Weekday Versus Weekend On-Road Mobile Source Emissions Activity Patterns in California's South Coast Air Basin

Tami H. Funk, Dana L. Coe, and Lyle R. Chinkin
Sonoma Technology, Inc., 1360 Redwood Way, Suite C, Petaluma, CA 94954-1169
tami@sonomatech.com; dana@sonomatech.com; lyle@sonomatech.com

ABSTRACT

Since the mid-1970s, episodes of high ozone concentrations tend to occur more often on weekends rather than weekdays in California's South Coast Air Basin (SoCAB). These weekend episodes seem counterintuitive because air pollutant emissions estimates are reduced for weekends (relative to weekdays).[1,2,3,4,5] If weekend emissions are reduced, then why are ozone episodes more likely to occur on weekends? And, what does the so-called "weekend effect" imply for development of effective ozone control strategies in the SoCAB? It is extremely unlikely that systematic weekday-to-weekend (WD-WE) differences in weather tendencies could explain the weekend effect. Rather, differences in the relative proportions of ambient air pollutants correlate with weekend ozone peaks.[6] 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.[7,8]

This paper examines variability in one of the SoCAB's most important generators of air pollutants—vehicular traffic. Traffic volume data were acquired from the California Department of Transportation (Caltrans), which operates an extensive network of weigh-in-motion (WIM) detectors across the SoCAB's freeway system. In addition, traffic data were collected at ten surface street locations for a period of ten days during Fall 2000. Significant WD-WE differences were observed in total daily traffic volumes and diurnal traffic patterns. The nature of these differences depended upon geography, road class, and vehicle type. Study findings support the following preliminary conclusions.

- On weekends in urban zones, daily traffic volumes—which are dominated by light-duty (LD) vehicles—are about 15-30% smaller than those on weekdays and tend to peak around midday rather than during the morning and afternoon rush hours.
- On weekends, truck and bus activities decrease to a far greater extent—by factors of 2 to 4—than do passenger vehicle activities.
- On weekends in areas just beyond the urban zones, daily traffic volumes increase somewhat on weekends and tend to peak in the late afternoon on Fridays and Sundays.
- When segregated by vehicle class, traffic patterns for freeways and surface streets in the central urban zone are similar in many respects. Heavy-duty (HD) truck patterns are a possible exception. On weekdays, a bimodal distribution in HD truck activity was observed on a handful of surface streets, while single-mode patterns were observed on freeways.

These results complement those from a major ambient air quality study conducted in Fall 2000 to provide reasons for the causes of elevated weekend ozone levels in the SoCAB.[8]

INTRODUCTION

Since the mid-1970s and possibly earlier, ozone concentrations in California's South Coast Air Basin (SoCAB) have been higher on weekends than on weekdays—a tendency that has been more pronounced in the western SoCAB.[5] This so-called "weekend effect" occurs despite the fact that emissions are estimated to be lesser on weekends than on weekdays and poses significant implications for the development of effective ozone control strategies. 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 nitrogen oxides (NO_x) in the atmosphere. The relative ambient concentrations of VOC and NO_x and 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. An understanding of these governing factors is a fundamental prerequisite to the development of less costly and more effective ozone abatement strategies.

Given the unlikelihood that weekend-to-weekday (WE-WD) weather differences cause the weekend effect, it has been theorized that day-of-week variations in the temporal and spatial patterns of VOC and NO_x emissions, coupled with complex physical and chemical interactions provide better grounds for an explanation .[7,8] Everyday observations and common sense suggest that aggregate variations in human activities, which produce air pollutant emissions and follow a WE-WD pattern, are the most plausible causes of the weekend effect. However, measurements and data analyses are needed to quantify the nature and extent of these WE-WD differences.

On-road mobile sources are major emitters of ozone precursors (VOC and NO_x) in the SoCAB. Figure 1 shows the relative contributions of various classes of emissions sources to total emissions in the SoCAB, where mobile emissions were estimated with EMFAC 2000 (version 2.0).[9] (Note that studies since 1987 have shown that mobile source emissions in the SoCAB have been significantly underestimated[10,11]—an issue that was addressed with the development of EMFAC 2000.) In Figure 1, on-road mobile sources contribute approximately 50% of total reactive organic gases (ROG, which are largely comprised of VOC) and 60% of total NO_x emissions in the SoCAB. HD trucks are responsible for about 40% of mobile-source NO_x and 10% of mobile-source VOC, while LD passenger vehicles contribute approximately 35% of NO_x and 60% of VOC.[9] Therefore, it would seem that WE-WD differences in traffic volumes, timing of traffic peaks, and/or vehicle fleet mix would likely affect the concentrations and relative quantities of ambient VOC and NO_x.

This paper summarizes and discusses a data collection effort undertaken in the SoCAB to examine and quantify WE-WD differences in traffic patterns. Traffic volume data were acquired from the California Department of Transportation (Caltrans), which operates an extensive network of weigh-in-motion (WIM) detectors across the SoCAB's freeway system. In addition, traffic data were collected for ten surface street locations for a period of ten days during Fall 2000. These data were analyzed to characterize WE-WD differences in weekly and daily traffic patterns.

DATA ACQUISITION AND ANALYSES FOR FREEWAYS

Traffic volume data for freeways were acquired for Caltrans WIM sites. The WIM network consists of sensors embedded in freeways that instantaneously record the number, weight, and speed of passing vehicles. The data are binned by 14 vehicle classes based on vehicle weight and axle spacing. The standard Caltrans protocol for processing WIM data is to summarize, quality assure, and archive two weeks' worth of data per month for every site. For this study, data from 1997 and 2000 were acquired through a collaborative effort with the California Air Resources Board (ARB) and Caltrans. Figure 2 shows the WIM site locations in the SoCAB for which data were acquired.

Traffic volumes were analyzed by day of week, hour of day, and vehicle type. The data were processed for annual and seasonal time periods and for a two-week study period that coincided with data collection on surface streets (September 29–October 11, 2000). When weekday/weekend travel patterns for these three time periods were compared, little difference was observed. Thus, driving behavior appears to be fairly consistent over the course of a year in the SoCAB, and the discussion presented here may be safely limited to annual average results.

WIM sites were classified into two groups, interior basin and inflow/outflow, based on characteristics of the observed traffic patterns. The groups were differentiated by day-of-week and diurnal traffic patterns. Two inflow/outflow sites are located along two major freeways (Interstate 5 and Highway 10), which are corridors to and from the SoCAB. Interior basin sites are scattered throughout the central urban zone of the SoCAB. One site, Long Beach, was treated individually because it did not fit well into either group. The Long Beach site's HD vehicle activity characteristics were unique, probably because the site is located on a stretch of the I-710 freeway that is the main artery to and from the Port of Long Beach. (The Port of Long Beach is the busiest container port in the United States and the sixth busiest in the world.)

Traffic volumes and fleet mixes were analyzed for each WIM site. Figure 3 shows the average fleet mixes and traffic volumes for the inflow/outflow sites, the interior basin group, and the Long Beach site. HD vehicles comprise relatively greater fractions of the total traffic volumes at the inflow/outflow and Long Beach sites than at the interior basin sites. HD vehicle volumes decrease on weekends by factors of 2 to 4 throughout the basin, while LD vehicle volumes decrease slightly on weekends in the interior basin but increase slightly at the inflow/outflow sites.

Figure 4 shows typical LD vehicle volumes by day of week and hour of day. LD vehicle patterns for Long Beach are similar to those for interior basin sites. At these locations, weekday LD vehicle volumes follow bimodal distributions with peaks during the morning and afternoon rush hours, and weekend LD vehicle volumes peak around midday. At the inflow/outflow sites, weekday LD volumes follow an attenuated bimodal distribution and are relatively high on Friday and Sunday afternoons. The increased volumes on Friday and Sunday afternoons are plausibly a result of vehicles departing for and returning from weekend recreation outside the SoCAB.

HD vehicle volumes by day of week and hour of day are shown in Figure 5. HD vehicle volumes are very high at the Long Beach site. Diurnal HD vehicle volumes are similar for the interior basin and Long Beach sites in that the volumes tend to peak at midday. At the inflow/outflow sites, HD vehicle volumes peak in the evenings at Indio (which is in the eastern region of the SoCAB on Highway 10) and in the morning and midday at Castaic (which is in the northwestern region of the SoCAB on Interstate-5).

DATA COLLECTION AND ANALYSES FOR SURFACE STREETS

Traffic volumes were monitored on surface streets with automated pneumatic devices (loop sensors) that detect tire passages. If two loop sensors are placed in a lane with a known distance between them, they may be used to disaggregate traffic volumes by vehicle type. The vehicle typing is performed via an algorithm that processes time intervals between tire passages, and from these time intervals the algorithm predicts number of axles, axle spacing, and vehicle type. The algorithm is associated with significant vehicle misclassification errors (much more so than WIM sites); however, these errors tend to cancel out when relative vehicle type counts are considered (e.g., number of trucks per day divided by the number of trucks per week).

Loop sensors were deployed on ten surface streets at various locations around the interior basin and were operated continuously for a period of nine to twelve days beginning on Friday, September 29,

2000. Of the ten sites, four received arrays of loop sensors for vehicle-type counts. The loop sensors were visited at least daily for maintenance—this was particularly important for streets with heavy traffic—because the adhesive that holds them onto the street surface tends to break down over time. This paper focuses on the results for five sites located on arterial streets and three sites located on collector streets, listed below. (Of the two sites not discussed here, one was operated on a residential street and the other at a recreational attraction.) Sites that received vehicle-type sensor arrays are indicated with an asterisk.

Arterial streets

- Azusa Avenue South of Industry Hills Parkway*, which was semi-collocated with Azusa Avenue North of Temple Avenue (La Puente, CA)
- San Gabriel River Parkway North of Beverly Boulevard (Pico Rivera, CA)*
- Vignes Street East of Main Street (downtown Los Angeles, CA)
- Beverly Boulevard West of San Gabriel River Road (Pico Rivera, CA)
- Foothill Boulevard East of Todd Avenue*, which was collocated with Foothill Boulevard West of Todd Avenue (Azusa, CA)

Collectors

- 800 North Main Street* (Los Angeles, CA)
- Main Street West of Azusa Avenue (La Puente, CA)
- West Sierra Madre Avenue East of Todd Avenue (Azusa, CA)

Average relative traffic volumes by day of week and hour of day are shown in Figures 6 through 9. These figures represent average observations for four weekend days and six weekdays. Traffic volumes ranged from 7,000 to 25,000 vehicles per day on arterials and from 2,500 to 4,500 on collectors. At every location where vehicle classes were monitored, about 85-95% of the total traffic volume was comprised of passenger-type vehicles (including cars, pickup trucks, SUVs, vans, and motorcycles). In addition, passenger vehicles seemed to dominate the traffic at all the other sites (as judged by human observers).

Figure 6 shows the day-of-week patterns in total traffic volumes. The average weekday captured 15% of total weekly traffic counts and the average weekend day captured 12-13% of total weekly traffic counts. This represents a drop of 13-20% in total daily travel activity on weekend days relative to weekdays. In addition, diurnal patterns of travel activity differed between weekends and weekdays (see Figure 7). On weekdays, bimodal distributions were observed with peaks corresponding to the morning and afternoon rush hours around 7:30 a.m. and 5 p.m. On weekends, single-mode distributions were observed with broad peaks centered around 1:30 pm.

Travel activity patterns were also found to vary by vehicle type: passenger vehicles, buses, medium-duty trucks (or single-unit trucks), and HD trucks (including double- or multi-unit trucks). Figure 8 shows that total daily travel activity for buses and trucks dropped 44-67% on weekends, while total daily travel activity for passenger vehicles dropped only 13% (relative to weekdays). Figure 7 shows a close approximation of the diurnal traffic patterns that were observed for passenger vehicles. The diurnal patterns for buses (not pictured) were fairly consistent between weekdays and weekends and followed a single-mode distribution with a broad peak between 11:30 a.m. and 2:30 p.m. Figure 9 illustrates the diurnal traffic patterns observed for trucks. The bimodal travel pattern observed for HD trucks on weekdays was unexpected and singularly different from the results for freeways. (In other respects, travel patterns for surface streets were consistent with those for freeways in the interior basin.) This distribution could be a result of vehicle misclassification errors, where multiple passenger cars traveling close together were mistaken for HD trucks. However, it should be noted that the San Gabriel River Parkway site, which is heavily influenced by a freeway off-ramp, did not show a noticeable bimodal distribution in the HD truck activity and was fairly consistent with interior basin freeway patterns. Surface street locations that were less closely associated with freeways displayed strong bimodal HD vehicle traffic patterns on weekdays. In addition, the fact that the WD-WE reduction in total daily HD vehicle activity was 67%, which is much larger than the 13% reduction seen for passenger vehicles and is more consistent with reductions noted in the freeway analysis, suggests that the loop sensors identified HD trucks relatively accurately.

CONCLUSIONS

Significant WD-WE differences in traffic volumes were observed at a number of freeways and surface streets throughout the SoCAB. The differences follow predictable patterns that depend upon geography, road class, and vehicle type. Preliminary conclusions follow:

- On weekends in urban zones, daily traffic volumes (which are dominated by light-duty vehicles) are about 15-30% smaller relative to weekdays and tend to peak around midday rather than during the morning and afternoon rush hours.
- On weekends, truck and bus activities decrease to a far greater extent—by factors of 2 to 4—than do passenger vehicle activities.
- On weekends in areas just beyond the urban zones, daily traffic volumes increase somewhat on weekends and tend to peak on Friday and Sunday late afternoons.
- When segregated by vehicle class, traffic patterns for freeways and surface streets in the central urban zone are similar in many respects. Heavy-duty truck patterns are a possible exception. On weekdays, a bimodal distribution in heavy-duty truck activity was observed on a handful of surface streets, while single-mode patterns were observed on freeways.

These results complement those from a major ambient air quality study conducted in Fall 2000 to provide reasons for the causes of elevated weekend ozone levels in the SoCAB.[8]

REFERENCES

1. Elkus, B.; Wilson K.R. “Photochemical Air Pollution: Weekend-Weekday Differences”, *Atmos. Environ.*, 1977, 11, 509-515.
2. Horie, Y.; Cassamassi, J.; Lai, L.; Gurtowski, L. “Weekend/Weekday Differences in Oxidants and Their Precursors”, EPA Contract No. 68-02-2595, Prepared for the U.S. Environmental Protection Agency by Technology Services Corporation. 1979.
3. Levitt S.B. and D.P. Chock, “Weekend-Weekday Pollutant Studies of the Los Angeles Basin”, *J. Air Poll. Control Assoc*., 1976, 26, 1091-1092.
4. Blier, W.; Winer, A.M.; Hansen, D.; Chavira, R. “Analysis of Weekday/Weekend Differences in Ambient Air Quality and Meteorology in the Sourth Coast Air Basin”; ARB Contract No. 95-334, Prepared for the California Air Resources Board by the Department of Atmospheric Sciences and Environmental Science and Engineering, University of California, Los Angeles, CA. 1998.
5. Austin J.; Hien, T. “A Characterization of the Weekend-Weekday Behavior of Ambient Ozone Concentrations in California”; Technical Support and Planning Division, California Air Resources Board, Sacramento, CA, 1999.
6. Blanchard, C.L. “The Effects of Reduced NO_x and Hydrocarbon Emission on Weekend Ozone Levels in Southern California”, Presented at the 11th CRC On-Road Vehicle Emissions Workshop, San Diego, CA, 2001.

7. Fujita, E. “What Do On-Road Motor Vehicles Have To Do With the Weekend/Weekend Ozone Effect in the South Coast Air Basin?” Presented at the 10th CRC On-Road Vehicle Emissions Workshop, Improving the Emissions Inventory, San Diego, CA, 2000.

8. Fujita, E.M.; Stockwell, W.; Keislar, R.E.; Campbell, D.E.; Roberts, P.T.; Funk, T.H.; McDonald, C.P.; Main, H.H.; Chinkin, L.R. “Weekend/weekday Ozone Observations in the South Coast Air Basin: Retrospective Analysis of Ambient and Emissions Data and Refinement of Hypotheses, Volume I - Executive Summary”; Prepared for National Renewable Energy Laboratory, Golden CO by Desert Research Institute, Reno NV and Sonoma Technology, Inc., Petaluma CA. 2000.

9. California Air Resources Board. Emission inventory data obtained from <http://www.arb.ca.gov/emisinv/maps/basins/abscmap.htm>, 2000.

10. Fujita, E.M.; Croes, B.E.; Bennett, C.L.; Lawson, D.R.; Lurmann, F.W.; Main, H.H. “Comparison of Emission Inventory and Ambient Concentration Ratios of CO, NMOG, and NO_x in California's South Coast Air Basin”. *J. Air & Waste Manag. Assoc*. 1992, 42, 264-276.

11. Fujita, E.M.; Lawson D.R. “Evaluation of the emissions inventory in the South Coast Air Basin”; Final report prepared for California Manufacturers Association, Southern California Air Quality Alliance, Southern California Gas Company, California Aerospace Environmental Association, Hughes Aircraft Company, Southern California Edison, and Anheuser-Busch Corporation by Desert Research Institute, Reno, NV. 1994.

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Figure 1. Relative contributions of various classes of emissions sources to total emissions in the SoCAB.[9]

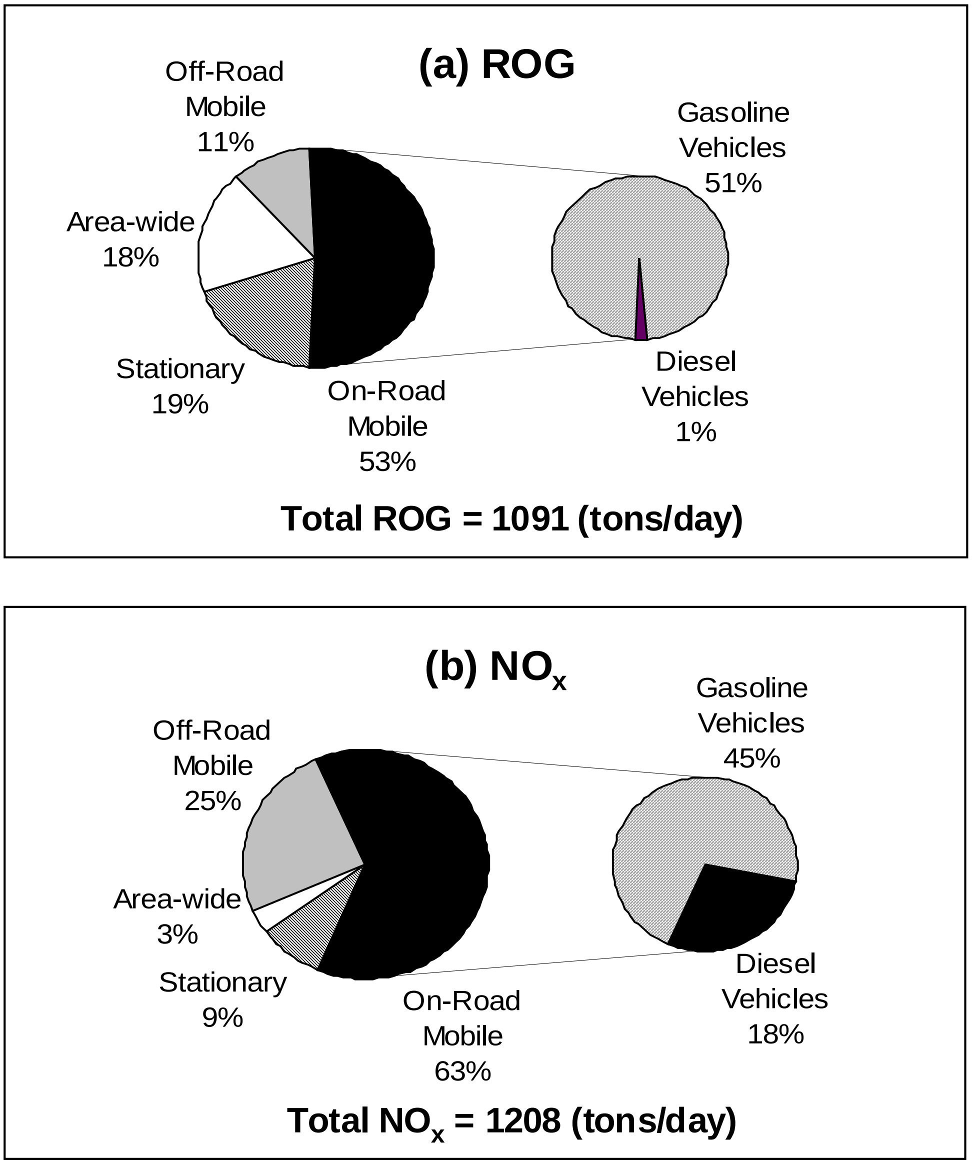


Figure 2. Locations of Caltrans weigh-in-motion (WIM) sensors analyzed for this study. The Southern California Air Basin (SoCAB) is outlined by the pale dashed line.

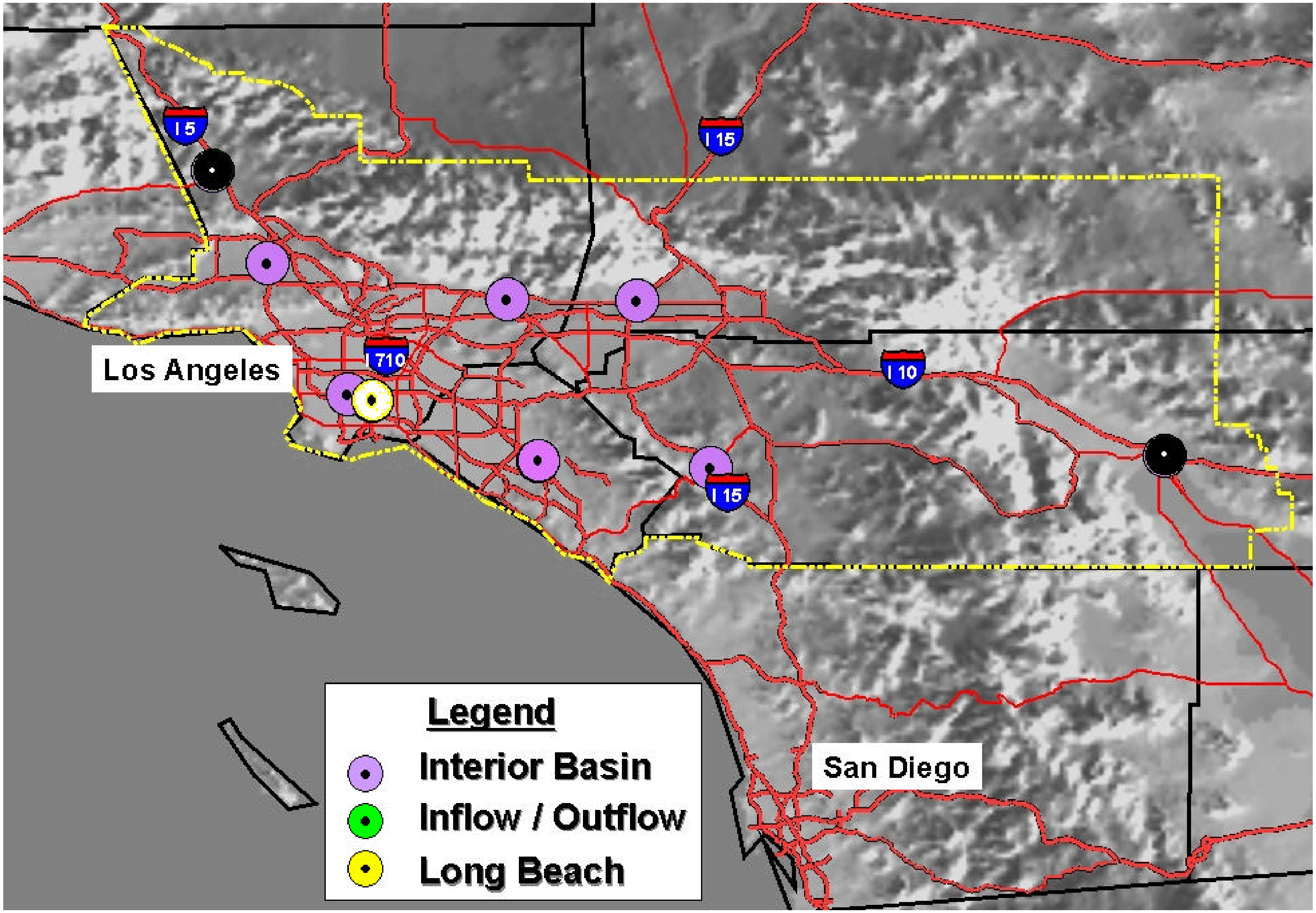


Figure 3. Average fleet mixes and travel volumes observed at freeway WIM sites on weekdays and weekends. (Note: Indio is located in the eastern region of the SoCAB, Castaic is in the northwestern region, and Long Beach is on the access route to the Port of Long Beach).

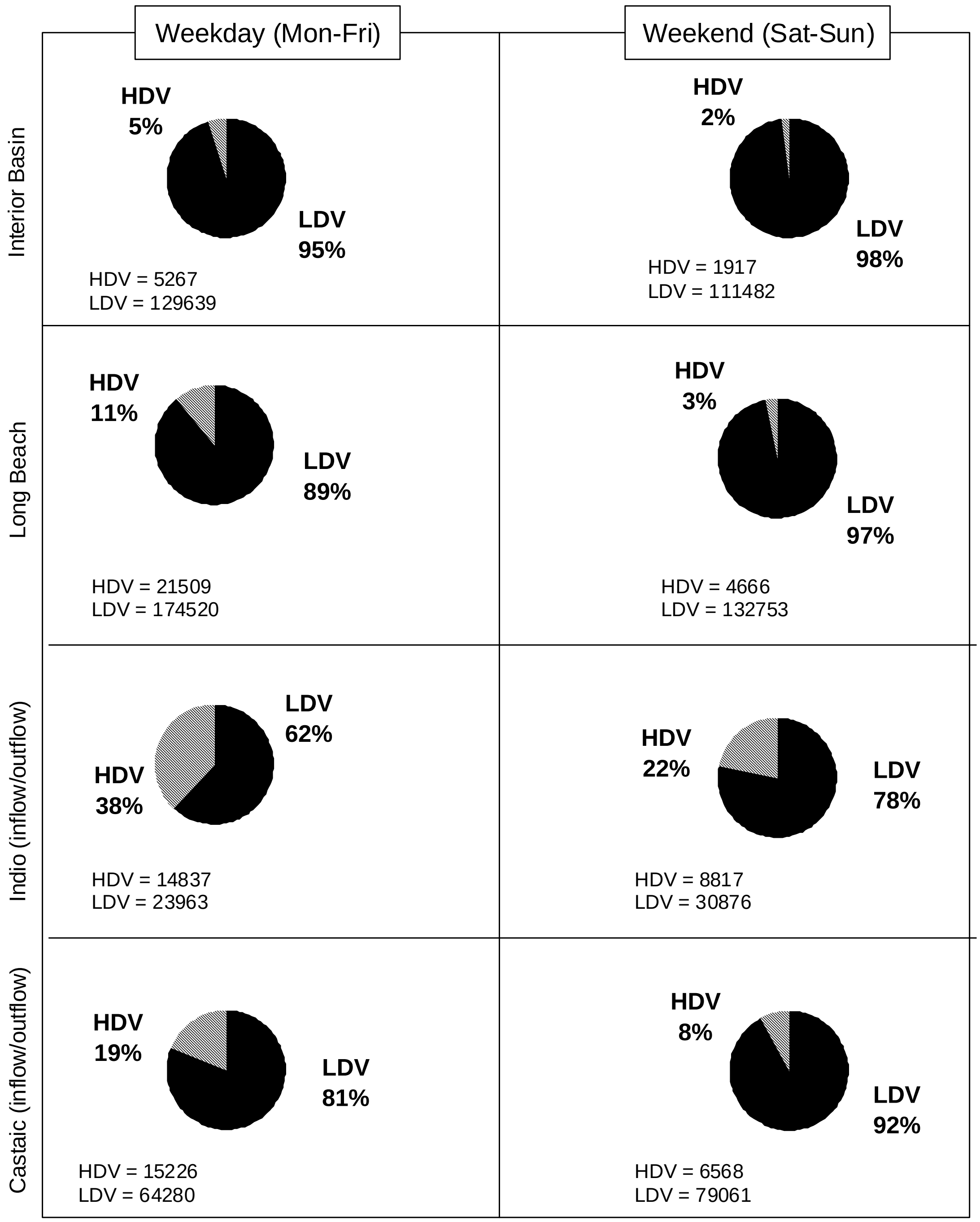


Figure 4. Average light-duty traffic volumes by hour of day and day of week observed at freeway WIM sites.

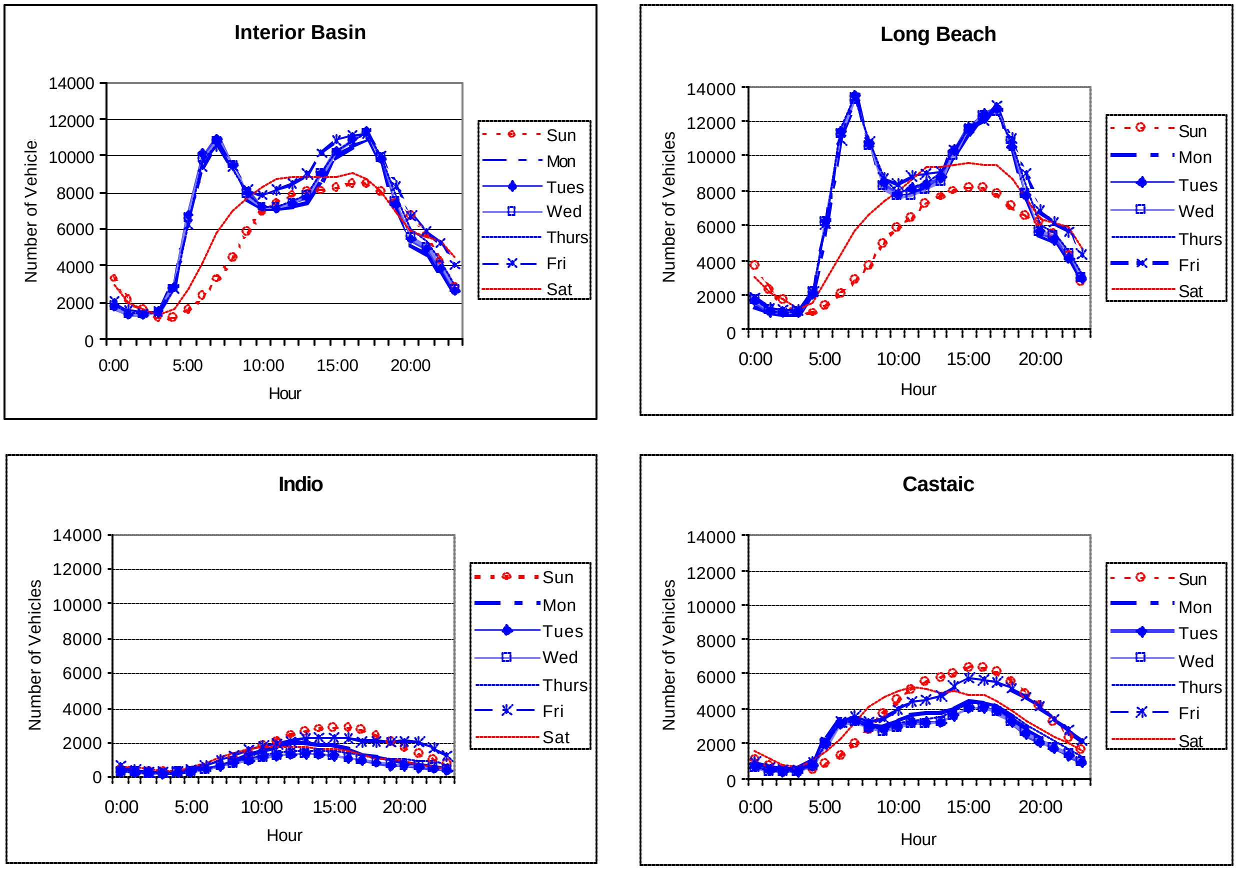


Figure 5. Average heavy-duty traffic volumes by hour of day and day of week observed at freeway WIM sites.

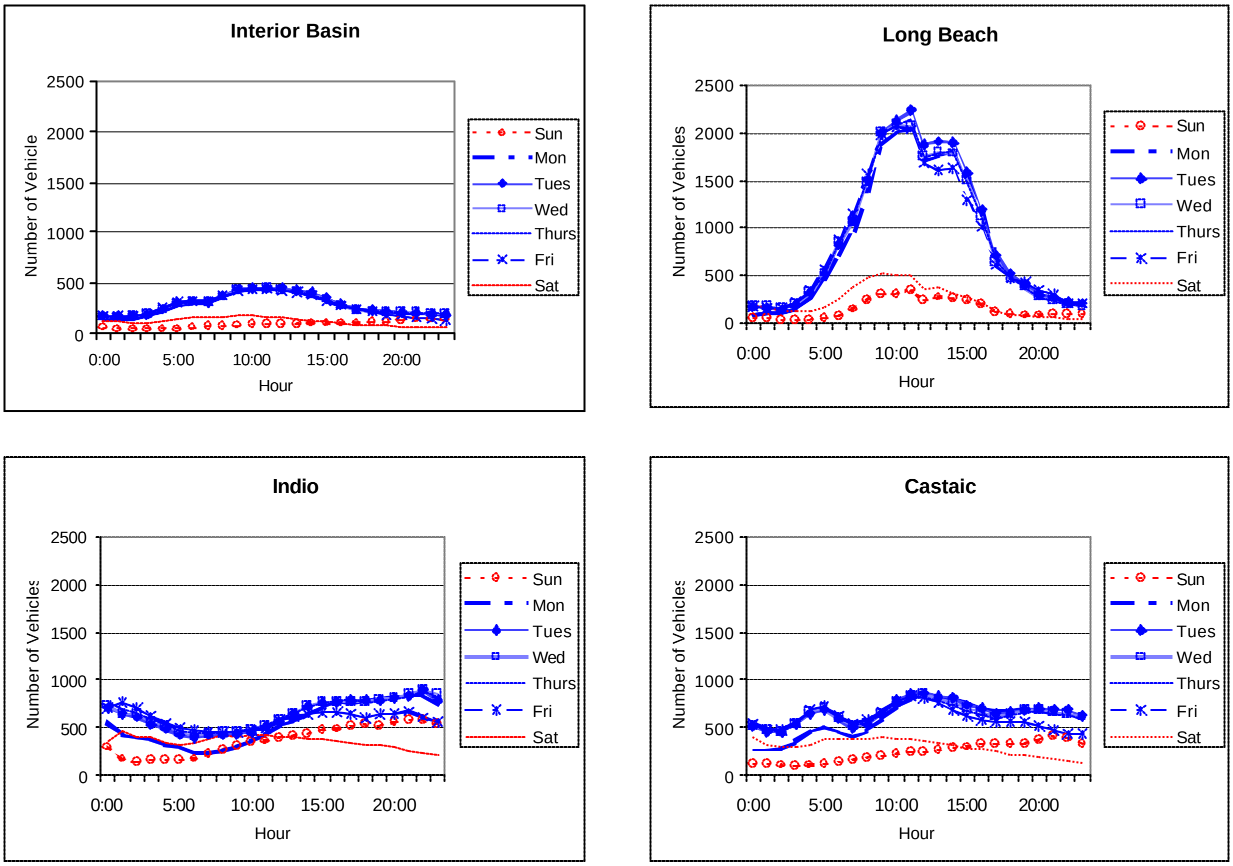


Figure 6. Average day-of-week traffic patterns observed for surface streets. Error bars bound 1 standard deviation.

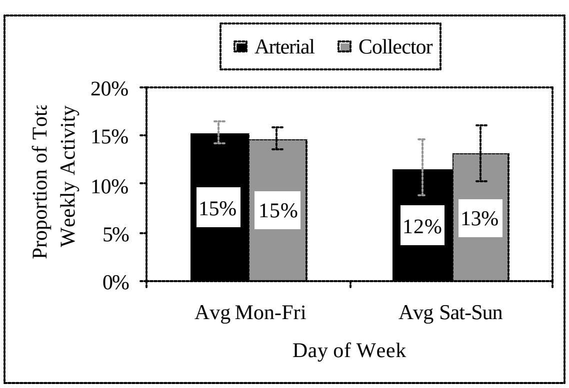


Figure 7. Average diurnal traffic patterns observed for surface streets.

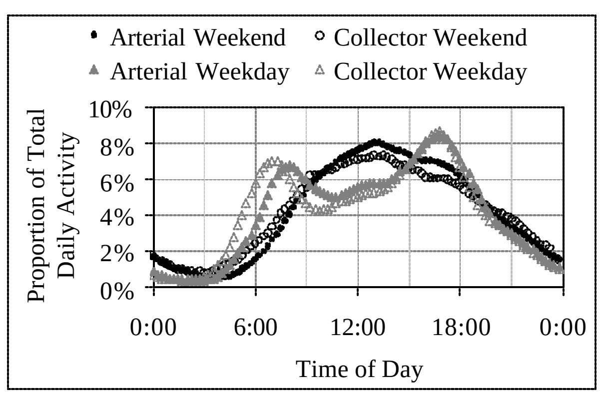


Figure 8. Average day-of-week traffic patterns observed for surface streets segregated by vehicle class. Error bars bound 1 standard deviation.

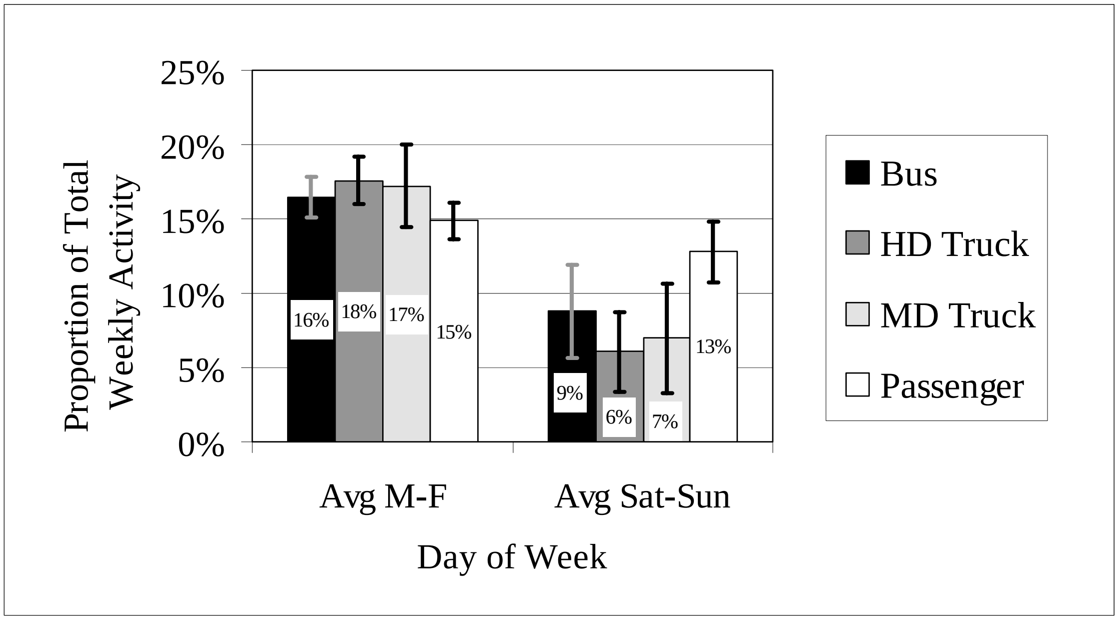
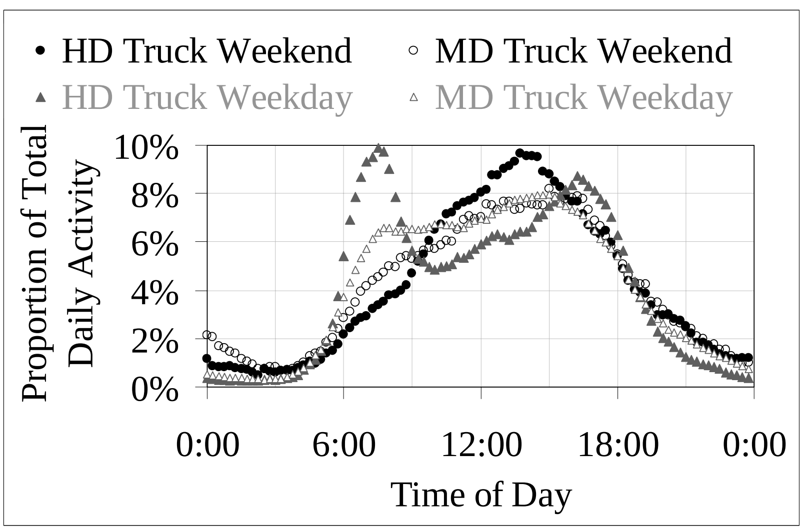


Figure 9. Average diurnal truck traffic patterns observed for surface streets (MD = medium-duty; HD = heavy-duty).



KEY WORDS AND PHRASES

weekend effect

on-road mobile sources

emissions activity data

traffic volumes

passenger vehicles

light-duty vehicles

heavy-duty vehicles

trucks

buses

South Coast Air Basin

Los Angeles

temporal patterns

diurnal patterns

weekly patterns

freeways

surface streets

arterials

collectors