Investigating the Impact of Driving Activity on Weekend Ozone Levels using GIS/GPS Technology

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ABSTRACT

For many years ozone concentrations in California's South Coast Air Basin have been higher on weekends than on weekdays, despite assumed lower weekend emissions. The "weekend effect" has potential implications for regional ozone control strategies. A multi-level field measurement program of air quality and emission activities was conducted to study the weekend effect. Because on-road mobile sources are the single largest regional source for ozone precursor pollutants, several different methods were used to collect light-duty motor vehicle activity data, one of which included in-vehicle GPS unit deployments. This paper discusses the GPS data QA/QC and aggregation into vehicle trips, the subsequent processing in ArcView 8.2 to capture temporal and spatial variations in light-duty vehicle driving activity, and the implications for regional ozone air quality.

INTRODUCTION

In recent years, California's South Coast Air Basin (SoCAB) has experienced peak ozone concentrations on weekends that are greater than weekday peaks.[1, 2, 3] This "weekend effect" occurs despite lower ozone precursor emissions on weekends at most locations.[4,5] Explanations are needed because the weekend effect has potential implications for development of ozone control strategies. It is extremely unlikely that systematic weekday-weekend (WD-WE) differences in weather tendencies could explain the weekend effect. Rather, differences in the relative proportions of ozone precursors correlate with weekend ozone peaks. Therefore, researchers postulate that an aggregate shift in human activities on weekends, which causes certain pollutants to be emitted in disproportionately lesser amounts, is the most plausible explanation for the weekend effect.[2,6,7]

During summer 2002, STI extended previous research projects it had conducted in 2000-2001 as components of coordinated field studies of air quality and emissions-related activity patterns.[8,9] The purpose of both the past and most recent studies was to generate information to improve the general understanding of weekday-weekend variability in air quality, which has been noted in Los Angeles and other urban areas.[2,3,8,9]

The 2002 project, "Collection and Analysis of Weekday/Weekend Activity Data in the South Coast Air Basin", encompassed an array of emissions source categories: on-road mobile, off-road mobile, major point, residential area, and small commercial area sources. Since on-road mobile sources are such important sources of ozone precursors in the SoCAB, the project used several different methods to collect on-road motor vehicle activity data. These included (1) in-vehicle activity data loggers for light-duty vehicles; (2) fixed location traffic counters on non-freeway surface streets; (3) Caltrans Weigh-In-Motion (WIM) data, and (4) phone surveys of homes and small businesses for light-duty and heavy-duty vehicle activity. However, for this conference, this paper summarizes and discusses only the use of in-vehicle mini-GPS units in the SoCAB to examine and quantify WD-WE differences in travel patterns.

Background

High ozone concentrations are a result of a complex photochemical process, in which the rate of ozone production is a non-linear function of the mixture of volatile organic compounds (VOC) and oxides of nitrogen (NO_x) in the atmosphere. In some circumstances, reducing NO_x emissions relative to VOC emissions will actually increase the rate of ozone formation, although potential peak ozone concentration may be lower. When this occurs, areas with dense populations and high emissions may experience higher ozone concentrations than they would if the rate of ozone formation were slower and approached its peak farther downwind. The relative concentrations of ambient VOC and NO_x, as well as the specific mix of VOCs, determine whether the rate of ozone formation is more sensitive to reductions in VOC emissions or reductions in NO_x emissions.

On-road mobile sources are major emitters of ozone precursors (VOC and NO_x) in the SoCAB. Figure 1 shows the contributions of various classes of emission sources to total emissions of NO_x and reactive organic gases (ROG, which are largely comprised of VOC) in the SoCAB.[8] (Mobile source emissions in Figure 1 were estimated with EMFAC2000, version 2.0.)

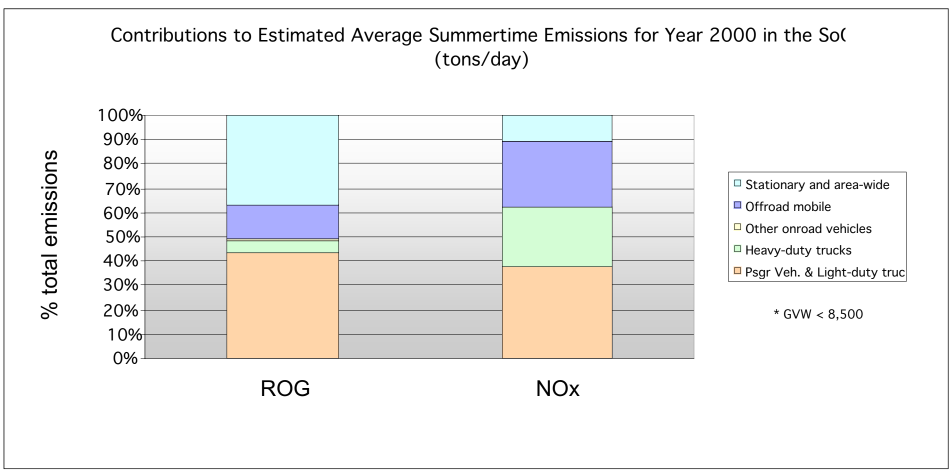

Figure 1. Contribution of various source categories to estimated average summertime emissions for 2000 in the SoCAB (tons/day).

Figure 1 shows that on-road mobile sources account for 50% of total ROG and 62% of total NO_x emissions in the SoCAB. Forty-three percent of total ROG emissions in SOCAB come from passenger vehicles and light-duty trucks. Almost 38% of total NO_x emissions are attributable to these same vehicle categories. ROG emissions from these vehicles represent 87% of mobile-source ROG, and 61% of mobile-source NO_x. ROG emissions from heavy-duty trucks account for 5% of total ROG emissions (11% of mobile-source ROG), and 24% of all NO_x emissions (39% of mobile-source NO_x).

Therefore, it seems likely that WD-WE differences in traffic volumes, timing of traffic peaks, and/or vehicle fleet mix would affect the concentrations and relative quantities of ambient VOC and NO_x. The findings of STI's research projects support this hypothesis.

Executive Summary of Methods and Conclusions

One hundred twenty households in the SoCAB were recruited via random-digit-dialed telephone surveys to participate in the study, and 67 were tapped for participation. The study period ran from May 17, 2002, through September 16, 2002, but was divided into four data collection "waves" of 10 to 11 days each. During each wave, 5 to 25 households participated. Data collection was suspended during the weeks of Memorial Day, Independence Day, and Labor Day to avoid unusual travel patterns.

STI field staff deployed and recovered the GPS units and transmitted the captured data to GeoStats. There, the 5-second data were collected into individual trips, reviewed for both point and trip validity, and translated into a project database. The GPS database was then returned to STI for assignment of road class, further point validation, and final analysis.

On average, vehicle miles traveled (VMT) was consistently higher on all weekdays than on either weekend day. Average VMT of light-duty utility vehicles (vans, minivans, sport-utility vehicles, and pickup trucks) was comparable to that of passenger cars. Average VMT was significantly higher on major highways than on arterials or on other roads.These findings corroborate earlier results and also include important new findings that are likely to further strengthen our previously reported hypotheses:[2,3,4,9]

1. WD-WE variabilities in emissions patterns from on-road mobile sources have quantifiable impacts on ROG and NO_x emissions in Los Angeles.
2. Furthermore, when these quantifiable impacts are considered together with WD-WE patterns for other types of emissions sources, it appears that overall weekend emissions patterns favor ozone formation in Los Angeles to a greater extent than do weekday emission patterns.
3. This phenomenon is due to increased ROG:NO_x ratios and reduced morning titration capacity of ozone by NO_x.

METHODS

Recruitment of Volunteers and Field Deployment

Approximately twice the necessary numbers of participants were recruited via random-digit-dialed telephone surveys to participate in the study. An excess of recruits was necessary to compensate for dropouts and irreconcilable scheduling conflicts. Of the recruited households, 67 ultimately participated. Figure 2 illustrates the distribution of the participating households throughout the SoCAB. After being recruited into the GPS portion of the study, each household was visited twice by STI technicians who installed, and later retrieved, the data loggers.

Figure 2. GeoLogger recruits from South Coast Air Basin.

During installation, the technicians inspected the proper functioning of nearly all the deployed GeoLoggers. In a few cases, one or more of a household's vehicles were unavailable during the installation visit. In these cases, an STI technician demonstrated proper installation and inspection procedures by using at least one of the household's vehicles so that the participant could perform a self-installation. The technicians followed up with the self-installations to remind and confirm proper installation. At the conclusion of each household's participation in the study, STI technicians visited the households to inspect and verify continuous functioning of the GeoLoggers and to retrieve the equipment.

Geologger Data Acquisition and Data Processing

The in-vehicle GeoLogger used to collect GPS data is a rugged yet simple GPS data-logging device (Figure 3). It has been deployed in household travel surveys and travel time studies within the United States and other countries. The GeoLogger is plugged into the vehicle's cigarette lighter socket and an integrated magnetic mount attaches the combination GPS receiver/antenna to the roof of the vehicle.

Figure 3: GeoStats GeoLogger.

The standard GPS data stream elements recorded by the GeoLogger include date, time, latitude, longitude, speed, heading, altitude, number of satellites, and horizontal dilution of precision (HDOP, a measure of positional accuracy). For the purpose of this study, the logging frequency was set at five seconds, and the GPS points were recorded using the speed filter to capture only those valid points for which the speed was greater than one mile per hour (MPH).

The processing of the GPS data involved a few key steps. The GPS data streams, once received, were parsed into a relational database and reviewed for potentially invalid or questionable data points. Then, the GPS data stream was processed by GeoStats' Trip Identification and Analysis System (TIAS) software to identify potential trip ends based on time intervals between consecutively logged points. For this study, 120 seconds was defined as the appropriate initial dwell time between GPS-recorded trips.

Next, an analyst reviewed each potential trip to identify both missing and false trip ends. This involved examining short duration delays (i.e., less than 120 seconds) for trip end characteristics and evaluating mid-range duration stops (i.e., between two and five minutes) for possible extended traffic congestion or signalization delay characteristics. Finally, those points that appeared not to belong to any trip, such as points logged while stationary, were blocked and removed from further analysis. Once this step was completed, the updated GPS-based trip file for a given household vehicle was saved into the project database.

After running the data through TIAS, queries were used to check the data for consistency and to identify any potential problems. Some of these queries identified those trips that had unrealistic attributes, such as durations under one minute or over an hour, and average speeds either above 60 or below 5 MPH. Trips that met these criteria were reexamined within TIAS. This process was repeated until no additional trips with unusual attributes could be identified. Once all trips were finalized, data quality and coverage measures were assessed, and software was run to populate the project deliverable database.

Lack of GPS data in the GPS data stream for an entire day can signify either non-travel by the participant or equipment/power failure. Days of missing data were classed into three groups—days with data missing at the beginning (Group 1), the middle (Group 2), or the end (Group 3) of the assigned period.

GPS data missing at the beginning of the assigned period (Group 1) could have resulted from non-travel days or only short trips made on these days (i.e, less than two minutes in duration), during which the GPS receiver was in cold start mode and could not acquire a satellite lock prior to each trip end.

GPS data missing from the middle of the assigned period (Group 2) could be the result of a respondent removing the power supply to the GPS logger (in addition to hosting the GeoLogger, the cigarette lighter socket is used to power cell phones and light cigarettes), lack of travel, or only short trips on one or more weekdays. However, we believe that the potential impacts of these possibilities were minimal, in part because an STI technician inspected or verified over the phone the proper functioning of all units at the beginning and end of data collection. Therefore, we interpreted all days in Groups 1 and 2 as "zero-travel" days.

Data missing from the end of the assigned period (Group 3) could be the result of GeoLogger battery failure, lack of travel, or only short trips made on these days. In some cases, STI technicians noted that the GeoLogger batteries failed before the end of the data collection period. Based on the technicians' logs of these incidents, we interpreted some of the days in Group 3 as missing data. However, when the technicians' logs confirmed that the GeoLoggers appeared to be functioning properly at the time of retrieval, we interpreted days in Group 3 as zero-travel days.

GIS Processing

The GPS database received from GeoStats contained over 800,000 data points in a Microsoft Access database. STI assigned a road class and analyzed the resulting data in several ways. Each data point in the GPS database was assigned a unique point identifier and a unique trip identifier. There were 6,448 trips in the point data. The point data table was then converted into a point layer in ArcGIS 8.2, where a spatial query was used to identify data points located within the SoCAB counties. To ensure accurate distance measurements, the point layer was then projected into Universal Transverse Mercator (UTM) projection, Zone 11 North, on the World Geodetic System 1984 (WGS84) Datum.

All GPS points from travel within the SoCAB were converted to a polyline layer, preserving selected attribute data, including the UTM coordinates, unique trip identifier, and unique point record number for the points that constituted the "from" and "to" portions of each segment of the trip polylines. Additionally, a length field was calculated so that distance traveled could be used in later analyses.

For the road class assignment and analysis, STI used the Summer 2002.2 Release of TeleAtlas' MultiNet 4.1 shapefile database. The MultiNet database is a premium quality, fully-attributed street network database. Recent TeleAtlas updates using 2000 TIGER data, aerial imagery, and GPS field surveys have resulted in enhanced positional accuracy for road networks. An example of MultiNet streets compared to TIGER streets is shown in Figure 4.

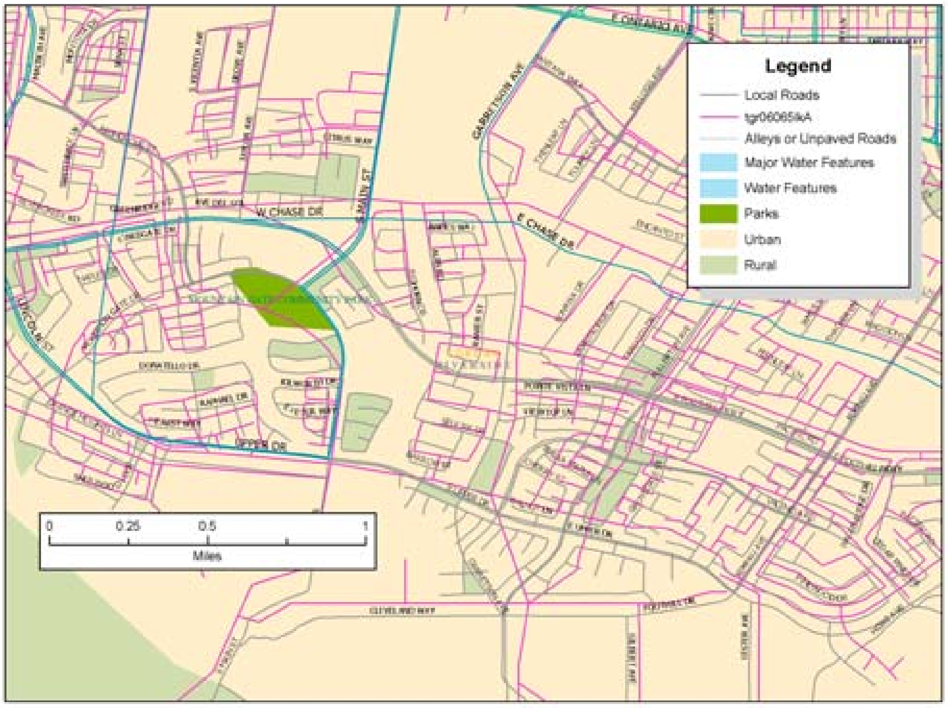

Figure 4. MultiNet streets (gray) and 2000 TIGER streets (pink)

The MultiNet shapefile database contains an attribute that identifies the functional road class (FRC) of each road segment. The six TeleAtlas FRCs relevant to this study are listed in Table 1. TeleAtlas considers traffic volume and average speed for FRC definitions, which is used primarily as impedence values in computing paths for route guidance applications. (Source: personal communication on March 31, 2003 with Christopher Green, Senior Technical Support Engineer, Tele Atlas North America, Inc). Each GPS point logged within the SoCAB was assigned one of these classes by using the GPS point layer and the MultiNet road layer in successive ArcGIS 8.2 spatial proximity queries. The six road classes were later re-grouped into three major road types for VMT analysis. GPS points located more than 25 meters from any road were classified as "other or unknown". This group includes off-road driving in parking lots or driveways and either GPS or MultiNet errors.

Table 1. Functional road classes in the MultiNet database.

FRC	Description	STI Road Type
0 and 1	Interstates, Limited Access Highways	Major Highwys
3	Other Highways	Major Highwys
4	Arterials	Arterials
5	Collectors	Other Roads
6	Locals	Other Roads

As a quality assurance review of the FRC assignment spatial query, the MultiNet street layer was thematically mapped by FRC and overlaid by the GPS point layer, which was also thematically displayed by FRC, using the same color scheme for both. The trip polyline layer was added as needed to identify the shape of trips. Approximately one-third of over 750,000 GPS data points in the SoCAB from all deployment periods and all SoCAB counties were manually reviewed and re-classified as needed, focusing on freeway overpasses and ramps, frontage roads paralleling freeways, and intersections. Less than 5% of the points reviewed required reclassification. An example of an FRC assignment quality assurance review map is shown below in Figure 5.

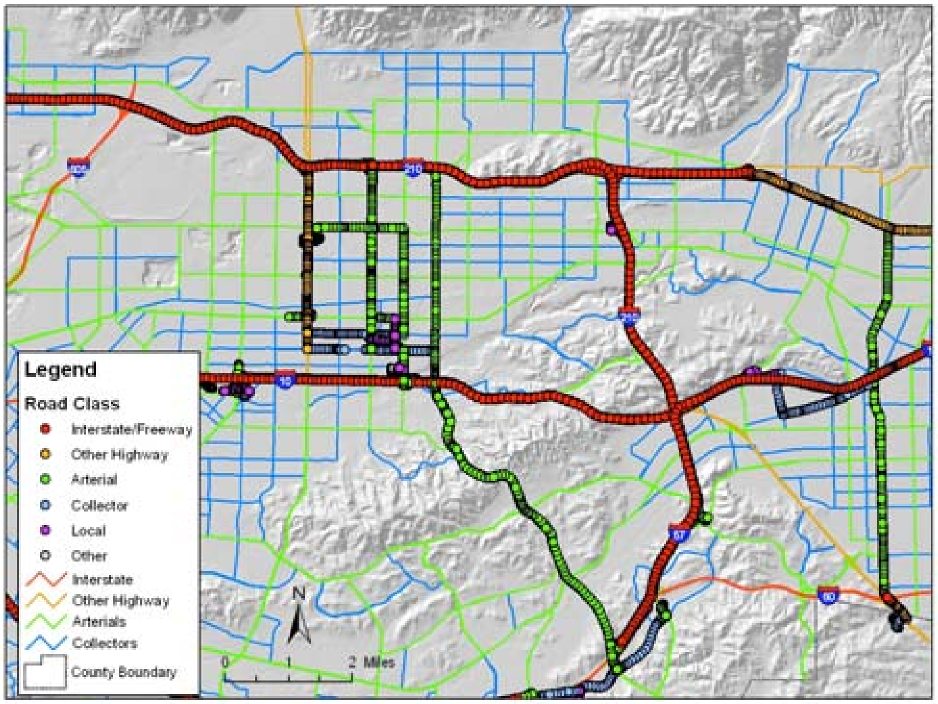

Figure 5. GPS point and Multinet street layers displayed for quality review.

FRC classification errors could be attributable to several sources. Sometimes it appeared the multi-storied freeway interchanges interfered with GPS reception, resulting in location coordinates too far from any street link to receive an FRC assignment or in an unreasonably long distance traveled between points. Tall vegetation along a street can also interfere with receiver accuracy, as can driving through "urban canyons" of tall buildings or natural topographic canyons. A few omissions were found in the MultiNet database, which resulted in misclassifications as non-road travel. Most of these omissions were missing either freeway ramps or recent road construction. And finally, GPS unit malfunctions may have caused a temporary loss of signal that resulted in an unreasonably long distance traveled between points.

After quality review, the attribute tables from both the GPS point layer and the trip polyline layer were imported into MS Access for final compilation of a trip segments table. Time, date, speed, and GPS accuracy data from the original GPS points table were added to the trip segments table based on the unique point record identifier. Vehicle type data was added from a third table. Vehicle types included passenger vehicles or light-duty utility vehicles, which included vans, minivans, sport-utility vehicles, and pickup trucks. Each trip segment record contains the attributes attached to the first or "from" GPS point used in the construction of the polyline segment. Trip segments of unreasonable length or with an unclassified FRC attribute were excluded from the final Trip Segments table in MS Access. Trip Segments fields are shown in Table 2.

Table 2. Final Trip Segments table.

Field	Definition	Example
ATTRIB	The "from" node in line segments, corresponds to a unique point record in original GPS points.	123654
TRIP_ID	Unique trip identifier; concatenation of household, vehicle, and trip number	8830000511
FRC	Functional road class, assigned from MultiNet database	6
LENGTH	Distance traveled from one trip point to another (meters), calculated in ArcGIS	13.87
VEHICLECLASS	Passenger Car or Light-Duty Utility Vehicle	Passenger Car
DATELocal	Day, month, and year data acquired	06-Jun-02
TIMELocal	Hour, minute, second data acquired	16:39:01
DOW	Day of week	Thursday
HOD	Hour of day	16
GPS_SPEED	Speed (miles/hour)	11.19
DELTASECONDS	Elapsed time between trip points	4

DATA ANALYSIS AND PRELIMINARY RESULTS AND CONCLUSIONS

Data Analysis

For each vehicle, a date/time range was established when the vehicle was equipped with a properly functioning GeoLogger, based on data and notes from the installation and retrieval control logs recorded by field personnel. The first valid date/time was 00:00:00 on the day following installation, and the last valid date/time was 23:59:59 on the day prior to retrieval of the unit. Where GPS batteries had failed by time of retrieval, the last recorded date logged by the GPS unit was treated as if it were the day of retrieval. Trip segment data from the valid period for each vehicle were retrieved from the GPS database and grouped for each day, and zero values were inserted for days of no use.

Average VMT for all vehicles was then calculated using Formulas 1 and 2 below. Data were then grouped by vehicle type, and again by road type, to calculate average VMT by vehicle type and by road type. The results are displayed in Figures 6 through 8 below.

Daily vehicle VMT (VMT_{ijkm}) is the sum of VMT for each valid date of travel by each vehicle.

Day-of-week vehicle VMT (VMT_{ijm}) is the average of each vehicle's daily VMT, averaged by day of the week (e.g. Sunday, Monday, Tuesday,...) (Equation 1).

Day-of-week average VMT (VMT_m) is the average of the day-of-week vehicle VMTs for all vehicles (Equation 2):

$$\frac{1}{n}\sum_{k} VMT_{ijkm} = VMT_{ijm} \qquad \textbf{(1)}$$

$$\frac{1}{n}\sum_{ij} VMT_{ijm} = VMT_{m} \qquad \textbf{(2)}$$

where

i	=	Household
j	=	Vehicle (ij identify a unique vehicle)
k	=	Valid Date
m	=	Day-of-Week (e.g., Sunday, Monday, Tuesday,…)
VMT	=	Vehicle Miles Traveled

Preliminary Results

Average VMT by day of week is displayed in Figure 6. Weekday VMT ranges from a low of 26 (Monday) to a high of 29 (Tuesday and Friday), and each weekday has higher VMT than either weekend day. VMT on Saturday is considerably higher than on Sunday (25 vs. 20). The average VMT for weekdays (Monday-Friday) is considerably higher than the average VMT for weekends (Saturday-Sunday) (28 vs. 23).

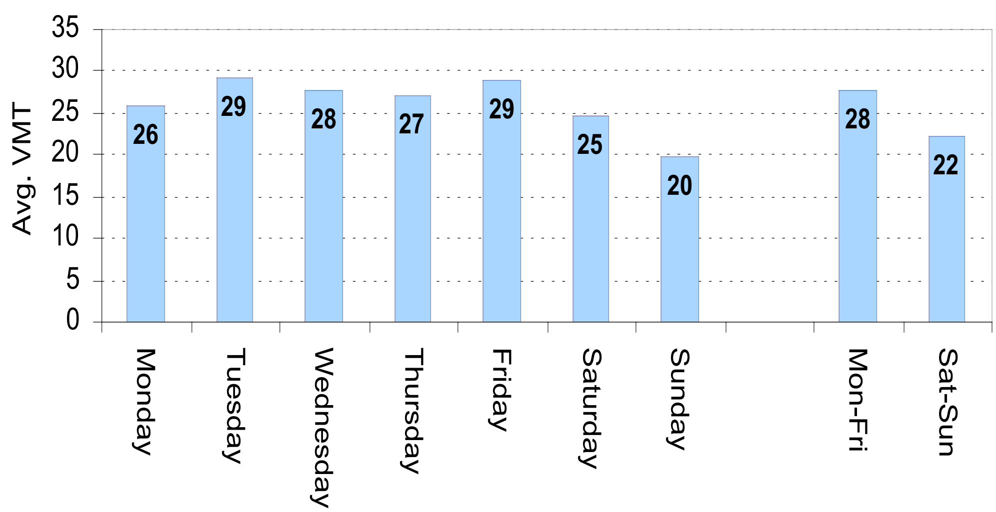

Figure 6. VMT by day of week, all vehicles.

Data were grouped by vehicle type, and a similar averaging process was used to examine VMT by vehicle type. There were 63 passenger vehicles and 42 light-duty utility vehicles among the 105 vehicles whose data were analyzed. Figure 7 shows some differences in the use of passenger vehicles compared to light-duty utility vehicles (LDUV); passenger vehicles logged more VMT Sunday through Monday, while the LDUV VMT was higher Thursday through Saturday. The average passenger vehicle VMT for weekdays was slightly higher than LDUV VMT (28 vs. 27). The average VMT for weekends is the same for LDUVs and passenger vehicles (22).

VMT by road type was also analyzed in a similar manner. Results are presented in Figures 8. Average VMT on major highways was consistently higher than VMT on either arterials or on other roads, both for each day of the week, and for weekdays and weekends. However, the relative distribution of total VMT by road type varied somewhat. Of total VMT, a somewhat larger proportion was driven on major highways on weekends than on weekdays.

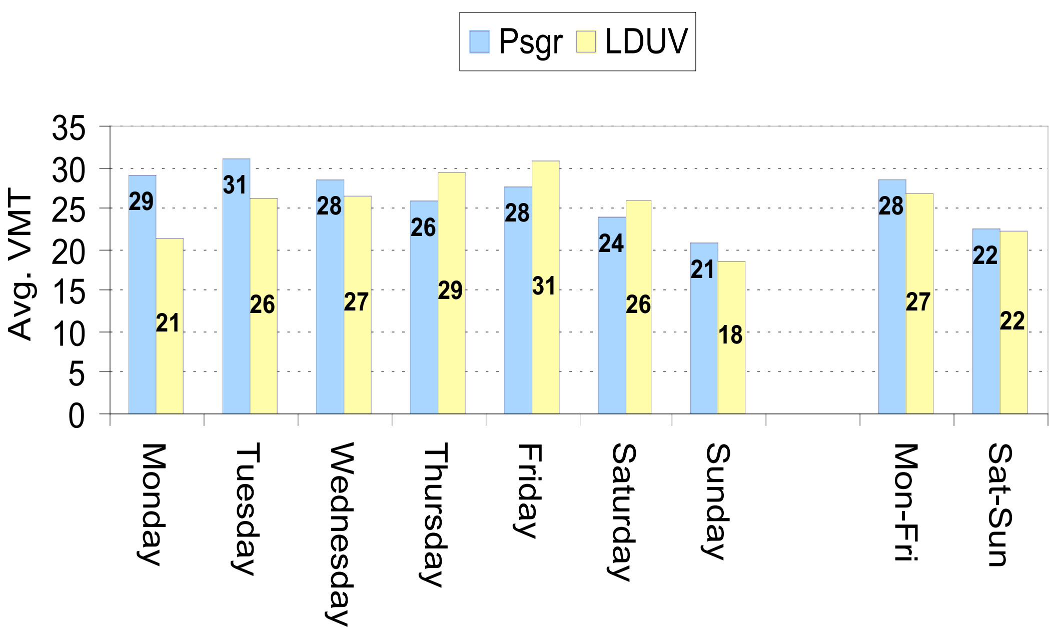

Figure 7. Average VMT by day of week and vehicle type.

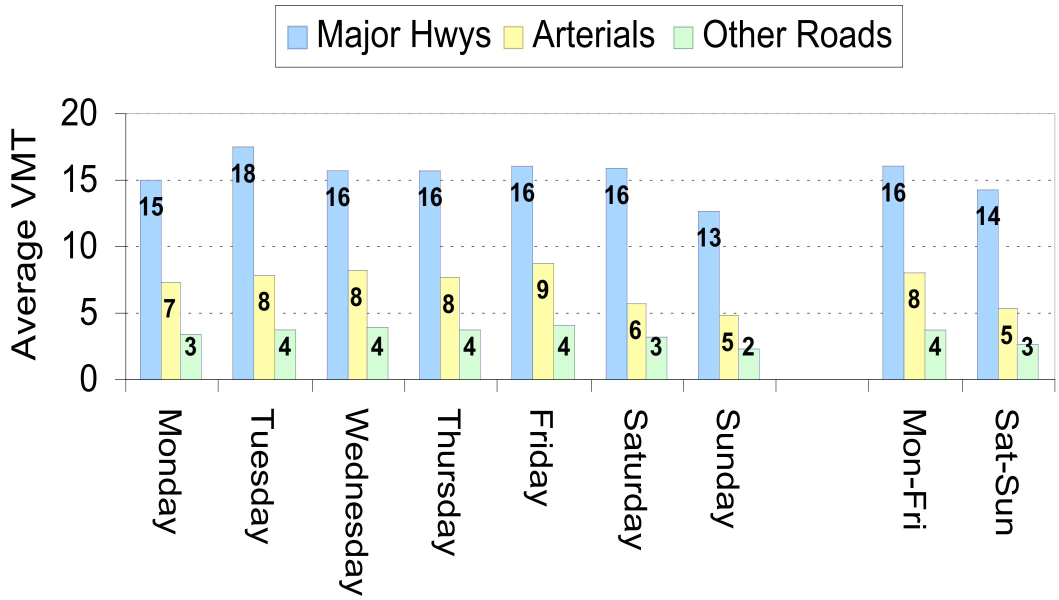

Figure 8. Average VMT by road type.

Preliminary Conclusions

From the results so far, we conclude that

- On average, travel on weekdays is consistently higher than on weekends.
- Light-duty utility vehicle travel seems to trend upwards during the workweek, while passenger vehicle travel seems to vary randomly. However, the differences in volumes by vehicle type are slight.
- Significantly more travel occurs on major highways than on arterials or other roads.
- The relative distribution of total VMT by road type shows a somewhat larger proportion of travel on major highways on takes place on weekends.

IMPLICATIONS OF RESULTS AND CONCLUSIONS FOR REGIONAL AIR QUALITY

Previously, we reported that weekend emissions patterns in Los Angeles favor ozone formation to a greater extent than do weekday emission patterns, despite predicted weekend reductions in total emissions of ozone precursors.[9] This conclusion was based on the development of scaling factors that were applied to summertime daily average emissions to approximate WD-WE variabilities in emissions. (Emissions were acquired from the California Air Resources Board,[10] but adjusted to reflect EMFAC2000-based mobile source emissions.)

Figures 9 and 10 summarize the results of that analysis. Figure 9 shows that estimated ROG and NO_x emissions decrease on Saturdays relative to weekdays, and they decrease even more on Sundays. Mobile sources were the largest contributors to these reductions. Based on these emissions estimates, Figure 10 illustrates the resultant WD-WE changes in the molar ratio of ROG:NO_x emissions. The ROG:NO_x ratio is important because it is an indicator of ozone formation potential, where higher ratios generally are more favorable for ozone production. The estimated ROG:NO_x emissions ratio increases on weekends relative to weekdays, especially during the hours of primary importance for rapid ozone formation, which are from 6:00 a.m. through 12:00 p.m. The increases occur because predicted weekend reductions in NO_x emissions (associated with heavy-duty trucks and other sources) are larger than the corresponding reductions in ROG emissions (associated with light-duty vehicles and other sources). The estimated increases in ROG:NO_x emissions ratios are consistent with ratios of measured air pollutants reported by Fujita et al. and others for the Los Angeles area.[2,3]

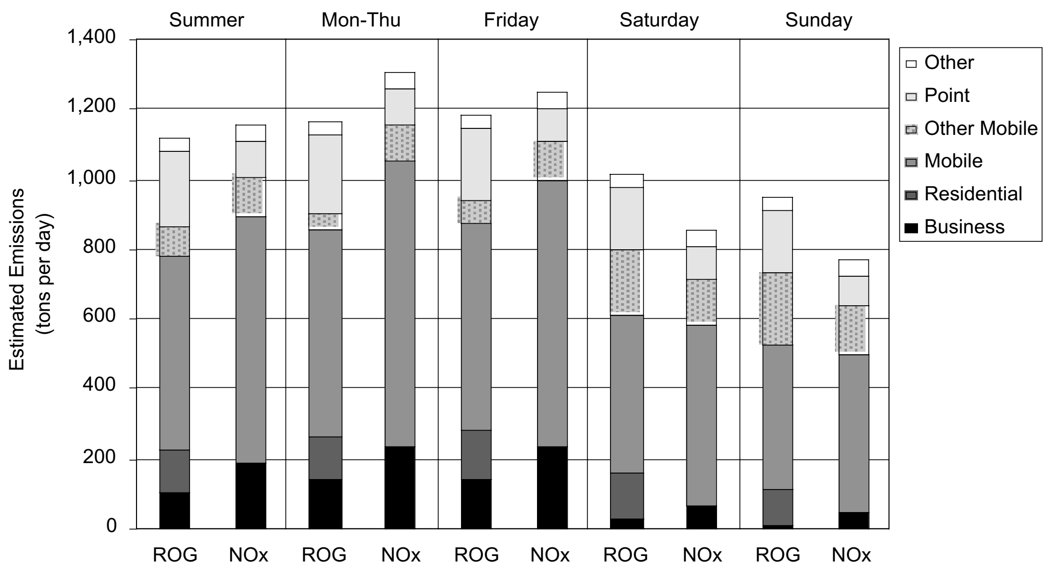

Figure 9. Estimated year-2000 summer emissions for the South Coast Air Basin by day of week and emissions source category.

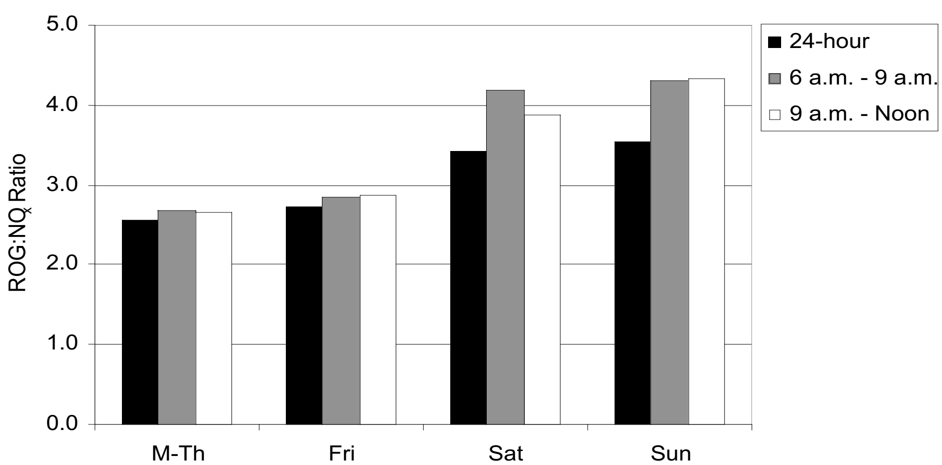

Figure 10. Estimated year-2000 emissions-based ROG:NO_x ratios for the South Coast Air Basin by day of week and time of day.

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