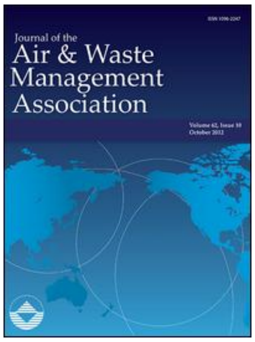

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Weekday versus Weekend Activity Patterns for Ozone Precursor Emissions in California's South Coast Air Basin

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ABSTRACT
Ambient O_3 concentrations in California's South Coast Air Basin (SoCAB) can be as much as 55% higher on weekends than on weekdays under comparable meteorological conditions. This is paradoxical because emissions of O_3 precursors (hydrocarbons, CO, and nitrogen oxides [NO_x]) are lower on weekends. Day-of-week emissions activity data were collected and analyzed to investigate the hypothesized causes of the "weekend O_3 effect." Emission activity data were collected for various mobile, area, and point sources throughout the SoCAB, including on-road vehicles, lawn and garden equipment, barbecues, fireplaces, solvent use, and point sources with continuous emission monitoring data. The results of this study indicate significant differences between weekday and weekend emission activity patterns and emissions. Their combined effect results in a 12–18% decrease in reactive organic gases (ROGs) and a 35–41% decrease in NO_x emissions on Saturdays and Sundays, respectively, relative to weekdays in summer 2000. These changes in emissions result in an increase of more than 30% in the ROG/NO_x ratio on weekends compared with weekdays, which, along with lower NO_x emissions, leads to increased O_3 production on weekends.

IMPLICATIONS

Ambient O_3 concentrations are as high or higher on weekends than on weekdays in many urban U.S. locations. However, because most emission inventories of O_3 precursors are intended to represent average weekday emissions, few weekend emission estimates and activity data are available. The current situation of lower O_3 precursor emissions on weekends allows air quality managers to answer a specific "what if" scenario regarding urban O_3 control strategies (i.e., a case in which NO_x is reduced more than ROG). For example, applying the day-of-week and time-of-day emission activity patterns developed in this study to emission forecasts results in a prediction of emissions-derived ROG/NO_x ratios on weekdays in 2010 comparable to those on weekends in 2000. This suggests the possibility that weekday O_3 in 2010 could be comparable to weekend O_3 in 2000.

INTRODUCTION
Since the mid-1970s, O_3 concentrations in California's South Coast Air Basin (SoCAB) have been higher on weekends than on weekdays, especially in the western SoCAB.[1,2] This phenomenon, the "weekend O_3 effect," occurs despite assumed lower emissions on weekends than on weekdays.[3–7] The weekend O_3 effect has been observed in other urban regions of the country and has generated strong interest because of its potential implications on O_3 control strategy development.[8–13]

Attempts to model the weekend O_3 effect relied on broad assumptions about changes in emissions-related activity on weekends. For example, the South Coast Air Quality Management District's 1997 Air Quality Management Plan stated that ". . . information on [weekend] on-road travel patterns are not readily available. . . " and that sensitivity runs could only be made assuming 50% fewer heavy-duty vehicle (HDV) emissions to represent less commercial activity on weekends.[14] Because of their contribution to total emissions, special focus has been placed on assessing day-of-week variations in on-road mobile sources. Conventional thinking about travel activity patterns by day of week suggests a sharp decline in urban routes, moderate increases in main rural routes, and substantial increases in recreational access routes.[15] Other efforts to assess travel activity in the SoCAB are under way by the California Department of Transportation (Caltrans) and the South Coast Association of Governments.[16,17]

Much of the difficulty in addressing the O_3 problem is related to its complex photochemistry in which its rate of production is a nonlinear function of the mixture of volatile organic compounds (VOCs) and nitrogen oxides

(NO_x) in the atmosphere. Depending on the relative concentrations of VOC and NO_x and the specific mix of VOC present, the rate of O_3 formation can be most sensitive to changes in VOC alone, to changes in NO_x alone, or to simultaneous changes in VOC and NO_x. Understanding the response of O_3 concentrations to specific changes in VOC or NO_x emissions is a fundamental prerequisite to the development of less costly and more effective O_3 abatement strategies. Measurements in the SoCAB provide evidence of reductions in NO_x concentrations on weekend mornings of approximately 40–70% relative to weekday mornings.[3,18] There are also some less substantial reductions in VOC concentrations resulting in an increase in the VOC/NO_x ratios of nearly 40% on weekend mornings. CO concentrations are also reduced on weekend mornings by 17–32%.[18]

Background

To aid the general understanding of the weekend O_3 effect, Sonoma Technology Inc. (STI) and Desert Research Institute participated in coordinated field studies and analyses of air quality and emission activity patterns in the SoCAB in 2000 and 2001. Phase I involved an in-depth analysis of the spatial, temporal, and statistical distributions of O_3 and O_3 precursors for routine air monitoring sites. Available emission activity data, VOC speciation, and meteorological phenomena in the SoCAB were assessed in the context of day-of-week variability.[19] Phase II involved the collection of air quality and emission activity data to examine the relationships between emission patterns and key air quality parameters relevant to the weekend O_3 effect.[4]

Atmospheric Environmental Research, Inc.,[20] Environ,[21] and Envair also conducted modeling studies of the weekend O_3 effect during the past 2–3 years.[18] Efforts were made to coordinate the exchange of information and results among all the investigators who were conducting investigations of emission sources and activity patterns and their relationship to the weekend O_3 effect. The California Air Resources Board (CARB) established a weekend O_3 effect working group and Web site, http://www.arb.ca.gov/aqd/weekendeffect/weekendeffect.htm, to facilitate the transfer of information.

Ozone Precursor Emissions and Their Relationship to the Weekend Ozone Effect

Everyday observations and common sense suggest that aggregate variations in human activities, which follow a weekday-weekend (WD-WE) pattern, likely cause observable differences in air quality. Because most O_3 precursor emission inventories developed for use in assessing emission control strategies are intended to represent average weekday activity patterns, there is a general absence of detailed information about weekend emission activity patterns, and, thus, emissions, on weekends. The emission activity phase of the SoCAB coordinated studies reported in this paper involved collection of WD-WE activity data to investigate day-of-week differences in emission activity levels of O_3 precursor emission rates.

Before emission activity data were collected, the SoCAB emission inventory was assessed to identify sources that contribute significantly to O_3 precursor emissions. Total emissions by source category and pollutant are presented in Table 1.[22,23] Based on these values, on-road mobile sources constitute the single largest source category for O_3 precursor pollutants, accounting for 49, 62, and 80% of average daily reactive organic gases (ROGs), NO_x, and CO, respectively, in the SoCAB. Most on-road emissions originate from gasoline vehicles; diesel vehicles contribute approximately 27% of total NO_x emissions. Second to on-road mobile sources, stationary and areawide sources emit significant levels of ROG, while off-road mobile sources are less important ROG emitters. In contrast, off-road

Table 1. Estimated average summertime emissions for 2000 in the SoCAB (t/day).[22]

Source Category	ROG	NO_x	CO	PM_{10}
Stationary and Area Sources				
Fuel combustion	11.6	87.3	42.7	7.8
Waste disposal	2.6	1.9	0.9	0.4
Cleaning and surface coatings (industrial)	137.1	0	0	0.1
Petroleum production and marketing	36.6	4.1	4.8	1.3
Industrial processes	22.5	10.5	5.8	13
Solvent evaporation (consumer)	182.1	0	0	0
Miscellaneous processes (e.g., residential fuel combustion, road dust)	16.4	24.3	82.8	283.9
Total of stationary and area sources	408.9	128.1	137	306.5
Mobile Sources				
Passenger cars	323	247	2990	9
Light- and medium-duty trucks	160	192	1896	8
Light-, medium-, and heavy-duty trucks (gasoline)	46	56	622	6.3
Light-, medium-, and heavy-duty trucks (diesel)	12.5	227	62.3	8.1
Other on-road mobile sources	10.3	1.4	106	2.4
Off-road mobile sources	154.6	313.4	1250.3	19.9
Total of on- and off-road mobile sources	706.4	1036.8	6926.6	53.7
Total of all anthropogenic categories	1115.3	1164.9	7063.6	360.2
Total of all biogenic categories[a]	125	—	—	—

[a]Current estimates of biogenic hydrocarbon emissions are uncertain. Benjamin et al.[23] estimate present biogenic hydrocarbon emissions of 125–200 t/day. However, "since the majority of the biogenic hydrocarbon emissions occur in the mountains located on the northern and eastern boundaries of the SoCAB, downwind of the most heavily populated areas, the actual impact of these emissions on air quality is probably less than is suggested by the magnitude of the inventory, even after taking into account the higher reactivity of the vegetative hydrocarbons."[23]

mobile sources generate relatively large emissions of NO_x, and stationary and areawide sources are less important NO_x contributors. CO emissions do not contribute significantly to O_3 formation, but CO serves as a tracer for mobile source emissions because it is associated primarily with mobile source fuel combustion. The on-road mobile source emission estimates in Table 1 are from CARB's mobile source emissions model EMFAC2000 Version 2.02.

APPROACH

To investigate the WD-WE differences in anthropogenic emission patterns, emission sources likely to show significant variations between weekdays and weekends were identified. Then, a data collection effort was undertaken to acquire relevant WD-WE activity data for those categories, specifically for on-road mobile sources, lawn and garden equipment sources, selected areawide sources, and major point sources in the SoCAB. Surveys of land use and emission source types near selected air quality monitoring sites were also conducted.

Traffic Volume Data Acquisition and Analyses for Freeways

On-road mobile sources are the largest single contributor to VOC and NO_x emissions in the SoCAB. Traffic volume data provide a measure of on-road mobile source activity. Caltrans operates a network of traffic counters called weigh-in-motion (WIM) stations located on California's major freeways. The WIM network consists of sensors embedded in freeways that instantaneously record the number, weight, and speed of passing vehicles. The data are binned into 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 2 weeks of data per month for every site. For this study, data from 1997 and 2000 were acquired through collaboration with CARB and Caltrans.

WIM sites were classified into two groups, termed "interior basin" and "inflow/outflow," based on their locations and the characteristics of the observed traffic patterns. The two groups were differentiated by day-of-week and diurnal traffic patterns. Two inflow/outflow sites are located along major corridors to and from the SoCAB. A site near Castaic, CA, records travel patterns into and out of the Los Angeles area to and from the north, while the site near Indio, CA, records the activity through the east-west corridor to and from Los Angeles. Interior basin sites are scattered throughout the central urban zone of the SoCAB. One site, located in Long Beach, CA, was treated individually because it did not fit well into either group. The Long Beach site's HDV activity characteristics are unique because the site is located on a stretch of Interstate 710 that is the main artery to and from the Port of Long Beach.

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 the 2-week study period that coincided with data collection on surface streets (September 29–October 11, 2000). When WD-WE 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 the year in the SoCAB.

Traffic volumes and fleet mixes were analyzed for each WIM site. Figures 1 and 2 show average light-duty vehicle (LDV) and HDV volumes by day of week and hour of day. LDV patterns for Long Beach are similar to those for interior basin sites, but its HDV patterns (discussed in more detail later) were very different. At these locations, weekday LDV volumes follow bimodal distributions with peaks during the morning and afternoon rush hours, and weekend LDV volumes peak around midday. At the inflow/outflow sites, weekday LDV volumes follow an attenuated bimodal distribution and are relatively high on Friday and Sunday afternoons. The increased volumes on Friday and Sunday afternoons may be the result of vehicles departing for and returning from weekend recreation activities outside the SoCAB.

HDV volumes by day of week and hour of day are shown in Figure 2. HDVs comprise relatively greater fractions of the total traffic volumes at the inflow/outflow and Long Beach sites than at the interior basin sites. HDV volumes are especially high at the Long Beach site, probably because of the HDV traffic traveling to and from the Port of Long Beach. Diurnal HDV volumes are similar at the interior Basin and Long Beach sites—the volumes tend to peak at midday. At the inflow/outflow sites, HDV volumes peak in the evenings at Indio (in the eastern region of the SoCAB on Interstate 10) and in the morning and midday at Castaic (in the northwestern region of the SoCAB on Interstate 5). Overall, HDV volumes decrease by 40–80% on weekends throughout the basin. LDV volumes decrease by approximately 15% on weekends in the interior basin and increase by 20–30% on weekends at the inflow/outflow sites.

Traffic Volume Data Collection and Analyses for Surface Streets

Traffic volumes were monitored on surface streets with automated pneumatic devices (loop sensors) that detect tire passages. Two loop sensors placed in a lane with a known distance between them may be used to disaggregate traffic volumes by vehicle type via an algorithm that processes time intervals between tire passages. From these time intervals, the number of axles, axle spacing, and

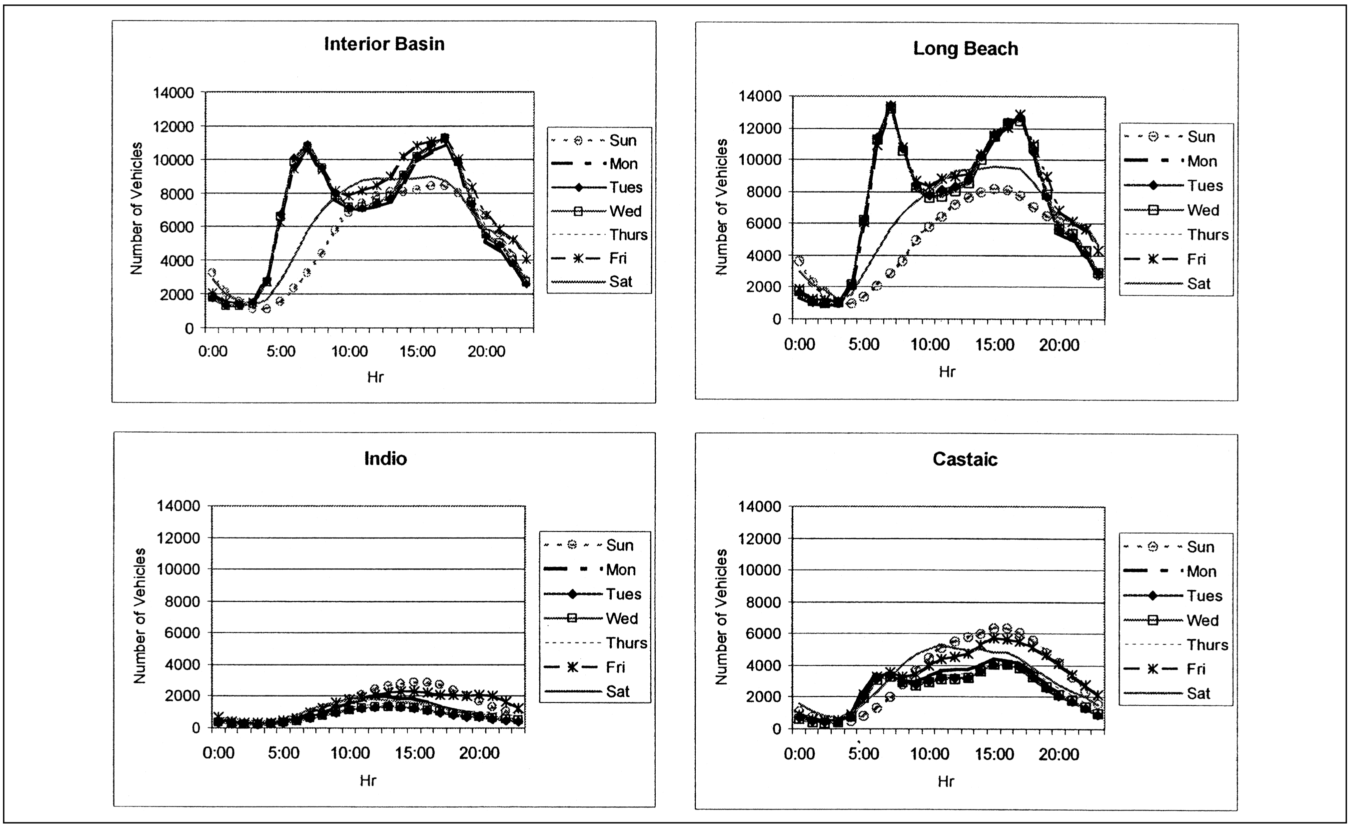

Figure 1. Average LDV traffic volumes by hour of day and day of week observed at freeway WIM sites.

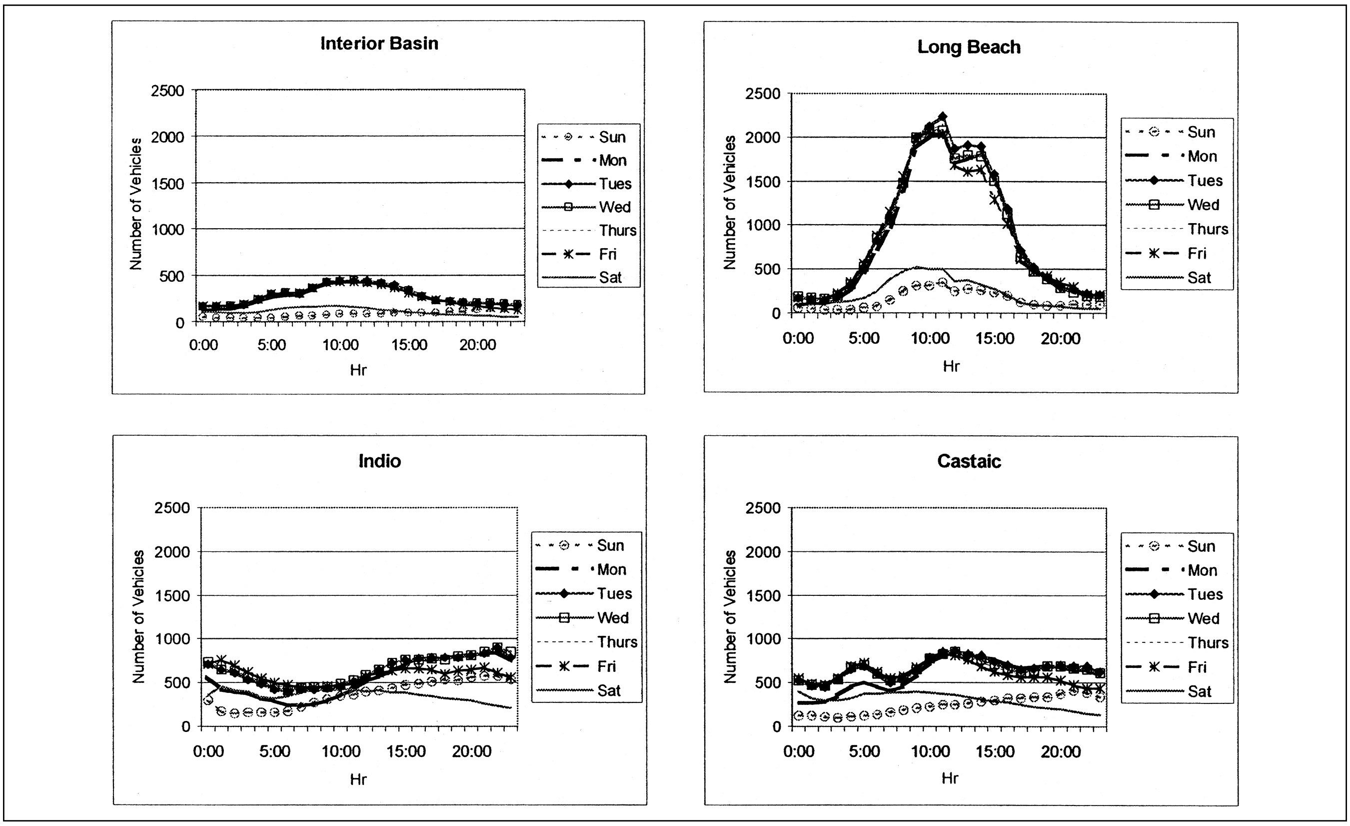

Figure 2. Average HDV traffic volumes by hour of day and day of week observed at freeway WIM sites.

vehicle type are predicted. Loop sensors were deployed on 10 surface streets at various locations around the interior basin and operated continuously for 9–12 days beginning on Friday, September 29, 2000. Of the 10 sites, four received arrays of loop sensors for vehicle-type counts.

Average relative traffic volumes by day of week and hour of day are shown in Figures 3–5. These figures represent average observations for four weekend days and six weekdays. Traffic volumes ranged from 7000 to 25,000 vehicles per day on arterials and from 2500 to 4500 on collectors. An arterial is a roadway that serves major traffic movements and, secondarily, provides access to abutting land (precise definitions vary among localities and states). A collector is an urban street that provides access within neighborhoods and commercial and industrial districts and that channels traffic between local streets and minor or major arterials.[24] At every location where vehicle classes were monitored, 85–95% of the total traffic volume was composed of passenger-type vehicles (cars, pickup trucks, sport utility vehicles, vans, and motorcycles).

Figure 3 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 4). On weekdays, bimodal distributions were observed with peaks corresponding to the morning and afternoon rush hours beginning around 7:30 a.m. and 5:00 p.m. On weekends, single-mode distributions were observed with broad peaks centered around 1:30 p.m.; the mode on Sunday peaked several hours later than that on Saturday.

Travel activity patterns also varied by vehicle type: passenger vehicles, buses, medium-duty trucks (or single-unit trucks), and heavy-duty trucks (including double- or

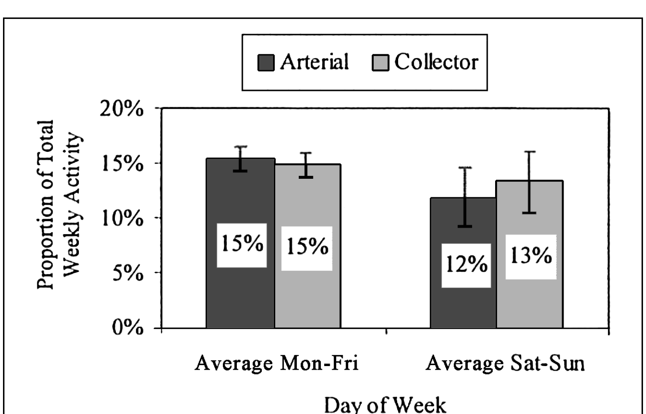

Figure 3. Average day-of-week traffic patterns observed for surface streets. Error bars bound 1 standard deviation.

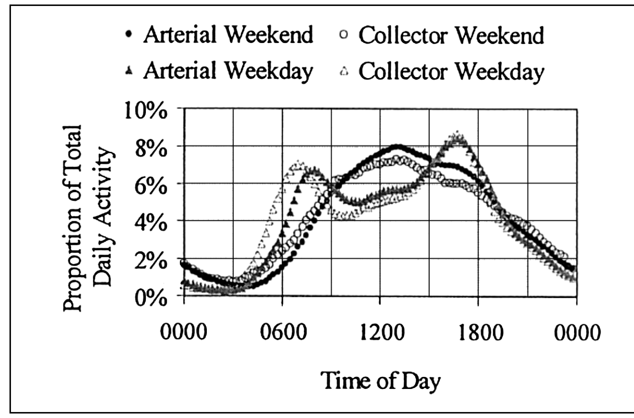

Figure 4. Average diurnal traffic patterns observed for surface streets.

multi-unit trucks). Figure 5a shows that total daily travel activity for passenger vehicles dropped only 13% (relative to weekdays); Figure 5b shows that total daily travel

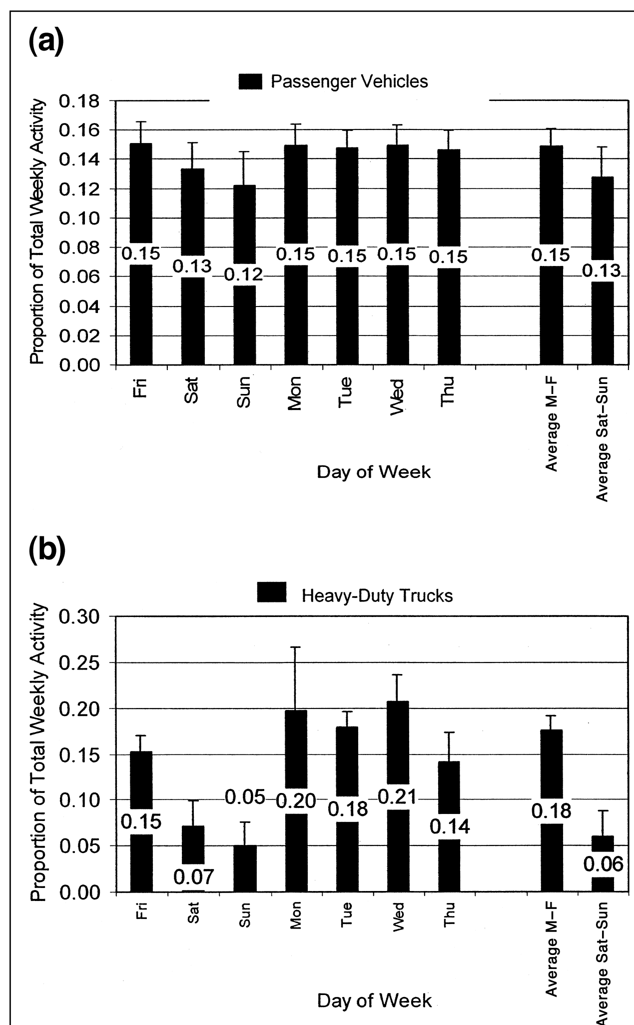

Figure 5. (a) Average day-of-week traffic patterns observed for passenger vehicles and medium-duty trucks on surface streets. Error bars bound 1 standard deviation. (b) Average day-of-week traffic patterns observed for heavy-duty trucks and buses on surface streets. Error bars bound 1 standard deviation.

activity for buses and trucks dropped 44–67% on weekends. A bimodal travel pattern was observed for HDVs on weekdays on surface streets, which was singularly different from the results for freeways. This distribution could be an artifact of vehicle misclassification errors on surface streets, where multiple passenger cars traveling close together were mistaken for HDVs. However, other observations refute this possibility. The San Gabriel River Parkway site, which is heavily influenced by a freeway off-ramp, did not show a noticeable bimodal distribution in the HDV activity but was fairly consistent with interior basin freeway patterns. In addition, surface-street locations that were less closely associated with freeways displayed strong bimodal HDV traffic patterns on weekdays. Lastly, the WD-WE reduction in total daily HDV activity was 67%, which is much larger than the 13% reduction observed for passenger vehicles and is more consistent with reductions noted in the freeway analysis. These observations suggest that the loop sensors identified HDVs quite accurately.

Residential and Small Business Activities

According to emission inventories, areawide and residential emission sources are responsible for approximately 35% of total ROG and 10% of NO_x emissions in the SoCAB. Emission activity data for households and commercial entities were gathered by telephone and mail surveys in four specific neighborhoods of Los Angeles (shown in Figure 6). Each neighborhood was a 4-km × 4-km area centered on a selected air quality monitoring site. In a coordinated study,[3] these sites were equipped with enhanced measurements to study WD-WE concentrations of O_3 and O_3 precursors.

Households were recruited in advance by telephone and by mail. Each participant received a letter and a daily activity diary in the form of a booklet of 10 date-stamped, postage-paid postcards. The study period began on a Friday and concluded 10 days later on a Sunday. Participants were instructed to complete one postcard each day of the study for return by mail. On the postcards, participants checked off responses to queries about daily and periodic household activities, including the use of barbecues, fireplaces, gas cans, paints/solvents, personal care products, paving/roofing materials, motor oils, lawn and garden equipment, and garden chemicals (pesticides and fertilizers).

Commercial entities participated in short telephone surveys during the 10-day study period. They were asked a series of detailed questions about the number of employees typically on duty during specific time periods. These numbers were established for each day of a typical 7-day week and for six 4-hr work shifts starting at midnight and were used as indicators of business activity levels. The survey included a series of questions to determine business characteristics: (1) type of workplace (office or other); (2) total number of employees; (3) business hours of operation by day of week; (4) use of surface coatings or solvents (including paints, solvents, thinners, stains, varnishes, or degreasers); (6) use of motor oils

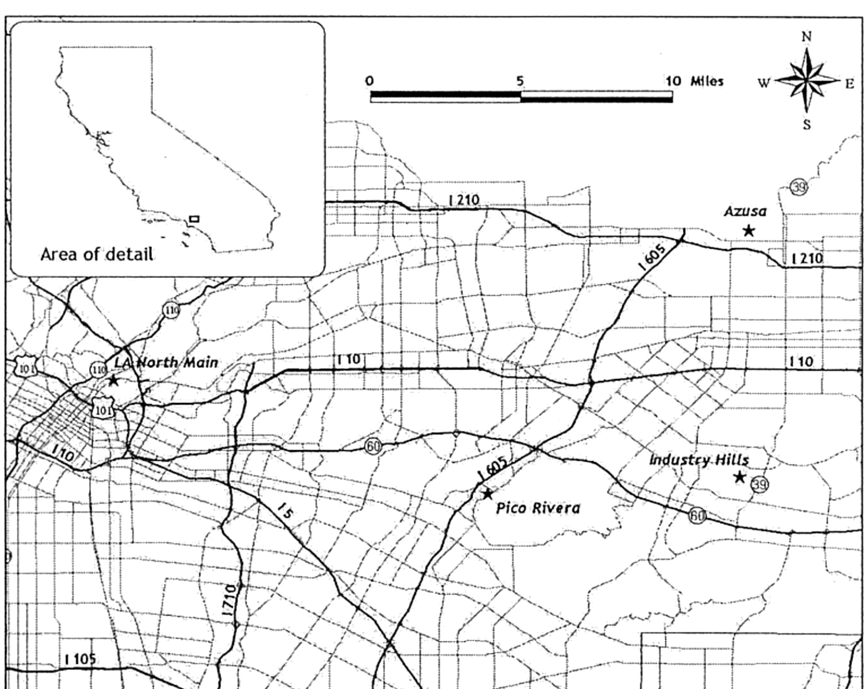

Figure 6. Locations of four Los Angeles neighborhoods—L.A. North Main, Pico Rivera, Industry Hills, and Azusa—that were included in the residential and commercial surveys.

(including gear oils, gear fluids, or brake fluids); (7) use of pesticides or fertilizers; (8) use of internal combustion (IC) engines; and (9) use of gas ovens.

A separate survey of entities that perform commercial lawn and garden maintenance services in Los Angeles was conducted from September 6 through September 25, 2001, or approximately 1 yr after the primary survey period. Like the general commercial survey, respondents were asked about the number of employees typically on duty for each day of a 7-day week and for six 4-hr work shifts. In addition, participants responded to questions about business characteristics: (1) types of residential and nonresidential properties served (e.g., cemeteries, airports); (2) numbers of properties typically served per week; (3) total land area typically served by the business during a summer week; (4) numbers of employees typically on duty during a summer workday; (5) types of equipment used (e.g., mowers, tractors, chainsaws, turf equipment, leaf blowers, and edgers/trimmers/cutters), number owned of each type, and power source of each (e.g., gasoline or diesel fuel, electricity, or manual power); and (6) use of pesticides or fertilizers by the business and the likelihood of use on specific days of week, typical duration of application, and frequency of use during the summer.

Summary of Survey Participation

One hundred thirty-one businesses participated in the commercial survey, 151 businesses participated in the lawn and garden equipment survey, and 450 households participated in telephone survey and agreed to be recruited into the mail survey. The commercial survey respondents employed 1914 workers, and the lawn and garden survey respondents employed 5436 workers. In aggregate, surveyed lawn care businesses reported that they typically service 21,000–71,000 acres per week in the summer, or 1–3% of the total area of Los Angeles County. On average, surveyed households had 3.6 household members. Of 450 households, 231 successfully completed and returned at least one postcard; 167 completed and returned all 10 postcards; and 202 completed and returned at least 8 postcards. Of the 4500 postcards that were mailed to residential survey participants (10 per household), 2070 (46%) were returned. Similar numbers of postcards were received for each day of the 10-day study (189–222 postcards per day). Postcard return rates declined slightly but insignificantly as the study progressed to its 10th day. Respondents indicated that 1436 (69%) returned postcards had been completed on the day of interest and that 330 (16%) returned postcards were completed within 1 day after the day of interest.

Residential Survey Results

Figure 7 illustrates day-of-week allocation factors that were estimated directly from the residential survey data. Figure 7 shows that several residential activities (including the use of barbecues, fireplaces, fuel cans, motor oils, lawn and garden equipment, and garden chemicals) were enhanced relative to weekdays by 40–140% on Fridays and weekends. Other activities (including the use of

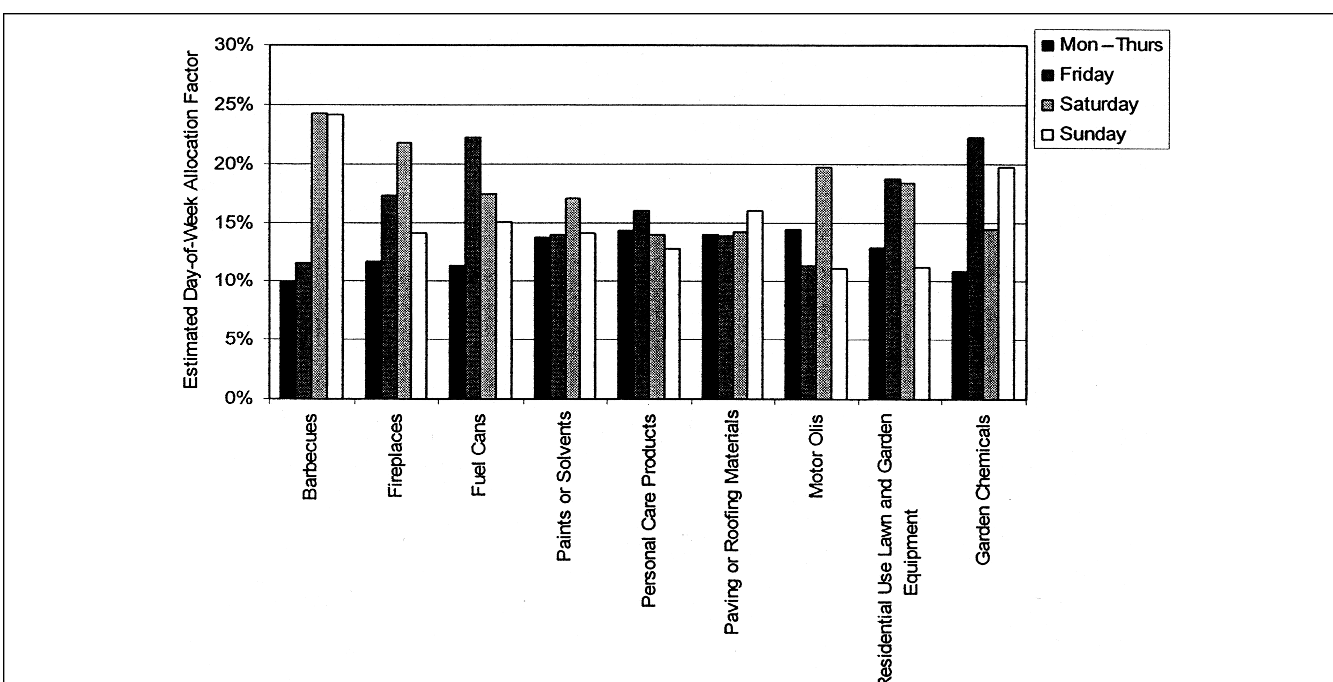

Figure 7. Survey-based estimated day-of-week allocation factors for residential activities.

paints or solvents, personal care products, and paving or roofing material) varied less than 25% by day of week.

Analysis of the responses by time of day for various residential activities showed that some activities tended to occur in the evenings (such as use of barbecues) and others in the mornings (such as use of personal care products). Activities that tended to occur during mornings and afternoons, but rarely in the evenings, included use of paints or solvents and lawn and garden equipment. Diurnal patterns of some activities varied somewhat by day of week. On weekdays, 60–80% of barbecue use occurred during the evenings. However, afternoon use of barbecues increased from 11% of total daily use, Monday–Thursday, to 35–50% on weekends. In contrast, diurnal variations for use of personal care products and of lawn and garden equipment were fairly constant and not WD-WE-dependent. Survey respondents infrequently indicated the use of fireplaces, gas cans, paving or roofing materials, motor oils, and garden chemicals. Therefore, too few time-of-day observations are available for these activities to draw conclusions about day-of-week variability in their diurnal patterns.

Business Survey Results

For all types of businesses in aggregate, weekend activity levels declined from weekday levels by 70 and 79% on Saturdays and Sundays, respectively (see Table 2). However, the declines varied somewhat by type of business. At one extreme, businesses that perform lawn and garden care services experienced reductions in activity levels of 92 and 95% on Saturdays and Sundays, respectively. At the other extreme, businesses that operate gas ovens had activity levels that were 45% lower on Saturdays. Figure 8 illustrates day-of-week allocation factors that were developed for commercial activities.

Table 2. Weekend reductions in activity for various types of surveyed businesses.

			Percent Reduction in Activity Level Relative to Weekdays	
Type of Business	***N***	***NE***	**Saturday Reduction**	**Sunday Reduction**
All businesses	131	1914	70%	79%
Offices	88	1138	65%	72%
Other workplaces	44	776	76%	89%
Businesses with equipment in use	26	651		
Gas ovens	8	245	45%	74%
IC engines	12	192	73%	77%
Motor oils	12	204	74%	80%
Paints or solvents	18	569	77%	90%
Lawn and garden equipment[a]	151	5436	92%	95%

Note: N = number of businesses sampled; *NE* = number of workers employed by sampled businesses; [a]Commercial-use lawn and garden data were collected during a separate, follow-up survey.

On weekdays and Saturdays, daily business activity levels peak from 8:00 a.m. to 4:00 p.m. However, individual types of businesses differ from the aggregate pattern. Businesses that use gas ovens peak in their activity levels later in the day, from 12:00 p.m. to 4:00 p.m., and sustain activity levels at around 70% of peak until late in the evening on weekdays (or through the 8:00 p.m. to midnight work shift). Activity levels for lawn and garden care services peak much earlier in the day. Commercial lawn services reach 70% of peak activity from 4:00 a.m. to 8:00 a.m., peak from 8:00 a.m. to 4:00 p.m., and precipitously drop in activity levels after 4:00 p.m. to less than 10% of peak. On Sundays, the diurnal activity profiles of offices and lawn care services resemble the corresponding weekday diurnal patterns. In contrast, Sunday activity levels for nonoffice workplaces were fairly flat and evenly distributed across all time periods, which differs from the corresponding weekday pattern that peaked from 8:00 a.m. to 4:00 p.m.

Stationary Source Continuous Emission Monitoring Data

Combined stationary and areawide NO_x emissions contribute approximately 10% of total NO_x emissions in the SoCAB (see Table 1). Daily continuous emission monitoring (CEM) NO_x data were acquired for the SoCAB from the South Coast Air Quality Management District for June–August of 1999 and 2000. Data for these sources were analyzed to characterize WD-WE differences in point source emissions. The CEM data obtained for this study represent approximately three-quarters of stationary source NO_x emissions in the SoCAB. On average, the CEM data indicated that NO_x emissions decreased by 13–25% on Fridays, Saturdays, and Sundays, relative to Monday–Thursday.

Observed Weekday-Weekend Variations in Ambient VOC Concentrations

For this project, analyses of the spatial and temporal characteristics of ambient VOCs were performed to support an understanding of the WD-WE O_3 effect. Hydrocarbon data from the photochemical assessment monitoring stations (PAMS) network were used extensively in the analysis. The PAMS network typically monitors 56 target hydrocarbons and two carbonyl compounds, O_3, NO_x and reactive oxidized nitrogen (NO_y), and meteorological measurements.[25] The number and type of PAMS sites varies among metropolitan statistical areas (MSAs). Ozone precursors (VOC and NO_x) and surface meteorology are required to be measured at 2–5 sites in an MSA, depending

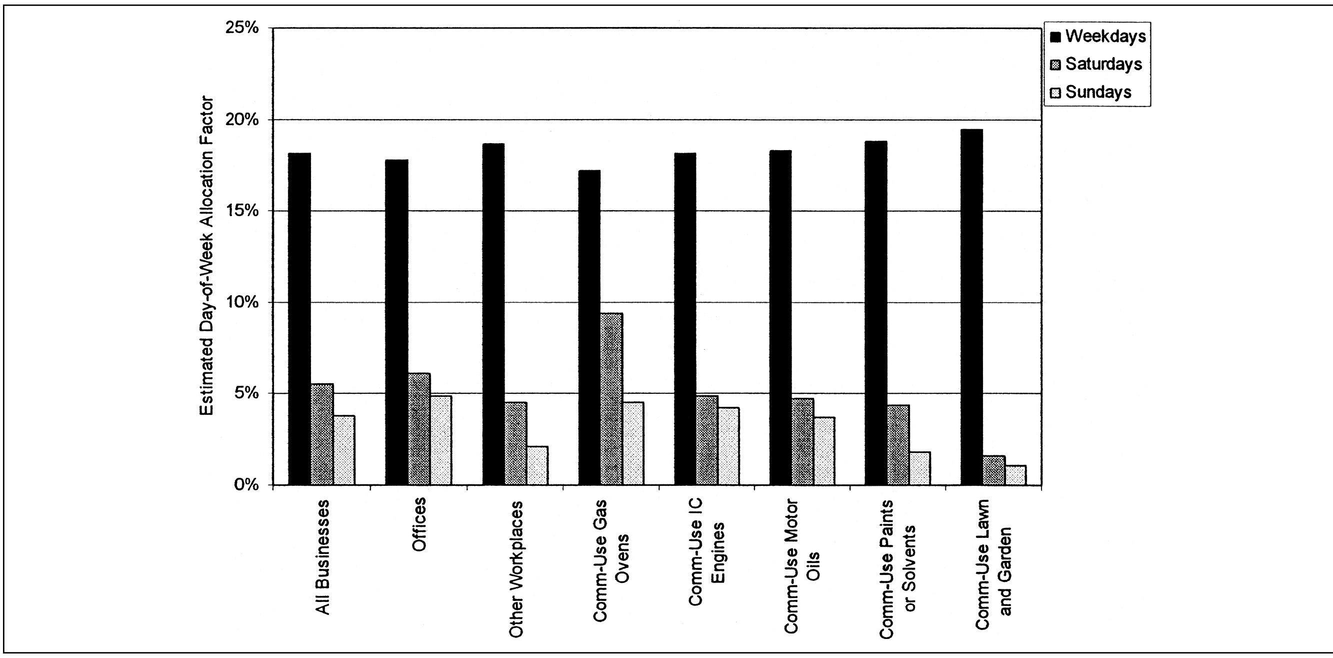

Figure 8. Survey-based estimated day-of-week allocation factors for business activities.

on the MSA population. PAMS VOC data for 1998–2000 were investigated from sites at Pico Rivera, Azusa, Banning, Upland, Hawthorne, Burbank, Santa Clarita, and Los Angeles–North Main.

Most of the VOCs identified as part of PAMS are components of gasoline evaporative or gasoline combustion (exhaust) emissions. Based on the results of these ambient data analyses and on previous studies in the SoCAB, mobile sources contribute significantly to ambient concentrations of VOC as measured by PAMS.[26–28] Therefore, the following observations may be made with respect to the temporal and spatial variations in VOC concentrations:

- Strong correlations occur among the PAMS target species in the SoCAB, indicating a common source, and most species point to motor vehicle emissions as their source;
- Fresh emissions affect the urban sites all day. The composition remains relatively unchanged with time of day at the urban core sites;
- Evaporative components from gasoline (e.g., butanes, pentanes) are a higher portion of the total VOC during midday when temperatures are highest;
- Photochemically produced species (e.g., formaldehyde) have higher concentrations at midday;
- Isoprene concentrations are low at night and higher at midday, which is consistent with biogenic emission patterns. Isoprene does not correlate with anthropogenic hydrocarbons;
- Photochemically reactive species (e.g., xylenes) are depleted relative to less reactive species at midday (e.g., benzene);
- The wt %, or composition, of the hydrocarbons did not appear to show a statistically significant day-of-week change, indicating the source of these species did not change with day of week; and
- Ambient VOC concentrations tended to be lower on Sundays than on other days. This observation can be supported statistically at most sites for many hydrocarbons. For the sites exhibiting a day-of-week difference, Sunday total nonmethane organic carbon concentrations were 24–27% lower than on weekdays. Saturday concentrations were 10–27% lower than weekdays.

DISCUSSION

The analyses of emission activity data provide clear evidence of significant day-of-week variations. The WD-WE differences in activity patterns presented in this paper vary among source categories. Furthermore, each source category contributes unequally to total VOC and NO_x emissions. To understand the net effect of the differences in WD-WE emissions activity patterns on total emissions, a set of source category-specific scaling factors by day of week was developed. These factors were then applied to the summertime daily average emission inventory for the SoCAB. The resulting day-of-week emission estimates by source category were used to develop total emissions by day of week in the SoCAB. Although this analysis is fairly speculative, it is a useful tool to formulate preliminary conclusions about the potential importance of WD-WE activity patterns and their implications for future air quality strategies in the SoCAB. Figure 9 depicts the results of the applied scaling factors for 2000.

As shown in Figure 9, it is estimated that total ROG and NO_x emissions decrease from weekdays to Saturday and decrease further on Sunday. It is estimated that basin-wide ROG emissions decrease by 12% from weekdays to Saturday and by 18% from weekdays to Sunday. NO_x emissions decrease 35% from weekdays to Saturday and 41% from weekdays to Sunday. The net emission changes result from the combination of variations in emissions among individual source categories. The greatest emission variations are associated with source categories that are large in magnitude and vary significantly in activity by day of week.

The single largest category of emissions is on-road mobile sources, which varies a great deal by day of week. As a result, the decrease in mobile source emissions activity is the single largest contributor to emission changes on the weekend. The observed WD-WE reductions in traffic counts were directly applied to scale emissions for on-road mobile sources. The use of traffic counts to estimate weekend emissions from weekday emissions relies on the assumption that vehicle counts are proportional to on-road mobile source emissions (i.e., changes in emissions caused by variations in trip characteristics, such as trip lengths and speed, are less important than changes in vehicle counts). Ongoing research by the CARB may provide evidence to substantiate this assumption.[29]

Second most important are emissions associated with small businesses, which decrease dramatically on weekends. Reduced employment activity rates were directly applied to scale WD-WE emissions for this category. This element relies on the assumption that employment is a good surrogate for these emission rates.

HDVs account for 7% of total ROG and 25% of NO_x emissions Monday–Thursday, 3% of ROG and 15% of NO_x on Saturday, and 2% of ROG and 12% of NO_x on Sunday. Thus, HDV emissions as a percentage of total emissions decline by approximately 50% on the weekend days relative to weekdays.

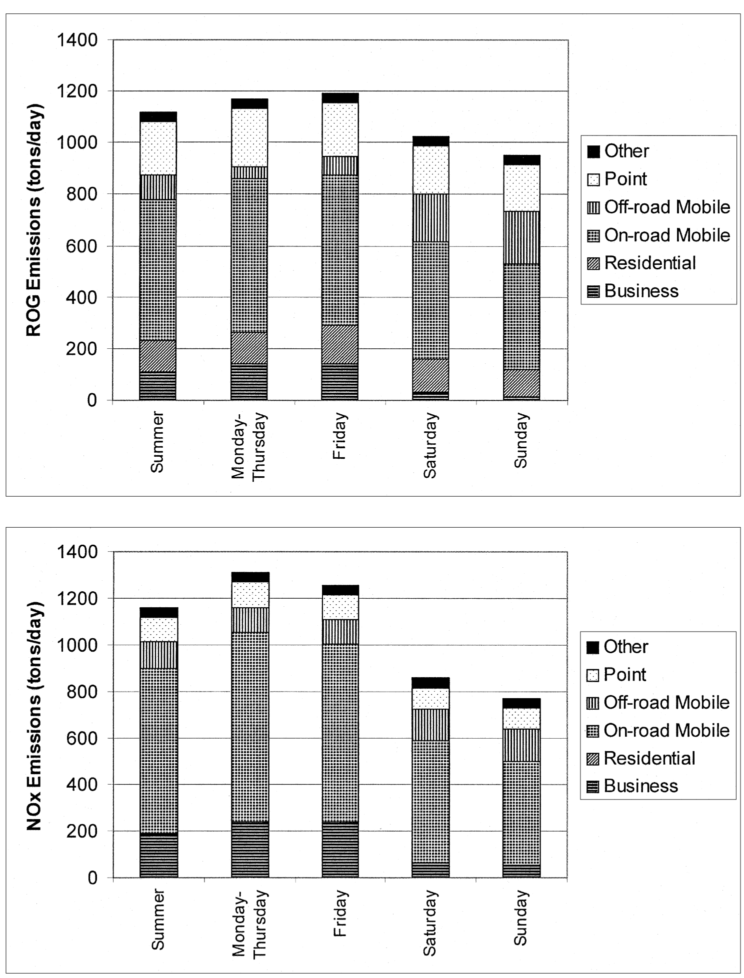

Figure 9. Estimated day-of-week 2000 emission inventory after applying emissions activity scaling factors.

Construction equipment is the largest off-road mobile source of NO_x. Because emission activity data for off-road mobile sources were not collected as part of this study, activity patterns for construction equipment are presumed to be the same as small business activity associated with IC engine use. This assumption results in a decrease in NO_x emissions from off-road construction equipment on weekends proportional to that of small businesses. Ongoing research may help clarify the role of construction equipment emissions.[29]

WD-WE patterns for recreational boats were estimated by applying the findings of a CARB-sponsored research project.[30] Recreational boats emit 3, 17, and 20% of total ROG Monday–Thursday, Saturday, and Sunday, respectively. Thus, according to the inventory, the importance of recreational boats to the ROG inventory is 6-fold greater on weekends. That is, they contribute significantly to total ROG emissions on weekends.

Lawn and garden equipment emissions for Monday–Saturday account for only 2% of ROG and 0.2% of NO_x, and on Sunday they account for 1% of ROG and 0.1% of NO_x. Thus, lawn and garden equipment emissions represent a small fraction of total emissions and show a decrease on weekends relative to weekdays.

One measure of the potential O_3 impact of the emission changes on weekends is the basinwide molar ratio of ROG to NO_x emissions. Higher ratios are generally more favorable for O_3 production. Figure 10 shows that the calculated ROG/NO_x emission ratio is higher on Saturday and Sunday compared with Monday–Friday. Morning emissions by day of week were computed by applying source-specific hourly and daily scaling factors (developed from the surveys and activity indicator data compiled in this study) to published CARB average summer daily emissions. The resultant ROG/NO_x emission ratio increase is enhanced during the morning hours (6:00 a.m.–9:00 a.m. and 9:00 a.m.–noon). As shown in Figure 11, total estimated morning NO_x emissions decrease 49% from weekdays to Saturday and 52% from weekdays to Sunday. Morning ROG emissions decrease by 20% from weekdays to Saturday and by 23% from weekdays to Sunday (see Figure 12). Thus, it is suggested that a larger decrease in NO_x emissions relative to ROG emissions occurs on weekend mornings, which helps explain the increase in the observed ROG/NO_x ratios on weekend mornings.

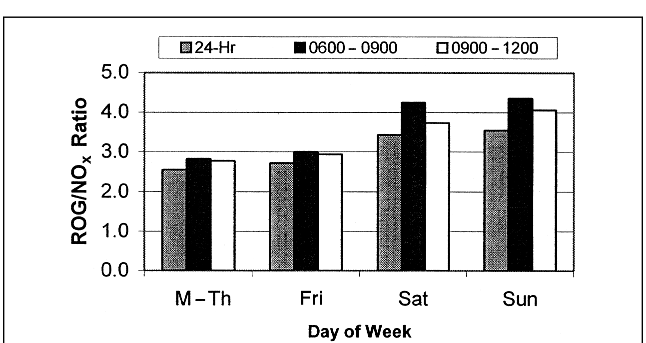

Figure 10. ROG/NO_x molar emissions ratios for 2000 in the SoCAB.

Another timing-related effect hypothesized to contribute to higher weekend O_3 concentrations is the difference in vehicle activity on Friday and Saturday evenings compared with other days. Figure 13 shows that, on Friday, Saturday, and Sunday from 8:00 p.m. to midnight, traffic volumes for LDVs are slightly higher than on weekdays. Figure 14 shows that HDV traffic volumes are slightly lower on Friday evenings and substantially lower on Saturday evenings than on weekdays. Figures 13 and 14 also show that traffic volumes for LDVs and HDVs are reduced during weekend mornings relative to weekday mornings. Thus, changes in travel patterns on Friday and Saturday evenings could have a small effect on subsequent morning O_3 precursor concentrations.

Because of high levels of NO_x emissions relative to ROG emissions in the SoCAB, the atmosphere remains VOC-limited on all days of the week. Even when NO_x emissions are reduced on weekends, O_3 production remains VOC-limited. Under VOC-limited conditions, O_3 production efficiency is a function of the ROG/NO_x ratio and, under the same meteorological conditions, O_3 production would be expected to increase as the ROG/NO_x ratio increases. Ozone accumulation is a function of the rate of O_3 production and the rate of O_3 destruction. On weekends, NO_x emissions are reduced more than ROG emissions, permitting O_3 to accumulate more quickly because of lower rates of destruction. Thus, higher ROG/NO_x ratios on weekends can result in higher O_3 concentrations even though the total mass of emissions decreases.

FUTURE EMISSION PROJECTIONS AND IMPLICATIONS

Precise predictions of O_3 concentrations from emission changes require comprehensive photochemical models. However, analyses of ambient air quality data and emissions forecasts for weekdays and weekends may improve the preliminary understanding of the effects of control strategies and future changes in emissions on future ambient O_3 concentrations. The day-of-week and time-of-day activity variations developed in this study were applied to CARB's future-year emission forecasts for 2010 in a manner similar to that described for the year 2000 inventory. The resultant prediction of O_3 precursor emissions is depicted in Figure 15. Emissions of ROG and NO_x are predicted to decrease on weekdays and weekends, compared with 2000 (compare Figure 15 with Figure 9). Continuing the analysis, the forecasted emissions by day of week can be used to estimate ROG/NO_x emissions

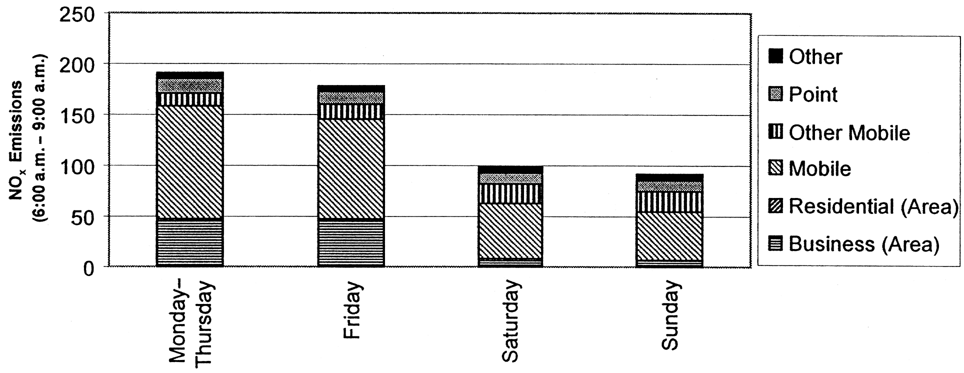

Figure 11. Estimates of days-of-week NO_x emissions 6:00–9:00 a.m. for 2000 in the SoCAB.

molar ratios. Figure 16 shows the forecast ratios for 2010 for the SoCAB. As in 2000, ROG/NO_x ratios increase on weekends. But perhaps even more importantly, ROG/NO_x ratios are forecasted to increase on weekdays and weekend days in 2010 relative to 2000. Thus, ROG/NO_x ratios on weekdays in 2010 are expected to be comparable to those on weekends in 2000 (see Figure 16 relative to Figure 10). This suggests the possibility that weekday O_3 in 2010 could be comparable to weekend O_3 in 2000 and that weekday and weekend O_3 concentrations could be even higher in future years unless the levels of NO_x control are large enough to change the atmosphere in the SoCAB to a NO_x-limited regime.

Another point of interest is a forecasted change in the source categories that are the largest contributors to O_3 precursor emissions in 2010. A comparison of the emissions in Figure 15 with those in Figure 9 shows that predicted reductions in mobile source emissions mean that point sources, residential sources, and other mobile sources will become more important contributors to total emissions. If these predictions are correct, more attention to these source types—particularly other mobile sources, which include recreational vehicles and construction equipment—will be needed to improve their emission estimates.

The finding that sources other than on-road mobile sources will become more important should be understood in the context of the state of knowledge to predict on-road mobile source emissions by CARB and the U.S. Environmental Protection Agency (EPA). Historically, mobile source emission modeling tools have underpredicted on-road motor vehicle emissions, a problem that is well-documented in various publications.[25,31–33] Both CARB and EPA have attempted to correct modeling problems with various model updates over the years.[34–37] New EMFAC and MOBILE model versions have generally increased emissions estimates. CARB's mobile emission model, EMFAC2000 (used in this study), now estimates that year 2000 emissions are 18–56% higher than emissions predicted by EMFAC-7G. Similarly, the January 2002 version of MOBILE6 estimates significantly higher near-term emissions than its predecessor, MOBILE5b. Thus, ROG and NO_x mobile source emissions forecasts for 2010 may be revised upward in the future.

CONCLUSIONS

The principal emphasis of this investigation of possible causes of the weekend O_3 effect was on emission activity data collection and analysis. In this effort, activity data were collected for several important emission source

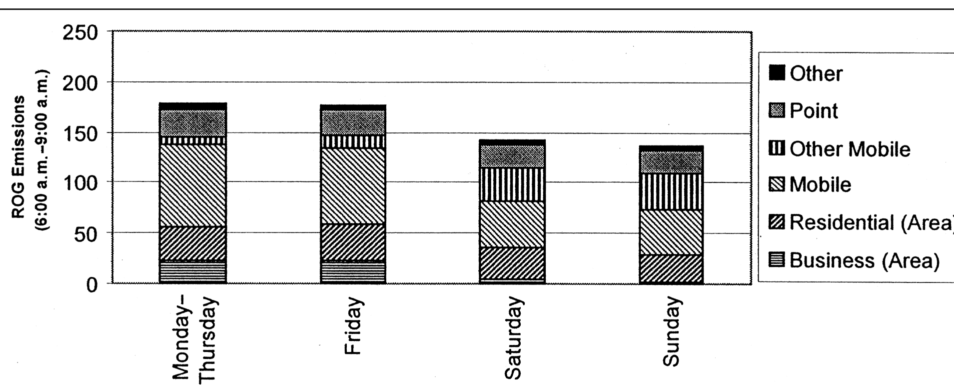

Figure 12. Estimates of days-of-week ROG emissions 6:00–9:00 a.m. for 2000 in the SoCAB.

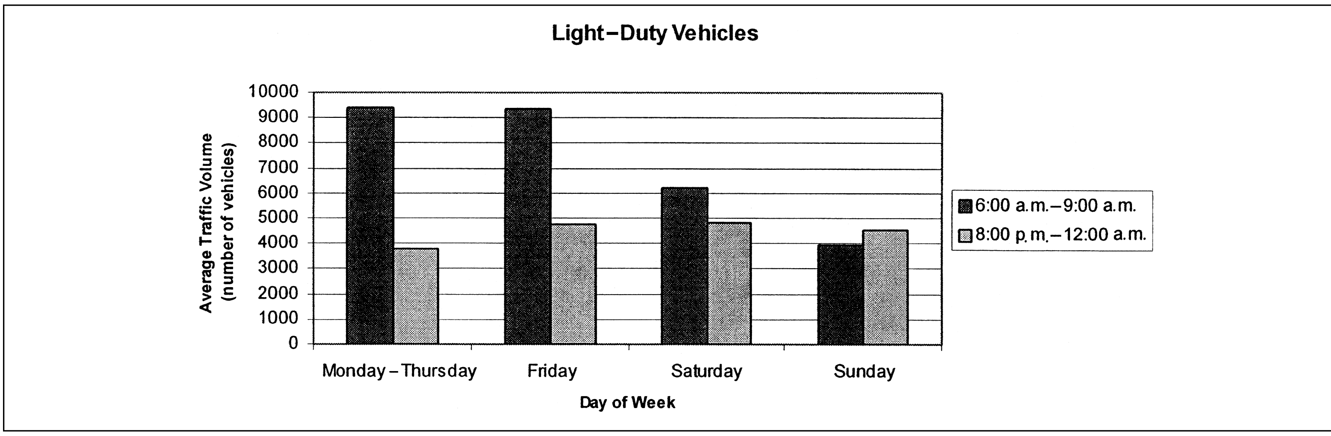

Figure 13. Friday, Saturday, and Sunday 8:00 p.m.–midnight LDV traffic volumes.

categories. This paper provides a summary of the data collection efforts and analyses performed to aid the general understanding of the weekend O_3 effect. The findings of this study support the following observations:

- Combined emission changes for all source categories by day of week suggest that total 2000 emissions in the SoCAB on summer weekends declined by 12–18% for ROG and 35–41% for NO_x on Saturdays and Sundays, respectively, relative to weekdays. These changes in emissions are predicted to result in an increase of the ROG-to-NO_x ratio by more than 30% on weekends;
- Business activity declined substantially on weekends (by as much as 80%);
- Some residential activity, such as the use of barbeques, increased on weekends;
- Freeway traffic volume information showed that truck and bus activities decreased by as much as 80% on weekends. In areas just beyond the urban zones, daily traffic volumes increased somewhat on weekends and tended to peak late afternoons on Friday and Sunday. In the urban areas of the SoCAB, surface street traffic volumes (which were dominated by LDVs) showed that traffic was reduced by 15–30% on weekends and tended to peak around midday rather than during the morning and afternoon rush hours as it does on weekdays;
- Major point source NO_x emissions on Friday, Saturday, and Sunday were 8–18% lower, on average, than on Monday–Thursday. If point source ROG reductions on weekends are proportional to NO_x reductions (not proven in this study), day-of-week variations in point source ROG emissions could also play a significant role in the weekend O_3 effect because point source emissions contribute 20% of ROG emissions;
- The summer 2000 inventory adjusted for Sundays indicates that ROG emissions from recreational boats were higher than ROG emissions from automobiles. This does not seem likely. Because the WD-WE activity data for recreational boats appear reasonable, we believe the summer 2000 ROG inventory for recreational boats may be too high, and further study of this issue is recommended;
- WD-WE off-road emissions were modeled using lawn and garden and business IC engine activity

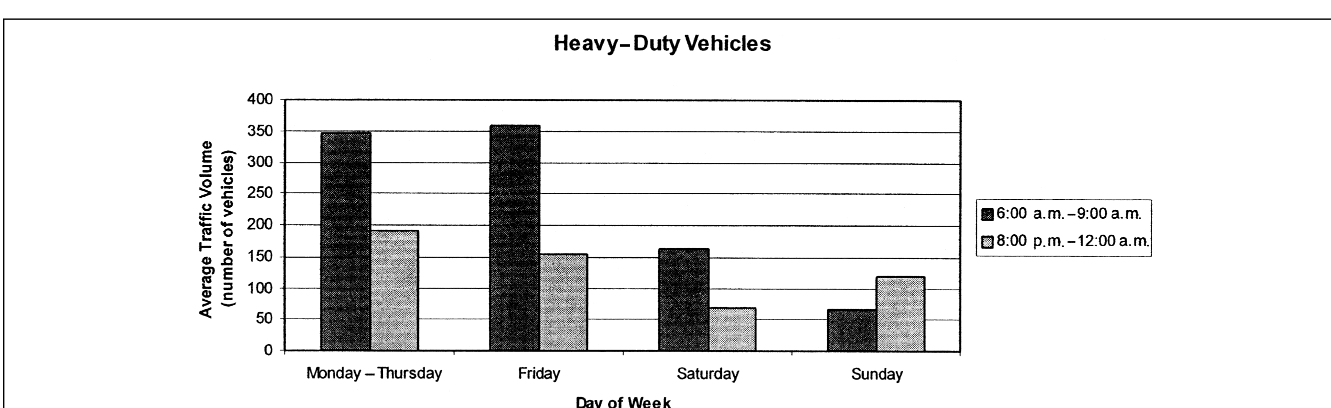

Figure 14. Friday, Saturday, and Sunday 8:00 p.m.–midnight HDV traffic volumes.

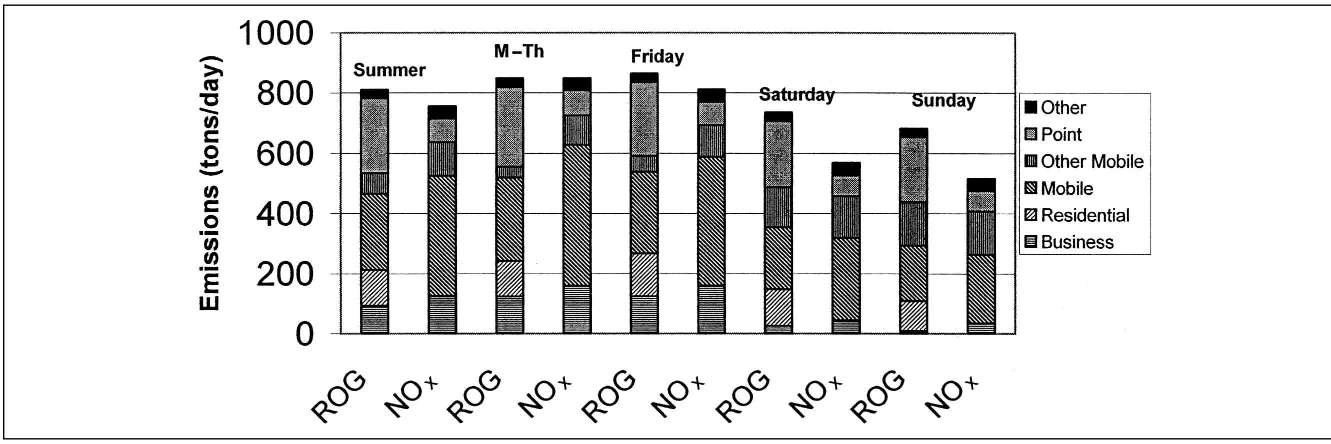

Figure 15. 2010 forecast of day-of-week emissions in the SoCAB.

data. These 2000 emissions in the summer declined on weekends by 41–64% for ROG and 72–78% for NO_x on Saturdays and Sundays, respectively, relative to weekdays. Day-of-week patterns of off-road engine use, other than lawn and garden equipment, are uncertain because the data collected during the business portion of the survey were limited and may not represent the proper WD-WE distribution of off-road IC engines; and

- Although projecting emission inventories into the future is quite uncertain, application of day-of-week patterns to future-year published emission inventories suggests that because of predicted increases in the ROG/NO_x emissions ratio, O_3 concentrations may not decline despite predicted decreases in emissions.

The authors have a high degree of confidence in the overall conclusions of this study. However, selected findings based on the survey data should be considered to have a slightly lower degree of confidence because they are derived from surveys conducted in late summer and early fall (not the peak of the O_3 season) and for only small areas of Los Angeles. CARB is sponsoring similar studies for summer 2002.[29] CARB's 2002 research efforts include expanding the geographic study area to the entire Los Angeles air basin as well as partially repeating the data collection efforts presented here. The findings of the 2002 CARB studies will be used to affirm, revise, and augment the findings presented here.

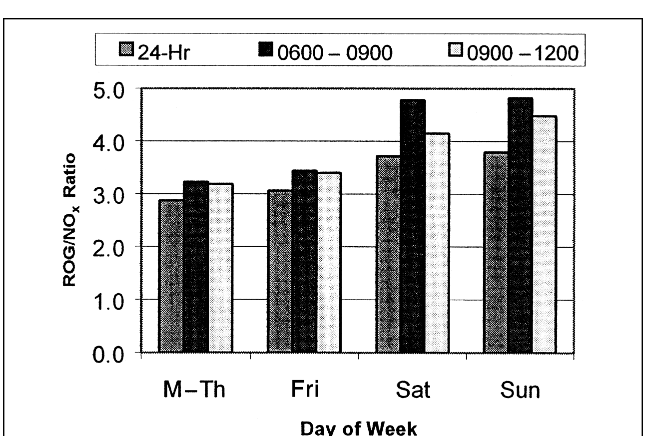

Figure 16. 2010 forecast of ROG/NO_x molar emissions ratios in the SoCAB.

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