jurisdiction of NDOT. Site 4 is in the jurisdiction of Clark County. CE-CERT applied for and obtained necessary permits from both agencies prior to the survey campaign. A copy of the approved permits and traffic control plans is attached to this report.

3.2.4 Equipment

The equipment required to perform a successful on-road license plate survey can vary by survey site. The equipment used in the 2017 License Plate Survey are listed below:

- *Video Cameras* – The quality of the camera is one of the major factors determining the usability of the videos. Six Cannon XA series (i.e., XA10/20/25) video cameras were used. An important feature of this series of Canon cameras is that they allow the DC power supply to be connected in parallel to the camera's battery. This is important because if the DC power supply can be used as the main source of electric power, especially for long survey days as designed in this study. Then, the camera's battery can serve as a backup power source to help avoid an immediate camera shutdown in case there is any issue with the main power source. The cameras used in this study do not have internal memory, so SD cards are required. 128 GB SD cards were used to store the video footages. A large memory was desired so that more footages can be stored before having to transfer to a hard disk for long-term storage. This eliminates data transfer sessions during the survey days.

- *12V Marine Battery* – When recording videos in the highest quality mode, the camera battery may not be enough to supply the power for a long survey period. And if a survey day includes multiple survey periods, there may not be enough time between the sessions to fully charge the camera battery. In this study, a 12V marine battery was used as the main power source at each survey site. It powered multiple cameras at a site for the entire survey day. Then, it was recharged through a standard power outlet at the end of the day.

- *12V to 120V DC-AC Inverter* – This adapter was used to connect the cameras to the marine battery. A 300W inverter was used at each site, which could supply power to multiple cameras simultaneously.

- *Tripods* – A sturdy, high quality tripod makes the setup easier while also helping keep the camera more stable during recording. The tripods used in this study have a hook at the bottom of the center column, which can be used to secure the tripod to a weight to help keep them stable during windy times.

- *Safety Vests* – All survey crews and the survey supervisor wore a reflective safety vest throughout the survey periods.

- *Digital Multimeter* – A digital multimeter was available at each survey site for keeping track of the 12V charge level.

- *12V Battery Charger* – Automatic battery chargers were used to recharge the 12V batteries at the end of each survey days.

- *Extension Cords* – Each video camera required an extension cord to connect to the inverter. 15-ft extension cords were used in this study.

- *Traffic Cones* – Traffic cones were placed on either side of the camera setup area at a distance where they would not come into contact with the tripod if someone accidently kicks them. Additional cones were also placed behind the parked vehicle of the survey crew to warn oncoming traffic.

- *Portable Hard Drives* – Portable hard drives were used to store video footages from the surveys. At the end of each survey period, the entire footages from each camera were downloaded to a portable hard drive, which were then copied over to another portable hard drive as backup.

3.2.5 Survey Procedures

The procedures for conducting the 2017 License Plate Survey are described below.

- *Initial Setup* – The survey crews arrived at the survey sites about 15 minutes before the start of each survey period to set up the equipment. The 12 V marine battery and the connecting DC-AC inverter were placed in the center of the working space, as shown in Figure 3-10. Extension cords, if necessary, were used to help connect the inverter with the cameras. Traffic cones were placed on either side of the camera setup area at a distance where they would not come into contact with the tripod if someone accidently kicks them. Additional cones were also placed behind the parked vehicle of the survey crew to warn oncoming traffic. If needed, each tripod was hooked with a weight at the center of their legs to provide stability. Figure 3-11 shows the equipment setup at Site 5 as an example.

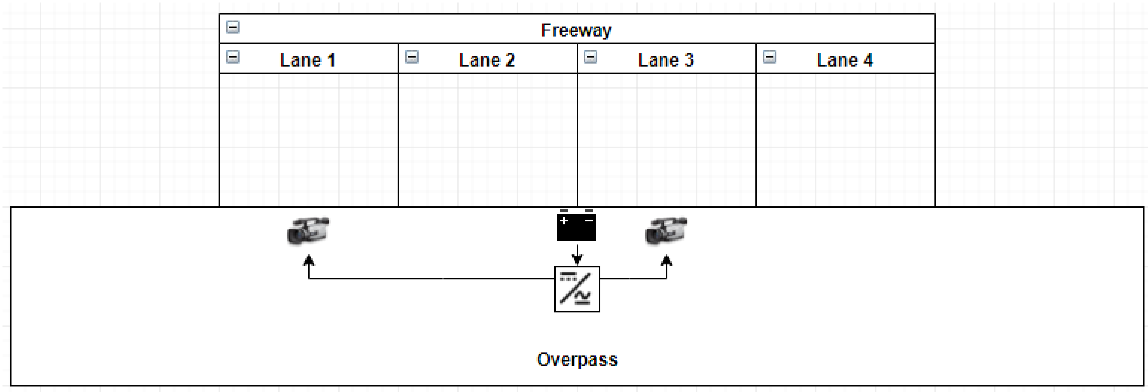


Figure 3-10. Diagram of the equipment setup at survey sites

Figure 3-11. Equipment setup at Site 5

- *Camera Angle and Zoom Level* – One of the most critical aspects to capturing good video footages of license plates is the shooting angle of the video camera. For the survey sites on overpasses, the cameras were placed as close to the ground as possible and tilted down as little as the optical zoom would still capture a full traffic lane (see Figure 3-12).

Having a flatter tilt angle to the freeway meant that vehicles would appear in the footage for a longer amount of time, which would make it easier to read the license plates. A trial-and-error approach was used to find an optimal tilting angle and zoom level for the cameras at each survey site. During the survey periods, the survey crews checked the cameras every 10-15 minutes for tilting angle, zoom level, as well as power.

Figure 3-12. Camera positioned close to the ground and tilted very little

- *Camera Glare* – Early morning and late afternoon glare can significantly degrade the readability of license plates in video footages. The survey crews checked and, if needed, manually readjusted the exposure setting on the cameras every 10-15 minutes as the position of the sun changed.

- *Camera Rotation* – At each survey site, the cameras were rotated so as to capture vehicles in all lanes of the roadway. The rotation scheme depended on the number of lanes of the roadway, the number of cameras, and the length of the survey period. Figure 3-13 shows the camera rotation scheme at Site 1 that has 6 lanes per direction. Two cameras were used to videotape traffic in two of the six lanes every fixed interval where the interval length varied by the length of the survey period.

Thursday and Friday

	Lanes						Time
AM: 06:30-07:00 **SB**							
	1	2	3	4	5	6	10
	1	2	3	4	5	6	10
	1	2	3	4	5	6	10
					Total Time		**30**
AM: 07:00-08:00 **SB**							
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
					Total Time		**60**
Mid: 10:00-11:00 **SB**							
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
					Total Time		**60**
Mid: 11:00-11:30 **SB**							
	1	2	3	4	5	6	10
	1	2	3	4	5	6	10
	1	2	3	4	5	6	10
					Total Time		**30**
PM: 05:00-07:00 **NB**							
	1	2	3	4	5	6	40
	1	2	3	4	5	6	40
	1	2	3	4	5	6	40
					Total Time		**120**

Saturday and Sunday

	Lanes						Time
AM: 09:00-10:00 **SB**							
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
					Total Time		**60**
Mid: 12:00-02:00 **SB**							
	1	2	3	4	5	6	40
	1	2	3	4	5	6	40
	1	2	3	4	5	6	40
					Total Time		**120**
PM: 04:00-05:00 **NB**							
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
					Total Time		**60**
PM: 05:00-06:00 **NB**							
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
	1	2	3	4	5	6	20
					Total Time		**60**

Figure 3-13. Camera rotation scheme at Site 1 (2 cameras for 6 lanes)

- *Battery Charging* – The stock battery on each camera was fully charged between the survey periods. Each 12V marine battery was charged overnight at the end of each survey days.

- *Downloading and Backing Up Videos* – At the end of each survey period, the entire footages from each camera were downloaded to a portable hard drive, which were then copied over to another portable hard drive as backup. After that, the SD card was emptied to be ready for the next survey period.

3.2.6 Site-Specific Setup Requirements and Issues Encountered

The general setup and survey procedures were the same for all sites. However, there were some site-specific setup requirements and issues encountered as described below.

- *Site 1* – Figure 3-14 shows the survey at Site 1. The setup was straightforward, and the survey went smoothly for the most part. However, due to the issue with providing power to the cameras at Site 2, stock batteries of the cameras from this site were sent to address that issue. This meant that these cameras were solely dependent on the marine battery. Unfortunately, one hour of video footages during the morning survey period of the last survey day was missing due to an inverter failure. The failed inverter was replaced with a new one, and the rest of the day proceeded without problems.

Figure 3-14. Equipment setup at Site 1

- *Site 2* – This site is unique as it is on a surface street rather than a freeway. That means there was no overpass to set up cameras and shoot videos from. For optimal recording angles, it was decided to have one camera on the sidewalk recording the two outermost lanes (Lanes 3 and 4; see Figure 3-15), and another camera in the median recording the two innermost lanes (Lanes 1 and 2; see
- Figure 3-16). One issue resulting from this setup was that since the powering system was designed for cameras being relatively close to each other, it would no longer work for this site. The workaround was to borrow the stock batteries from the cameras at Site 1.

Figure 3-15. Equipment setup on the sidewalk at Site 2

Figure 3-16. Equipment setup in the median at Site 2

- *Site 3* – This site was more challenging than the others. First, the southbound direction was thought to have six lanes originally, but one of those turned out to be an exit lane (marked by the green line in Figure 3-17). The amount of traffic in that lane was very little as compared to the other lanes. Thus, it was decided to only videotape traffic in the other 5 lanes. The northbound direction remained unchanged at 7 lanes. Second, since there were an odd number of lanes in both directions of traffic while having two cameras, complex camera schemes needed to be developed that allowed all lanes to get an equal amount of recording time.

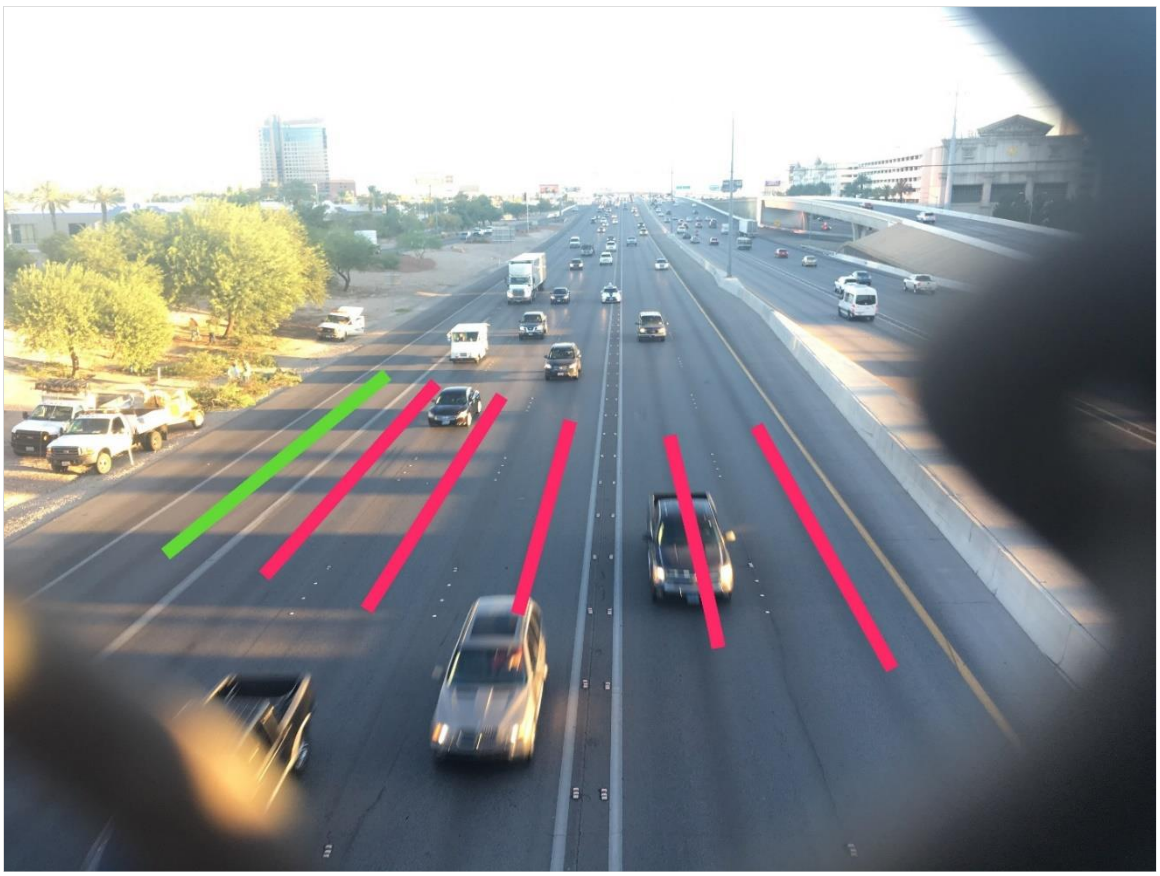


Figure 3-17. Southbound traffic at Site 3

- *Site 4* – This site was assigned 3 cameras. Since the eastbound had 3 lanes, it was straightforward to use one camera per lane without camera rotation. The westbound was thought to have 3 lanes but turned out to have 4 lanes, as shown in Figure 3-18. So, only two cameras were used and rotated to record vehicles in the 4 lanes with an equal amount of time.

- *Site 5* – This site also had 3 cameras assigned to it. The eastbound direction at this site also had a different number of lanes than expected. Five lanes were expected but on the survey days the innermost lane was closed off due to construction at a nearby interchange. So, only two cameras were used and rotated to record vehicles in the 4 remaining lanes with an equal amount of time.

Figure 3-18. Westbound traffic at Site 4

Figure 3-19. Eastbound traffic at Site 5

- *Low Lighting* – At the time of the year when the survey took place, the sun was setting rather early. Thus, the planned survey period of 5-7 p.m. on weekday suffered from very low light, especially during the last half hour of the survey. After reviewing videos from the first day of the survey, it was decided to shift this survey period half an hour earlier to avoid such low lighting.

- *Portable Hard Drive Failure* – One of the portable hard drives completely failed during the second day of the study. Fortunately, no data was lost because all the data were also backed up in another portable hard drive—the survey procedures included downloading all the video footages to a portable hard drive at the end of each survey period, which were then copied over to another portable hard drive as backup. However, a new portable hard drive had to be purchased at a local store on that day in order to maintain this data redundancy.

3.2.7 Video Processing

The extraction of license plate numbers was done manually. The main advantage of manual extraction is the interpretation ability of the data technician. Due to the relatively ad hoc nature of the data collection process, the size of a license plate number, the amount of lighting on the plate, and the amount of time the plate is captured on film can vary greatly from one video to another. The human eye, however, is quick to adjust and able to interpret license plates. Moreover, the manual extraction technique allows for the collection of more vehicle attributes than just the license plate number, for example, state of registration, vehicle class, or even vehicle make and model in some cases.

For the 2017 License Plate Survey, the video processing involved a team of data technicians, each assigned a set of videos from the surveys. The data technicians went through the video footage, paused at each vehicle, and attempted to read the license plate number and interpret the state of registration, and then recorded the information on spreadsheet. When possible, a dual-computer or dual-monitor setup such as that shown in Figure 3-20 was used to help make the video processing faster.

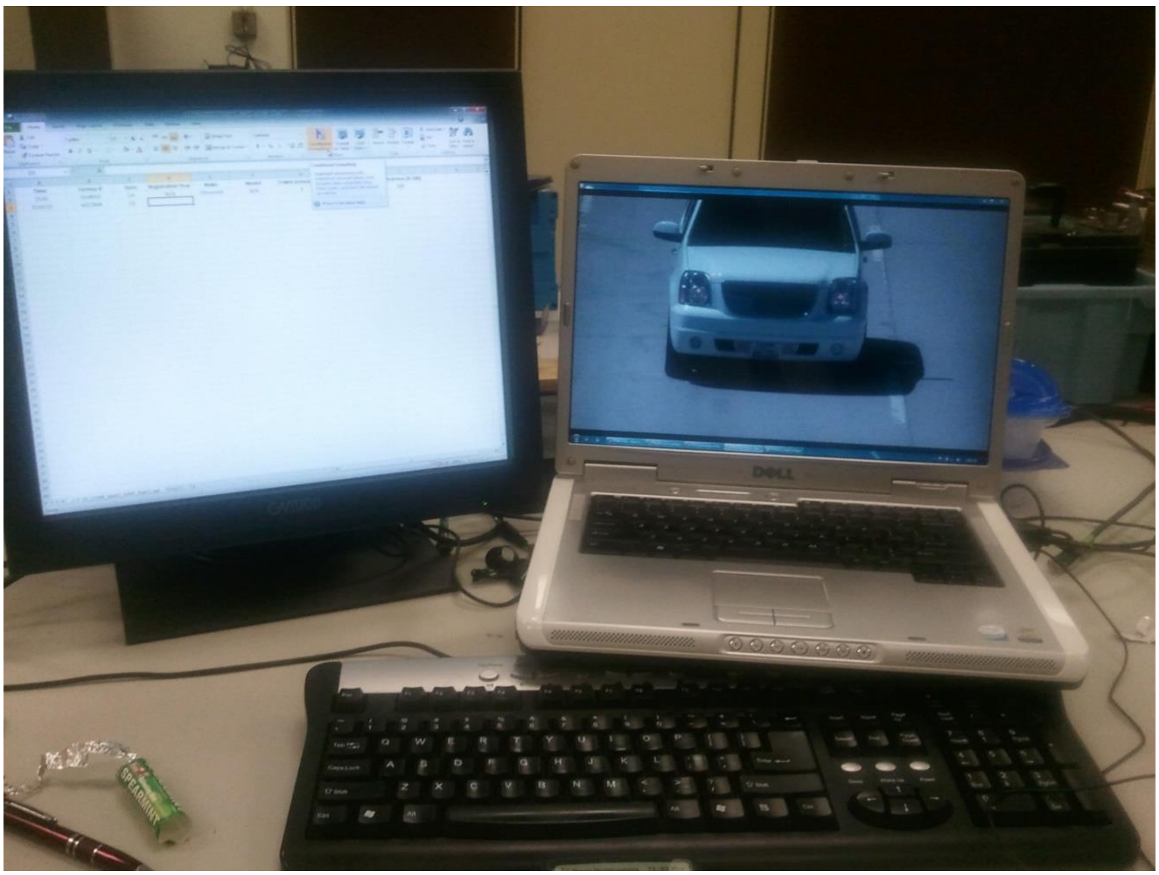


Figure 3-20. Dual-computer setup for license plate number extraction

3.2.8 Issues Encountered

Despite the best efforts during the survey, there are unavoidable issues with the video images that prevent the extraction of some license plate numbers. These issues are shown and described in this section.

- *Low-light condition* – The afternoon period of the surveys, especially after 6:30 p.m., suffered from insufficient sunlight. This caused the video images to be dark, as shown in Figure 3-21. Using a function in the media player software to increase brightness and exposure helped increase the visibility of the license plate, but the overall quality of the video image degraded to the point that made it impossible to discern the actual plate characters. In the later survey days, the afternoon survey period was started half an hour early, which helped improve the lighting condition and the quality of the video images. Still, video images from some minutes in the afternoon were still relatively dark and difficult to process.

Figure 3-21. Video image from Site #5 on 9/14/17, 6:30-7 p.m.

- *Glare* – In contrast to the low-light condition, direct exposure to sunlight especially in early morning and late afternoon can cause glare, which degrades the sharpness of video images. Figure 3-22 shows an example of a video image with glare from sunlight, making it difficult to read the license plate number. While the survey crews frequently readjusted the exposure setting on the cameras, it was not possible to have an optimal exposure setting all the time.

Figure 3-22. Video image with glare.

- *Blurriness* – Even under a good lighting condition, the video images could still appear blurry, as shown in Figure 3-23. Some blurry images were due to vibration of the video camera caused by wind. Some others were due to the vehicles traveling so fast that they looked blurry throughout the moment they appeared in the video footage. In the later survey days, the angle of the video cameras was adjusted upward to increase the amount of time vehicles appeared in the video footage while maintaining the level of optical zoom.

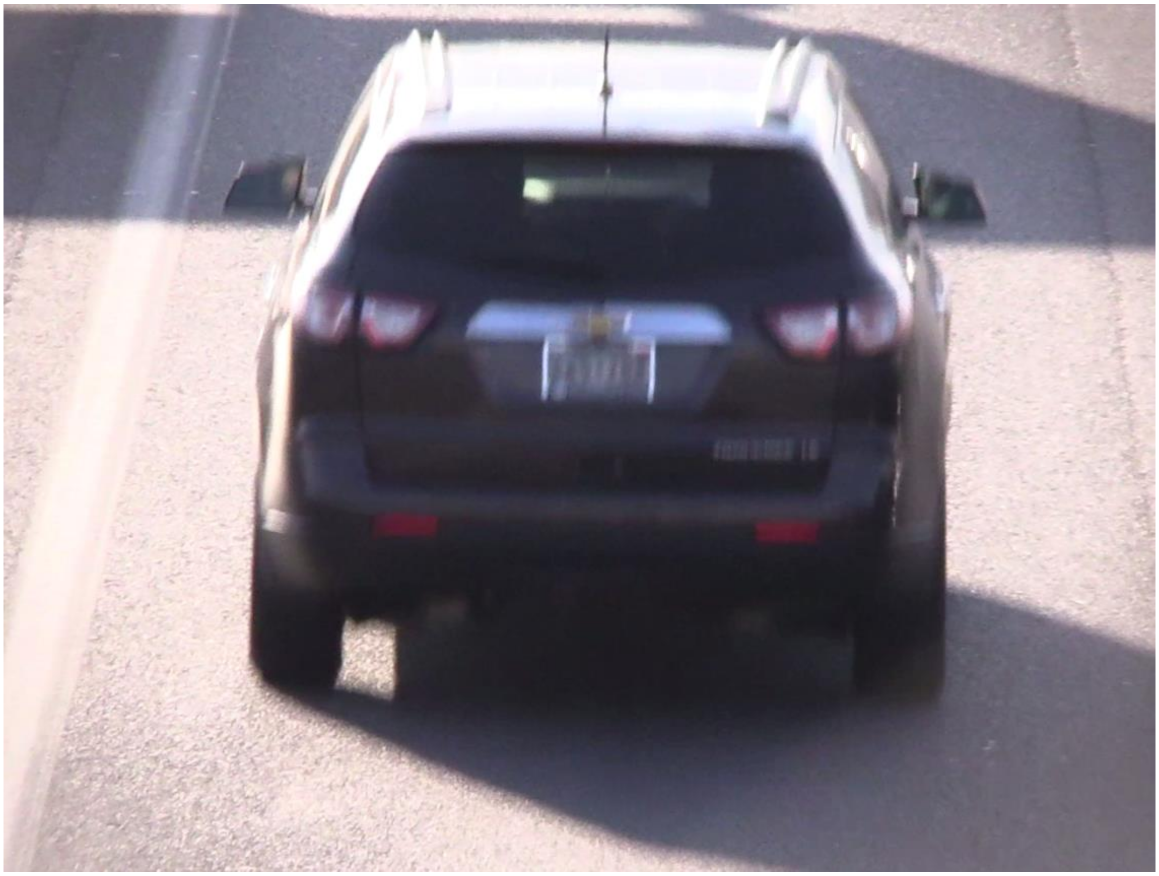


Figure 3-23. Blurry video image

- *Occlusion* – This issue was specific to Site 2 where the video cameras were set up on the same ground as the roadway as opposed to on an overpass. One camera was placed on the sidewalk to capture vehicles in the two outermost lanes (Lanes 3 and 4) while another camera was placed in the median to capture vehicles in the two innermost lanes (Lanes 1 and 2). With this set up, the camera view when shooting the lane not adjacent to the camera could sometime be blocked by vehicles in the lane adjacent to the camera, as shown in Figure 3-24.

Figure 3-24. Occlusion of vehicle in Lane 2 by vehicle in Lane 1 at Site 2

3.2.9 Matching License Plates to VINs

Periodically, the teams of CE-CERT data technicians completed batches of tag-edited plates and sent them to ERG. The tag-edited results included the site and lane number, date, time, license plate state and characters. Table 3-6 shows a sample of 5 lines of tag-edited plates.

Table 3-6. Sample License Plate Survey Tag-Editing Results

Site	Lane	Date	Time	State	Plate
4	1	9/14/17	10:30	NV	089YYW
4	1	9/14/17	10:30	NV	43E723
4	1	9/14/17	10:30	NV	34G235
4	1	9/14/17	10:30	NV	121A36
4	1	9/14/17	10:30	NV	15F364

ERG performed quality assurance checks on the batches of license plates to ensure that reported survey date and times were consistent with each other (Table 3-5) and forwarded the license plate lists to IHS Markit, who used current registration data from all 50 states to attempt to match each plate to a unique vehicle (VIN). Table 3-7 shows an example of the same 5 records matched to a VIN and the vehicle's characteristics. Note that only partial VINs are returned to protect vehicle owners' identity.

Table 3-7. Sample License Plate Survey Results

Site	Lane	Date	Time	State	Plate	VIN Stem	State, County of Registr.	Model Year	Make	Model	Gross Vehicle Weight	Number of Wheels	Engine Displ. CI	Fuel
4	1	9/14/17	10:30	NV	089YYW	5TETX22N*8	NV, CLARK	2008	Toyota	TACOMA	0 - 6,000#	4	164	Gas
4	1	9/14/17	10:30	NV	43E723	2C4RDGBG*H	NV, CLARK	2017	Dodge	GRAND CARAVAN	6,001 - 10,000#	4	220	Flexible
4	1	9/14/17	10:30	NV	34G235	1N6DD26S*Y	NV, CLARK	2000	Nissan	FRONTIER	0 - 6,000#	4	146	Gas
4	1	9/14/17	10:30	NV	361YPN	JA32U2FU*D	NV	2013	Mitsubishi	LANCER		4	122	Gas
4	1	9/14/17	10:30	NV	121A36	5LMJJ3HT*H	NV, CLARK	2017	Lincoln	NAVIGATOR	6,001 - 10,000#	4	214	Gas

A license plate can only be matched to a VIN if the two following conditions are met: (1) the data technicians correctly identified the state and characters from the video image and (2) the registration record of the VIN included the license plate. As previously mentioned, the license plate coverage varies widely by state. Nevada has the lowest plate coverage on registration records of any state in the U.S. at only 46%, while neighbors California, Arizona, and Utah have high coverage at 100%, 85%, and 90% respectively[7]. Over 90% of the vehicles observed during the 2017 License Plate Survey had Nevada plates, and nearly 75% of those were registered in Clark County.

[7] Personal communication with IHS Markit on May 10, 2018.

The license plate match rate for this study has varied from 73% to 84%, depending on the batch. The limitation of 46% plate coverage in the Nevada registration data appears to be a large limiting factor in achieving a higher match rate. Upon further investigation, ERG learned that within Nevada, the plate coverage varies widely among DMV offices and the average plate coverage in Las Vegas is 75%[8]. Another source of potential error causing non-matches could be human error where data technicians incorrectly identify the state of a plate (a challenge due to the large number of layout designs per state and a tendency of plate frames to cover the text portion of the state) or incorrectly identifying the characters. For examples of the latter, the letter "O" can look a lot like the number "0", and likewise for the letter "I" vs. "L" vs. number "1", or the letter "B" vs. number "8". These lookalikes can be difficult to distinguish on vehicles in motion.

In CE-CERT's previous 2010 license plate surveys on the outskirts of Las Vegas, CE-CERT matched plates with the registration data of four state DMVs (CA, NV, AZ, and UT). In the case of Nevada, the DMV did the matching and returned 11,061 plates out of 22,700 (49% match rate).

3.3 Data Conversion into Traffic Profiles

ERG developed a set of Python scripts (hereafter referred to as the "Tool") that extract traffic volumes from thousands of input files and perform the calculations to transform them into vehicle activity profiles that can be used directly in MOVES, SMOKE, and CONCEPT. We selected Python and MySQL as the programming languages for the Tool because Python is computationally efficient, MySQL is transparent, and both are open source.

The first step in running the Tool is to customize user settings near the top of each of the four Python scripts, under a section labeled User-Specific Inputs. In this section of the scripts, local paths and filenames should be set as well as the MySQL login credentials. Then, the user may run the Tool by executing the following four Python scripts in order. The list below provides an overview of each script.

1. *extractFromXLS.py* – This first of four Python scripts reads the nearly 9,000 NDOT monitor data Excel spreadsheets and extracts the important information such as site number, roadway name, HPMS functional class, date, hour, FHWA vehicle class, and the hourly volume. The script creates and populates one database table for each monitor type (classification, continuous, and HPMS). It also performs important cleanup steps such as excluding duplicate records (two records with the same station number, date, hour, and volume), which was a common problem in the continuous volume monitor data at the beginning and end of each year. It also removes partial days of monitor data by deleting a full station-date set of records, if one or more hours did not have a reported volume (i.e., missing data).

[8] Personal communication with IHS Markit on May 22, 2018.

2. *loadInputFiles.py* – The second of four Python scripts reads the files that specify the fractions of passenger cars vs. light trucks (discussed more in Section 3.3.1), long-haul trucks (Section 3.3.2), and other minor source types' fractions that are based on recent U.S. EPA work and local bus VMT data (Section 3.3.3); optional VMT-weighting adjustment factors by source type and calendar year; and cross-reference files that map HPMS road types to MOVES, survey time periods to 24 hours, etc. The full list of these inputs is below. The dates in the file name are not important to the program; however only one version of each file type should be present in the data directory listed for the variable name 'dataDir' in the *loadInputFiles.py* script.

    - Fractions_Survey_CarLightTruck_18Jun2018.csv
    - Fractions_FAF_LongHaul_21may2018.csv
    - Fractions_OtherSplits_27jun2018.csv
    - Xref_FAF_CONCEPTRoadTypes_5mar2018.csv
    - Xref_Survey_TimePeriods_5mar2018.csv
    - sourceTypeYearVMTadj_18jun18.csv
    - FHWA_to_MOVES_groupID_13mar18.csv
    - MOVES_groupID_to_MOVES_sourceTypeID_13mar18.csv

3. *generateTables.py* – The third Python script loads user-provided annual VMT for a given year the distribution of VMT by MOVES road type. These data should be specified through a CDB named in generateTables.py, through the tables *sourceTypeYearVMT* and *roadTypeDistribution*. The script uses these inputs (along with monitor data imported by the first script and fractions files imported by the second script) to build the 20 new tables (4 for MOVES, 4 for SMOKE, and 12 for CONCEPT) full of modeling profiles, listed below. Note that the Tool does not estimate total VMT inputs for MOVES or SMOKE; the magnitude of annual total VMT in Clark County comes from the input CDB table *sourceTypeYearVMT*. The final VMT mix by vehicle type reflected in the output MOVES-ready *sourceTypeYearVMT* table and the output SMOKE-ready VMT table reflects the data from this study. The 20 output tables produced by *generateTables.py* include:

    - MOVES_hourVMTFraction
    - MOVES_dayVMTFraction
    - MOVES_monthVMTFraction
    - MOVES_sourceTypeYearVMT

    - SMOKE_diurnal_mtpro
    - SMOKE_weekly_mtpro
    - SMOKE_monthly_mtpro
    - SMOKE_vmt_mbinv

    - CONCEPT_hourlyprof_all
    - CONCEPT_hourlyprof_I15
    - CONCEPT_hourlyprof_notI15
    - CONCEPT_dailyprof_all

- CONCEPT_dailyprof_I15
- CONCEPT_dailyprof_notI15
- CONCEPT_monthlyprof_all
- CONCEPT_monthlyprof_I15
- CONCEPT_monthlyprof_notI15
- CONCEPT_vmtmix_all
- CONCEPT_vmtmix_I15
- CONCEPT_vmtmix_notI15

The *generateTables.py* script performs actions such as aggregating the vehicle and road type categories; re-splitting categories using fractions; identifying and excluding partial data from monitors that could bias the profiles; and finally, sum the traffic volumes and normalize to generate the various modeling profiles. The script writes the 20 files to a subdirectory named *intermediateFiles*. They aren't final because the final script fills gaps to complete the profiles.

One of the early aggregation steps performed in *generateTables.py* is to map the 13 FHWA vehicle classes into MOVES Group IDs, following the many-to-one map in Table 3-8. Because FHWA Class IDs 2 and 3 cannot be reliably distinguished from a monitor, the Tool adds them together as MOVES Group ID 25. FHWA Class IDs 5, 6, and 7 are all single unit trucks, so these roll up to MOVES Group ID 50. Likewise, for the FHWA Class 8 through Class 13 trucks, the Tool aggregates all tractor-trailers into the MOVES Group ID 60, combination unit trucks.

Table 3-8. Map of FHWA Vehicle Class to MOVES Groups of Source Types

FHWA Class ID	FHWA Class Description	MOVES Group ID	MOVES Source Types Included in Group
1	Motorcycles	10	11 Motorcycle
2	Passenger Cars	25	21 Passenger Car 31 Passenger Truck 32 Light Commercial Truck
3	Pickups, Panels, Vans		
4	Buses	40	41 Intercity Bus 42 Transit Bus 43 School Bus
5	Single Unit 2-Axle Trucks	50	51 Refuse Truck 52 Single Unit Short Haul Truck 53 Single Unit Long Haul Truck 54 Motor Home
6	Single Unit 3-Axle Trucks		
7	Single Unit 4 or More-Axle Trucks		
8	Single Trailer 3- or 4-Axle Trucks	60	61 Combination Unit Short Haul Truck 62 Combination Unit Long Haul Truck
9	Single Trailer 5-Axle Trucks		
10	Single Trailer 6 or More-Axle Trucks		
11	Multi-Trailer 5 or Less-Axle Trucks		
12	Multi-Trailer 6-Axle Trucks		
13	Multi-Trailer 7 or More-Axle Trucks		

After aggregating the FHWA vehicle categories into groups compatible with MOVES, the Tool splits the MOVES groups into the 13 source types required for on-road emissions models. The Tool splits Passenger Cars from light trucks (Passenger Truck & Light Commercial Truck) by day type and hour, then divides the Passenger Truck vs. Light Commercial Truck using a single, flat fraction from EPA's NEI (see Table 3-19 in Section 3.3.3). The Tool can use the same data source (or alternatively, local data on bus VMT) to divide MOVES Group ID 40 into MOVES source types 41, 42, and 43; and to apportion approximately 6% of the MOVES Group ID 50 total into source types 51 (Refuse Truck) and 54 (Motor Home). The remainder and majority of MOVES Group ID 50 are the Single Unit Short-haul and Long-haul Trucks. The Tool divides the single unit trucks (source type IDs 52 and 53) and the combination trucks (source type IDs 61 and 62) into short-haul and long-haul operation types using FAF-based fractions in Section 3.3.2.   Table 3-9 summarizes the splitting approach and the data sources used for each MOVES source type.

Table 3-9. Map of MOVES Groups to MOVES Source Types

MOVES Group ID	Disaggregation Approach	MOVES Source Type ID	MOVES Source Type Description
10	None required.	11	Motorcycle
25	1) Divide into cars (21) vs. trucks (31+32) based on the 2017 License Plate Study. 2) Divide trucks (31+32) into 31 vs. 32 categories following US EPA methods for NEI, specific to Clark County.	21	Passenger Car
		31	Passenger Truck
		32	Light Commercial Truck
40	Divide into 41, 42, and 43 following US EPA methods for NEI, specific to Clark County. Alternatively, use local data on bus VMT from transit and school buses.	41	Intercity Bus
		42	Transit Bus
		43	School Bus
50	1) Back out the refuse trucks (51) and motor homes (54) from the single unit truck fraction US EPA methods for NEI, specific to Clark County. 2) Divide remainder single unit trucks (52+53) into short-haul (52) and long haul (53) based on FAF.	51	Refuse Truck
		52	Single Unit Short Haul Truck
		53	Single Unit Long Haul Truck
		54	Motor Home
60	Divide the combination unit trucks into short-haul (61) and long-haul (62) based on FAF.	61	Combination Unit Short Haul Truck
		62	Combination Unit Long Haul Truck

Another aggregation step the Tool performs is mapping the HPMS functional classes from NDOT monitor data into MOVES road types, as required for both MOVES and SMOKE profiles.

The CONCEPT set of profiles retain the HPMS roadway type detail, and the Tool further separates the Principal Arterial Interstates (HPMS road types 11 and 23) according to whether the monitor is located on the southern portion of Interstate-15 from the California border to Spring Mountain Road. Table 3-10 summarizes the many-to-one transformation of HPMS to MOVES roads.

Table 3-10. Map of HPMS Road Types to MOVES Road Types

HPMS Road Type	MOVES Road Type
11 Rural Principal Arterial – Interstate	2 Rural Restricted Access
13 Rural Principal Arterial - Other	3 Rural Unrestricted Access
15 Rural Minor Arterial	
17 Rural Major Collector	
19 Rural Minor Collector	
21 Rural Local System	
23 Urban Principal Arterial – Interstate	4 Urban Restricted Access
25 Urban Principal Arterial – Other Freeways	
27 Urban Principal Arterial – Other	5 Urban Unrestricted Access
29 Urban Minor Arterial	
31 Urban Collector	
33 Urban Local System	

After the grouping and splitting of the vehicle classes and road types, the Tool scans the monitor data to assess which sites should be included in each type of profile. Only appropriate monitor types with sufficient data over the applicable time periods for the profile are included. For example, for MOVES monthly profiles, only the continuous volume monitor type is useful because it reports data from the same station across 12 months of the year. The HPMS and vehicle classification monitors only cover 1 week per year. In the case of MOVES monthly profiles, the Tool only includes continuous volume monitors that operated 24 hours a day, for at least 7 different day types of week in each month. Very few monitors operated over the full 24 hours x 365 days in a year for reasons such as roadway construction or a technical malfunction in the sensing equipment or reporting systems. The Tool prepares monthly profiles for MOVES and SMOKE by averaging volumes for each of the 7 day types and 12 months at the station level, discarding any stations that do not have 7 days x 12 months, then calculating month total volumes by scaling the average day volume (average of 7 days) by number of days in the month (e.g., 31 days for January). CONCEPT monthly profile calculations are similar except do not use scaling by number of days in month.

All three monitor types are useful for the daily and hourly profiles, so the Tool merges the monitor data for these. For the daily profiles, the Tool includes any monitor that reports a full 24 hours of 7 continuous days. For the hourly profiles, the Tool includes any monitor that reports a full 24 hours of any day; having 7 consecutive days isn't required, though it is ideal. The Tool prepares hourly profiles by averaging with the same day type from other monitors. SMOKE and CONCEPT models differentiate activity and emissions by 7 days of week, whereas EPA designed MOVES to use 2 types of days (weekday and weekend). By averaging the available monitor-day type combinations, the Tool includes more data in the hourly profiles without introducing bias.

For fleet mix profiles, only the classification monitor data are useful. These monitors report data 24 hours per day for 7 consecutive days. Due to the limitation of data in only 1 month per monitor per year, the Tool doesn't produce any seasonal variability in the fleet mix. However, there are interesting trends by hour of the week and road type, as discussed in the results in Section 4.0. Similar to the total volume hourly profiles, the Tool requires only 24 hours of any day to be included in a fleet mix profile for CONCEPT.

Fleet mix for MOVES and SMOKE are input very differently than CONCEPT. For CONCEPT, the source type fractions sum to 1 in each hour (24 hours by 7 days by 12 months). In contrast, for both MOVES and SMOKE the fleet mix is specified in directly to the models through annual total VMT listed by vehicle type. For use in MOVES, the Tool produces an output CDB table *sourceTypeYearVMT* reflecting total VMT and distribution across roadways from user inputs, volume-based fleet mix from the study, and optional source type VMT weighting factors. First, the Tool weights the volumes by source type over MOVES road types, because the distribution of monitors doesn't necessarily reflect the distribution of VMT. It is well known that monitors aren't located on smaller functional classes. Table 3-11 shows an example user input table for Clark County taken from EPA's 2014 NEI version 2. It shows that the majority of the county's VMT occurs on Urban Unrestricted Access Roads, particularly for light-duty vehicles and buses. For heavy duty trucks, there is more significant travel on rural roads and restricted road types.

Table 3-11. Example User Input *roadTypeDistribution* Table for Clark County

MOVES Source Type ID	Percent of VMT by MOVES Road Type				
	2 - Rural Restricted Access	3 - Rural Unrestricted Access	4 - Urban Restricted Access	5 - Urban Unrestricted Access	*Total*
11 - Motorcycle	0.2%	0.1%	0%	99.7%	*100%*
21 - Passenger Car	3%	3%	24%	70%	*100%*
31 - Passenger Truck	4%	3%	24%	69%	*100%*
32 - Light Commercial Truck	4%	3%	25%	68%	*100%*
41 - Intercity Bus	5%	3%	20%	71%	*100%*
42 - Transit Bus	5%	3%	20%	71%	*100%*
43 - School Bus	6%	4%	21%	70%	*100%*
51 - Refuse Truck	30%	11%	26%	33%	*100%*
52 - Single Unit Short-haul Truck	19%	10%	31%	40%	*100%*
53 - Single Unit Long-haul Truck	21%	10%	30%	38%	*100%*
54 - Motor Home	11%	10%	35%	44%	*100%*
61 - Combination Short-haul Truck	31%	11%	26%	32%	*100%*
62 - Combination Long-haul Truck	33%	11%	25%	31%	*100%*

Second, the Tool aggregates over the four road types producing a set of vehicle volumes by source type. These volumes are one of two data sources used to redistribute user-input VMT for any given year to reflect the study fleet mix. The other data source is optional VMT weighting factors. In an earlier version of this work, ERG considered using MOVES2014a national average annual mileage accumulation rates by source type for the weighting factors. However, the current version of the optional VMT weighting factors file is populated with values of "1" for each source type, effectively turning off the VMT weighting. Table 3-12 lists an example set of input VMT for 2014 for Clark County, the distribution of source type vehicle volume from this study (i.e., the monitor data with supplemental fractions), and it illustrates the impact of using annual mileage accumulation to weight the final VMT distributions in the rightmost three columns. The resulting example output VMT mix for MOVES for Clark County without VMT weighting has 4% VMT from heavy-duty vehicles (source types 41 and higher), whereas the weighted version has 15%. In each case, the total VMT is the same as the input, but the distributions by source type reflect the 2014 to 2016 NDOT monitors and, for the example output with VMT weighting, the MOVES mileage accumulation rates.

Though currently turned off, the VMT weighting functionality remains in the Tool. ERG specifically recommend not using it unless a defensible set of weighting factors can be developed that reflects source type travel within the county that the monitors do not already account for. Furthermore, the use of annual mileage accumulation rates is inappropriate because it overestimates heavy-duty trucks which travel longer distances annually (but not likely confined to the county).

Table 3-12. Example User Input VMT, Mileage Accumulation Rates, and Tool Output VMT

MOVES Source Type	Example Input 2014 VMT for Clark County (miles)	Example Vehicle Volume Distribution Study (--)	Optional VMT Weighting (mileage accumulation rates from MOVES, miles/veh/yr)	Example Output 2014 VMT (miles)	
				With VMT Weighting	Without VMT Weighting
11 - Motorcycle	81,662,908	0.006	2,191	17,439,375	102,114,439
21 - Passenger Car	8,916,069,198	0.504	10,743	7,347,044,328	8,772,049,697
31 - Passenger Truck	6,948,796,166	0.405	12,059	6,634,148,709	7,056,833,034
32 - Light Commercial Truck	743,621,797	0.043	12,294	723,813,026	755,184,051
41 - Intercity Bus	27,469,413	0.002	84,753	239,253,533	36,210,224
42 - Transit Bus	30,484,264	0.002	45,516	142,591,666	40,184,406
43 - School Bus	21,138,550	0.002	14,069	30,562,770	27,864,843
51 - Refuse Truck	7,465,949	0.001	23,461	24,053,549	13,150,895
52 - Single Unit Short-haul Truck	120,741,350	0.012	14,620	244,085,035	214,154,494
53 - Single Unit Long-haul Truck	11,144,051	0.001	19,058	26,973,141	18,154,825
54 - Motor Home	1,017,723	0.000	2,216	309,674	1,792,666
61 - Combination Short-haul Truck	115,029,341	0.009	30,246	370,331,571	157,057,663
62 - Combination Long-haul Truck	389,755,984	0.013	94,244	1,613,790,319	219,645,457
Total	**17,414,396,695**	**1**	**-**	**17,414,396,695**	**17,414,396,695**

For SMOKE, VMT mix is specified as annual VMT by source category code (SCC), a numeric code that includes MOVES source type, fuel, and road type. The Tool automatically populates the SMOKE VMT by SCC annual file by running a flat file 10 (FF10) generation script published with EPA's NEI modeling platforms. Because the FF10 generation script is publicly available, we integrate it into the Tool. The FF10 generation script reads the MOVES county database (updated by the Tool with *sourceTypeYearVMT*, *hourVMTFraction*, *dayVMTFraction*, and *monthVMTFraction* tables in this study) and prepares SMOKE-ready activity that is fully consistent with the CDB. The FF10 generation script is written in MySQL and is called by the *generateTables.py* script and reads other tables in addition to ones developed under this study, namely, the Alternative Vehicle Fuels and Technology (*AVFT*) table which contains fuel type splits, and the *roadTypeDistribution* table. The results of the FF10 generation script may be found in a database named *clarkcountyff10*. The final FF10 VMT file is written to an output directory by the fourth and final script; there is no intermediate version of this table in the *intermediateFiles* directory.

After aggregating categories, splitting categories, and filtering out the monitors with insufficient data reporting, the *generateTables.py* performs the calculations of profiles by summing volumes by source type, road type, month, day, and/or hour, depending on the profile type. The Tool then normalizes the volumes to produce fractions that sum to one, over the parameters (e.g., day type) expected by each model. Note that the SMOKE-ready files contain integers (rather than fractions) consistent with SMOKE's data type requirements.

4. *fillGapsAndOutputFiles.py* – The fourth and final Python script in the Tool fills in the missing profiles that did not have enough data (see Section 3.3.4 for a complete list of traffic profile substitutions). The script then exports the 20 final modeling profiles to comma separated value (CSV) formatted files in a subdirectory called *outputs*.

3.3.1 Fractions of Car vs. Light-Duty Trucks

The relative fractions of passenger cars vs. light-duty trucks are important to estimate because these vehicles make up a large portion of the Clark County on-road emissions inventory and light trucks emit at higher rates than cars, yet their relative proportion in the fleet is not well understood.

In U.S. EPA's version 2 of the 2014 NEI, cars and light trucks together comprised 95% of the VMT[1] and 89%, 95%, and 63% of the emissions[2] of volatile organic compounds, carbon monoxide, and nitrogen oxides in the on-road mobile source sector for Clark County.

Table 3-13 shows MOVES national emission factors for gasoline-fueled light-duty vehicles. Passenger Trucks emit 1.3 to 1.7 times higher than Passenger Cars on a per-mile basis. Note that the MOVES model has separate categories for Personal Trucks (source type 31) and Light Commercial Truck (source type 32), though the two emit similarly. Thus, it is less important to distinguish between the two truck classes than it is to determine the fraction of cars.

Table 3-13. Average EFs for Gasoline-Fueled Vehicles in 2014[9]

Pollutant	21-Passenger Car	31-Passenger Truck	32- Light Commercial Truck	Ratio of Passenger Truck to Car Emissions
(Grams Per Mile)				(-)
VOC	0.530	0.685	0.608	1.3
CO	4.153	6.825	6.664	1.6
NOx	0.574	0.978	0.922	1.7
(Lbs. Per Vehicle)				(-)
VOC	2.8	4.1	3.7	1.4
CO	22.3	41.1	41.0	1.8
NOx	3.1	5.9	5.7	1.9

To estimate the fractions of Passenger Cars, the VIN-decoded characteristics of Make, Model, Model Year, and gross vehicle weight rating (GVWR) were used, in addition to EPA's emissions certification lists. First, vehicles were extracted from the VIN list based on GVWR. Blank values of GVWR signify mostly cars, whereas GVWR of 0-6,000 lbs. and 6,001-10,000 lbs. are light-duty trucks. All trucks (and only trucks) are rated by GVW, while cars (as well as motorcycles and unpowered trailers) do not have a weight rating. Second, the motorcycles and trailers were removed based on Make and Model (e.g., Harley Davidson, Yamaha, Kawasaki are known motorcycle makes, whereas Suzuki has some motorcycle and some car models). After removing blank GVWR values that are not cars as well as GVWR values above 10,000 lbs., only cars and light-duty trucks remaining. The definition of a blank vs. non-blank is the definition of automaker which largely coincided with the definitions of car vs. truck according to EPA certifications lists. The third step was checking vehicles against EPA's certification list which specify certain combinations of Make/Model/Model Year that are a car or a truck. The IHS Markit dataset cars vs. truck designations largely agreed with EPA's certification list with the few exceptions (to date, as of May 21, 2018). Only 176 vehicles were re-classified, as shown below in Table 3-14.

Table 3-14. Makes and Models Changed from "Truck" to "Car"

Make	Model	Count of VINs
Honda	ELEMENT	103
Chrysler	PT CRUISER	79
Toyota	SCION XB	106
Total		**288**

[9] National Scale 2014 Model Run, using the December 2017 release of MOVES2014a with database version movesdb20161117.

The fourth and final step was to calculate the car fractions by survey day (Thursday, Friday, Saturday, Sunday) and survey hour (four per day, listed previously in Table 3-5). The counts of cars and trucks were summed by the 16 time periods (4 days x 4 hours), then the passenger car fractions were calculated as the number of cars divided by the number of cars + trucks. As of June 5, 2018, the available sample size is 74,630 license plates, but a few hundred more plates are expected in the next two weeks. Table 3-15 shows that the fractions of passenger cars relative to cars and light trucks varies from 46% to 58% depending on the period; in general, the midday period has lower fractions of cars than other periods. Table 3-16 is similar to Table 3-15 but restricted to the survey site number 3 (Interstate 15 at W. Flamingo Road); these fractions are used in the CONCEPT VMT mix profiles specific to I-15.

Table 3-15. Car Fractions based on all Survey Sites

Day of Week	Survey Time Period	Car Fraction
Thu	AM (7:00-8:00 AM)	0.5467
	MD (10:00-11:00 AM)	0.5040
	PM (5:00-6:00 PM)	0.5449
	PM (6:00-7:00 PM)	0.5695
Fri	AM (7:00-8:00 AM)	0.5348
	MD (10:00-11:00 AM)	0.5269
	PM (5:00-6:00 PM)	0.5526
	PM (6:00-7:00 PM)	0.5797
Sat	AM (9:00-10:00 AM)	0.5365
	MD (12:00-1:00 PM)	0.5195
	MD (1:00-2:00 PM)	0.5150
	PM (5:00-6:00 PM)	0.5458
Sun	AM (9:00-10:00 AM)	0.5613
	MD (12:00-1:00 PM)	0.5346
	MD (1:00-2:00 PM)	0.5415
	PM (5:00-6:00 PM)	0.5521
Overall Weighted Average		**0.5352**

Table 3-16. Car Fractions for Site 3 (Interstate 15)

Day of Week	Survey Time Period	Car Fraction*
Thu	AM (7:00-8:00 AM)	0.5470
	MD (10:00-11:00 AM)	0.5257
	PM (5:00-6:00 PM)	0.5010
	PM (6:00-7:00 PM)	TBD
Fri	AM (7:00-8:00 AM)	0.5179
	MD (10:00-11:00 AM)	0.4576
	PM (5:00-6:00 PM)	0.5134
	PM (6:00-7:00 PM)	0.5427
Sat	AM (9:00-10:00 AM)	0.5330
	MD (12:00-1:00 PM)	0.4809
	MD (1:00-2:00 PM)	0.5665
	PM (5:00-6:00 PM)	0.5184
Sun	AM (9:00-10:00 AM)	0.5446
	MD (12:00-1:00 PM)	0.5357
	MD (1:00-2:00 PM)	0.5820
	PM (5:00-6:00 PM)	0.5374
Overall Weighted Average		**0.5203**

*TBD = To Be Determined (when more survey data arrive)

Comparison to Other Data Sources of Car vs. Light Truck Splits

Other than the Parsons 2013 study, to the best of our knowledge there are no studies detailing car vs. truck splits by day type or time of day. The 2013 study reported higher car proportions (57-83% on Thursday/Friday and 57-86% on Saturday/Sunday) than the new survey. There is another data source estimating these splits at the local and national level based on registered vehicles. The most recent data source is the 2014 NEI version 2. EPA used car vs. light truck splits at the county level based on mid-year 2014 registrations from IHS Markit. The national average of this split for cars was 48%. The NEI's percent of cars in Nevada varied from 22% to 54% by county – Clark County had the 54% car split. To date, the overall data car split matches the NEI's estimate for Clark County at 54%, though this study's car percent could shift as more data are compiled and the size of the sample grows. The close match makes sense because most of the license plates observed during the survey turned out to be registered in Clark County.

The results of the Clark County Vehicle Classification Study field campaign to date suggest reasonable values of the relative amount of car vs. light truck traffic and provide additional detail in the variability by time of day.

3.3.2 Fractions of Long-haul Trucks

Vehicle classification monitors are unable to distinguish between which heavy-duty trucks are used in short-haul vs. long-haul operation. The MOVES model makes this distinction for both single unit trucks and combination units (tractor trailer). While the running emission rates are similar for short-haul vs. long-haul trucks, it is important to capture the long-haul fraction o combination unit trucks because of the implications for extended idling emissions which typically scale with VMT in the emission inventory. To estimate the relative fractions of long-haul traffic by road type, ERG leveraged the FAF dataset for 2012 (shown previously in Figure 3-2) to calculate the fraction of long-haul VMT with regional specificity. The first set of results presented are specific to the West U.S. census region (13-state area shown previously in Figure 3-3) by MOVES roadway type.

Methodology

To begin, we downloaded the latest available years of data to update long-haul fractions in previous work, including 2012 FAF[10] and 2015 HPMS[11] datasets and imported the link level information into a MySQL database. The FAF dataset only reports estimate of total long-haul mileage, without distinction by truck type. ERG estimated the long-haul VMT separately for combination and single-unit trucks by multiplying total FAF long-haul VMT by truck allocation factors reported in the FAF documentation. According to the documentation, these allocation factors were developed from the 2002 Vehicle In-Use Survey (VIUS 2002) to assist in

[10] https://ops.fhwa.dot.gov/FREIGHT/freight_analysis/faf/faf4/netwkdbflow/index.htm
[11] https://www.fhwa.dot.gov/policyinformation/hpms/shapefiles.cfm

apportioning long-haul commodity flow demand to available truck capacity.[12] For long-haul trips (defined as trips over 200 miles from home base), the single unit truck allocation for long-haul trips was 10.3 percent, with the rest being from combination trucks. Based on the single unit allocation factor, ERG split the total FAF long-haul VMT estimates into combination and single-unit categories using factors of 0.897 and 0.103, respectively. We then developed long-haul fractions by combining long-haul VMT allocations from the FAF with combination and single unit truck VMT allocations from HPMS. The common point of the FAF and HPMS datasets is that both estimate total single unit+combination truck VMT. This becomes the point of reference for the two datasets; FAF can provide the ratio of long-haul VMT to total single unit+combination VMT, while HPMS can provide the ratio of combination and single unit VMT (separately) to the combined total. The long-haul fractions were then derived from these ratios. This approach provides a way for the inconsistency in analysis year of the datasets (2012 vs. 2015) to be addressed, and to extract long-haul allocations from FAF based on internally consistent comparisons.

Long-haul fractions for combination and single unit trucks were calculated for each road type as follows: 1) Estimate the ratio of long-haul VMT to total truck VMT (single+combination) from the FAF data, separately for combination and single unit trucks; 2) Estimate the ratio of combination truck VMT and single unit truck VMT to total single+combination VMT from 2015 HPMS; and 3) Estimate long-haul fraction by dividing the results of steps 1 and 2.

Results

Figure 3-25 and Figure 3-26 show long-haul fractions using 2012 FAF and 2015 HPMS for the current study and how they compare to older data used in CRC A-88 study that U.S. EPA applied to Clark County in the NEI.

[12] Battelle, Inc "FAF3 Freight Traffic Analysis" Final Draft Report, March 2011 http://faf.ornl.gov/fafweb/Data/Freight_Traffic_Analysis/faf_fta.pdf

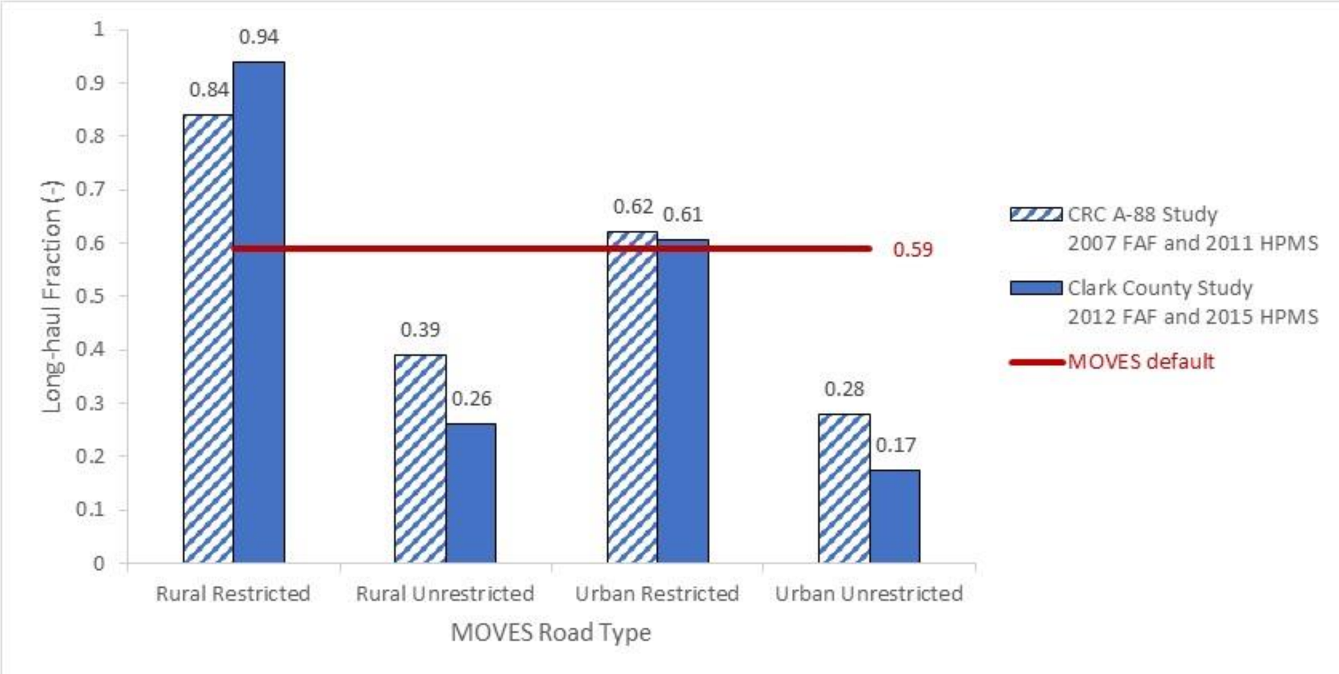


Figure 3-25. Long-haul Fractions for Combination Unit Trucks, West Census Region

According to the CRC study, the MOVES default value of long-haul fractions from combination trucks is 59% of VMT, which appears to be a reasonable approximation for the West census region on Urban Restricted roads, but it overestimates the long-haul VMT significantly on both urban and rural unrestricted roads and underestimates the long-haul VMT on rural restricted roads. Figure 3-26 below shows the comparison for single unit trucks.

Figure 3-26. Long-haul Fractions for Single Unit Trucks, West Census Region

Table 3-17 lists the West region results with more decimal places for precision for the Clark County Study seen above in Figure 3-25 and Figure 3-26. Table 3-17 is sorted from smallest value of long-haul VMT fraction to largest. Unrestricted roads (surface streets) have lower fractions of long-haul VMT than restricted access roads (freeways), and urban roads have lower long-haul VMT than rural. Combination unit trucks have much higher fractions of long-haul VMT than single unit trucks on all road types.

Table 3-17. Long-haul Truck VMT Fractions by MOVES Road Type, West Census Region

MOVES Road Type ID	MOVES Road Type Name	Single Unit Trucks	Combination Unit Trucks
5	Urban Unrestricted	0.01096	0.17493
3	Rural Unrestricted	0.03594	0.26051
4	Urban Restricted	0.08340	0.60571
2	Rural Restricted	0.40011	0.93839

Table 3-18 lists the results by HPMS functional class and area type, so that the long-haul fractions can be used in CONCEPT VMT mix profiles. The FAF and HPMS do not cover the local roads, but other higher functional classes are represented. Table 3-18 is sorted by functional class in descending order (i.e., less traveled minor collectors at the top of the table, and interstates at the end). In general, note that the long-haul fractions increase with decreasing HPMS road type ID and again urban roads have lower long-haul VMT fractions than rural.

Table 3-18. Long-haul Truck VMT Fractions by HPMS Road Type, West Census Region

HPMS Road ID	Area Type	HPMS Road Type Name	Single Unit Trucks	Combination Unit Trucks
6	Urban	Minor Collector	0.00014	0.00181
6	Rural	Minor Collector	0.00100	0.01658
5	Urban	Major Collector	0.00872	0.18770
5	Rural	Major Collector	0.00954	0.10044
4	Urban	Minor Arterial	0.00610	0.10100
4	Rural	Minor Arterial	0.01910	0.19537
3	Urban	Principal Arterial - Other	0.01188	0.18633
3	Rural	Principal Arterial - Other	0.04852	0.31351
2	Urban	Principal Arterial - Other Freeways and Expressways	0.02831	0.33874
2	Rural	Principal Arterial - Other Freeways and Expressways	0.08179	0.36883
1	Urban	Interstate	0.11288	0.72924
1	Rural	Interstate	0.41366	0.95007

3.3.3 Fractions of Other Minor Source Types

In addition to the 2017 License Plate Study and 2012 FAF data, additional fractions are needed to estimate the fractions of all 13 source types, to estimate the VMT from Passenger Trucks relative to Light Commercial Trucks, among three bus classes, and the small portion of single unit truck VMT that comes from Refuse Trucks and Motor Homes. The data source for these minor categories is US EPA's 2014 version 2 NEI, although other sources of local data can be substituted to recalculate the fractions. In particular, local data on transit bus and school bus VMT is available. For the NEI, EPA purchased data for the entire U.S. from IHS Markit, representing a nationwide snapshot in July 1, 2014. The relative portions of vehicles registered in Clark County for the following categories are summarized in Table 3-19. These fractions were applied to all hours, day types, and months traffic profiles. By contrast, the relative VMT of the five MOVES Group IDs vary by 24 hours and 7 day-types, and the car vs. light-duty truck fractions vary by blocks of days and blocks of hours.

Table 3-19. EPA Fractions for Minor Source Type Categories

MOVES Source Type Relying on an EPA Fraction	MOVES Source Types in the Denominator	Fraction	Sum of Fractions
31- Passenger Truck	31 + 32	0.90333	1
32- Light Commercial Truck	31 + 32	0.09667	
41- Intercity Bus	41 + 42 + 43	0.34731	1
42- Transit Bus	41 + 42 + 43	0.38543	
43- School Bus	41 + 42 + 43	0.26726	
51- Refuse Truck	51 + 52 + 53 + 54	0.05319	0.06044
54- Motor Home	51 + 52 + 53 + 54	0.00725	

The fractions of Refuse Truck (source type 51) and Motor Home (54) do not sum to one because they are intended to apportion the small amount of the VMT from the total activity of Single Unit Trucks (MOVES group ID 50), leaving just the source types 52 and 53 VMT to be split into short-haul and long-haul VMT by roadway classification using FAF data (Section 3.3.2).

There is an alternative data source for the bus fractions because local data on VMT are available for Las Vegas, which is preferable to registered population-based fractions. CCDAQ provided 2014 transit bus VMT from the National Transit Database (25 million miles) and a 2014 school bus estimate of approximately 22 million miles. These two numbers can be used with the 2014 estimate of total bus VMT (104 million miles) to calculate the intercity bus VMT (57 million miles), and the resulting fractions shown below. The 104-million-mile total was the sum of the three source types' VMT in the Tool's final MOVES annual table, *SourceTypeYearVMT* for a calendar year 2014.

MOVES Source Type	Local Data Bus VMT Estimate for 2014	Fraction	Sum of Fractions
41- Intercity Bus	104,262,435 – (25,254,198 + 22,252,437) = 56,755,800	0.54436	1
42- Transit Bus	25,254,198	0.24222	
43- School Bus	22,252,437	0.21343	

Compared to Table 3-19, the VMT-based intercity bus fraction is much higher while the transit and school bus fractions are lower. This large increase in intercity bus VMT fraction is plausible as there are a high number of tour buses in Las Vegas, and they wouldn't necessarily all be registered in Clark County.

3.3.4 Gap Filling the Profiles

Monitor data were sparse on the local roads, which results in unstable or 'noisy' profiles and sometimes longer time periods without any coverage. The lack of coverage presents a problem for emissions modeling, because all road types and vehicle categories need a profile into temporalize VMT activity and include it in the inventory.

Thus, upon review of the full set of traffic profiles for Clark County, we made the following substitutions outlined in the table below. The MOVES tables did not require any substitutions due to better data coverage in broader categories (2 days instead of 7, and 4 roads instead of 12, etc.). SMOKE and CONCEPT profiles did require gap filling to ensure full coverage.

Table 3-20. Traffic Profile Substitutions due to Low Data

Model and Profile Type	Description of Subsets Needing Replacement	Replacement Profile(s)
SMOKE Hourly Profile	Road Type 2, Source Type 11	Road Type 2, Source Type 21
	Road Type 3, Source Types 51-54	Road Type 3, Source Type 61
CONCEPT Monthly Volume	Road Types 19 & 21	Road Type 17
	Road Types 31 & 33	Road Type 29
CONCEPT Daily Volume	Road Types 19 & 21 (all months)	Road Type 17 (all months)
	Road Type 31, December and February	Road Type 31, January
	Road Type 33, December and February	Road Type 33, January
CONCEPT Hourly Volume	Road Types 19 & 21 (all months)	Road Type 17 (all months)
	Road Type 33, December	Road Type 33, January
CONCEPT Hourly Mix	Road Types 19 & 21 (all months)	Road Type 17 (all months)
	Road Type 33, December	Road Type 33, January
	Road Type 11, I-15	Road Type 11, not I-15

In addition to low data for the lower functional class road types (rural road types 19 & 21, and urban 31 & 33), the rural interstates (road type 11) in the CONCEPT profiles did not have sufficient data for non-I15 roads. Only four HPMS monitors were available on non-I15 rural interstates, located on SR-739 (Sloan Rd) and IR-215. Therefore, both sets of rural interstate CONCEPT profiles (I15 and non-I15) use the rural I15 profiles. In general, the profiles listed above in Table 3-20 as needing replacement are minor road categories that don't contribute significantly to overall VMT in Clark County.

4.0 Results

This section presents a sample of the Clark County VMT temporal profiles and VMT mix profiles developed for the MOVES, SMOKE, and CONCEPT models. The results are organized according to profile type, with subsections specific to Monthly, Day of Week, Hourly, and VMT Mix Profiles.

4.1 Monthly Traffic Profiles

The monthly VMT profiles for MOVES, SMOKE, and CONCEPT are displayed in Figure 4-1, Figure 4-2, and Figure 4-3, respectively. The MOVES model distributes annual VMT to monthly totals using the Figure 4-1 month VMT fractions. Each of the profiles sums to one across the 12 months of year. Clark County's monthly variation does not indicate a strong influence of season on VMT.

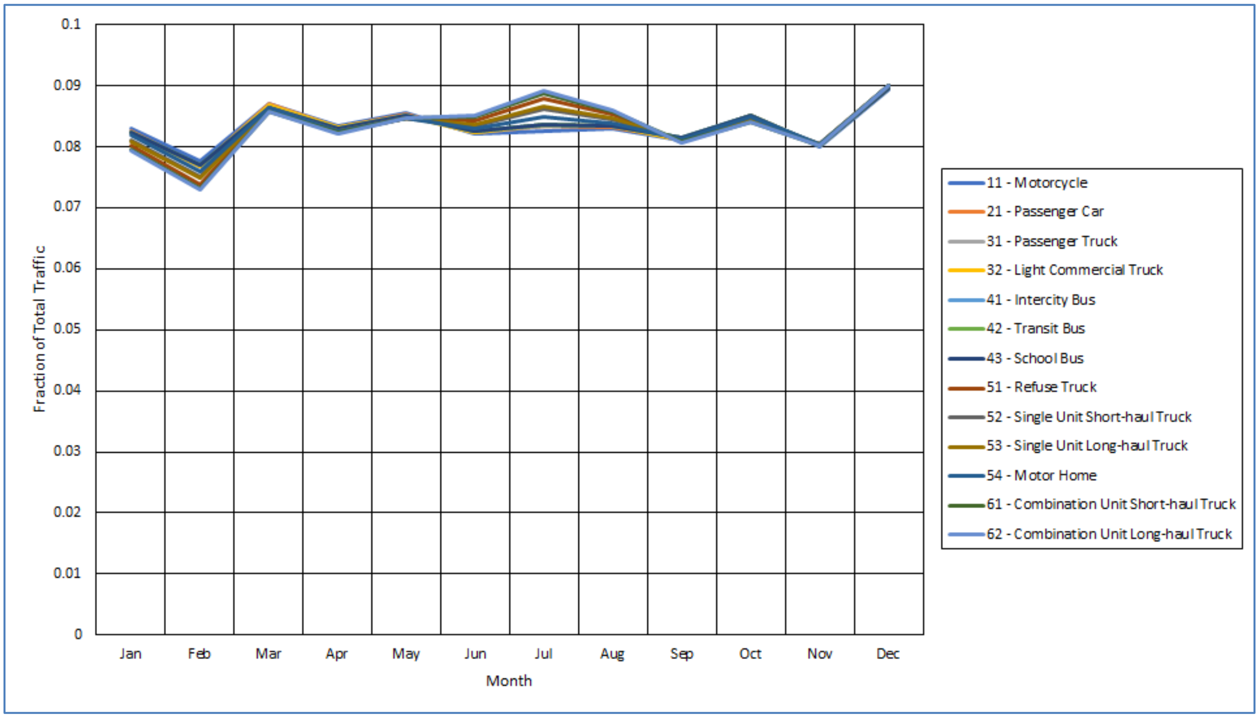


Figure 4-1. MOVES Month VMT Fractions

SMOKE monthly temporal profiles (Figure 4-2, below) are similar to MOVES in that they distribute annual VMT to month, but in SMOKE the profiles also vary by road type. Out of the four MOVES road types, Rural Restricted Access (Road Type 2, in Red) has the highest relative summertime VMT, with a peak spanning June through August. Rural Unrestricted Access (Road Type 3, Yellow), Urban Restricted (Road Type 4, Blue), and Urban Unrestricted (Road Type 5, Purple) do not show much seasonal variation. Because most of the VMT in Clark County is on Urban Unrestricted Access Roads (Purple in Figure 4-2), the relatively flat shape is what dictates the MOVES areawide monthly profiles in Figure 4-1.

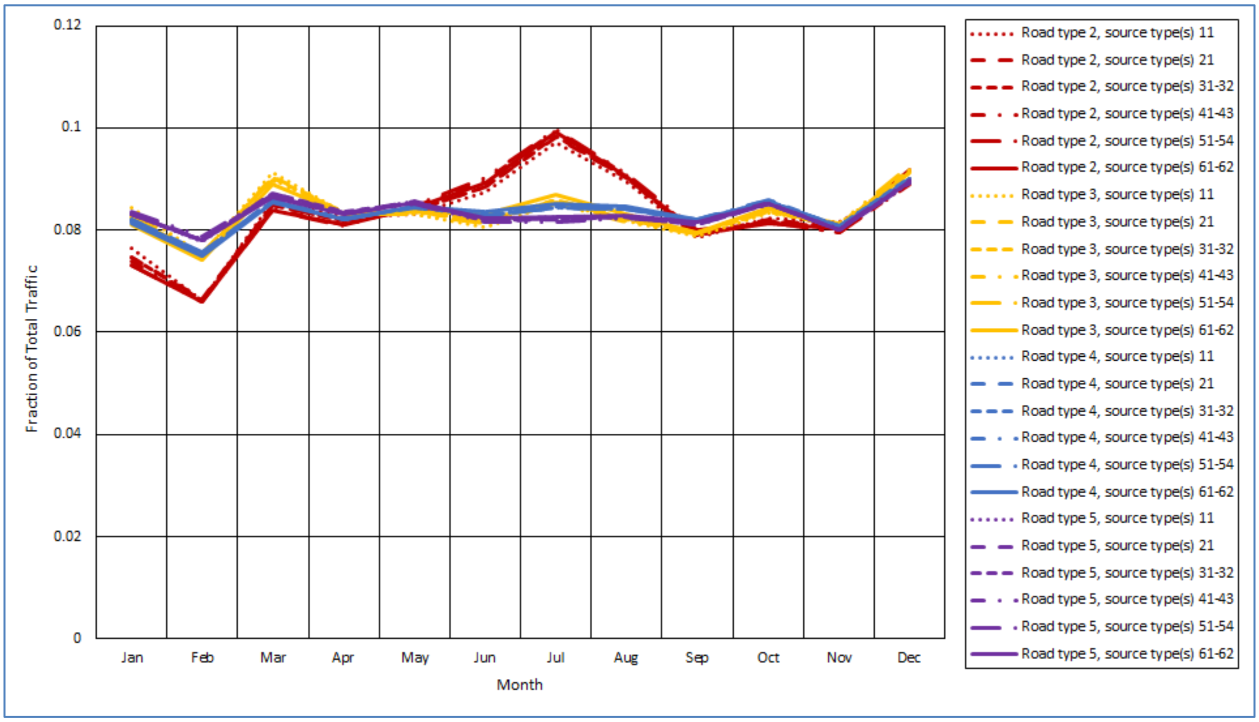


Figure 4-2. SMOKE Monthly Temporal Profiles

CONCEPT’s monthly temporal profiles (Figure 4-3) operate differently than those for MOVES and SMOKE. First, they’re not unique by vehicle type. Second, they don’t apportion annual VMT to 12 months, and therefore do not account for differences in the number of days in months. Instead CONCEPT uses monthly total volume temporal profiles to scale VMT from one day type (e.g., June average day) to another (e.g., July or August day) as needed to prepare emissions for air quality modeling. Third, CONCEPT’s the road type system is more detailed than MOVES or SMOKE to match the detail available in link-level travel demand models which use HPMS functional classifications. In addition, for CONCEPT the Tool tracks extra detail of “I15” and “not I15” on Principal Arterial Interstates (HPMS classes 11 and 23, rural and urban, respectively) to capture the unique activity along the southern portion of Interstate 15 in Clark County from the CA/NV border until Spring Mountain Road.

With 61 HPMS monitors and 3 continuous volume monitors along southern I15, there was sufficient data available for unique I15/not-I15 profiles for CONCEPT’s monthly, daily, and hourly total volume profiles. However, there was not enough vehicle classification monitor data for CONCEPT’s VMT mix profiles on I-15 rural interstates, requiring the substitution listed in Table 3-20. Interestingly, in the monthly profiles of Figure 4-3 the urban I-15 has a July peak, which makes it look more like rural principal arterial classes 11 and 13 than the nearest urban functional class profile.

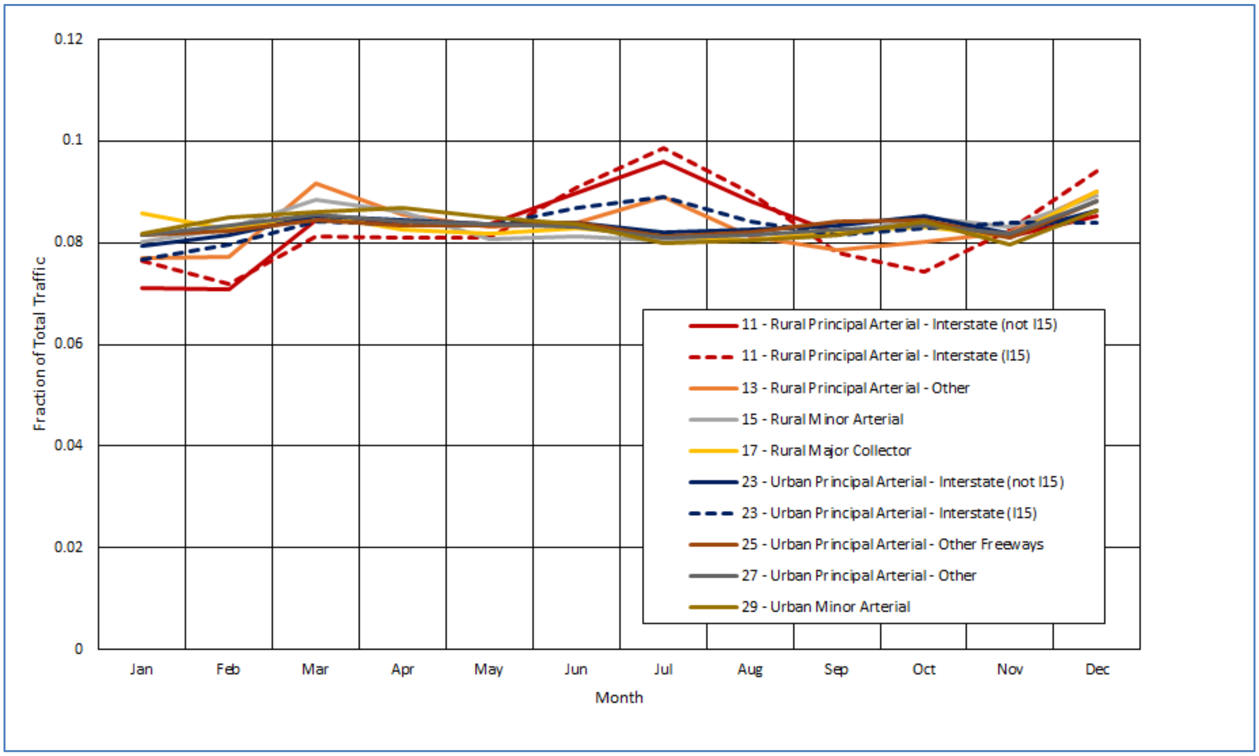


Figure 4-3. CONCEPT Monthly Total Volume Profiles

4.2 Day of Week Traffic Profiles

The day of week profiles in MOVES apportion week VMT to two periods of the week – "Weekday" consisting of 5 days and "Weekend" consisting of 2 days. The MOVES profiles sum to one over these weekday and weekend day types, by source type, road type, and month. Figure 4-4 shows a sample of the profiles for source type 21. The ratio of weekday to weekend VMT grows from Left to Right moving from rural road types 2 and 3 to urban roads 4 and 5. This pattern of higher weekday VMT on urban roads and unrestricted roads was generally true for the other source types.

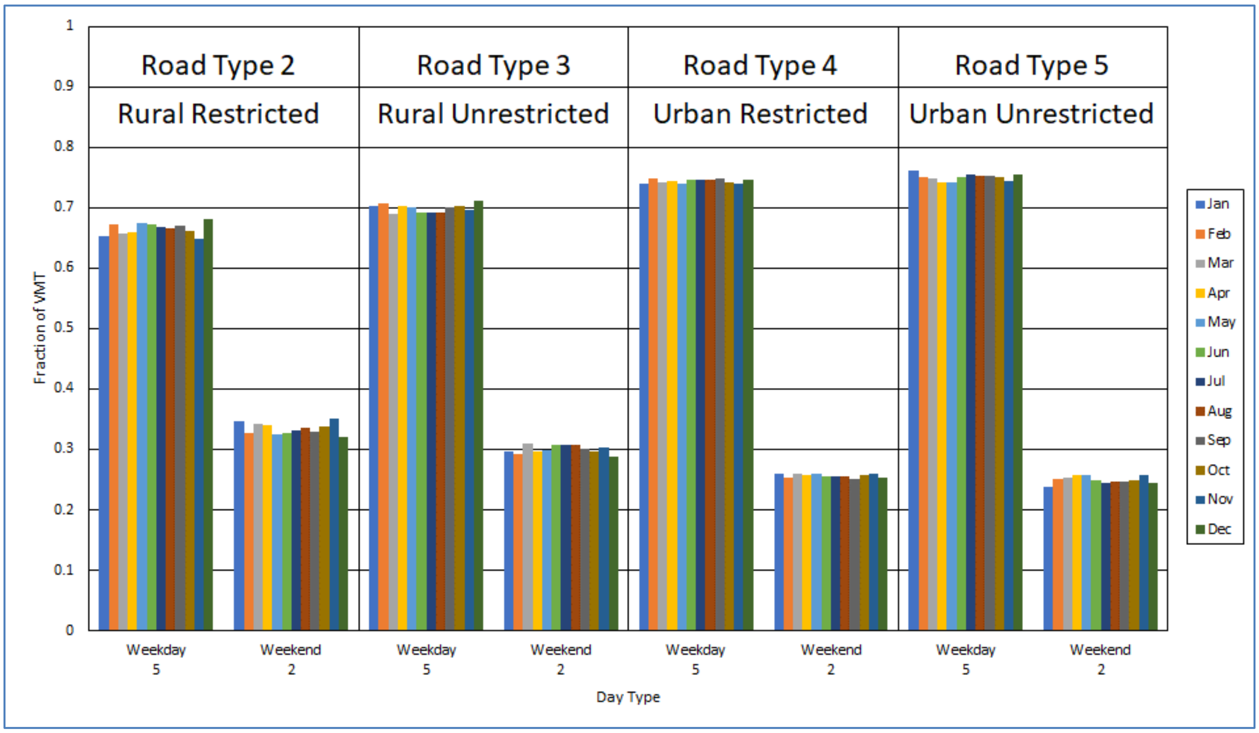


Figure 4-4. Sample MOVES Day VMT Fractions (Passenger Cars)

The SMOKE weekly temporal profiles in Figure 4-5 sum to one over 7 days of the week, for each MOVES road type, source type, and month. This sample of profiles are for July. In general, Monday through Friday have the highest fraction of VMT per day, with notable exceptions of motorcycles (source type 11) on Rural Restricted Access roads (Red) and Rural Unrestricted Access (Yellow). Other source types on Rural Restricted Access roads have higher Sunday and Saturday VMT with notable depressions in VMT on Tuesday and Wednesday. The urban road types (Blue and Purple) resemble the patterns of other U.S. cities. Motorcycles (source type 11) that operate on rural roads have much higher VMT on Sunday and Saturday than weekdays.

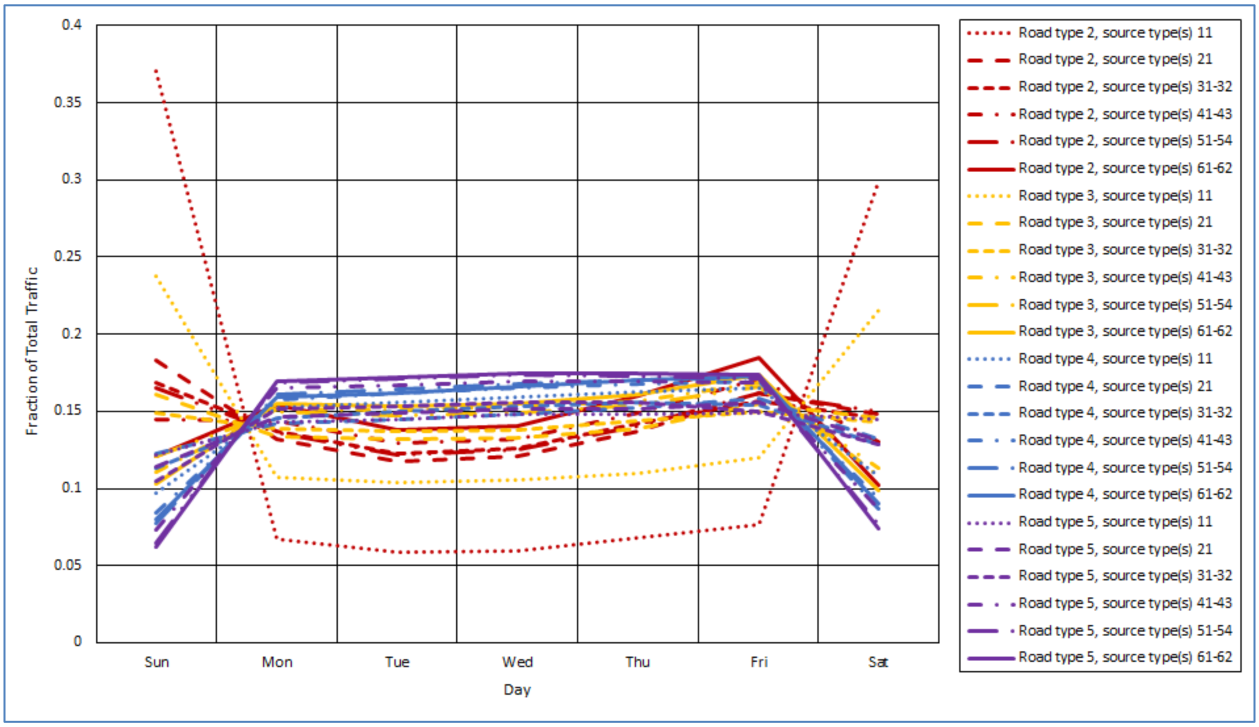


Figure 4-5. Sample SMOKE Weekly Temporal Profiles (July)

The next two figures show examples of CONCEPT day of week temporal profiles. Rural Principal Arterial Other (Non-Interstates) in Figure 4-6 show that generally the highest VMT occurs on Sundays, followed by a decline into Monday and Tuesday. By Wednesday, VMT starts to increase again through Friday where it peaks then declines Saturday. Rural principal arterials appear to be dominated by vehicles traveling to Clark County for the weekend because the highest VMT occurs on Fridays and Sundays. The second set of sample profiles in Figure 4-7 describes Urban Principal Arterial – Other Freeways, where VMT steadily rises Monday through Friday (in most months), with lower VMT on Saturday and lowest on Sunday.

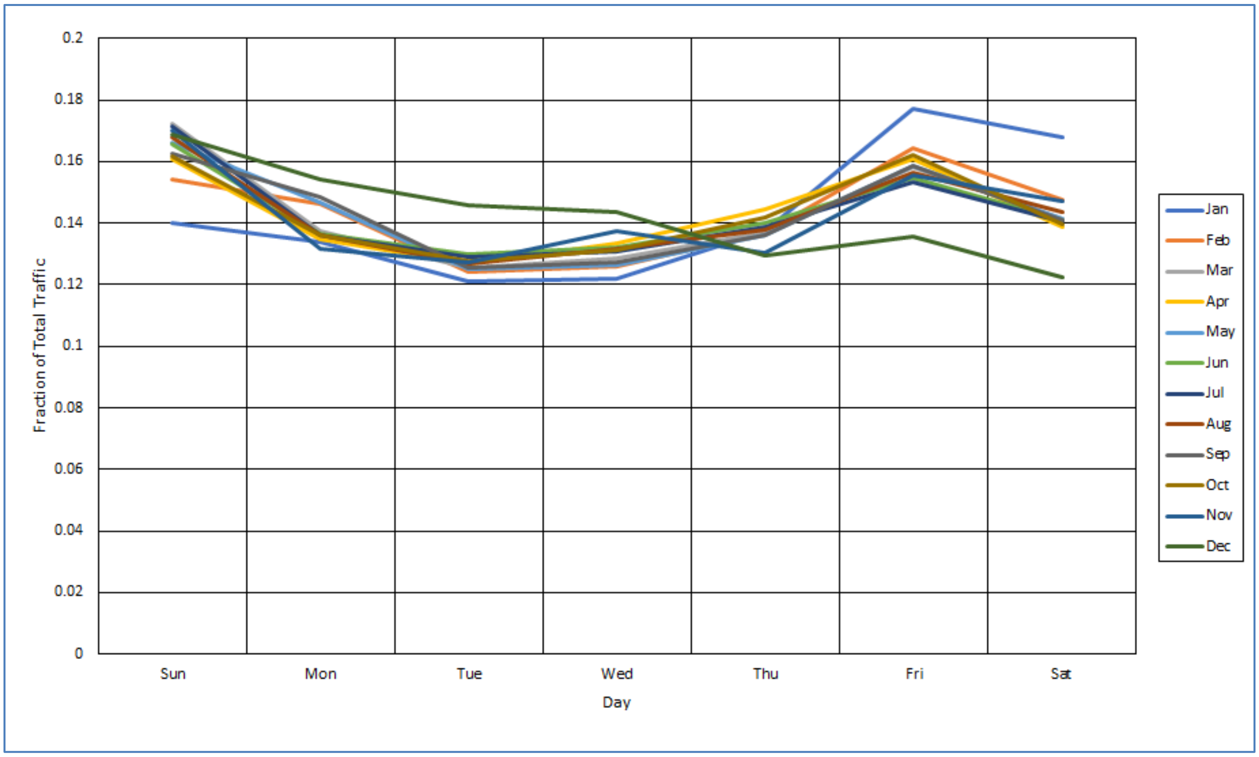


Figure 4-6. Sample CONCEPT Daily Profiles (Rural Principle Arterial – Other)

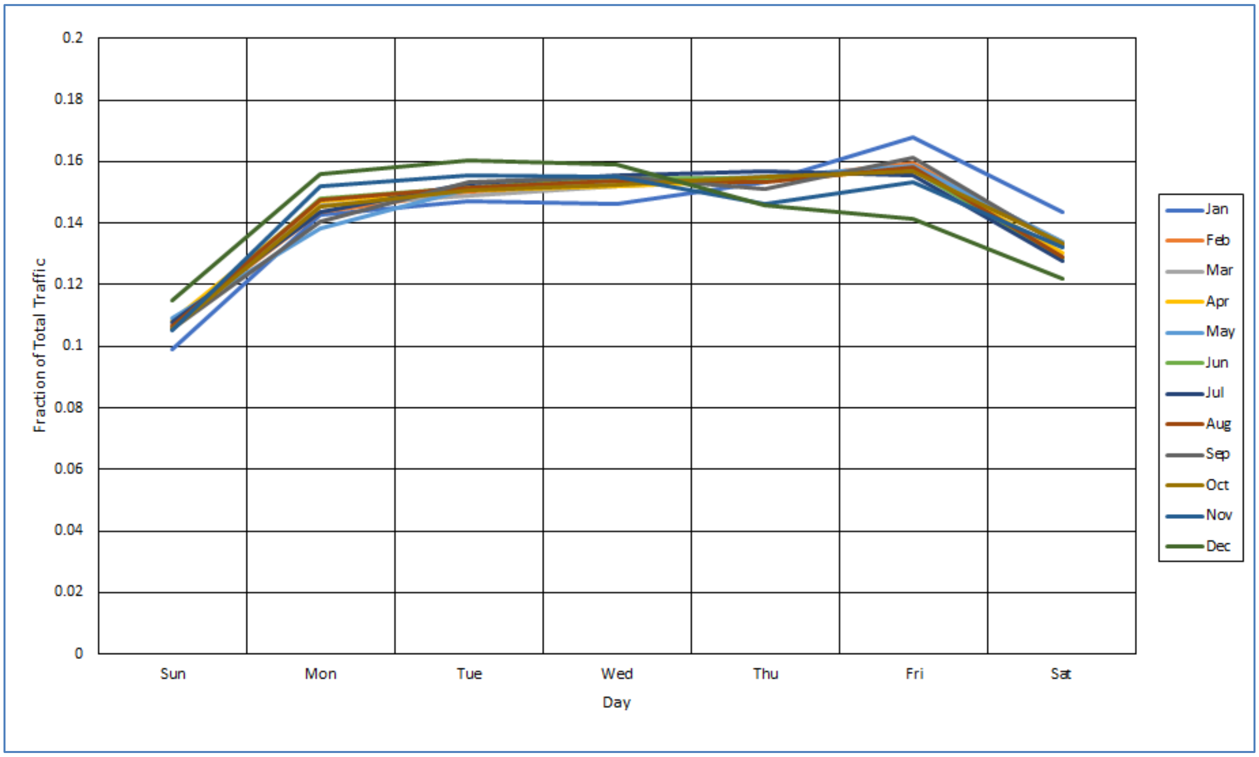


Figure 4-7. Sample CONCEPT Daily Profiles (Urban Principle Arterial – Other Freeways)

4.3 Hourly Traffic Profiles

Figure 4-8 shows Sample MOVES hour VMT fractions for passenger cars traveling on weekdays (solid line series) and weekends (broken line series) for each of the four MOVES road types in Clark County. On weekdays, the two urban road types 4 and 5 (grey and yellow) have prominent morning peaks in VMT fraction. Weekend profiles on all road types reach their high point midday between the hours of about noon to 4 PM.

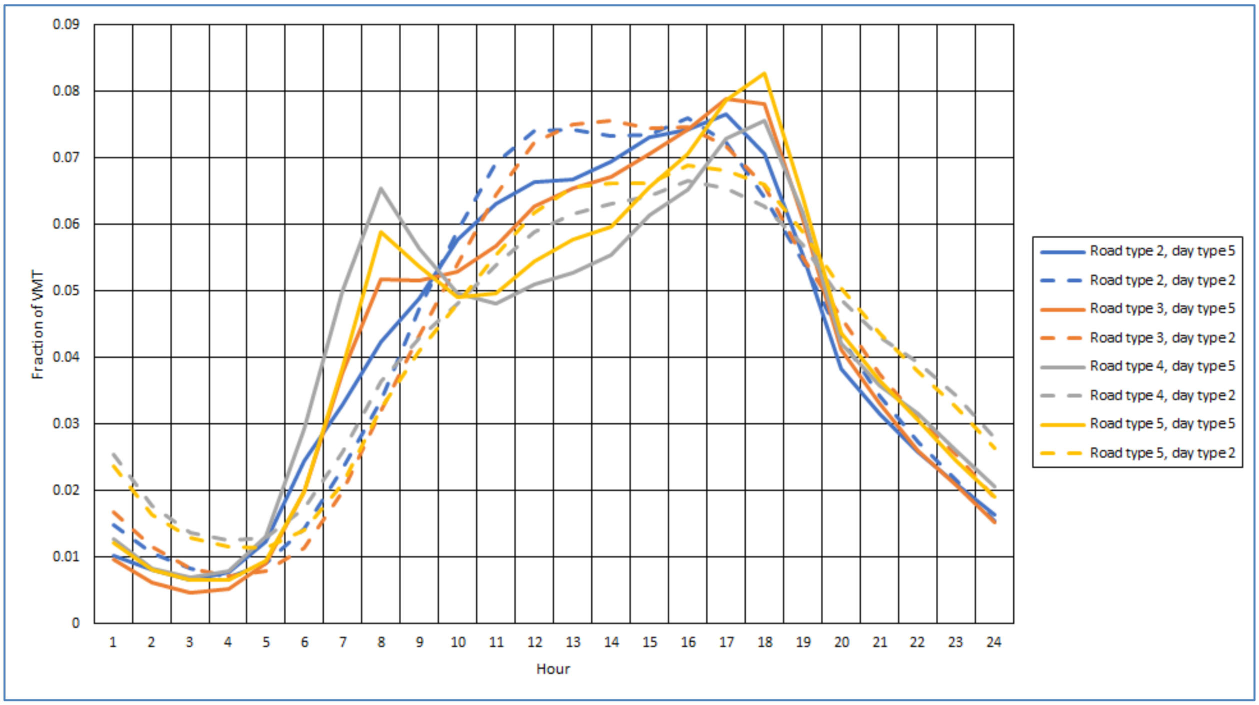


Figure 4-8. Sample MOVES Hour VMT Fractions (Passenger Cars)

The hourly VMT profiles for SMOKE and CONCEPT vary by 7 days of the week and 12 months. SMOKE profiles (Figure 4-9) also vary by vehicle class, while CONCEPT's do not. The two figures below show series where the hourly fractions sum to one within each of the 7 day types, from left to right corresponding to Sunday through Saturday. Motorcycles, passenger cars, and light-duty trucks have a large afternoon peak in VMT on weekdays, while the heavy-duty vehicle classes bus, single unit truck, and combination truck show their VMT patterns shifted earlier in the day. CONCEPT's profiles in Figure 4-10 do not vary much by month and show the typical patterns on weekdays (AM and PM peaks) and weekends (single midday peak).

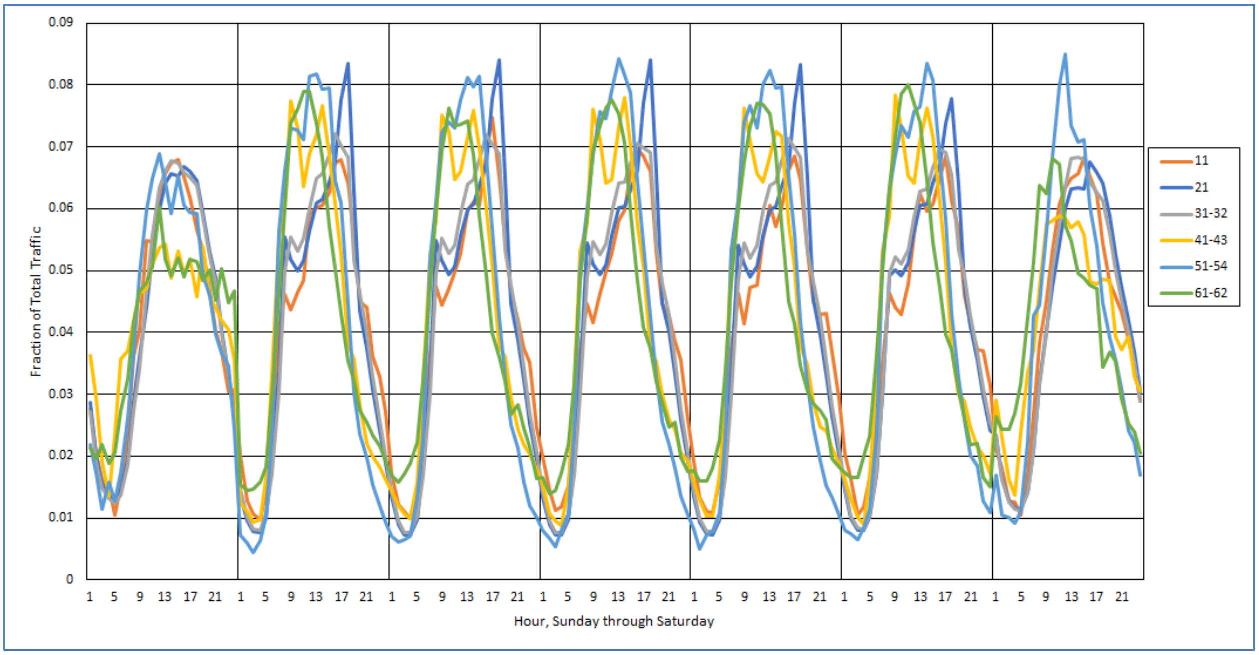


Figure 4-9. Sample SMOKE Diurnal Temporal Profiles (July, Urban Unrestricted Roads)

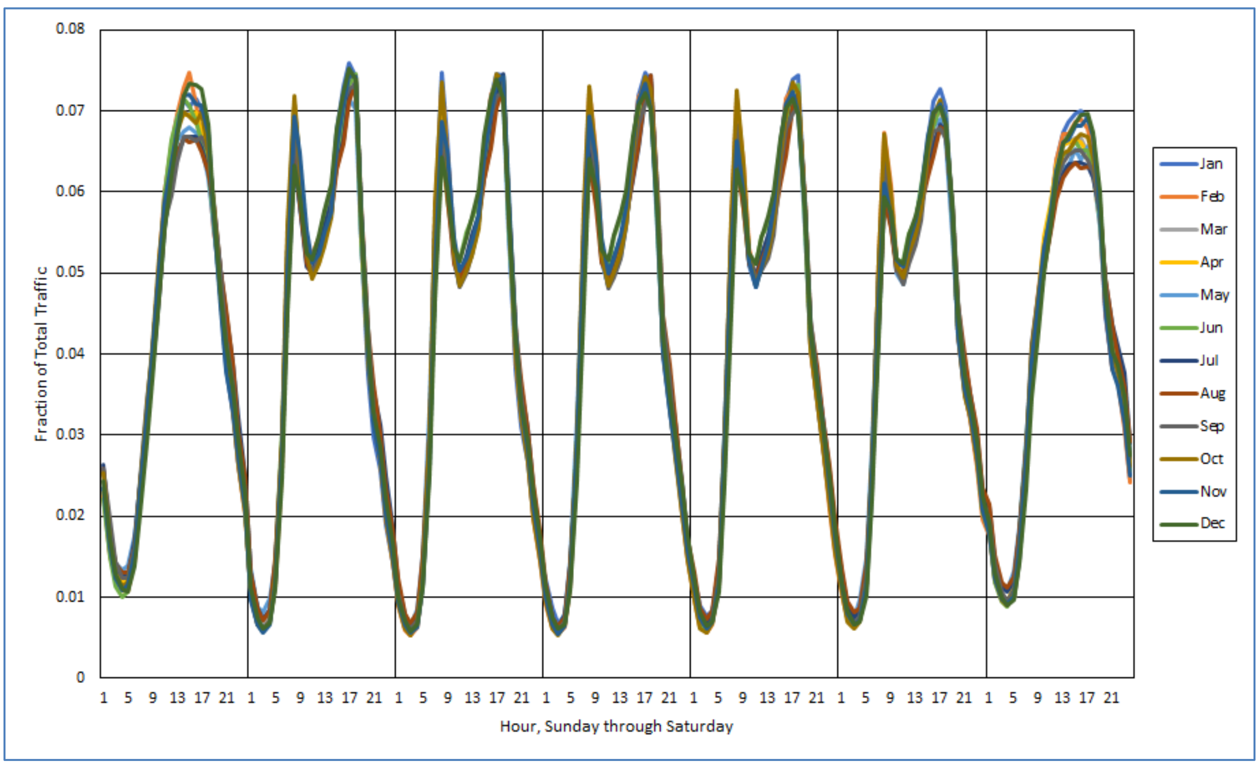


Figure 4-10. Sample CONCEPT Hourly Profiles (Urban Principle Arterial – Other Freeways)

4.4 VMT Mix Profiles

Fleet mix is specified in both MOVES and SMOKE as annual totals, so the next two figures show the percent contribution to the annual VMT. Figure 4-11 shows the MOVES percent of VMT by source type in Clark County, from top to bottom arranged in the same order as shown in the legend. Motorcycles make up a negligible amount (barely visible), followed by the two largest contributors, passenger cars (green) and passenger trucks (dark blue) at about 50% and 40%, respectively. Light commercial trucks make up about 4% of the annual VMT while all heavy-duty vehicles together make up another 4%.

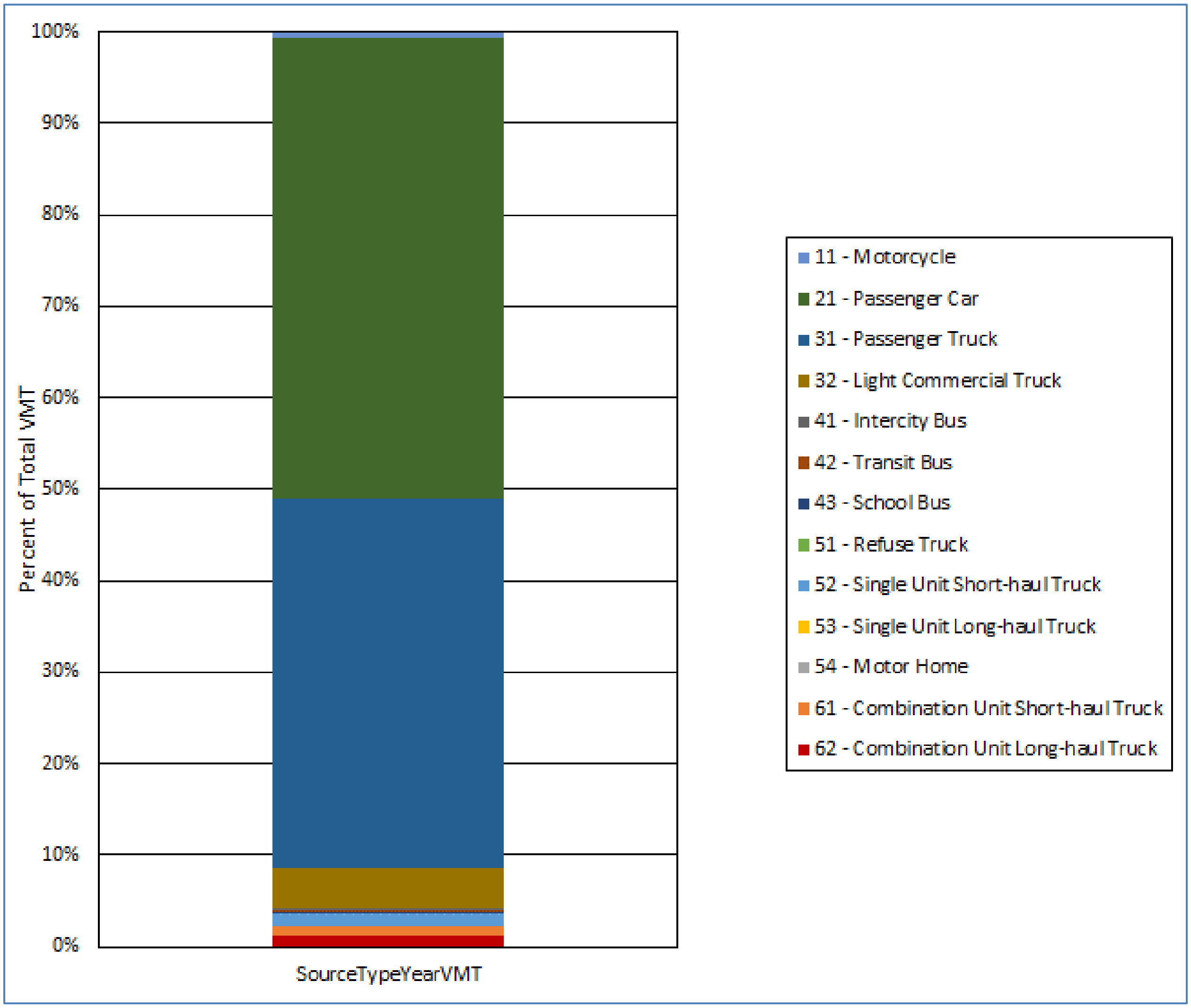


Figure 4-11. MOVES Annual VMT Mix

Figure 4-12 shows the SMOKE fleet mix as the contribution to annual VMT by MOVES road type. Rural Restricted Access (Road Type 2) has the highest amount of heavy-duty VMT (24%) which decreases Left to Right in the figure, from Road Type 2 to Rural Unrestricted Access (Road Type 3) to Urban Restricted Access (Road Type 4) to Urban Unrestricted (Road Type 5). Note that the MOVES fleet mix (Figure 4-11) most resembles the urban profiles below because the majority of the VMT in the county occurs on urban roads.

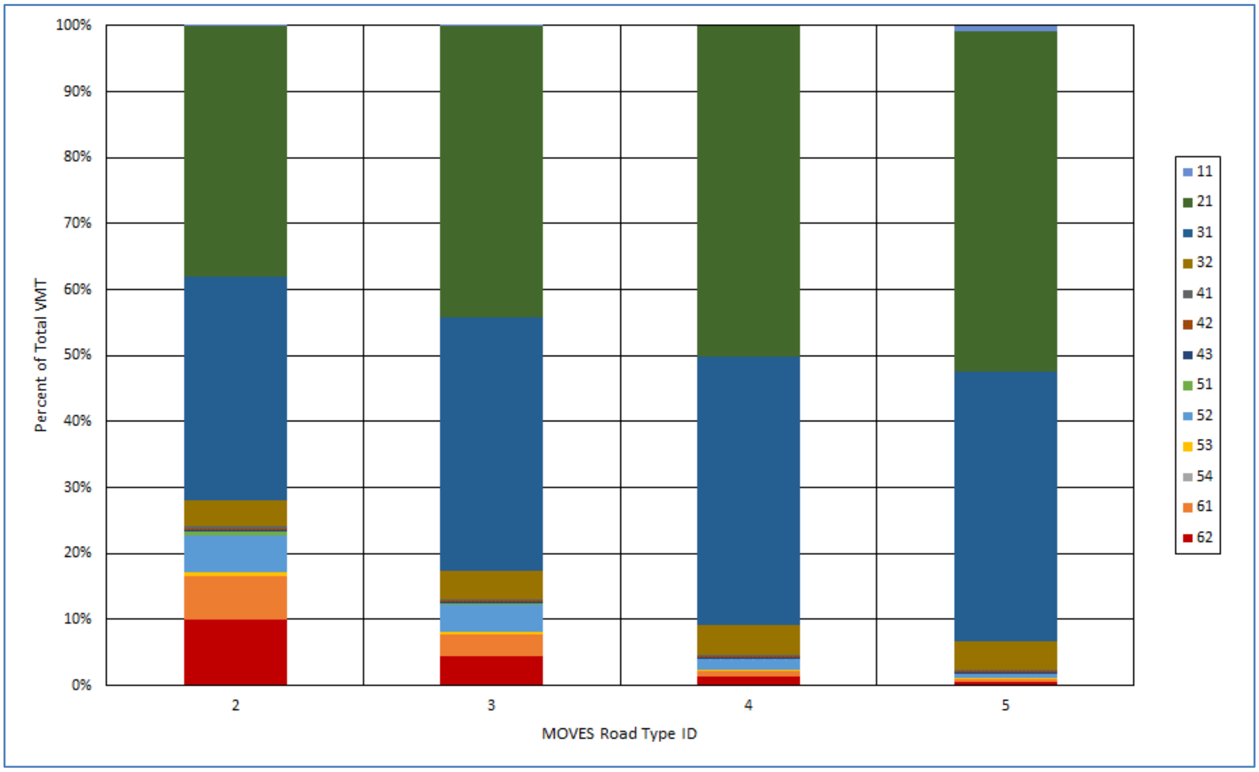


Figure 4-12. SMOKE Annual VMT Mix by Road Type

The next two figures show Sample CONCEPT fleet mix profiles for two road types. Figure 4-13 shows Rural Principal Arterial – Other (Non-Interstate) hourly fractions that sum to 1 in each hour of the week, presented below in order from Sunday to Saturday, Left to Right. The largest components of fleet mix are passenger cars and passenger trucks, even on large rural roads. Although, short- and long-haul combination unit trucks have a nontrivial presence. The combination trucks tend to have their largest relative VMT fraction during early morning hours when the passenger traffic is at its lowest.

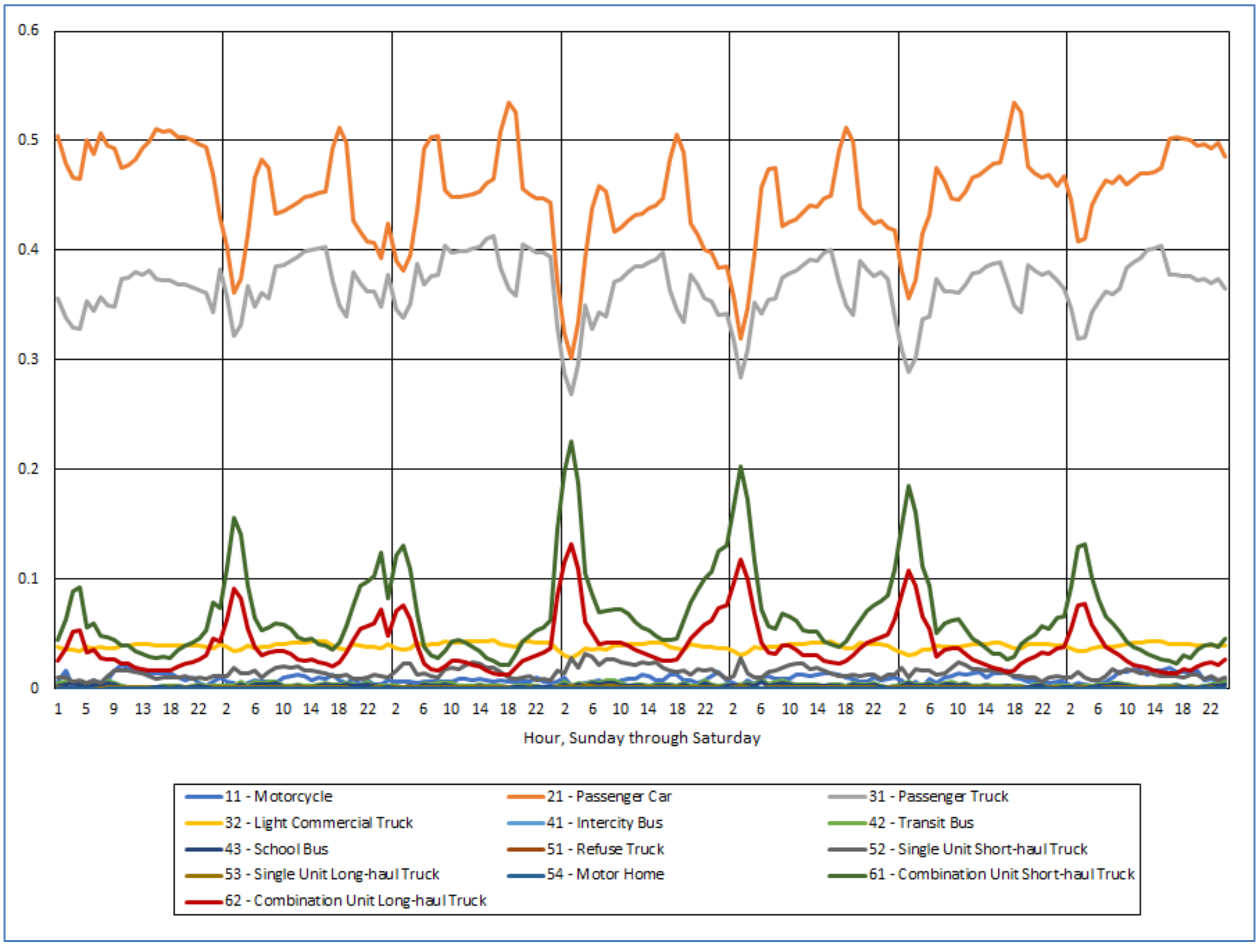


Figure 4-13. Sample CONCEPT VMT Mix Profiles (Rural Principal Arterial - Other)

Figure 4-14 shows sample CONCEPT hourly fleet mix profiles for Urban Principal Arterial Other roadways. Passenger Cars and Passenger Trucks dominate the VMT at over 90%, and the other source types' contributions aren't easily distinguishable aside from the Light Commercial Trucks.

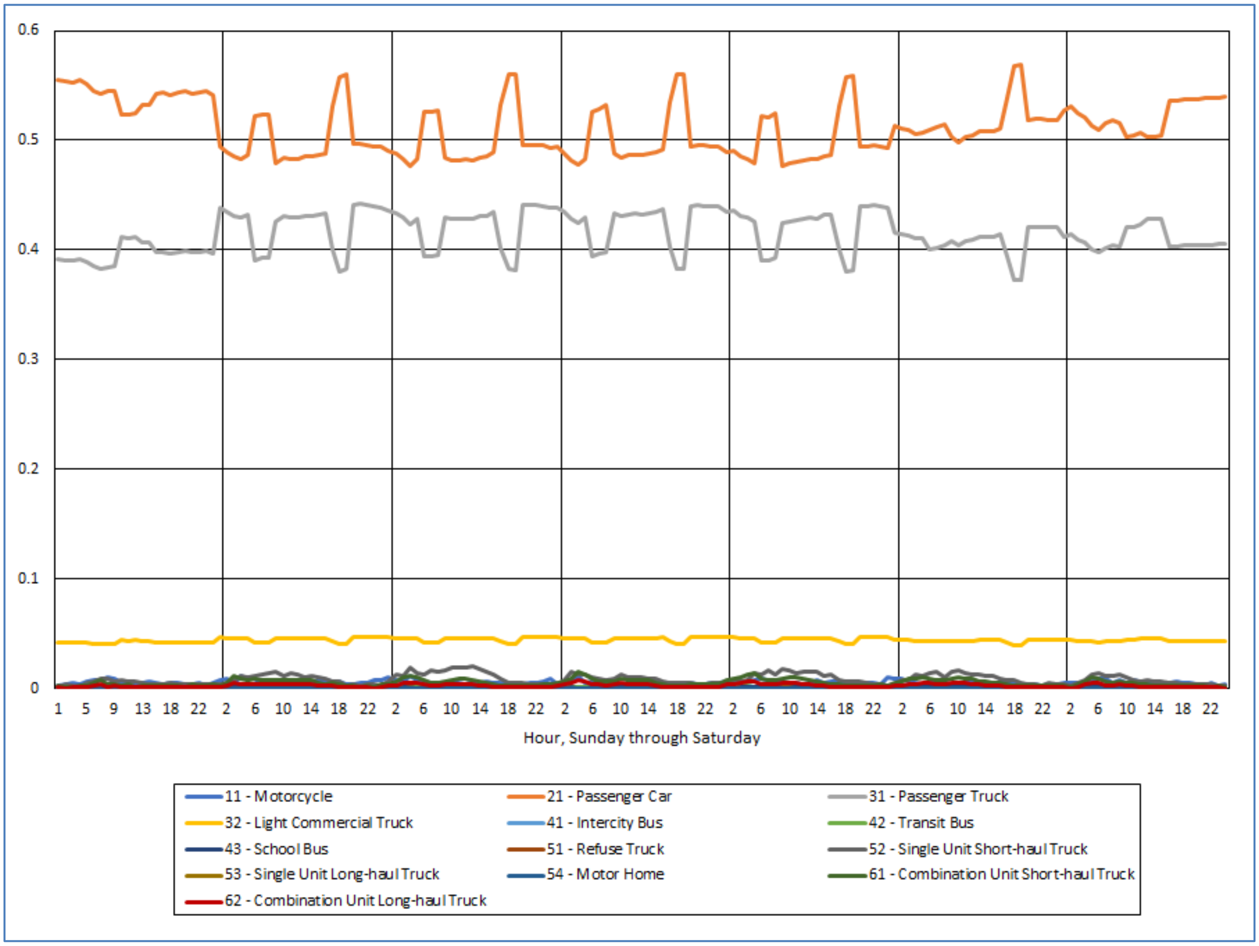


Figure 4-14. Sample CONCEPT VMT Mix Profiles (Urban Principal Arterial – Other Freeways)

5.0 Summary

The Clark County Vehicle Classification Study produced new VMT temporal profiles and VMT mix profiles based on three recent years of NDOT monitor data and a two-week 2017 License Plate Survey with video recording of plates, matching to VIN, and VIN decoding into attributes that allowed classification of cars vs. light-duty trucks consistently with EPA definitions. The traffic modeling profiles were prepared in formats for three different on-road emissions models MOVES, SMOKE, and CONCEPT and are applicable to calendar years 2014 and into the future until Clark County's next update.

Challenges faced during this study included difficulty in reading the state on license plates, which is required to match the plate to a VIN. Low license plate coverage on Nevada DMV's registration records was also a challenge to achieving a higher plate-VIN match rate.

The car fractions of the cars plus light-duty trucks coming out of the 2017 License Plate Survey are generally in agreement with Clark County registration data purchased by US EPA for the 2014 NEI v2, but the survey provides additional temporal detail showing that the midday car fractions are lower than during peak periods on weekdays, possibly because light-trucks are more often use commercially rather than parked during business hours. The car fractions in this study are lower than those reported in the 2013 study, which could be due to differences in methodology to identify cars.

As one of the Clark County Vehicle Classification Study products, ERG designed a Python-based Tool to read Excel files of NDOT monitor data and calculate the profiles using fractions from the license plate survey and FAF through input files. We recommend that CCDAQ update these profiles regularly when new years of NDOT traffic monitors become available; in addition, including more than 3 years at a time would result in smoother profiles based on more data points. Vehicle classification is a crucial component for developing on-road emission inventories, and this study prepared recent, local data for Clark County's near-term modeling needs.

6.0 Acknowledgements

The authors gratefully acknowledge the Clark County Department of Air Quality for devising project objectives and providing funding, specifically the project leaders Russell Merle and Zheng Li who provided technical guidance throughout the study; the University of California at Riverside CE-CERT for conducting the license plate survey, tag-editing, and contributing sections to this report; the Nevada Department of Transportation (NDOT) for providing several years of monitor data. We also thank IHS Markit for their participation through matching license plates to VIN and decoding the vehicle characteristics.

Appendix A

Table A-1, Table A-2, and Table A-3 describe the format and contents of the MOVES, SMOKE, and CONCEPT profiles that ERG delivered to CCDAQ under the Clark County Vehicle Classification Study.

Table A-1. Format of the MOVES Tables

Field #	Field name	Data type	Contents description
MonthVMTFraction CDB Table			
1	sourceTypeID	Integer	13 source types
2	monthID	Integer	12 months
3	monthVMTFraction	Float	Fractions sum to one (1) over the 12 months.
DayVMTFraction CDB Table			
1	sourceTypeID	Integer	13 source types
2	monthID	Integer	12 months
3	roadTypeID	Integer	4 road types
4	dayID	Integer	2 day types (weekday, weekend)
5	dayVMTFraction	Float	Fractions sum to one (1) over the 2 day types.
HourVMTFraction CDB Table			
1	sourceTypeID	Integer	13 source types
2	roadTypeID	Integer	4 road types
3	dayID	Integer	2 day types (weekday, weekend)
4	hourID	Integer	24 hours
5	hourVMTFraction	Float	Fractions sum to one (1) over 24 hours.
***Fractions for the* SourceTypeYearVMT CDB Table**			
1	yearID	Integer	Any calendar year, 2014 or later.
2	sourceTypeID	Integer	13 source types
3	VMTFraction	Float	Fractions sum to one (1) over the 13 source types.

Table A-2. Format of the SMOKE Profiles

Field #	Field name	Data type	Contents description
MONTHLY MTPRO			
1	profileCode	Integer	Autoincremented integer from 1 to N number of profiles
2	Jan_weight	Integer	Whole number representing a portion of field 14 "Total."
3	Feb_weight	Integer	Whole number representing a portion of field 14 "Total."
…	…	…	…
13	Dec_weight	Integer	Whole number representing a portion of field 14 "Total."
14	Total	Integer	Sum of integers in fields 2 through 13.
15	Comment	Char	Optional description.
WEEKLY MTPRO			
1	profileCode	Integer	Autoincremented integer from 1 to N number of profiles
2	Mon_weight	Integer	Whole number representing a portion of field 9 "Total."
3	Tue_weight	Integer	Whole number representing a portion of field 9 "Total."
…	…	Integer	…
8	Sun_weight	Integer	Whole number representing a portion of field 9 "Total."
9	Total	Integer	Sum of integers in fields 2 through 8.
10	Comment	Char	Optional description.
DIURNAL MTPRO			
1	profileCode	Integer	Autoincremented integer from 1 to N number of profiles
2	H00_weight	Integer	Whole number representing a portion of field 26 "Total."
3	H01_weight	Integer	Whole number representing a portion of field 26 "Total."
…	…	…	…
25	H23_weight	Integer	Whole number representing a portion of field 26 "Total."
26	Total	Integer	Sum of integers in fields 2 through 26.
27	Comment	Char	Optional description.
***Fractions for* the VMT MBINV File (FF10 Format)**			
1	country_cd	Char	Country code; "US"
2	region_cd	Char	FIPS code for the state and county "32003"
3	tribal_code	Char	Indicates the tribe submitting data (N/A)
4	census_tract_cd	Char	Not currently used by SMOKE.
5	shape_id	Char	Not currently used by SMOKE.
6	scc	Char	Source Category Code (combines source, fuel, and road)
7	CD	Char	Not currently used by SMOKE.
8	MSR	Char	Not currently used by SMOKE
9	activity_type	Char	"VMTFRAC"
10	ann_value	Double	Annual fraction of county total VMT for the SCC
11	calc_year	Integer	Any calendar year, 2014 or later.
12	date_updated	Char	Date the table was populated, in YYYYMMDD format.
13	date_set_id	Char	Optional description.
14	jan_value	Double	Fraction of field 10 "ann_value" allocated to January.
15	feb_value	Double	Fraction of field 10 "ann_value" allocated to February.
…	…	…	…
25	dec_value	Double	Fraction of field 10 "ann_value" allocated to December.
26	comment	Char	Optional description.

Table A-3. Format of the CONCEPT Profiles

Field #	Field name	Data type	Contents description
MONTHLY Total Volume Profiles			
1	functionalClass	Integer	12 HPMS functional classes.
2	profileType	Char	“VOL”
3	timePeriod	Char	“MONTHLY”
4	month	Char	Blank.
5	DOW	Char	Blank.
6	vehClass	Integer	Blank.
7	Value_01	Decimal	January fraction.
8	Value_02	Decimal	February fraction.
…	…	Decimal	…
18	Value_12	Decimal	December fraction.
DAY OF WEEK Total Volume Profiles			
1	functionalClass	Integer	12 HPMS functional classes.
2	profileType	Char	“VOL”
3	timePeriod	Char	“DOW”
4	month	Char	12 months (e.g., JAN, FEB, MAR, …, DEC)
5	DOW	Char	Blank.
6	vehClass	Integer	Blank.
7	Value_01	Decimal	Monday fraction.
8	Value_02	Decimal	Tuesday fraction.
…	…	Decimal	…
13	Value_07	Decimal	Sunday fraction.
HOURLY Total Volume Profiles			
1	functionalClass	Integer	12 HPMS functional classes.
2	profileType	Char	“VOL”
3	timePeriod	Char	“DOW”
4	month	Char	12 months (e.g., JAN, FEB, MAR, …, DEC)
5	DOW	Char	7 days (e.g., MON, TUE, WED, …, SUN)
6	vehClass	Integer	Blank.
7	Value_01	Decimal	Hour 00:00 (midnight) to 00:59 fraction of VMT.
8	Value_02	Decimal	Hour 01:00 to 1:59 fraction of VMT.
…	…	Decimal	…
30	Value_24	Decimal	Hour 23:00 to 23:59 fraction of VMT.
VMT Mix Profiles			
1	functionalClass	Integer	12 HPMS functional classes.
2	profileType	Char	“MIX”
3	timePeriod	Char	“HOURLY”
4	month	Char	12 months (e.g., JAN, FEB, MAR, …, DEC)
5	DOW	Char	7 days (e.g., MON, TUE, WED, …, SUN)
6	vehClass	Integer	13 source types (e.g., 11, 21, 31, …, 61, 62)
7	Value_01	Decimal	Hour 00:00 to 00:59 fraction* of source type VMT.
8	Value_02	Decimal	Hour 01:00 to 01:59 fraction* of source type VMT.
…	…	Decimal	…
30	Value_24	Decimal	Hour 23:00 to 23:59 fraction* of source type VMT.

*VMT fractions sum to one (1) over the 13 source types within each hour.