Analysis of GPS-Based Vehicle Activity Data and their Impact on CO_2 Emissions

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Acknowledgements: **Kanok Boriboonsomsin, George Scora, and students**

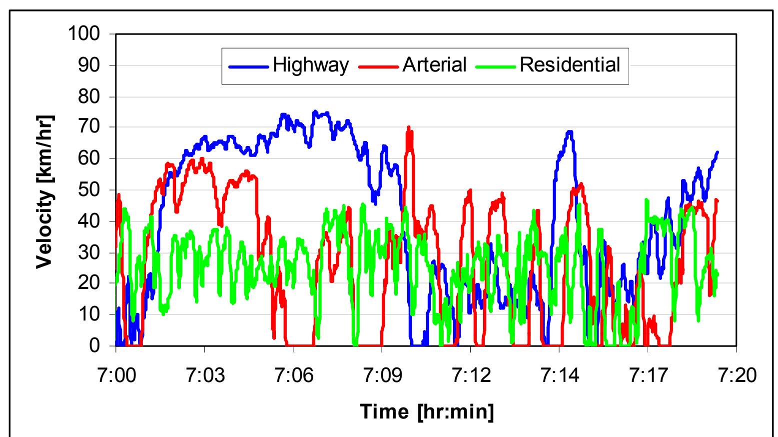
Vehicle Activity Studies as part of building a Mobile Source Emissions Inventory

- Three components of building an emissions inventory:
  - Emissions Factors
  - Vehicle Activity
  - Fleet Characterization

- Vehicle Activity Data typically consist of:
  - number of trips
  - amount of travel (i.e., VMT)
  - how is activity performed (speeds, accelerations, etc.)

Vehicle Activity Data Sources

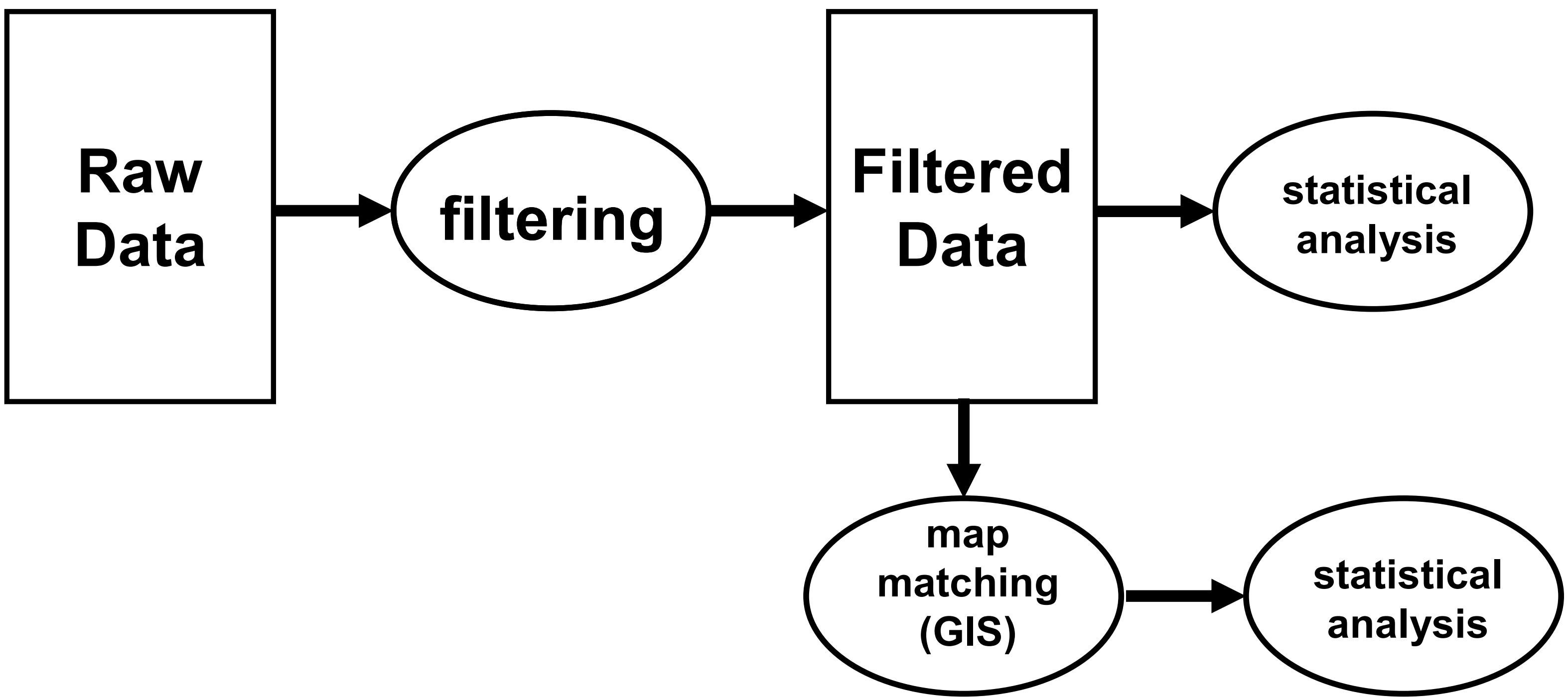
- Traffic Counts and speed measurements
- Department of Transportation Surveys (travel times)
- surveys and trip diaries
- on-board data-loggers:
  - speed measurements and binning
  - speed data logging
  - GPS-Based Data loggers



GPS-Based Vehicle Activity Measurements

- **measure time, position, speed, (and acceleration) for moving objects**
- **GPS measurements are useful for numerous activities:**
  - **vehicle activity analysis**
  - **fleet management (telematics)**
  - **(lane-level) roadway network derivation (Caltrans)**
  - **automated vehicle position control**
- **Typical Measures that can be captured from GPS:**
  - **time/location of vehicle start and stop events**
  - **number of vehicle starts**
  - **trip length statistics (e.g., VMT per trip, VMT per day)**
  - **velocity trajectory characteristics**

Basic GPS Data Processing



Data Processing Steps

- observe HDOP, VDOP parameters, eliminate suspect data
- conversion of UTC time to local time
- trip detection (e.g., trip starts vs. data drop outs)
- trip characterization (determination of trip start location, trip end, trip duration, trip distance, etc.)
- trip route and roadway facility type characterization through map matching
- create database of vehicle activity data sets

Vehicle Activity Database Structure

Dataset title	Date	Number of vehicles	Number of seconds	Acquisition frequency	Parameters
Selev	142 days: 2001/2002/2003/2004	25	1,603,910	Mostly 5Hz with some 1 Hz	Speed, lat.; long.; alt.
......	......	......	......	......	......

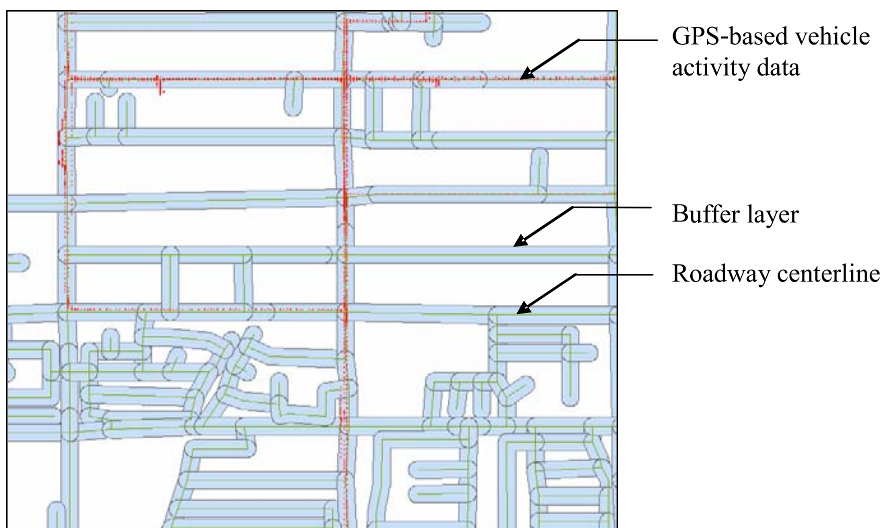
Run	Data	Start time	Vehicle	Duration	Frequency
1	6/9/2004	1:03:54	motorcycle	14,105	1Hz
2	6/8/2004	21:52:17	bus1	15,655	1Hz
......	......	......	......	......	......

Date	UTC time	Latitude	Longitude	RTCM_D	Alt	Speed	......
6/9/2004	1:03:54	31.17111	121.4259	0	-18	0.124	......
6/9/2004	1:03:55	31.17135	121.4257	0	22.3	0.062	......
......	......	......	......	......	......	......	......

Roadway Facility Type Characterization

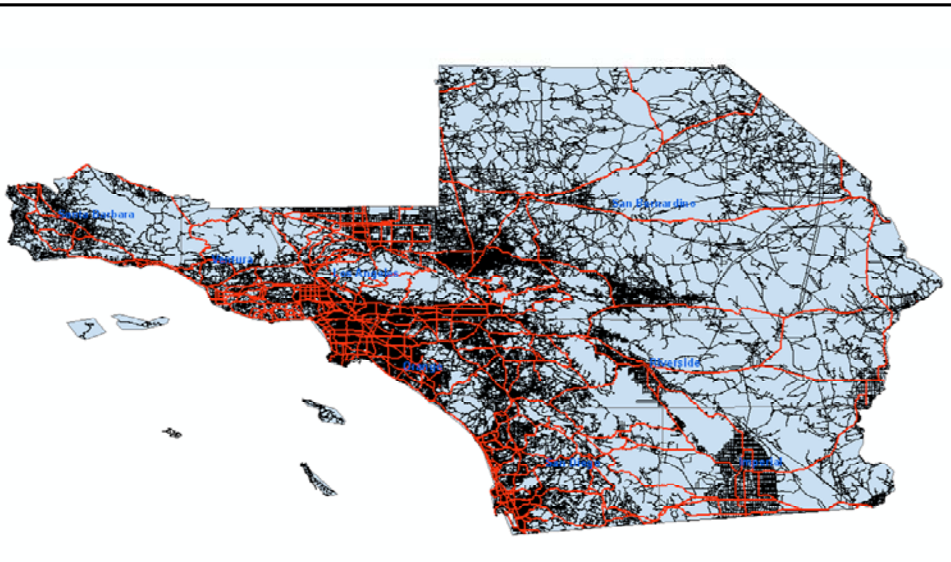
Map matching

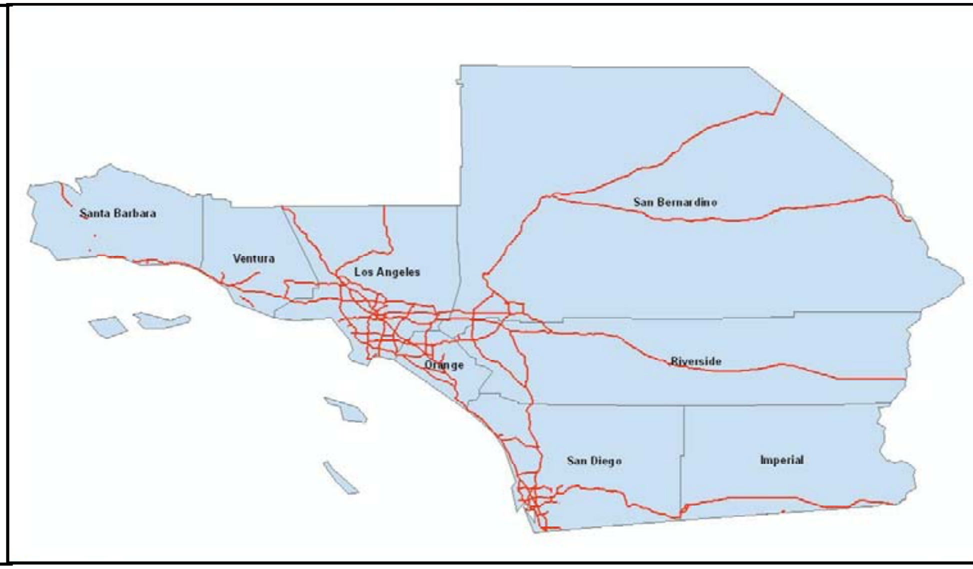
House_ID	Vehicle	GPS_ID	Latitude	Longitude	Speed	Time	Flag	Chain_SeqNo	Trip_SeqN	RoadType
2009745	1	1	32.78063	-115.5744	3.33	10/1/2001 6:51:19 PM	5	1	1	F
2009745	1	2	32.78062	-115.5743	7.87	10/1/2001 6:51:22 PM	0	1	1	F
…	…	…	…	…	…	…	…	…	…	…
2009745	1	4	32.78049	-115.5743	16.7	10/1/2001 6:51:24 PM	0	1	1	R
2009745	1	5	32.7804	-115.5743	19.54	10/1/2001 6:51:25 PM	0	1	1	R
…	…	…	…	…	…	…	…	…	…	…
2009745	1	7	32.78023	-115.5743	23.35	10/1/2001 6:51:27 PM	0	1	1	A
2009745	1	8	32.78014	-115.5743	24.92	10/1/2001 6:51:28 PM	0	1	1	A



GIS-based Roadway Network Data

- **TIGER/Line 2000 Roadway Data Set**
- **Advanced Roadway Network Datasets: NAVTEQ, etc.**





Specific Vehicle Activity Data Sets:

1. **Caltrans 2001 statewide household travel survey program (272 households)**

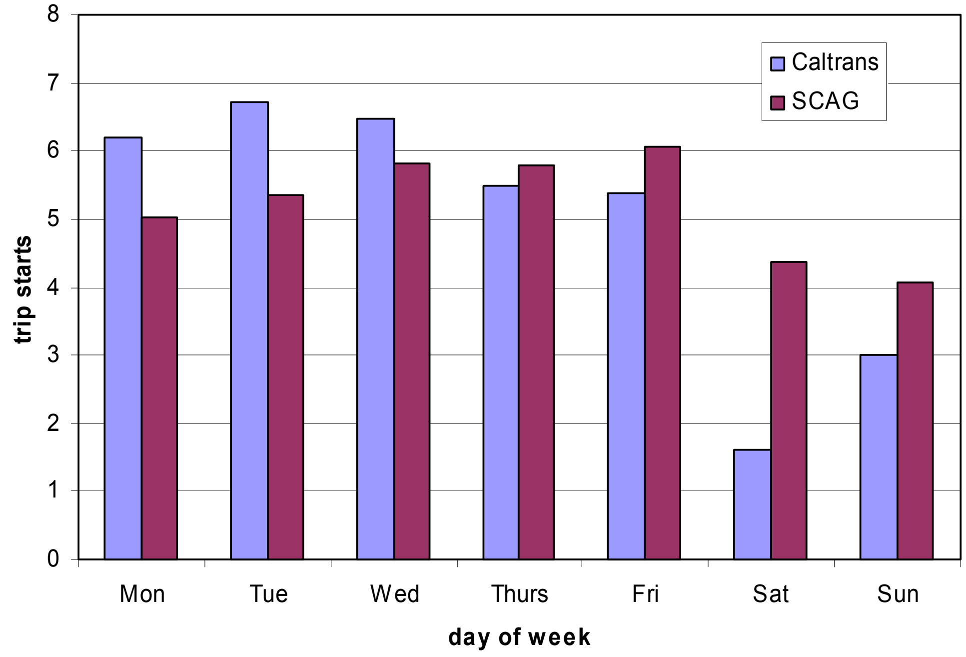
2. **SCAG's 2001 post-census travel survey (467 households)**

Statistics	CALTRANS	SCAG
Households	272	467
Total Cars	414	626
Cars/Household	1.52	1.34
Total days	283	163
Total Trips	2382	6583
Total miles of Trips	16235	28000

Global Statistics of CALTRANS and SCAG datasets

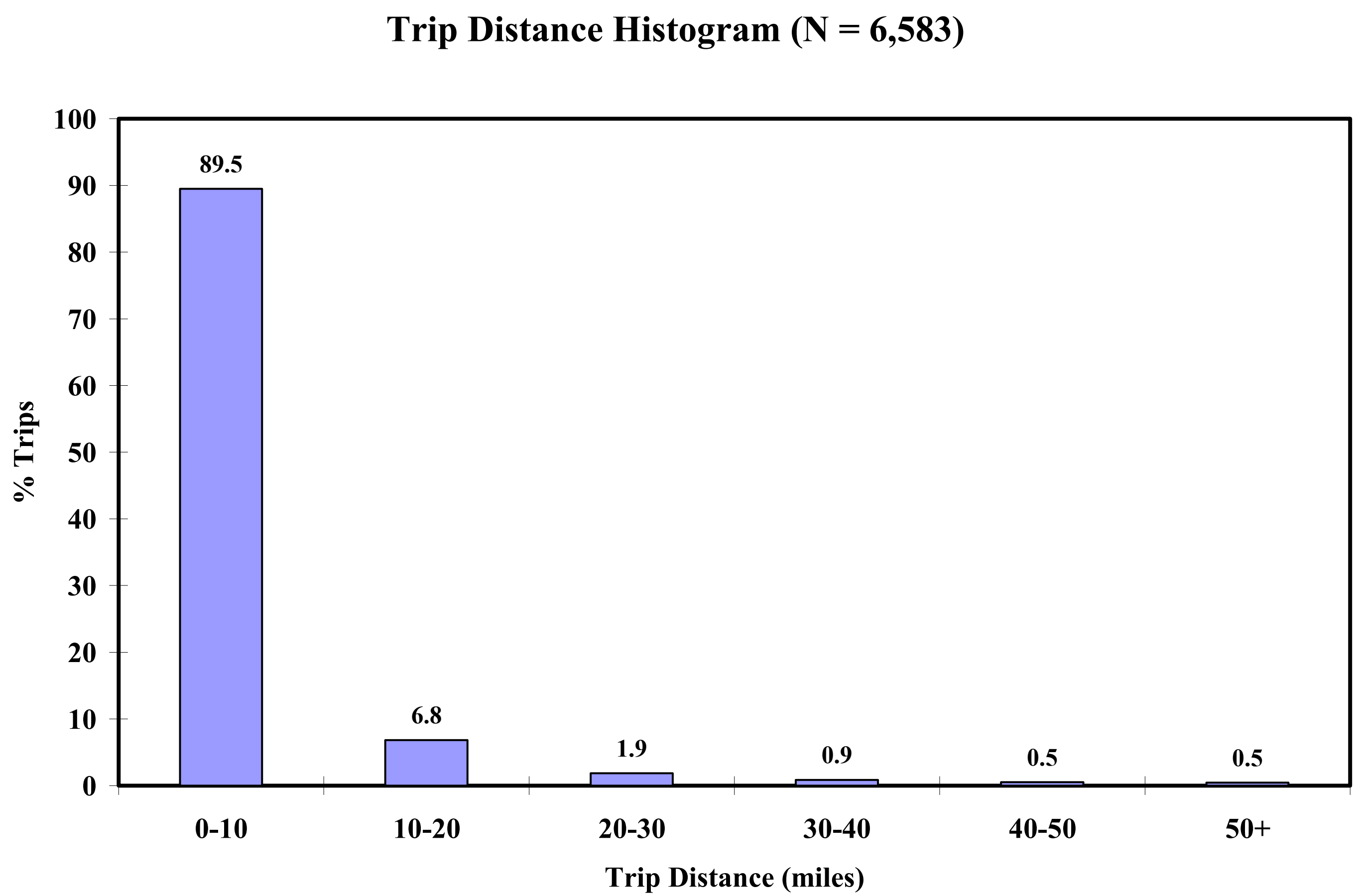
Statistics	CALTRANS	SCAG
Average distance per trip (miles)	6.8	4.25
Min distance per trip (miles)	0.1	0
Max distance per trip (miles)	134	146.14
Mean trips per day per household	8.55	6.82
Min. trips per day per household	1	1
Max trips per day per household	36	52
Mean trips per day per vehicle	4.78	5.205
Min trips per day per vehicle	1	1
Max trips per day per vehicle	27	37
Average speed per trip (mph)	31.48	25.3
Average time per trip (min)	8.12	12.1

Day of Week Differences

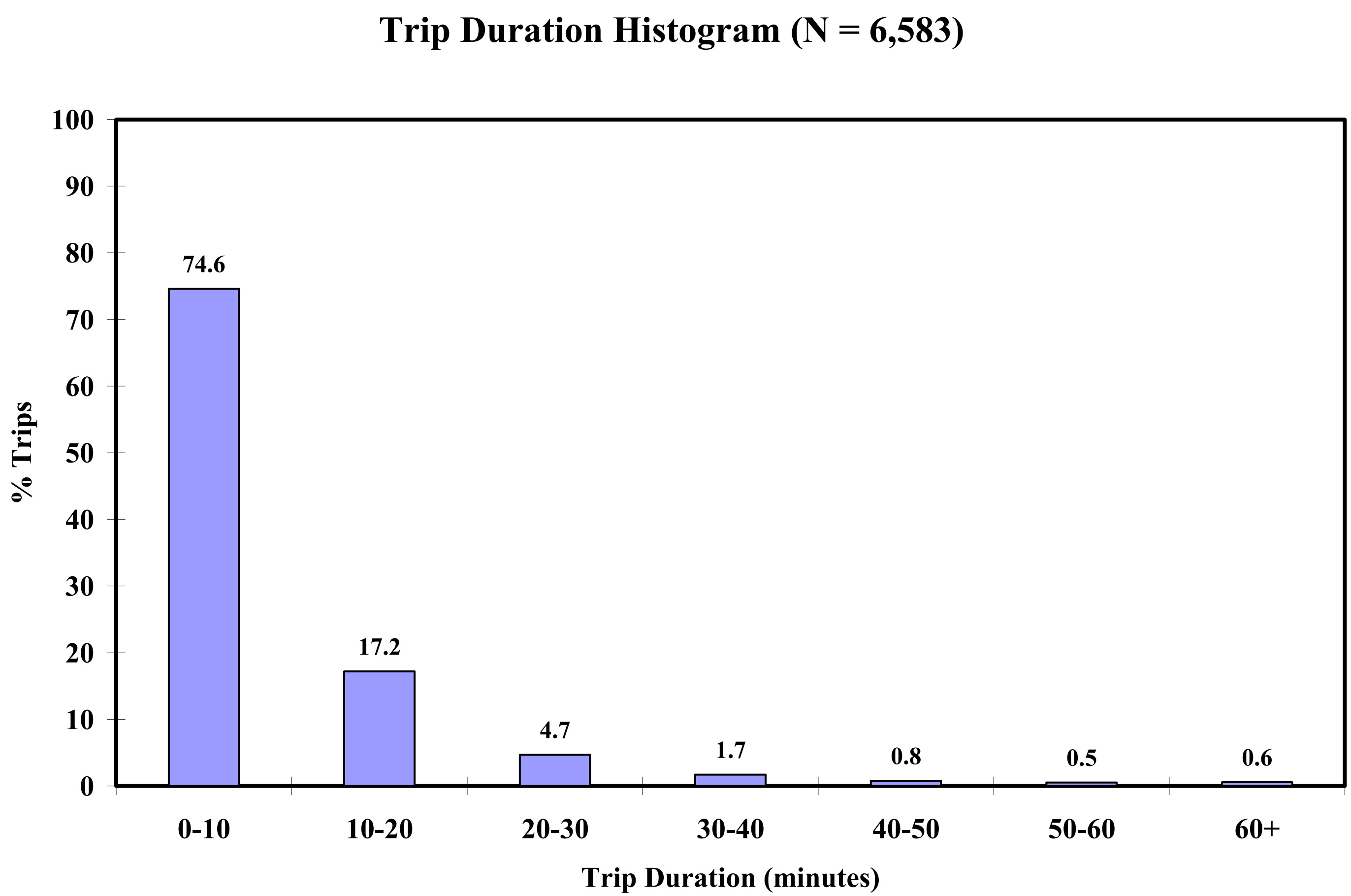


Day	No. of trips		No. of vehicle days		Avg. trips per day per vehicle	
	CALTRANS	SCAG	CALTRANS	SCAG	CALTRANS	SCAG
Mon	441	840	71	167	6.21	5.02
Tue	612	1068	91	200	6.725	5.34
Wed	616	1531	95	263	6.484	5.82
Thurs	515	1310	94	226	5.479	5.79
Fri	382	1241	71	205	5.38	6.05
Sat	8	367	5	84	1.6	4.36
Sun	3	301	1	74	3.0	4.06

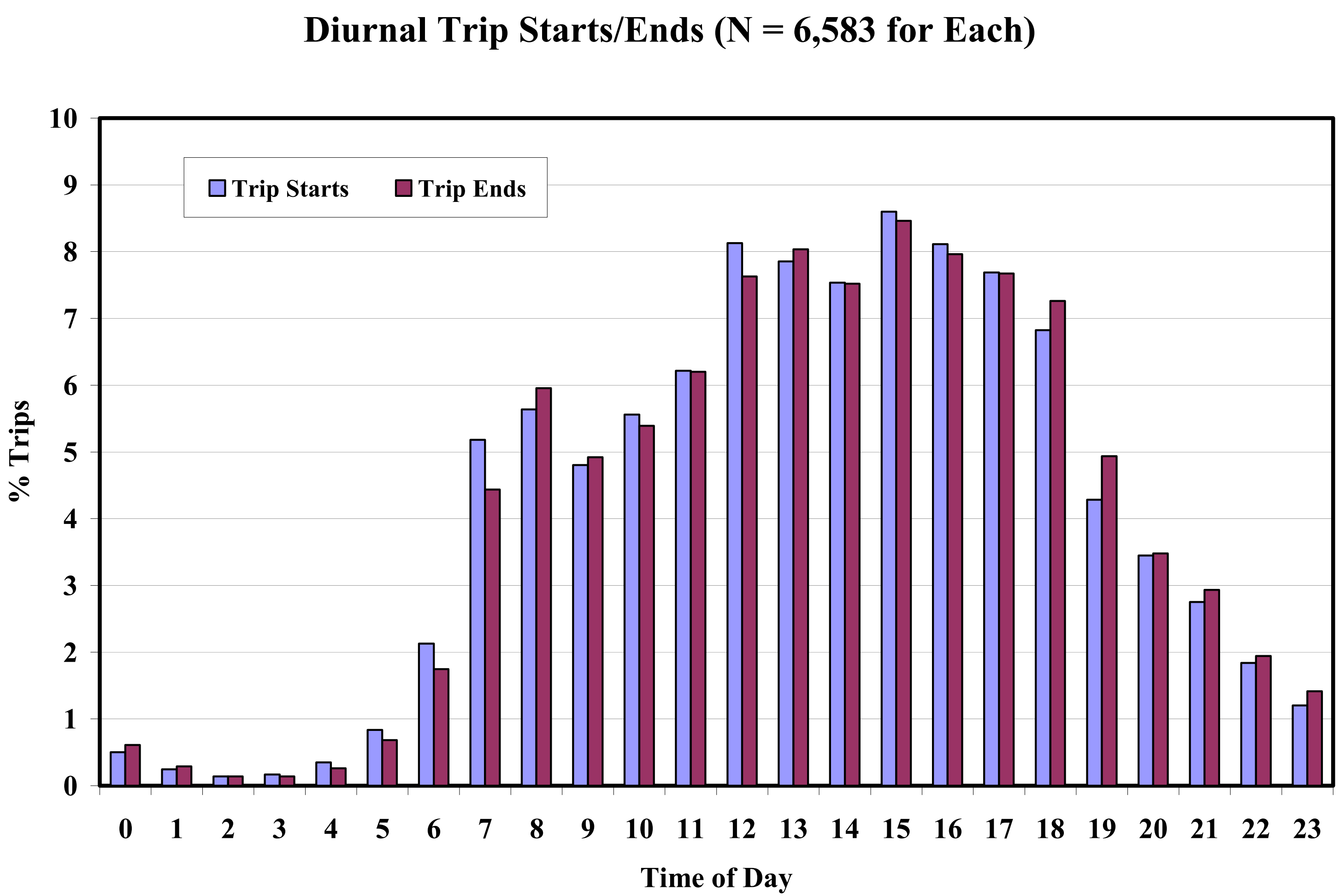
Trip Distance Analysis



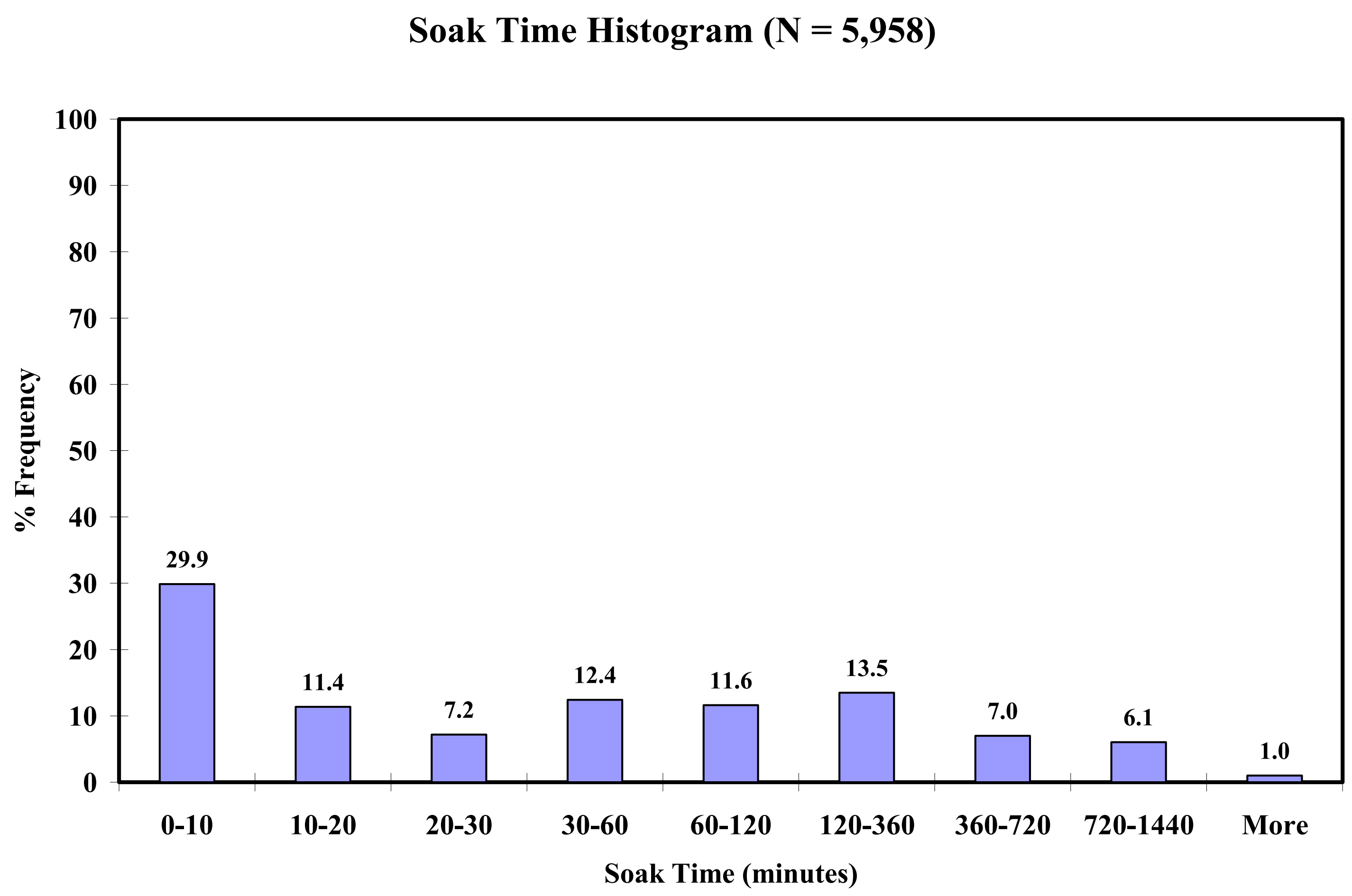
Trip Duration Analysis



Diurnal Pattern of Trip Starts and Ends



Soak Time Analysis



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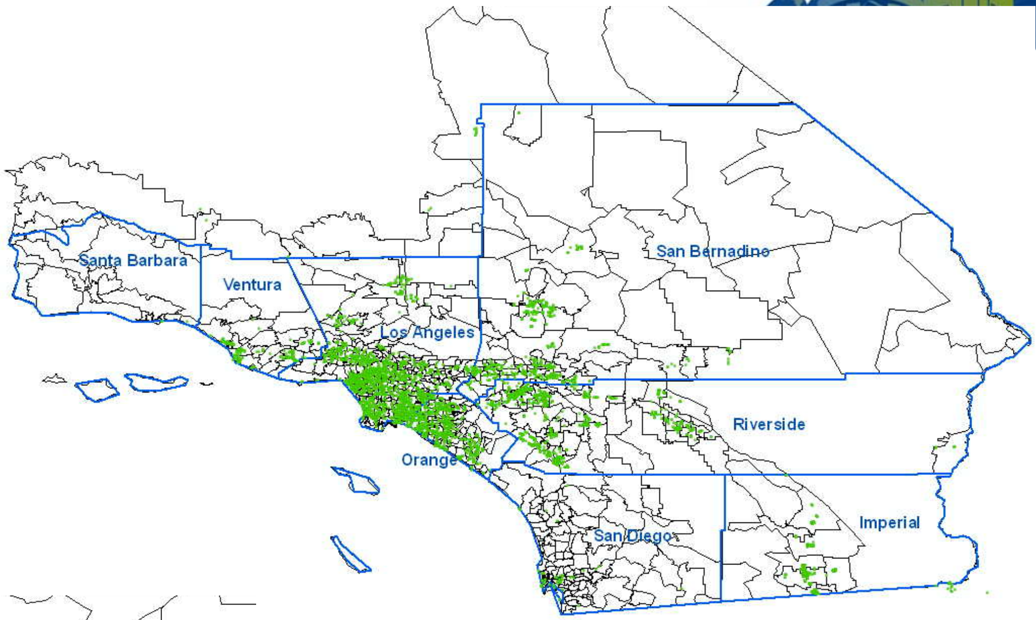
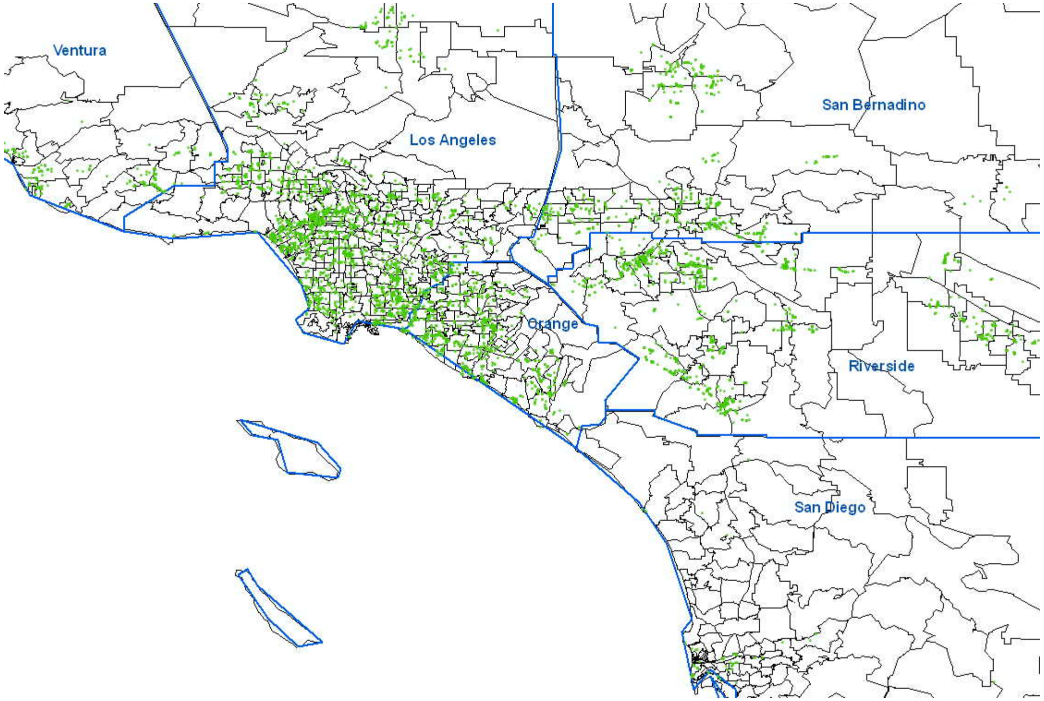
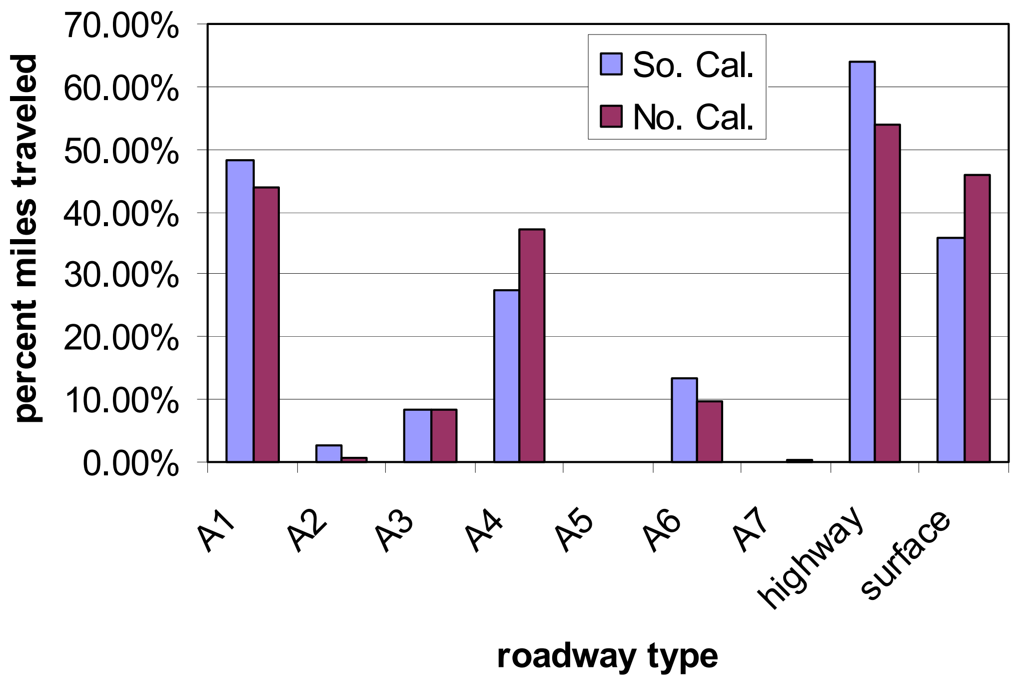
Trip Start Locations





Roadway Facility Type Analysis:

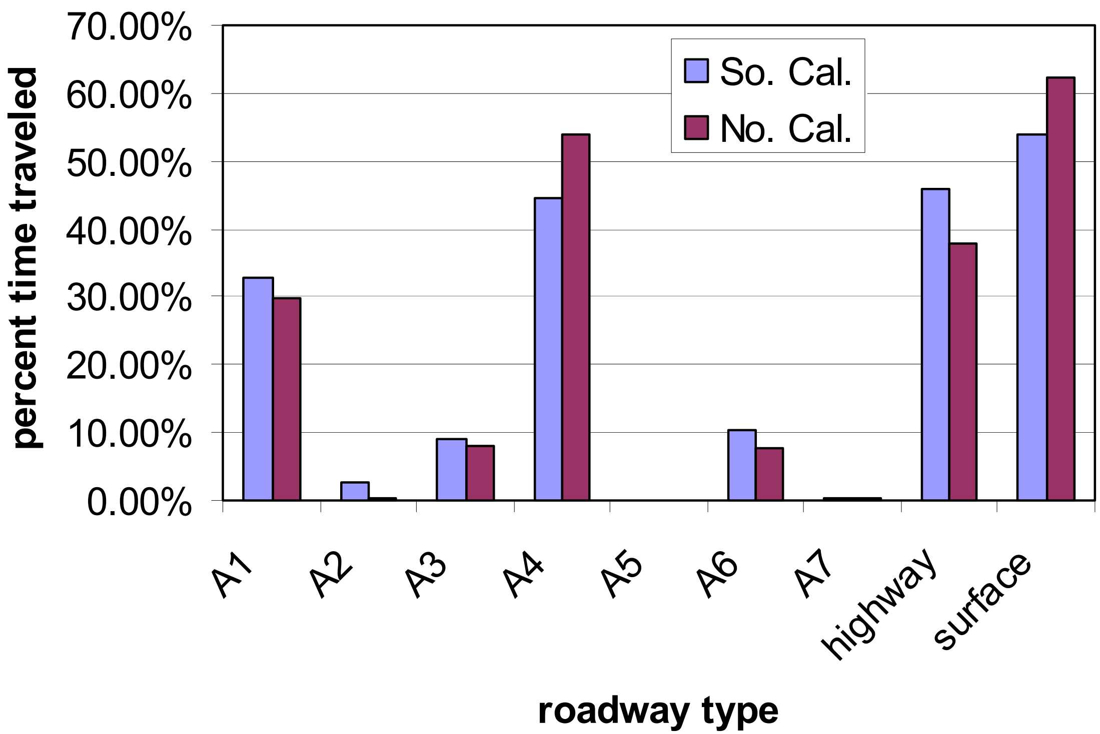
Percent of Travel by roadway type:



		Facility Type						
	Total Distance (mi)	A1	A2	A3	A4	A5	A6	A7
So. Cal.	6,169	2,979	158	513	1,689	2	819	9
No. Cal.	9,301	4,078	54	776	3,468	1	900	25
	Total Distance (%)	A1	A2	A3	A4	A5	A6	A7
So. Cal.	100 %	48.29%	2.55%	8.31%	27.37%	0.03%	13.28%	0.13%
No. Cal.	100 %	43.84%	0.57%	8.33%	37.28%	0.00%	9.67%	0.26%

Roadway Facility Type Analysis:

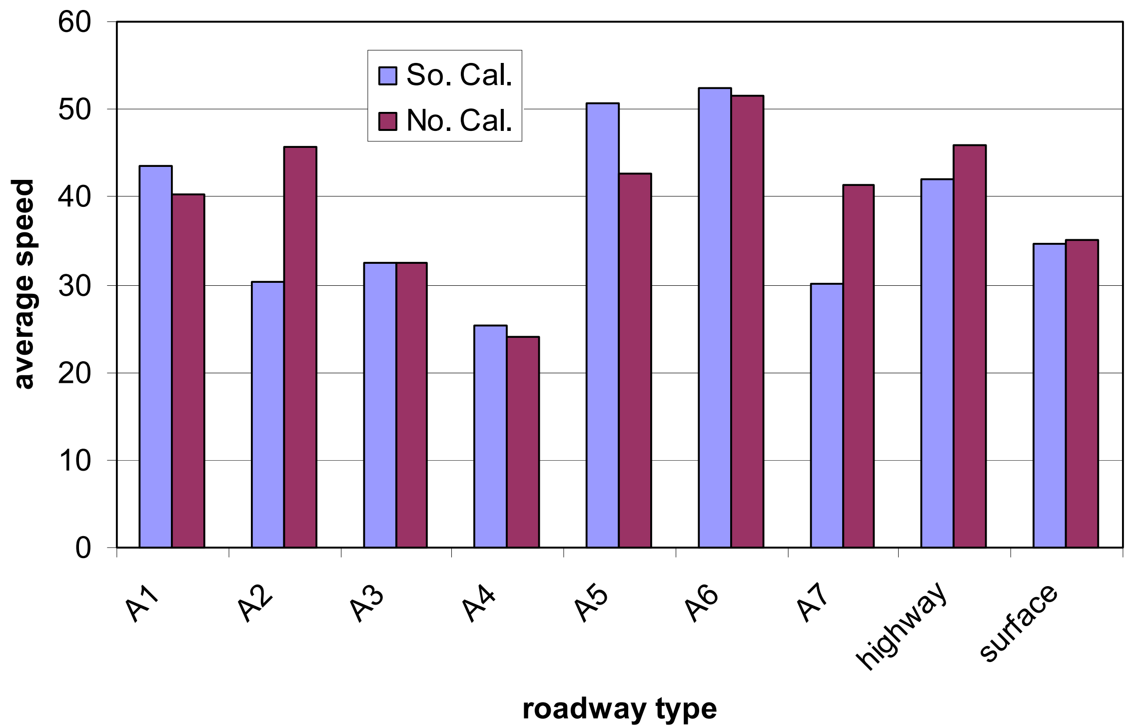
Trip Duration by roadway type:



	Total Time (s)	Facility Type						
		A1	A2	A3	A4	A5	A6	A7
So. Cal.	597,344	197,028	15,323	54,693	266,242	185	62,178	1,695
No. Cal.	918,388	273,922	3,548	73,911	494,513	81	70,046	2,367
	Total Time (%)	A1	A2	A3	A4	A5	A6	A7
So. Cal.	100%	32.98%	2.56%	9.15%	44.57%	0.03%	10.40%	0.28%
No. Cal.	100%	29.82%	0.38%	8.04%	53.84%	0.008%	7.62%	0.25%

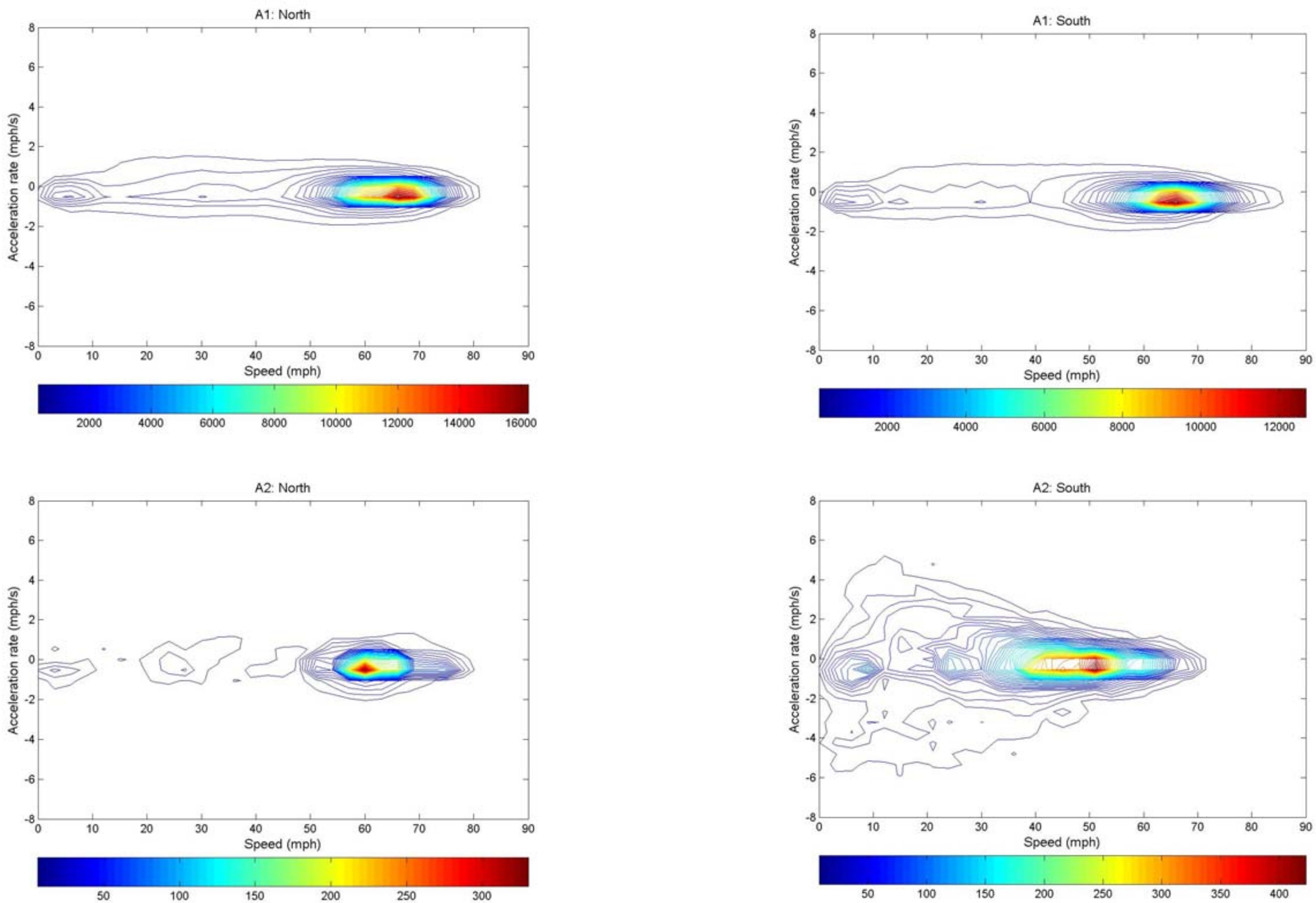
Roadway Facility Type Analysis:

Average Vehicle Speed by roadway type:



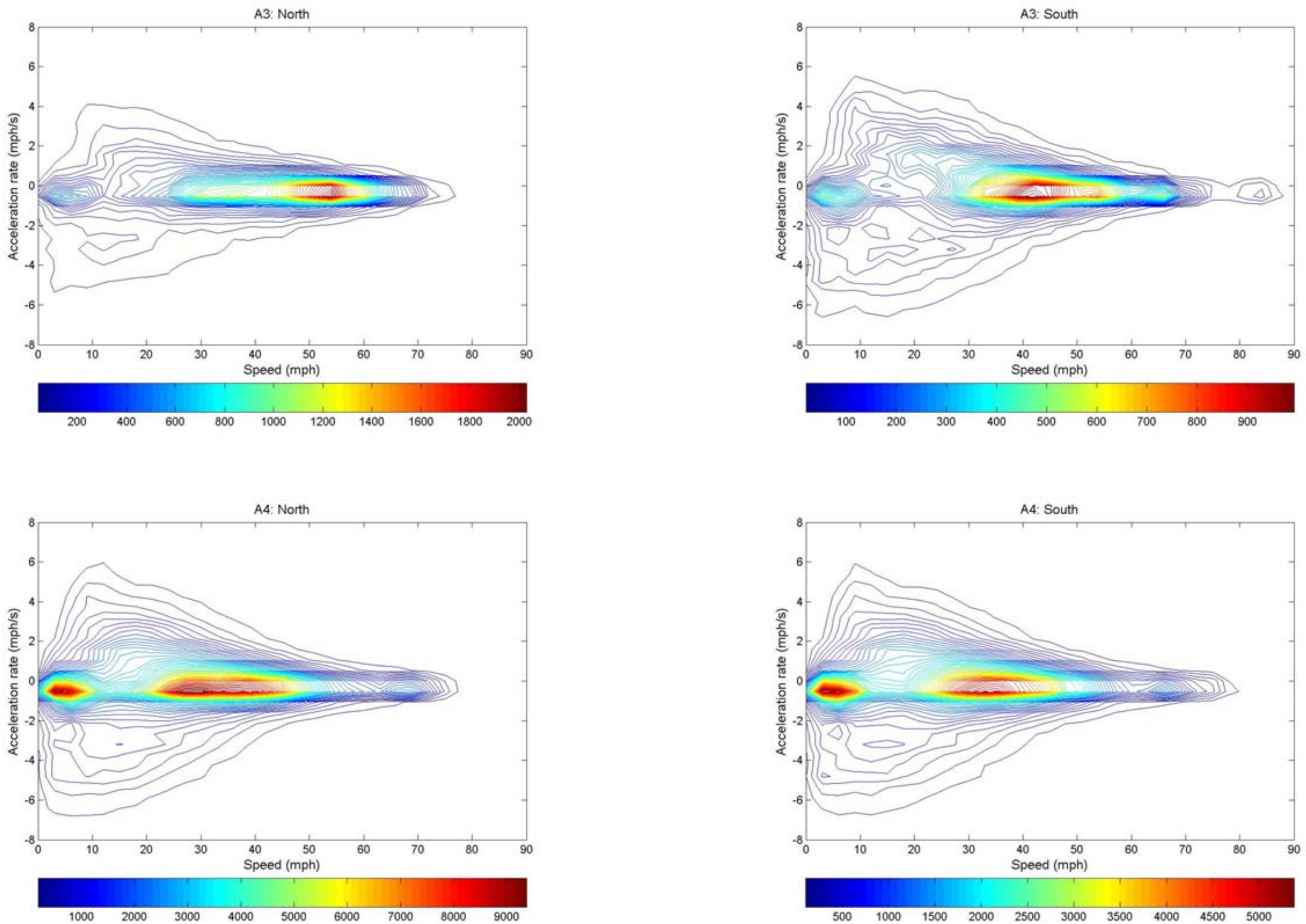
Roadway Facility Type Analysis:

Speed/Acceleration Histograms by roadway type:



Roadway Facility Type Analysis:

Speed/Acceleration Histograms by roadway type:



Findings:

- The average distance per trip was relatively short (4 to 6 miles), with trips slightly shorter in Southern California compared to Northern California
- The number of trips per day per vehicle was approximately 5 for both data sets
- The average trip duration for the datasets was around 8 to 12 minutes, slightly longer in Southern California
- The household-based datasets showed that there were little differences of travel from Monday – Friday, however on Saturdays and Sundays, the trips were significantly reduced
- An analysis of the diurnal trip patterns for the two household datasets did not show a typical commute pattern with a distinctive AM morning peak and a PM afternoon peak. Instead, most activity peaked during the early afternoon in a single mode distribution
- An analysis of the soak time periods of the vehicles showed a two-mode distribution, where one peak occurring for 10 minutes of less (30% of the distribution and the other less pronounced peak occurring in the range of 120 – 360 minutes (13.5% of distribution).

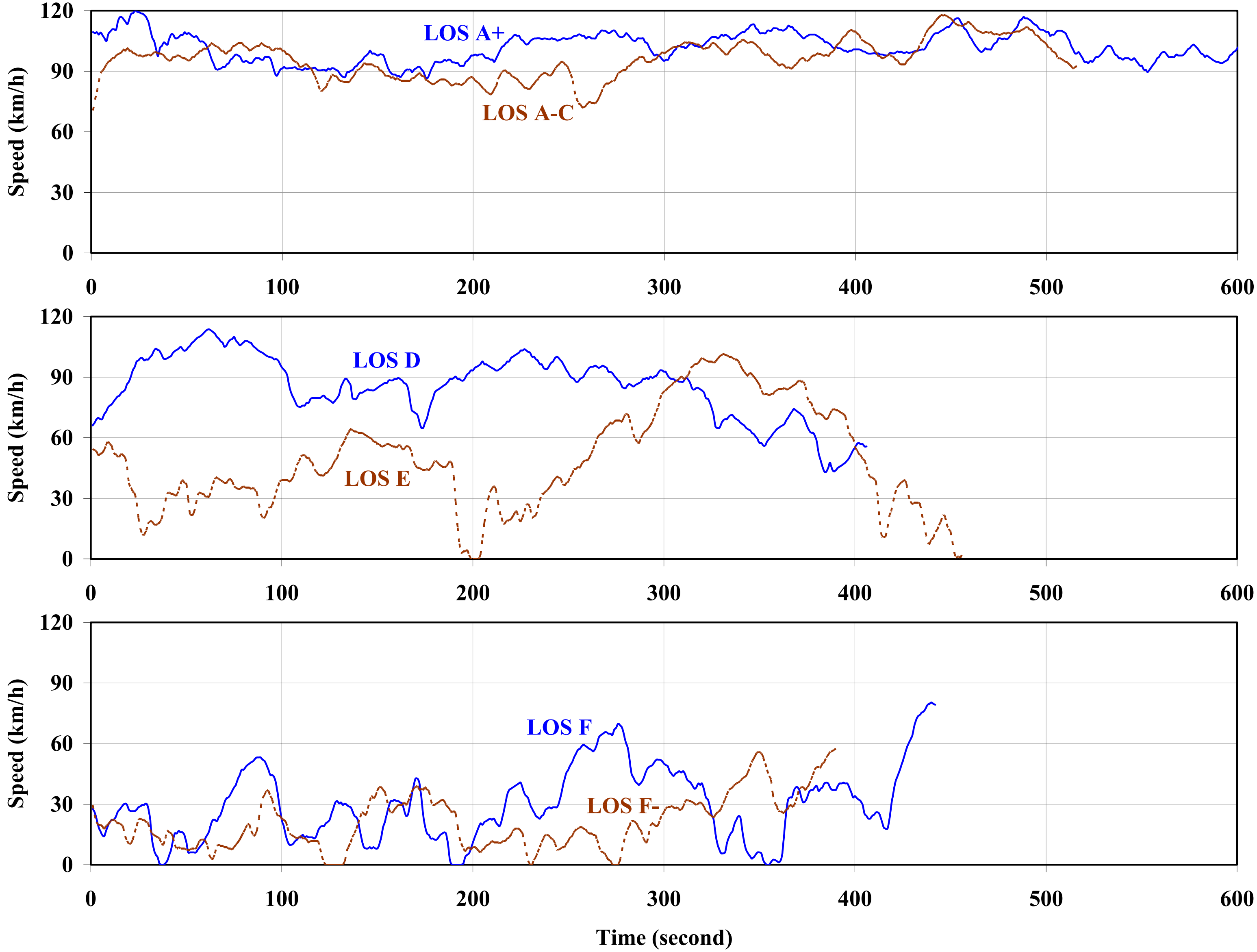
Findings (continued):

- After disaggregating the dataset by roadway facility type, it was seen that approximately 55% - 65% of VMT occurs on freeways, and the remaining 35% - 45% occurs on surface streets
- In contrast, trip time spent on highways is approximately 35% - 45% while for surface streets, it was approximately 55% - 65%
- Average speeds were significantly higher on highways (as expected) compared to surface streets. Northern California had slightly higher speeds overall
- A number of speed-acceleration parameters and speed-acceleration frequency distributions were evaluated across the vehicle activity databases; as expected, surface streets displayed greater speed-acceleration fluctuation compared to highway travel

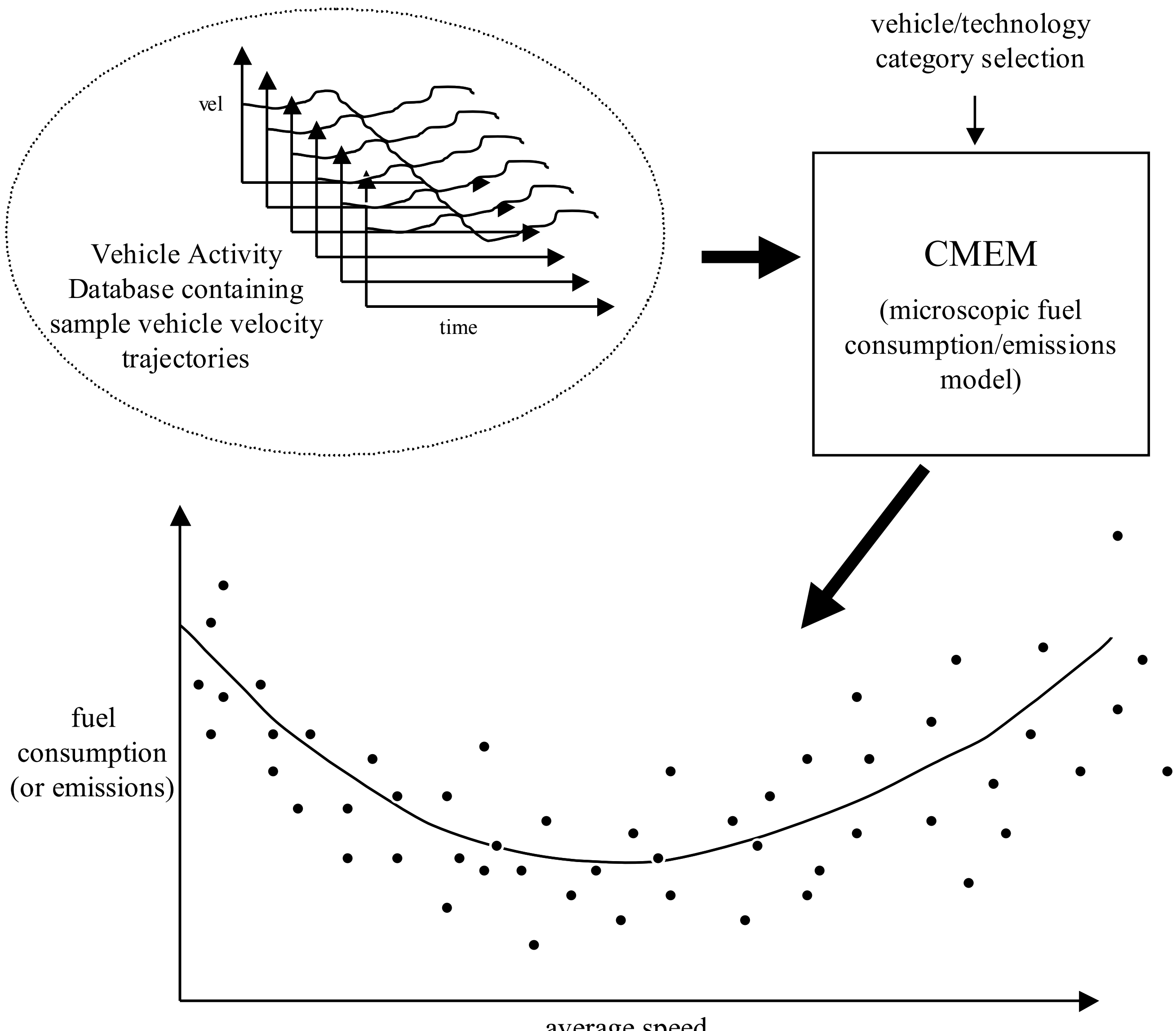
Recommendations

- Create *roadway facility specific emission factors*:
  - take driving snippets from the corresponding facilities and run them through a modal emissions model (weighted for a specific fleet)
  - link-based emissions inventory would result where activity is measured on a link-by-link basis then multiplied by the corresponding emissions factor.
- and/or create representative “driving cycles” that correspond to specific roadway facility types: These driving cycles could also be used to create facility-specific emission factors through a real-world test program.
- Carryout additional vehicle activity studies:
  - low cost
  - processing techniques are now refined
  - truck travel pattern study?

Congestion: Levels of Service (LOS) on today's highways

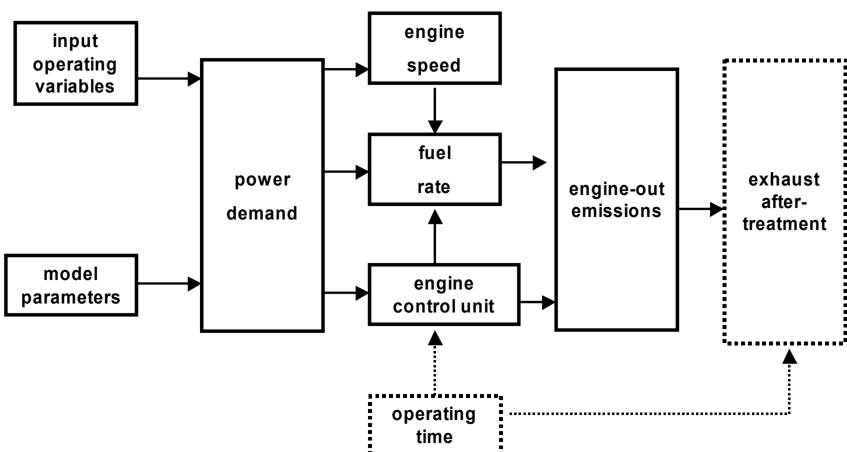


General Methodology



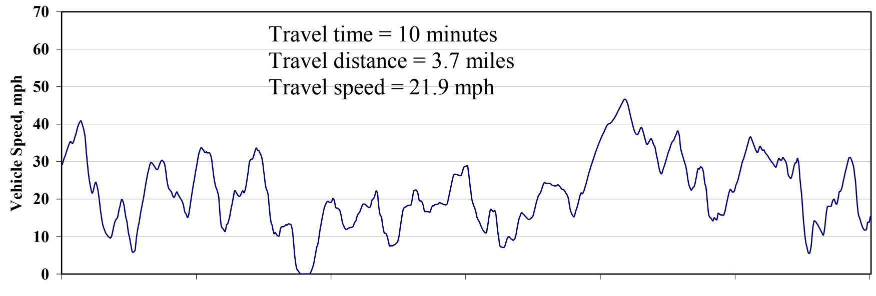
Background: Comprehensive Modal Emissions Model (CMEM):

- **predicts second-by-second emissions and fuel consumption given arbitrary vehicle activity (speed, grade)**
- **28 vehicle/technology categories including light- and heavy-duty vehicles**
- **can be used with measured vehicle activity data (e.g., velocity vs. time from GPS)**
- **is easily integrated with transportation simulation models**



$$tailpipe\,emissions = FR \bullet \left(\frac{g_{emissions}}{g_{fuel}}\right) \bullet after\,treatment\,pass\,fraction$$

Category #	Vehicle Technology Category
	Normal Emitting Cars
1	No Catalyst
2	2-way Catalyst
3	3-way Catalyst, Carbureted
4	3-way Catalyst, FI, >50K miles, low power/weight
5	3-way Catalyst, FI, >50K miles, high power/weight
6	3-way Catalyst, FI, <50K miles, low power/weight
7	3-way Catalyst, FI, <50K miles, high power/weight
8	Tier 1, >50K miles, low power/weight
9	Tier 1, >50K miles, high power/weight
10	Tier 1, <50K miles, low power/weight
11	Tier 1, <50K miles, high power/weight
24	Tier 1, >100K miles
50	LEV PC
51	ULEV PC
52	PZEV
	Normal Emitting Trucks
12	Pre-1979 (<=8500 GVW)
13	1979 to 1983 (<=8500 GVW)
14	1984 to 1987 (<=8500 GVW)
15	1988 to 1993, <=3750 LVW
16	1988 to 1993, >3750 LVW
17	Tier 1 LDT2/3 (3751-5750 LVW or Alt. LVW)
18	Tier 1 LDT4 (6001-8500 GVW, >5750 Alt. LVW)
25	Gasoline-powered, LDT (> 8500 GVW)
40	Diesel-powered, LDT (> 8500 GVW)
41	Pre 1991, 2-stroke HDDT
42	Pre 1991, 4-stroke HDDT
43	1991 to 1993, 4-stroke, Mech. FI HDDT
44	1991 to 1993, 4-stroke, Elect. FI HDDT
45	1994 to 1997, 4-stroke, Elect. FI HDDT
46	1998, 4-stroke, Elect. FI HDDT
47	1999 to 2002, 4-stroke, Elect. FI HDDT
	High Emitting Light Duty Vehicles
19	Runs lean
20	Runs rich
21	Misfire
22	Bad catalyst
23	Runs very rich

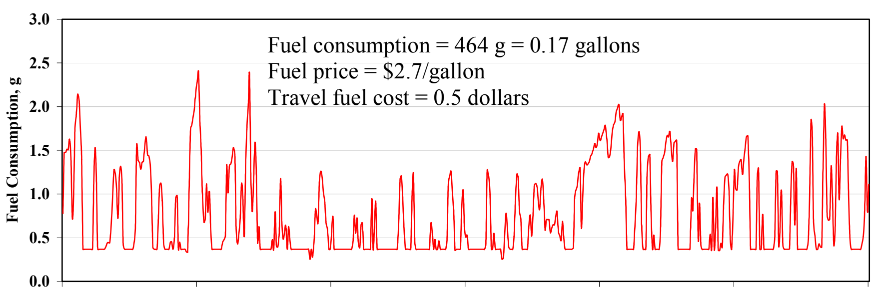


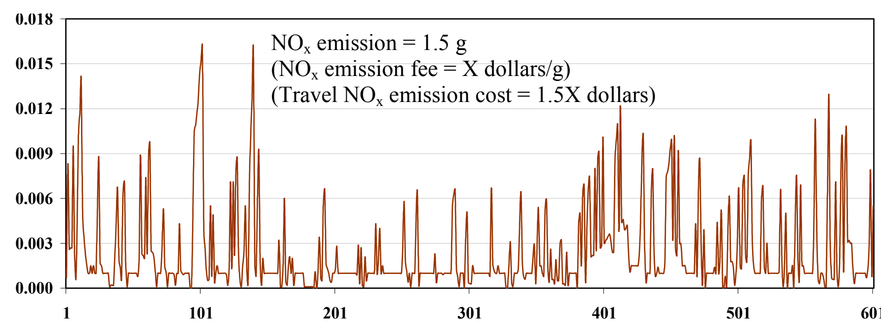
vehicle activity

(velocity trajectory and grade if available)

CMEM

calibration parameters

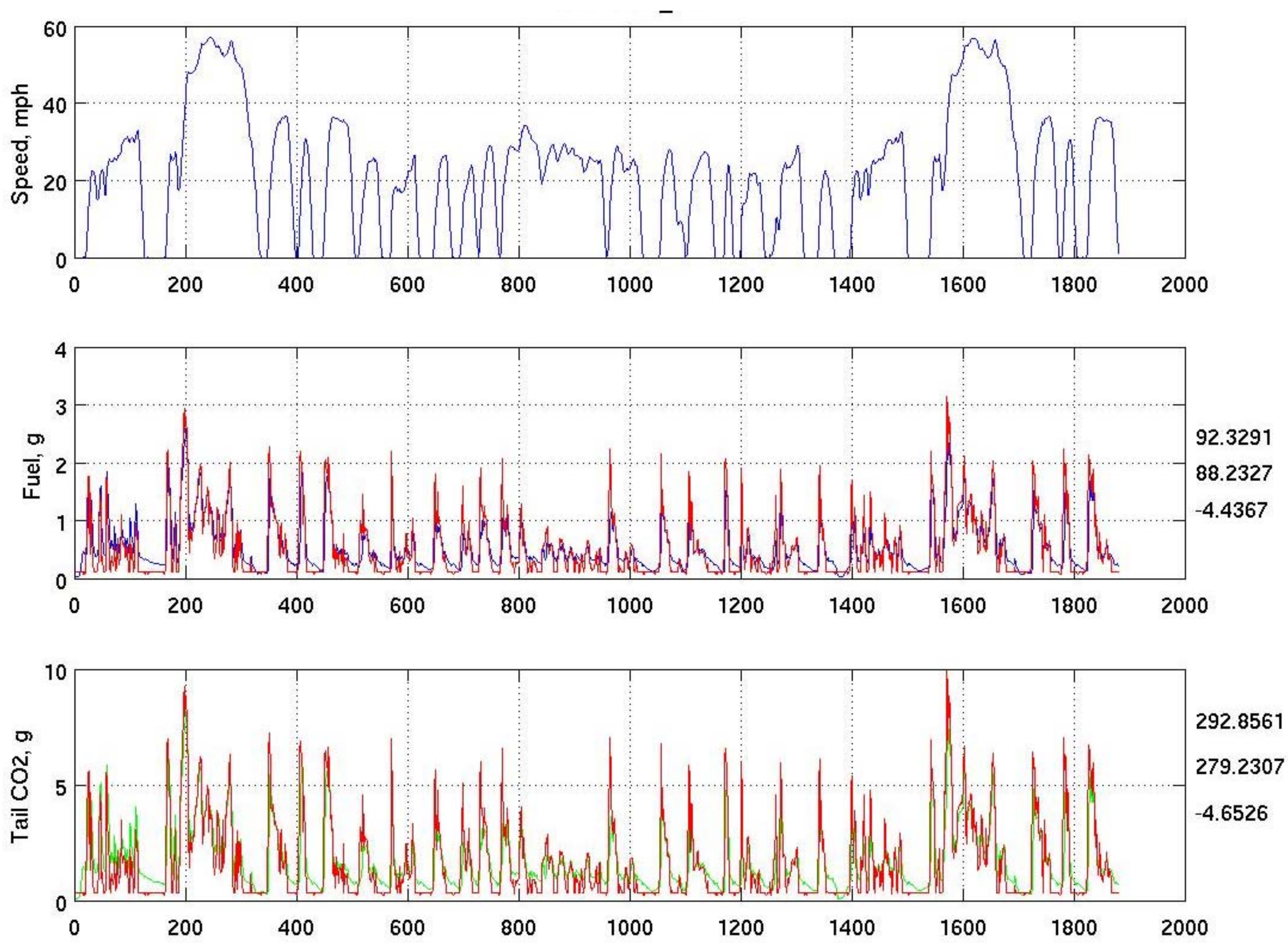




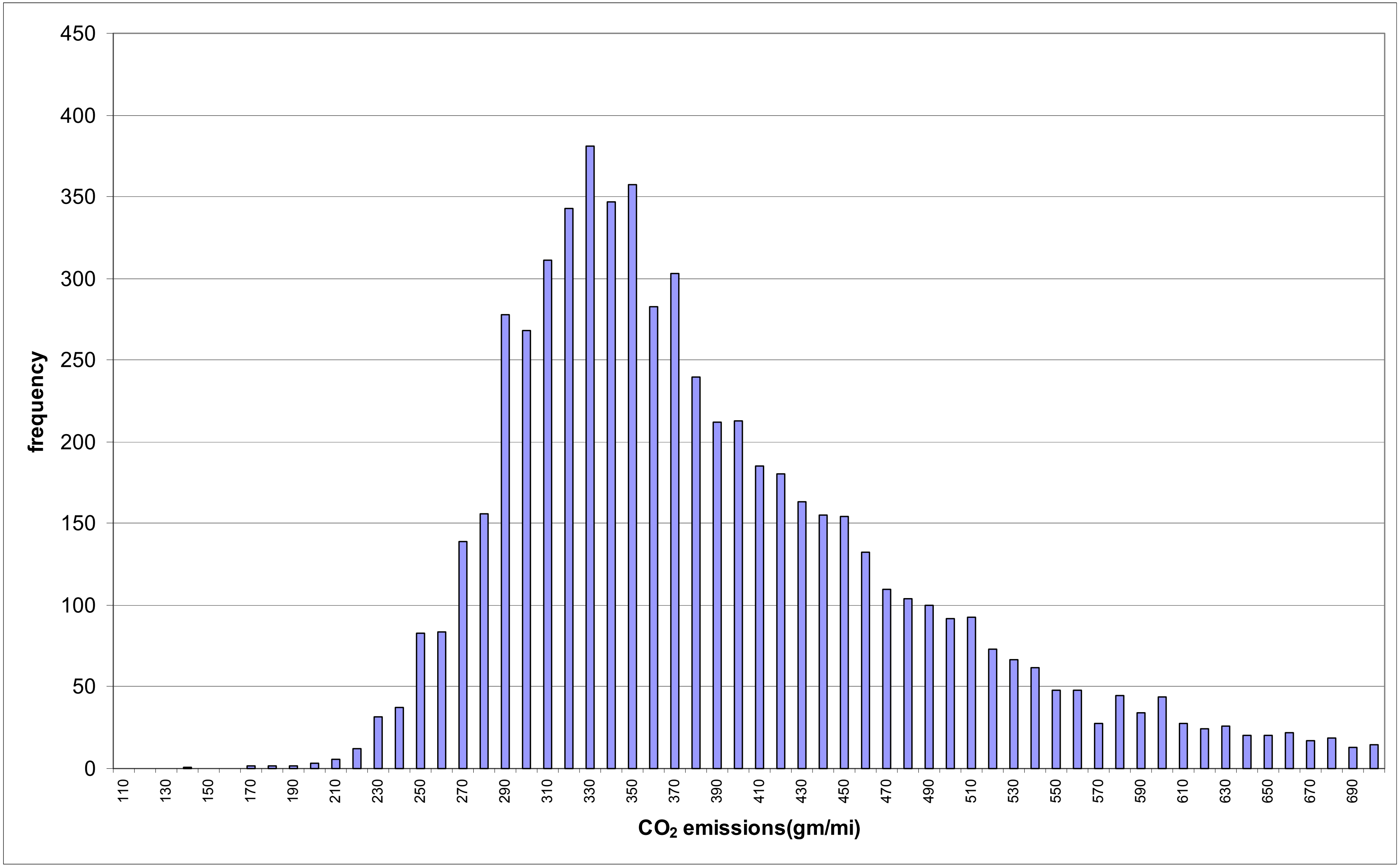
fuel consumption

emissions

CO_2 emissions modeled vs. measured validation



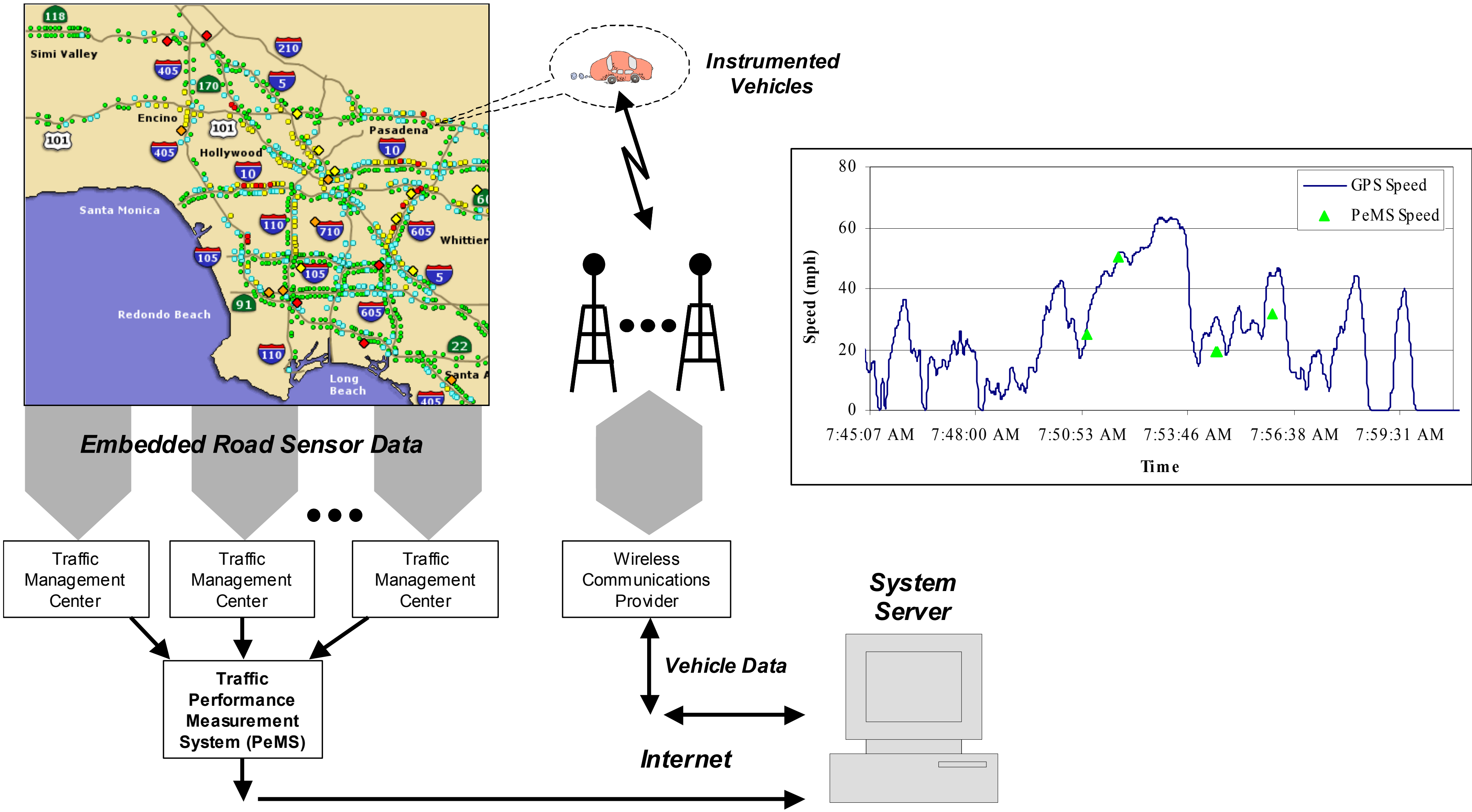
CO_2 emissions histogram for a representative database of trip in Southern California



Real-Time Traffic Data

- real-time traffic density, speed, and flow is become more readily available
- Example: California Traffic Performance Measurement System (PeMS)
- Real-Time data can be used measure congestion

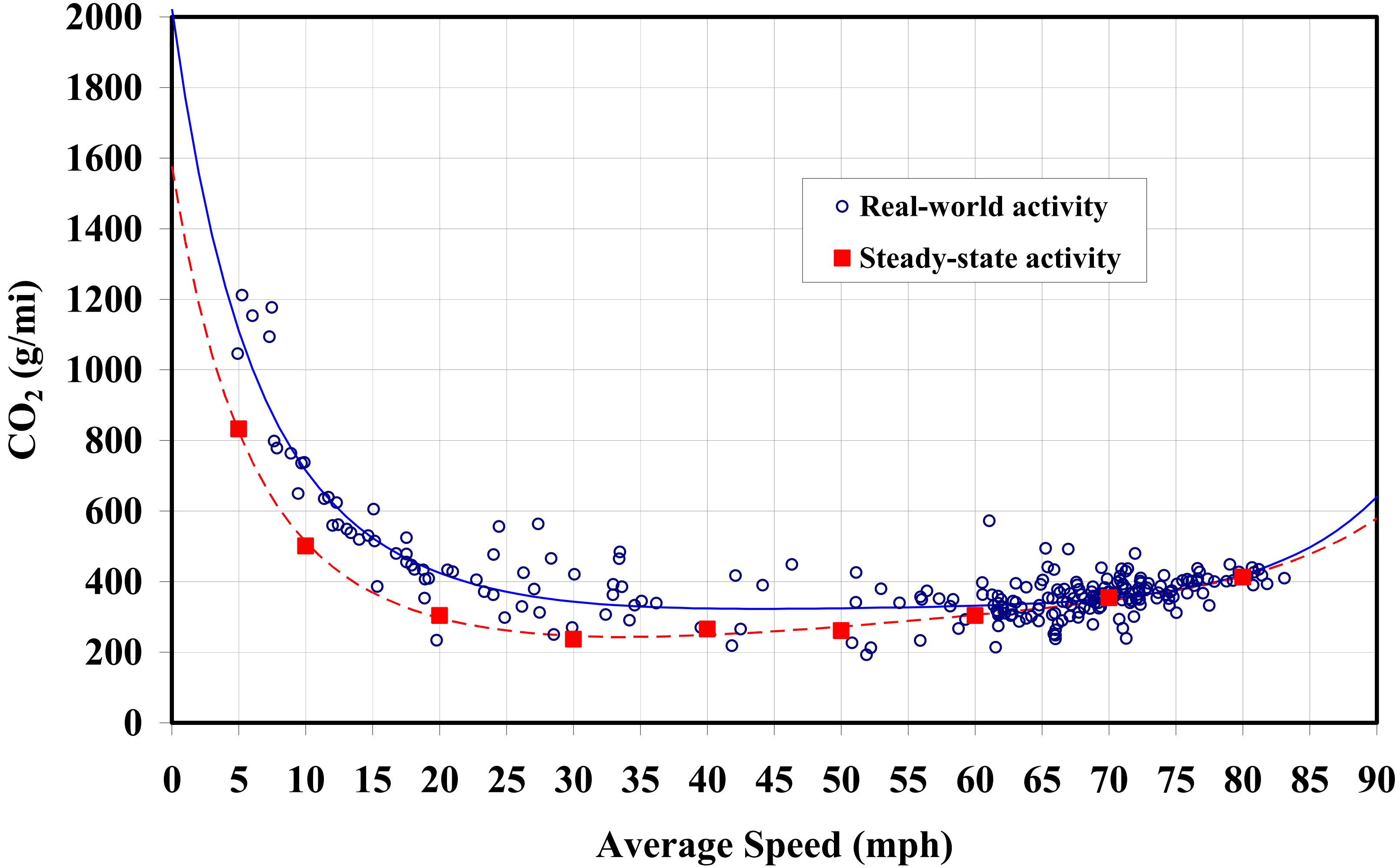
Simultaneous Data Collection of Traffic Data and Vehicle Velocity Measurements



CO_2 as a function of Average *Traffic* Speed

$$\ln(y) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4$$

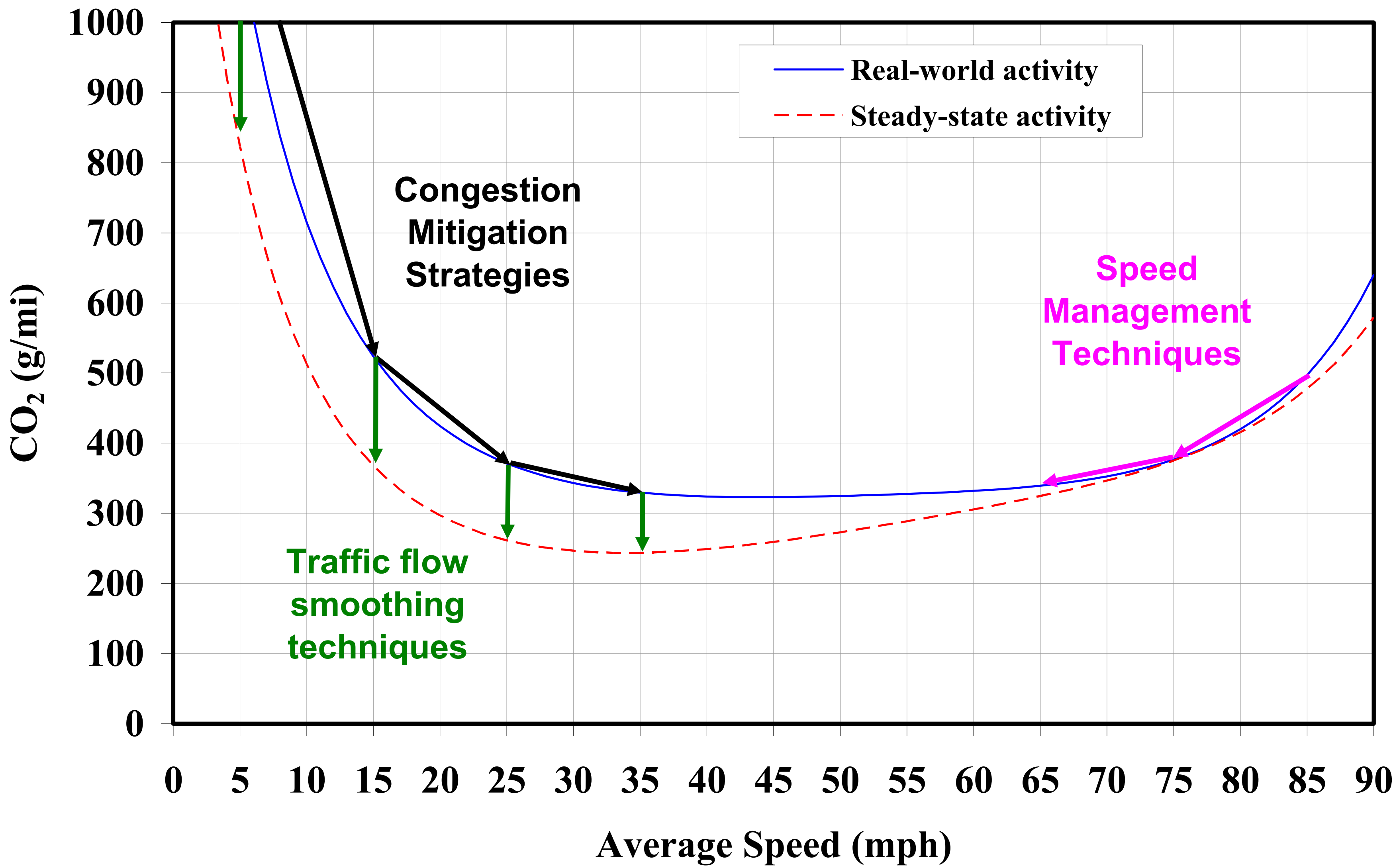
	Real-World	Steady-State
N	241	9
R^2	0.668	0.992
b_0	7.613534994965560	7.362867270508520
b_1	- 0.138565467462594	- 0.149814315838651
b_2	0.003915102063854	0.004214810510200
b_3	- 0.000049451361017	- 0.000049253951464
b_4	0.000000238630156	0.000000217166574



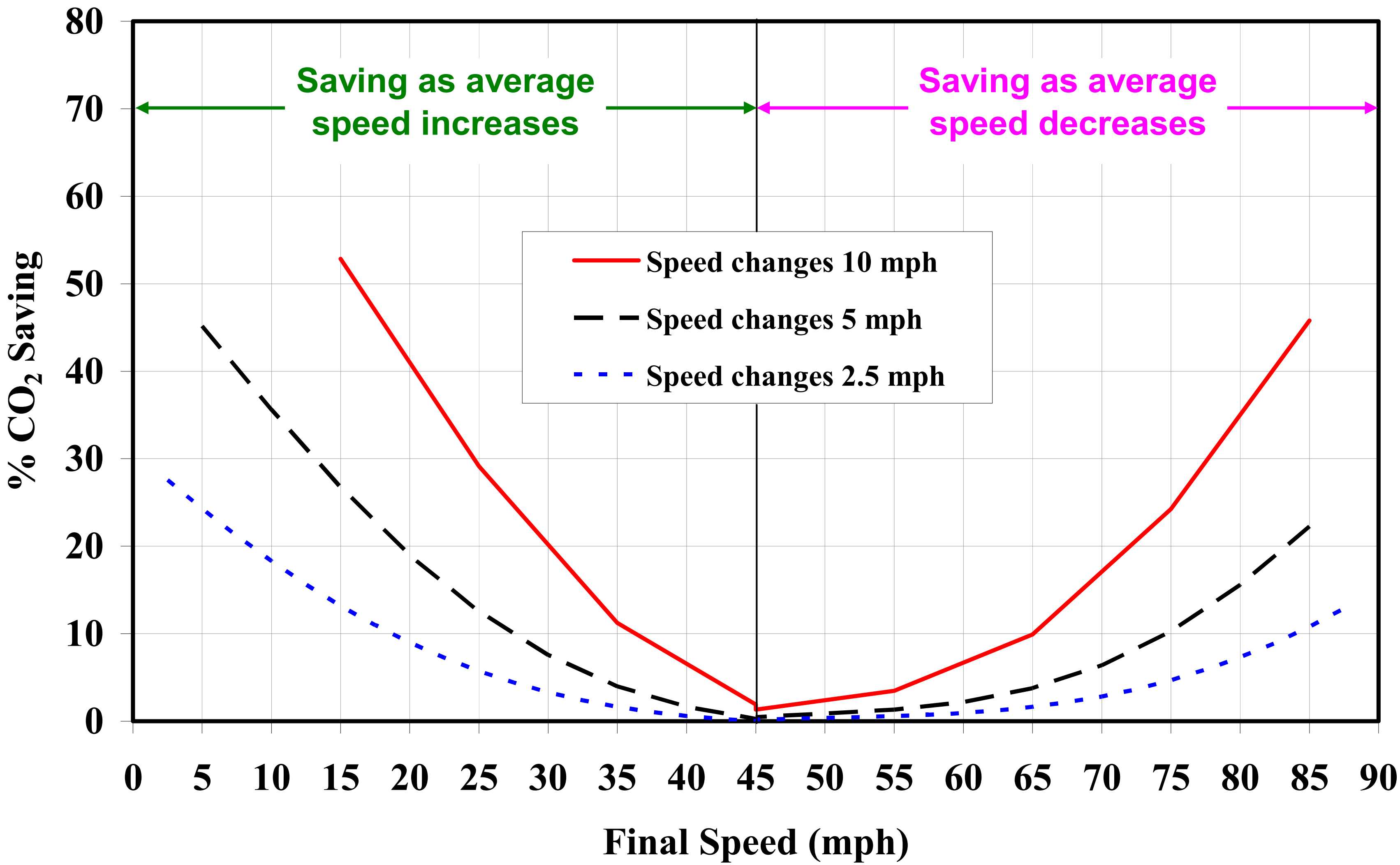
Congestion-Based Fuel Consumption and Emissions

- **Anytime congestion brings average vehicle speed below 45 mph (for a freeway scenario), there is a net negative fuel consumption and emissions impact; vehicles are spending more time on the road and as a result fuel economy is worse and total emissions is greater**
- **If congestion brings average speed down from a freeflow speed of around 65 mph to a slower 45 - 50 mph, then congestion is actually helping improve fuel consumption and emissions**
- **If relieving the congestion such that the average traffic speed increases back to the freeflow state, fuel consumption and emissions increases**
- **If the real-world stop-and-go velocity pattern of vehicles were somehow smoothed out where average speed was preserved, then significant fuel consumption and emissions savings could be achieved**
- **similar (but more complex) for arterial and residential roads**
- **fuel/emissions congestion effects are more pronounced with heavy-duty trucks (lower power-to-weight ratios)**

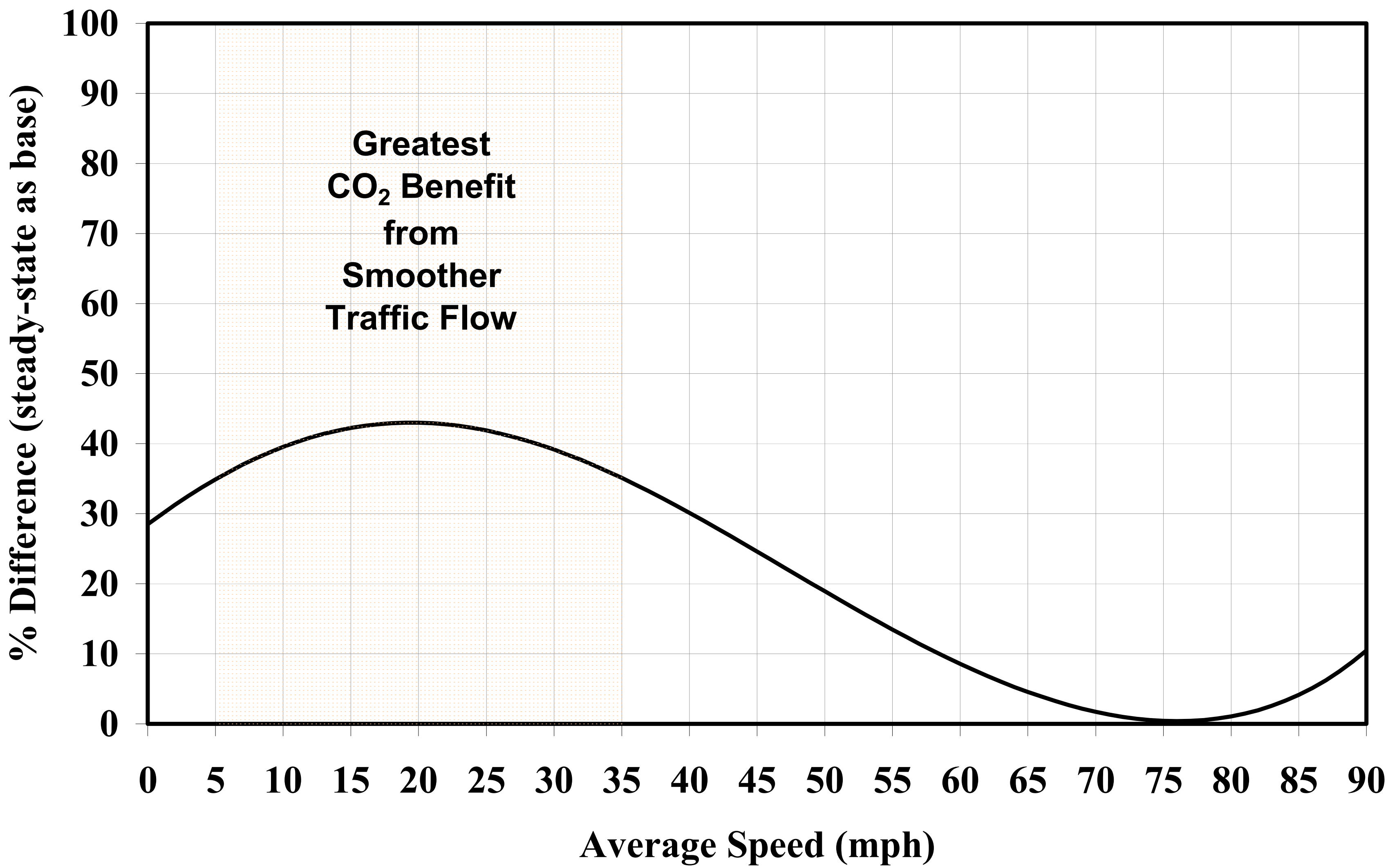
Possible traffic operation strategies to reduce on-road CO_2 emission



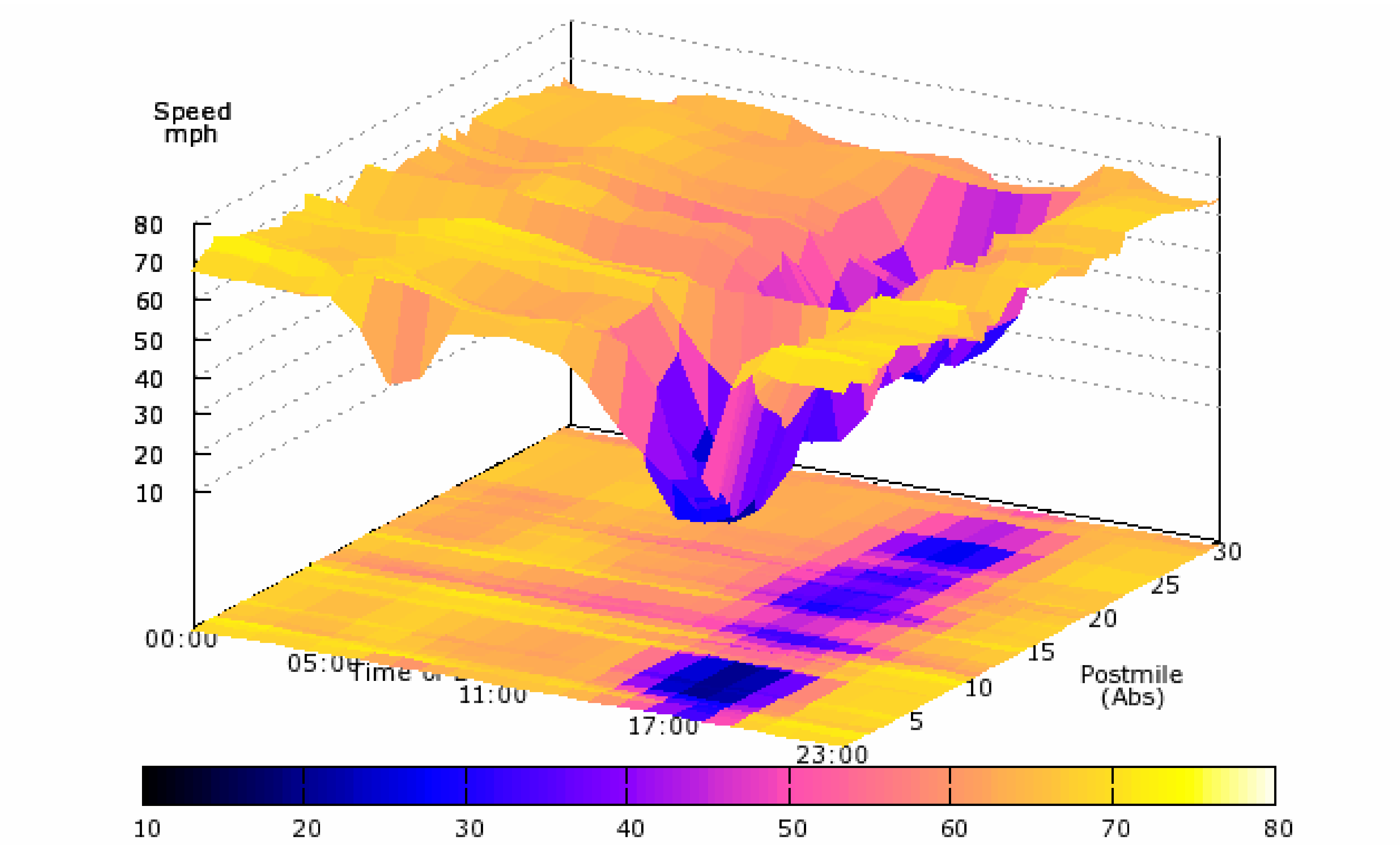
Potential CO_2 reduction as a result of speed changes

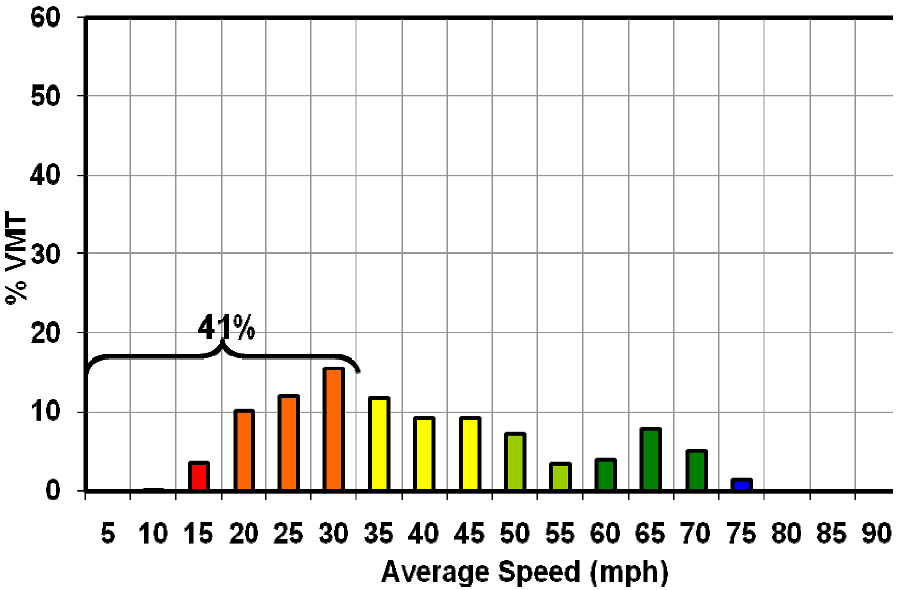


Potential CO_2 reduction as a result of smoother traffic flow



Real World Congestion: Average traffic speed along the SR-60 eastbound corridor by time-of-day (x-axis) and distance (y-axis)



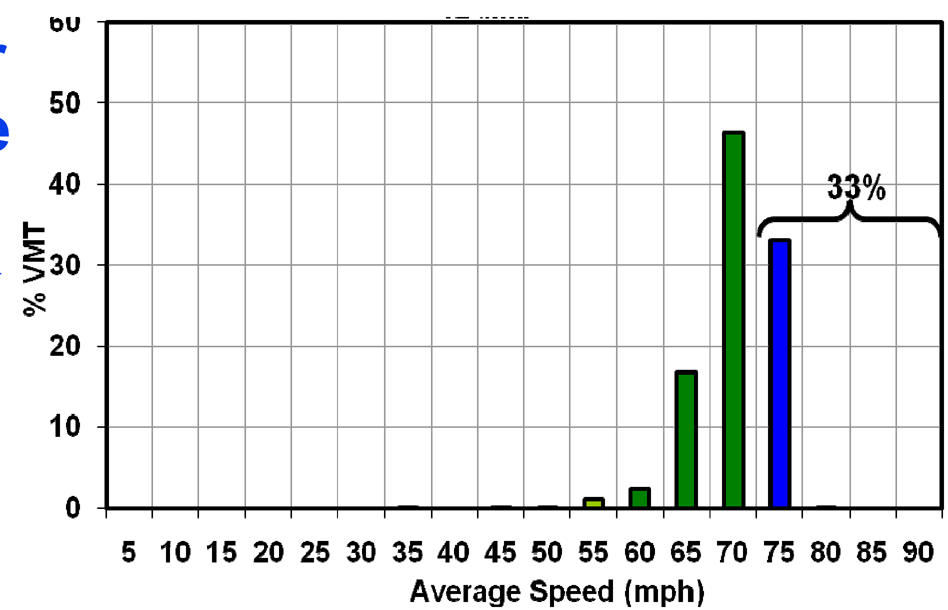


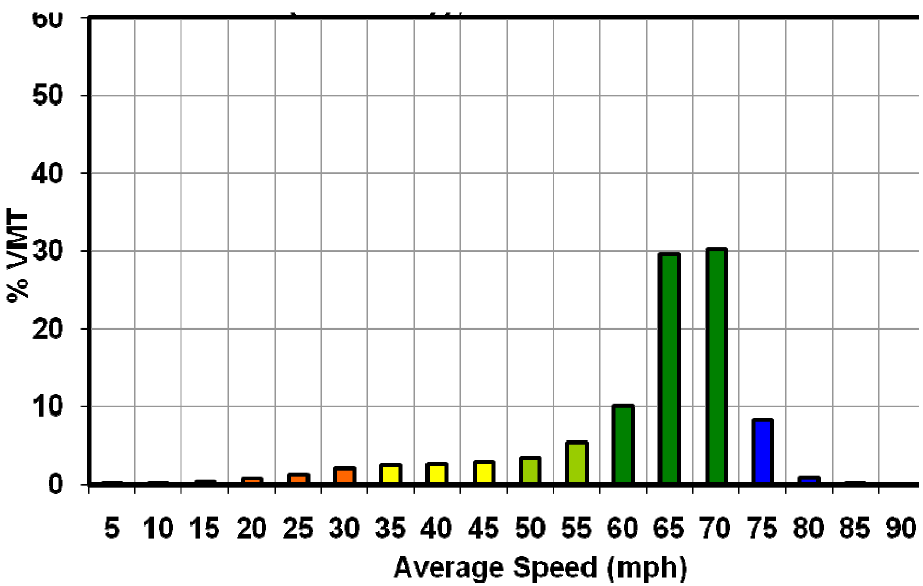
%VMT-speed distribution for SR-60E for the month of June 2007 during the PM peak hour

conversion to steady-state 60 mph: 7% CO_2 savings

%VMT-speed distribution for SR-60E for the month of June 2007 during a late night hour

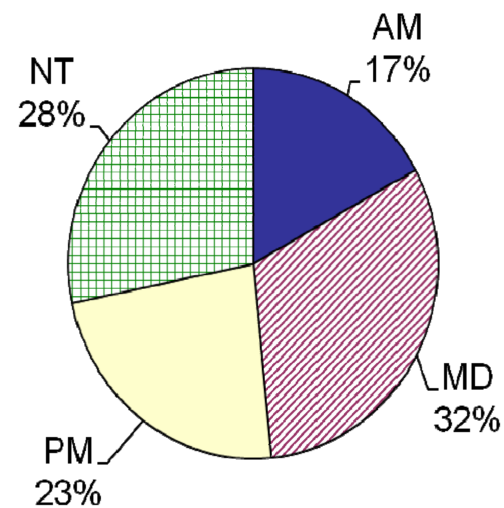
conversion to steady-state 60 mph: 8% CO_2 savings





%VMT-speed distribution for Los Angeles freeway network across 24 hours for the month of June 2007

fraction of total daily VMT for different time periods



Summary: CO_2 Emissions and Traffic Congestion:

- **Traffic congestion has a significant impact on CO_2 emissions**
- **Improved traffic conditions can be accomplished through:**
  - **congestion mitigation strategies that reduce severe congestion such that higher average traffic speeds are achieved (e.g. ramp metering, incident management);**
  - **speed management techniques that can bring down excessive speeds to more moderate speeds of approximately 55 mph (e.g. enforcement, active accelerator pedal); and**
  - **traffic flow smoothing techniques that can suppress shock waves, and thus, reduce the number of acceleration and deceleration events (e.g. variable speed limits, ISA)**
- **Each can save 5 – 12%, can be additive for greater savings**
- **Currently carrying out road grade analysis**
- **Extending work to arterials and surface streets**