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ITS Strategies for Reducing Vehicle Energy Consumption and Emissions

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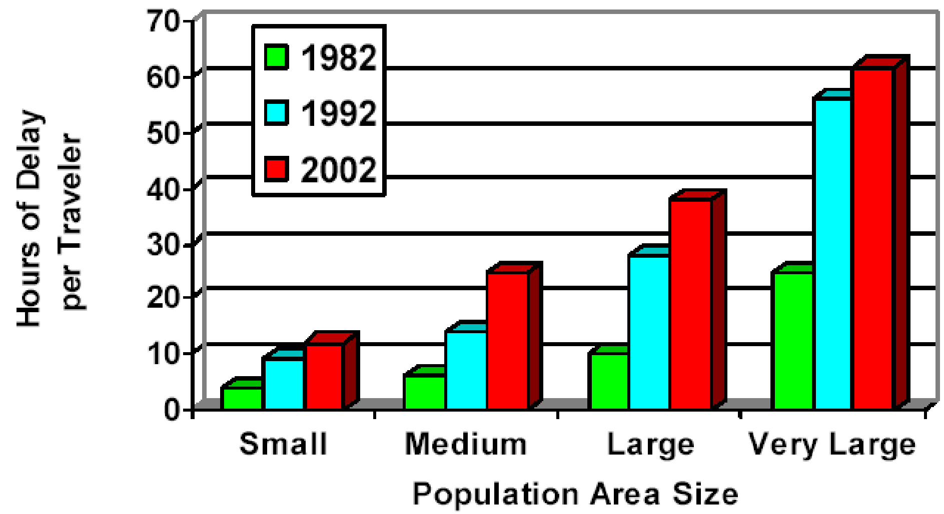
Transportation: Energy and Emissions

- **Increasing concern to stabilize greenhouse gases to below levels emitted today (while still meeting energy needs)**
- **Transportation accounts for 33% of U.S. CO_2 emissions**
- **80% of transportation CO_2 comes from cars and trucks**
- **Major emphasis is on cleaner, more efficient vehicles:**
  - **making vehicles lighter (and smaller) while maintaining safety**
  - **improving powertrain efficiency**
  - **developing alternative technologies (e.g.,hybrids, fuel-cell vehicles)**
- **Focus has also been placed on alternative fuels:**
  - **biofuels (cellulosic ethanol)**
  - **synthetic fuels**

Roadway Congestion: impacts on energy and emissions



"slow speeds caused by heavy traffic and/or narrow roadways due to construction, incidents, or too few lanes for the demand"

- **Texas Transportation Institute Annual Mobility Study:**
  - **http://mobility.tamu.edu/ums**
  - **congestion has grown everywhere in areas of all sizes**
  - **congestion occurs during longer portions of the day and delays more travelers and goods than ever before**
  - **billions of gallons of fuel are wasted every year, more emissions**

General Solutions to Roadway Congestion

- ***Manage Supply:***
  - **build more lanes to increase roadway capacity**
  - **build more infrastructure for alternative modes (bike, rail, transit)**
    shown to be more cost effective (Lipman, 2006)
  - **improve system operations (e.g., respond quickly to incidents)**
  - **implement *intelligent transportation system* techniques**

- ***Manage Demand:***
  - **implement pricing mechanisms to limit use of resources**
  - **provide greater range of alternative modes**
  - **allow for alternative work locations and schedules**
  - **have employers provide travel support programs**

- ***Manage Land Use:***
  - **implement better urban design**
  - **provide for mixed use development of land**
  - **increase housing and industrial density**
  - **allow for innovative planning and zoning**
  - **implement some type of growth management**

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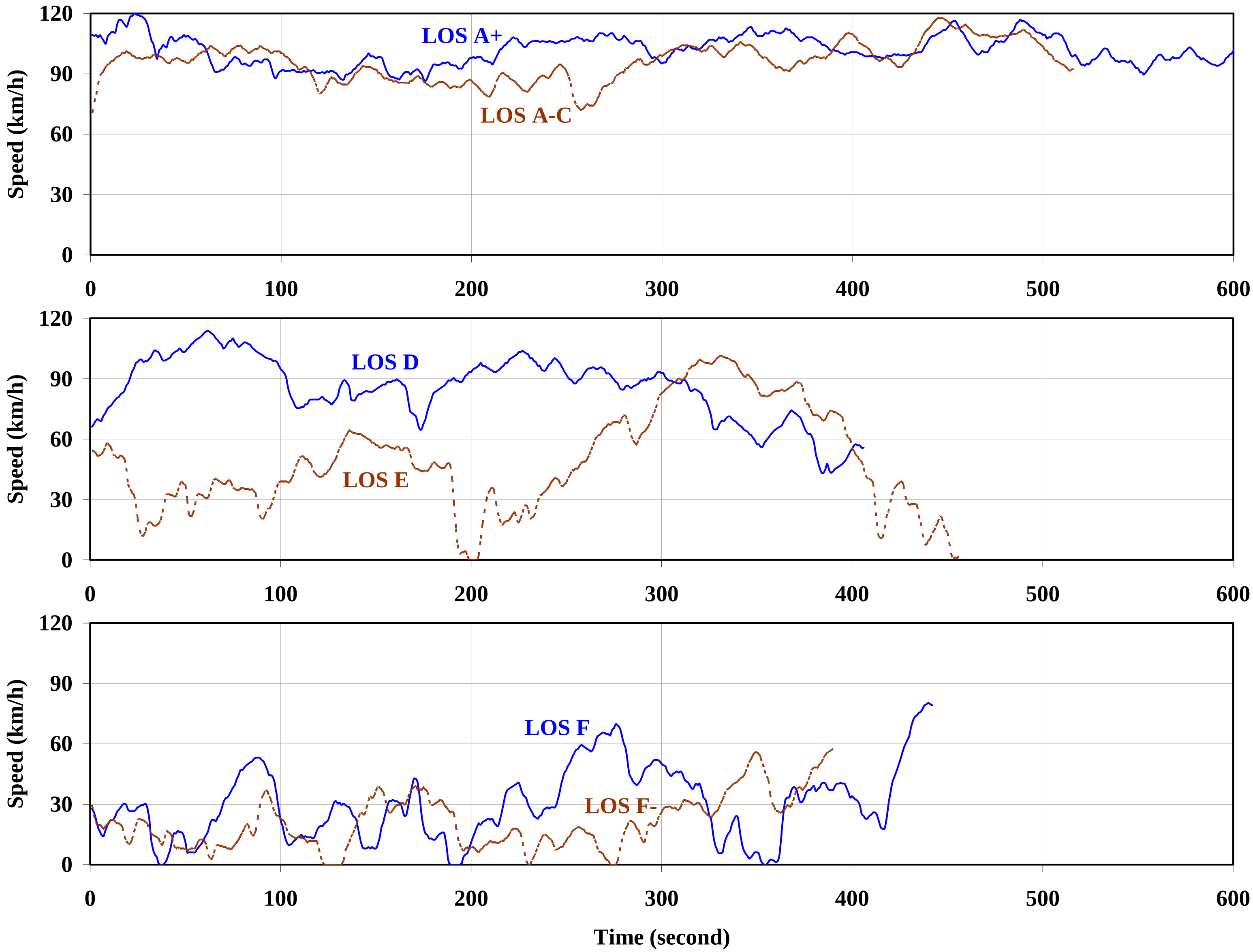
Levels of Service (LOS) on today's highways



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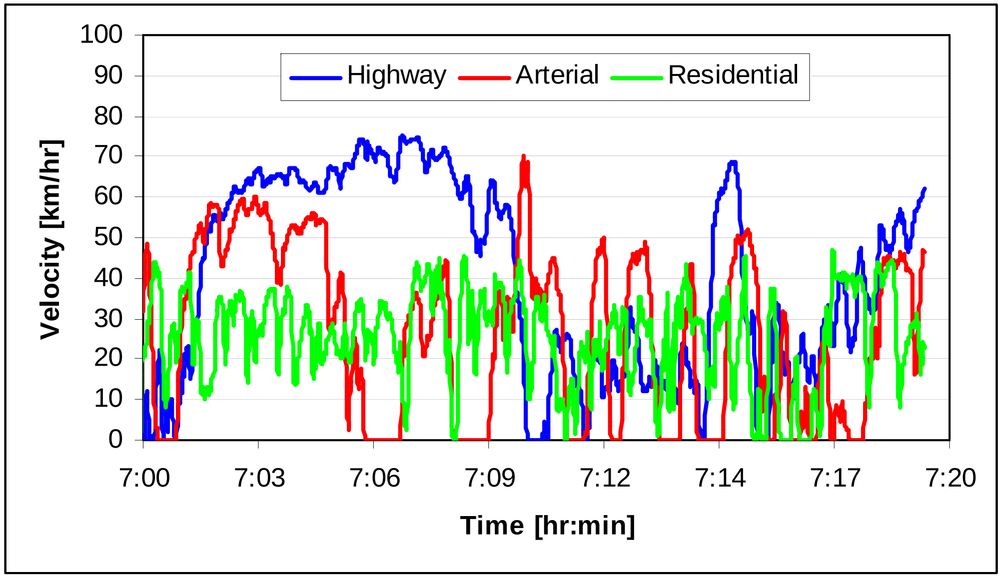
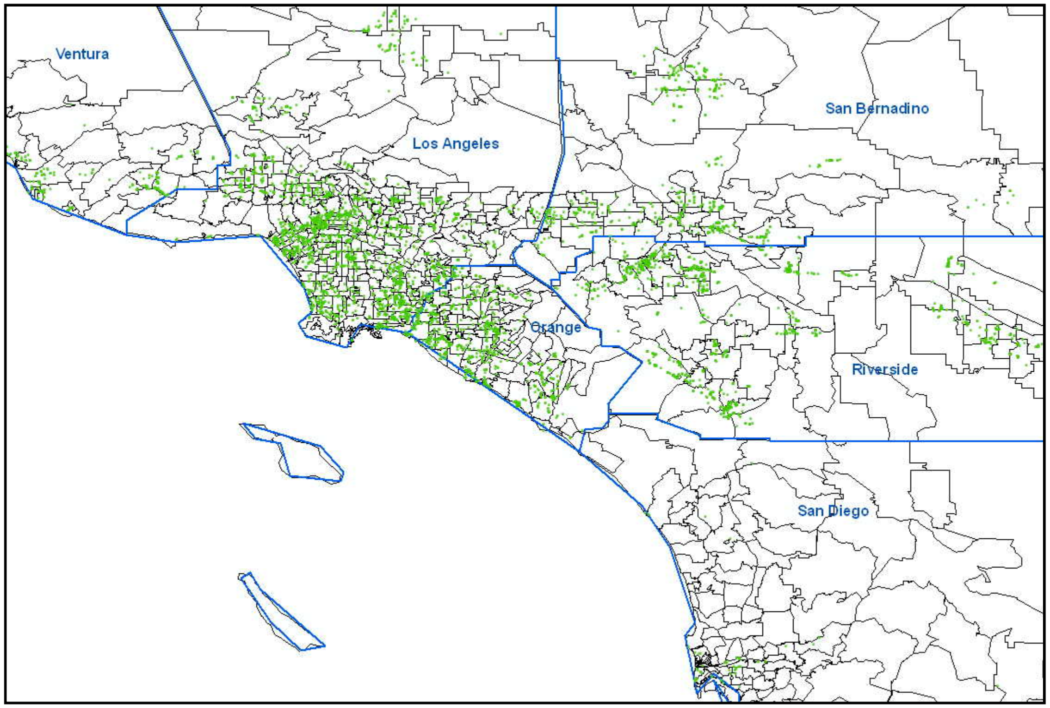
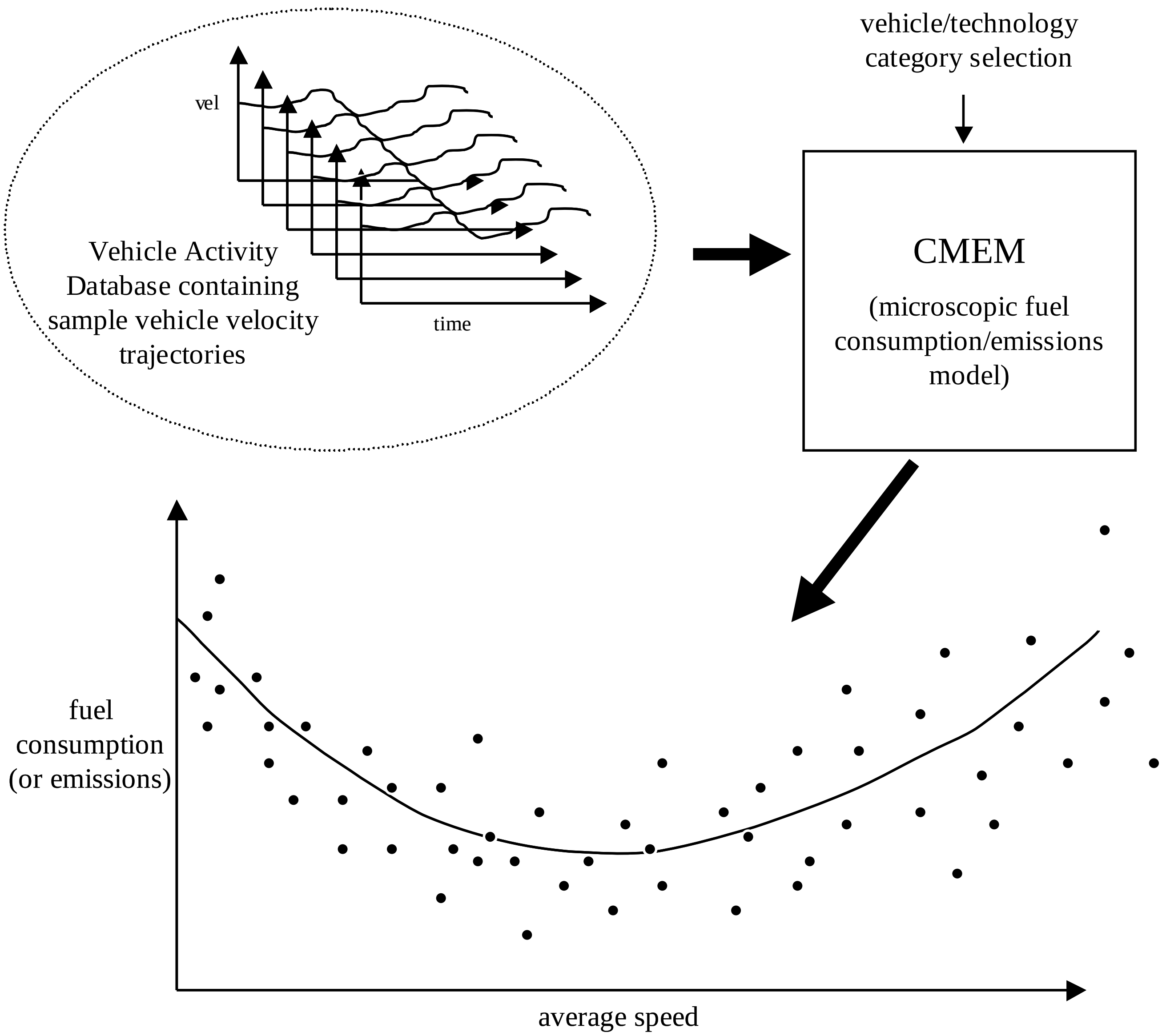


Vehicle Activity Data Collection in Southern California



General Methodology



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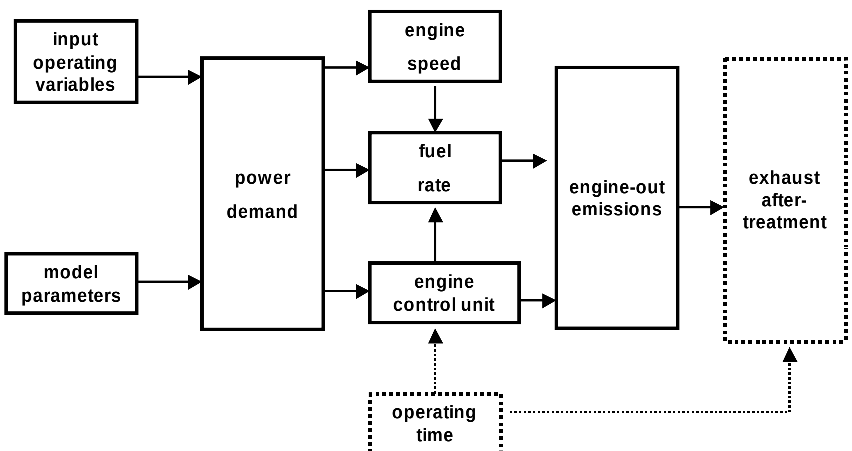
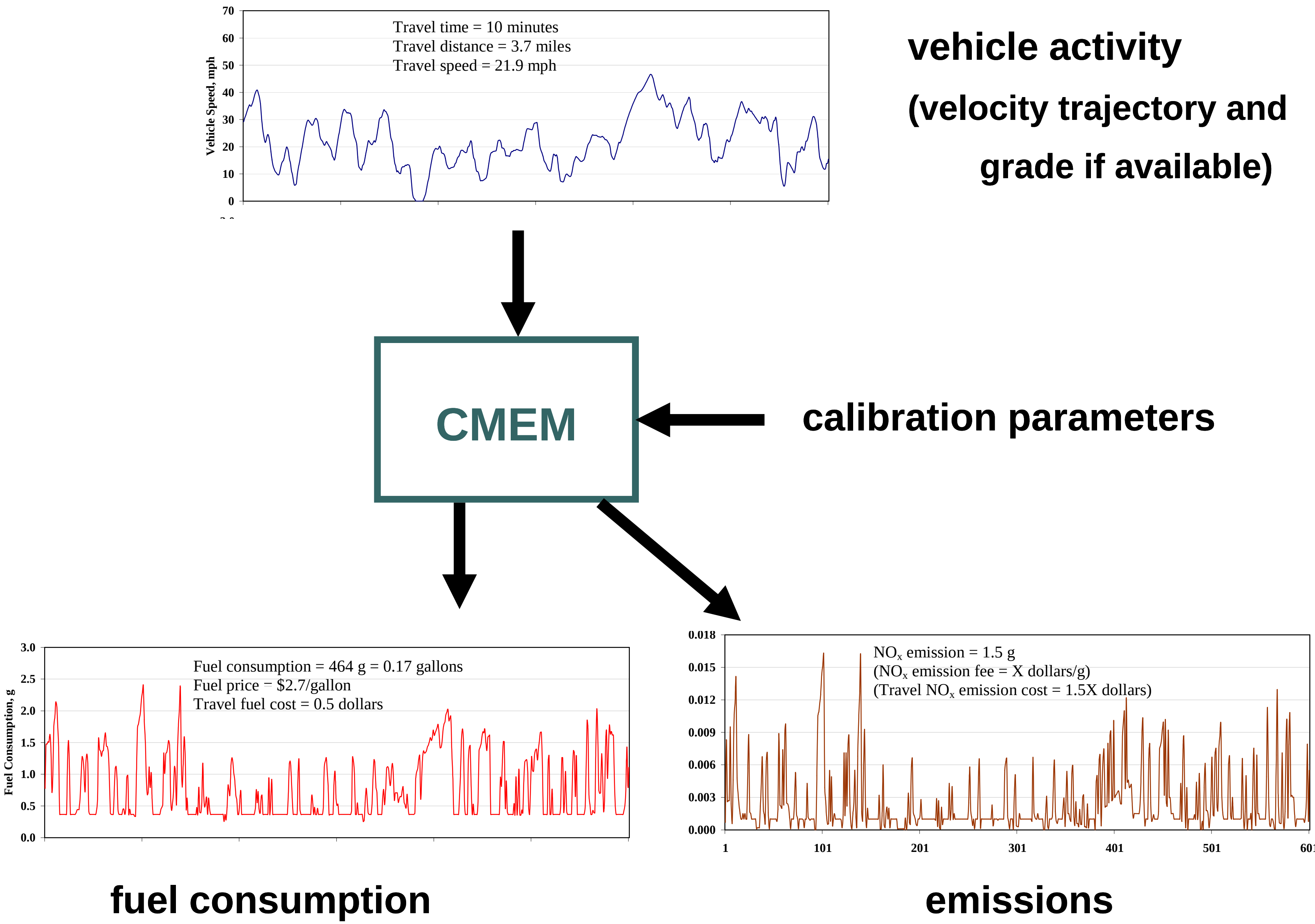
Background: Comprehensive Modal Emissions Model (CMEM):

- 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


Travel time = 10 minutes
Travel distance = 3.7 miles
Travel speed = 21.9 mph
Vehicle Speed, mph
vehicle activity
(velocity trajectory and
grade if available)
CMEM
calibration parameters
Fuel consumption = 464 g = 0.17 gallons
Fuel price = $2.7/gallon
Travel fuel cost = 0.5 dollars
Fuel Consumption, g
NOx emission = 1.5 g
(NOx emission fee = X dollars/g)
(Travel NOx emission cost = 1.5X dollars)
fuel consumption
emissions

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

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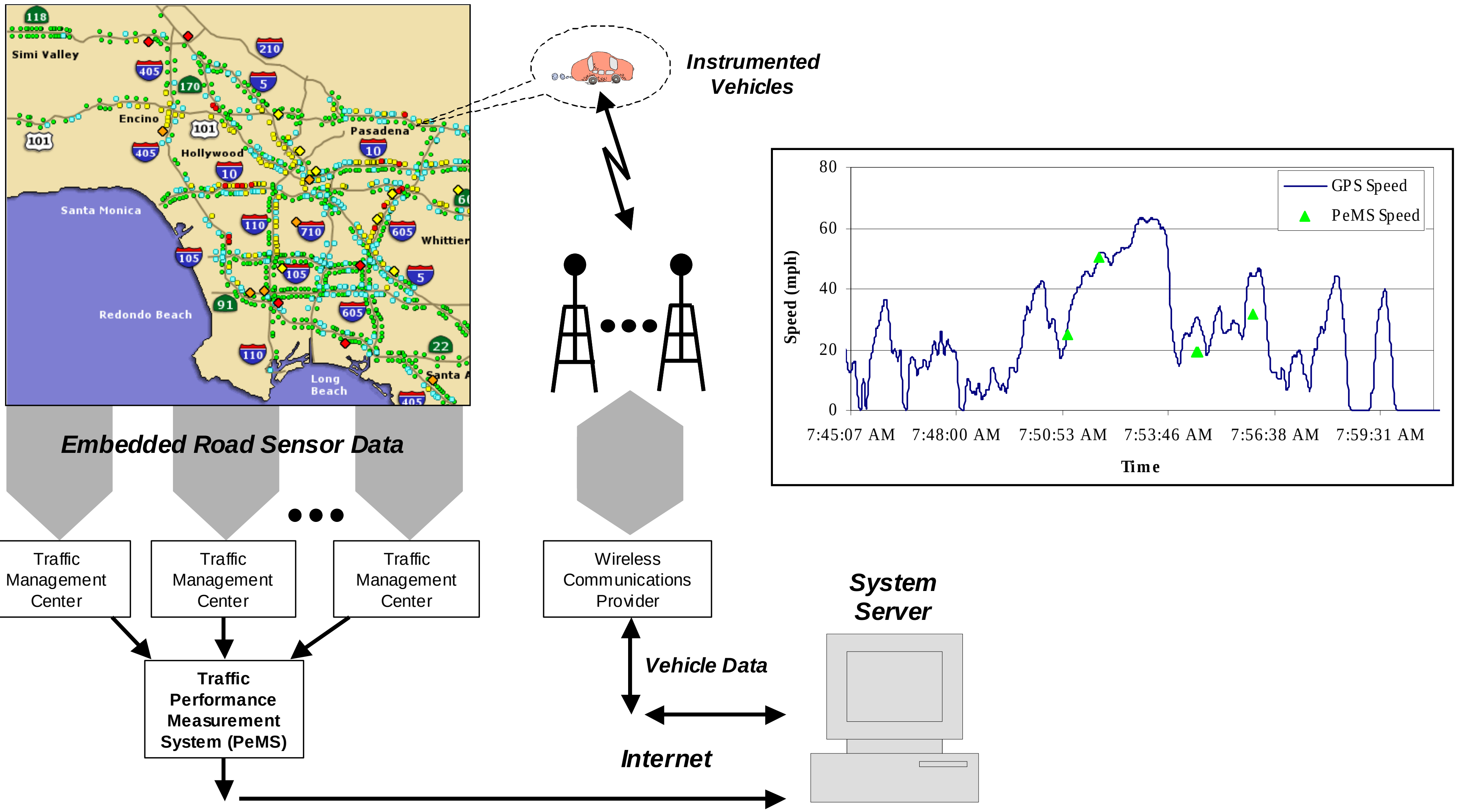
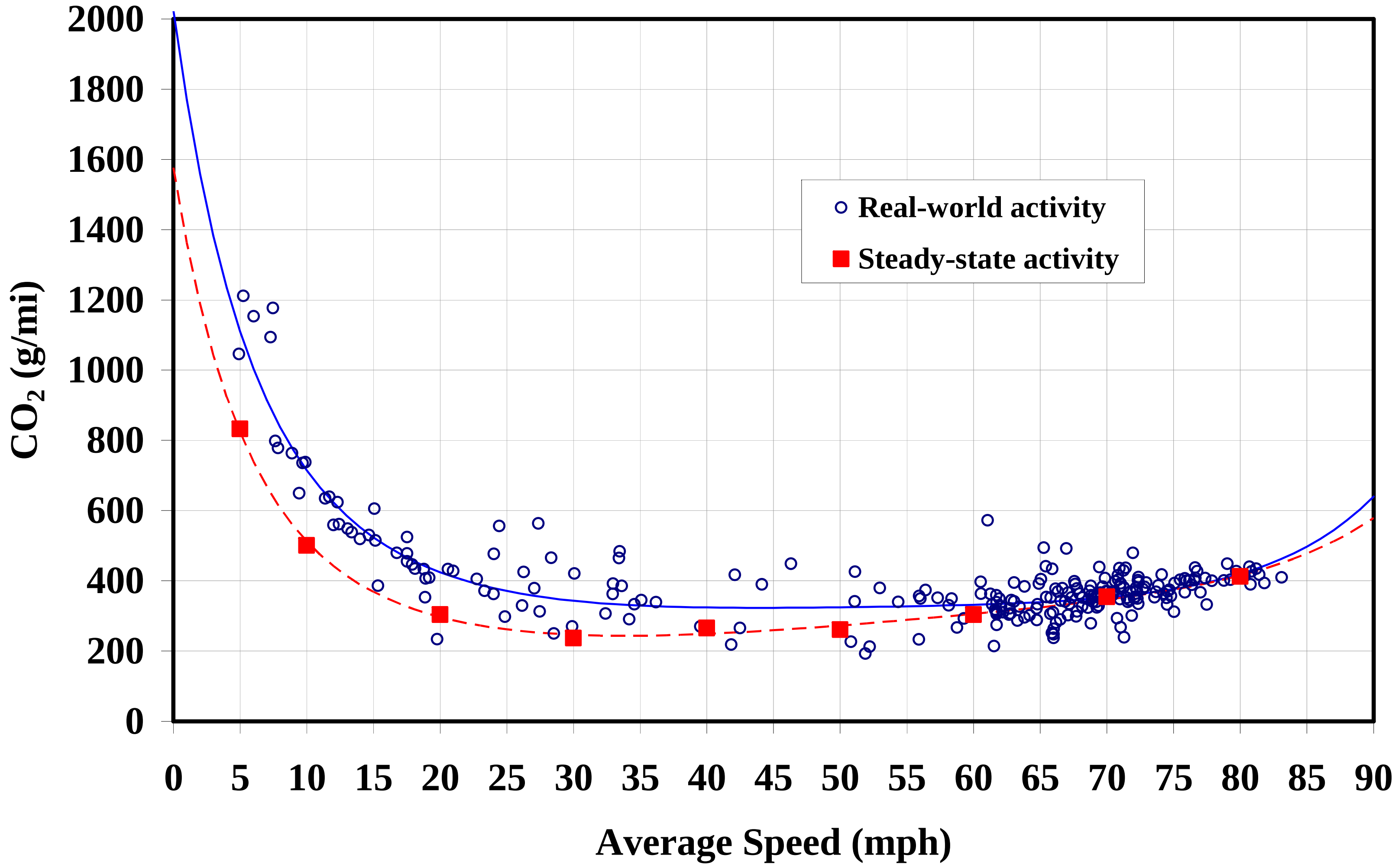
Simultaneous Data Collection of Traffic Data and Vehicle Velocity Measurements



Emissions as a function of Average *Traffic* Speed

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

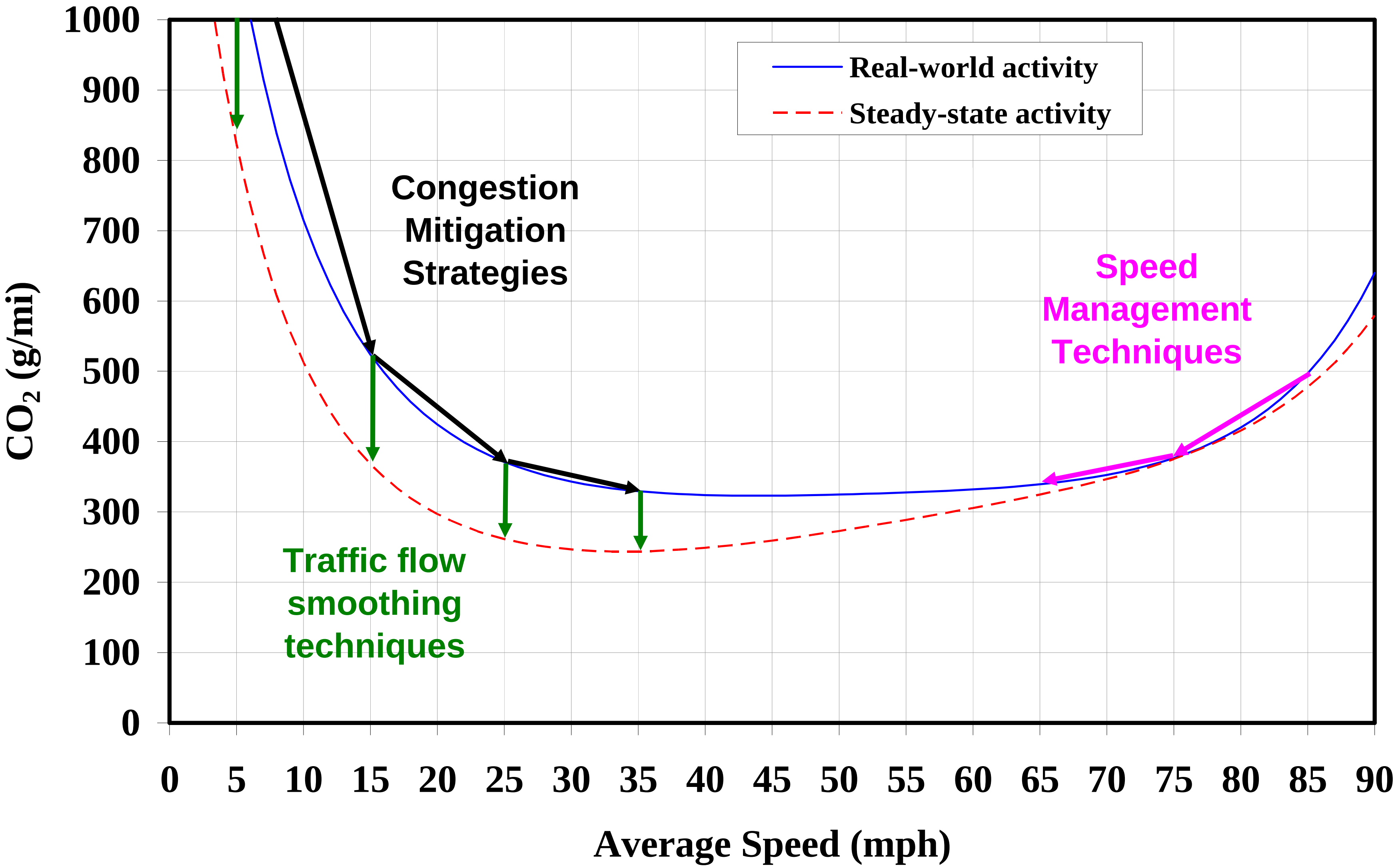
	Real-World	Steady-State
N	241	9
R^2	0.668	0.992
b_0	7.613534994965560	7.362867270508520
b_1	- 0.138565467462594	- 0.149814315838651
b_2	0.003915102063854	0.004214810510200
b_3	- 0.000049451361017	- 0.000049253951464
b_4	0.000000238630156	0.000000217166574



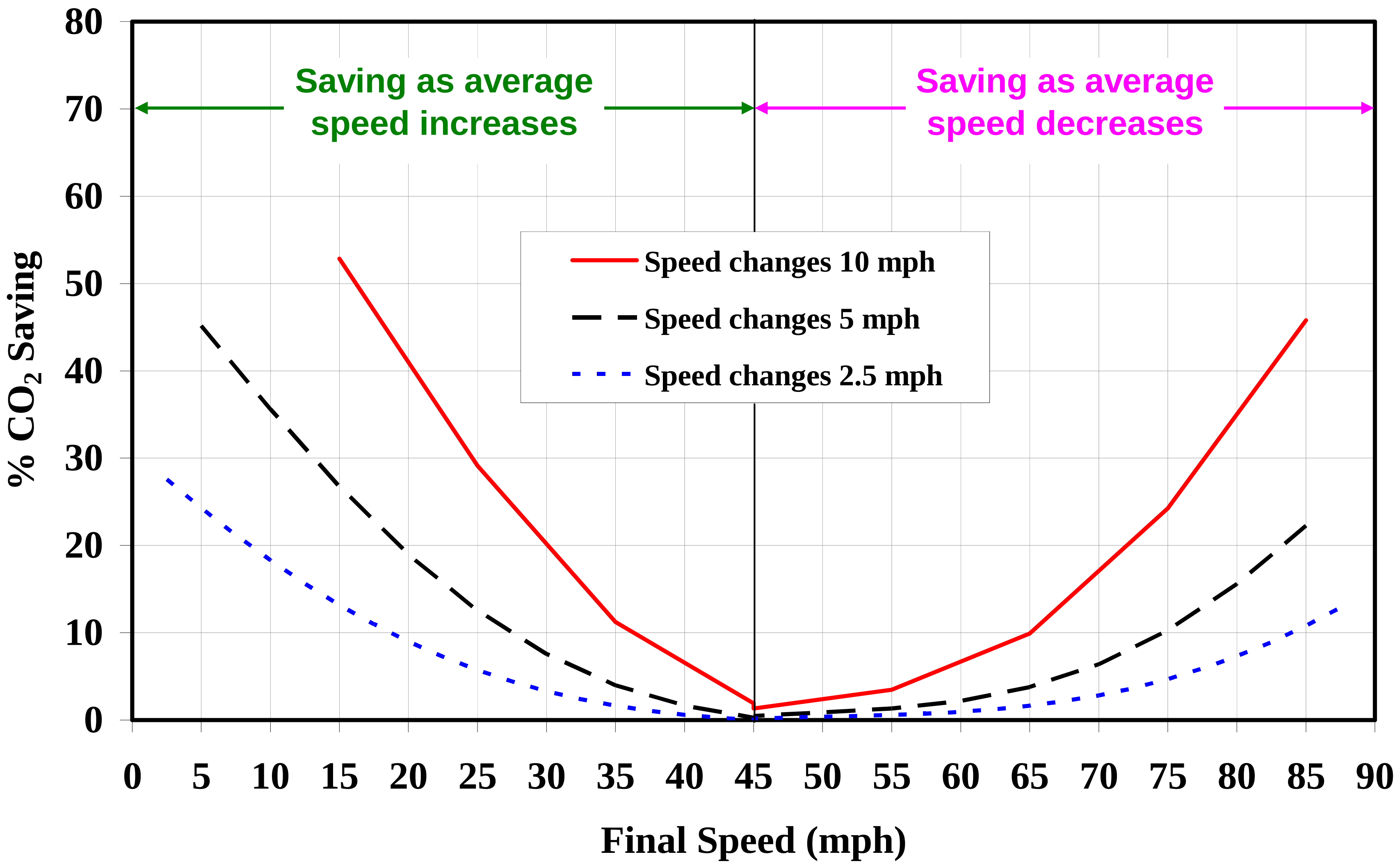
Congestion-Based Fuel Consumption and Emissions

- 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)

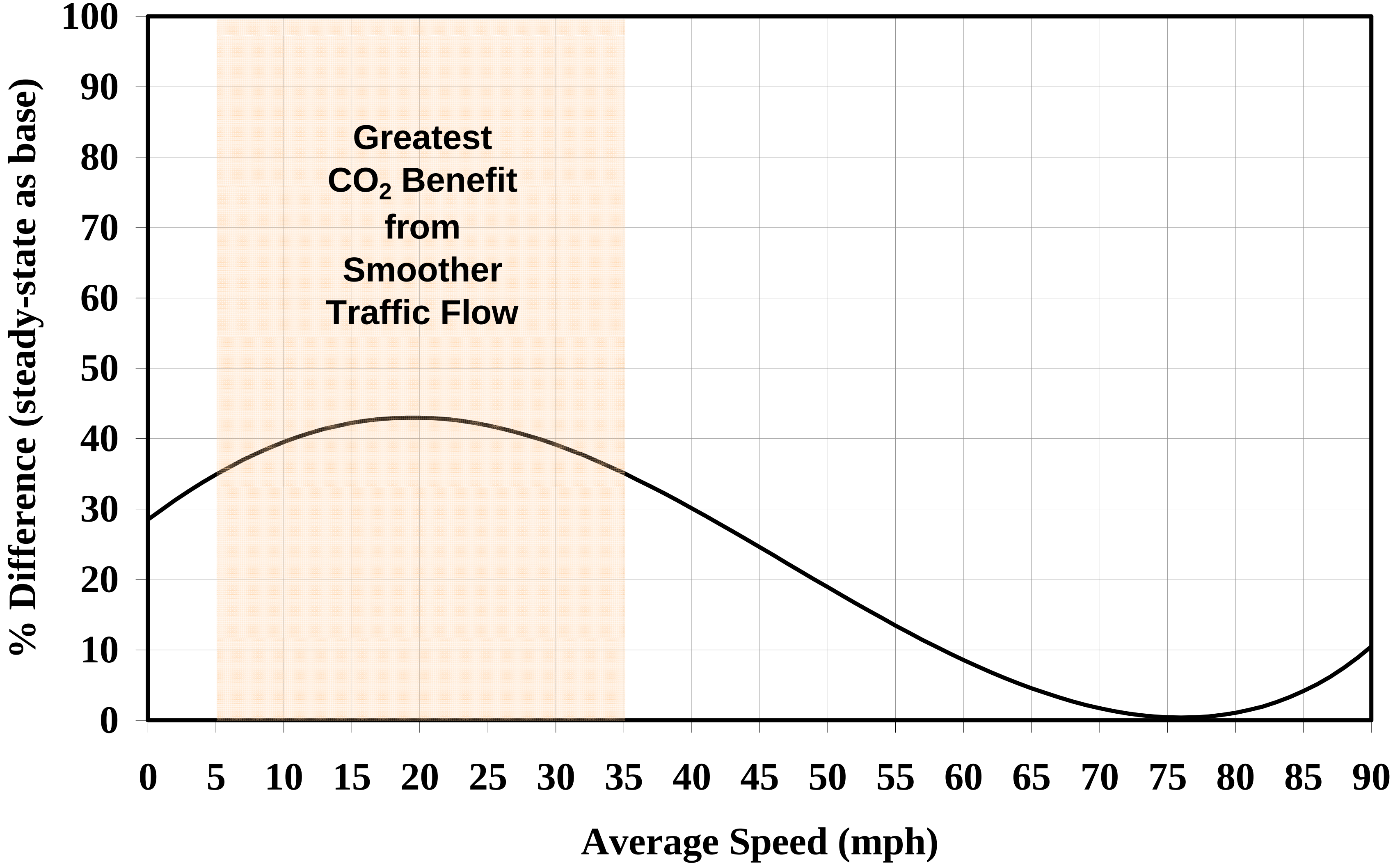
Possible traffic operation strategies to reduce on-road emission



Potential CO_2 reduction as a result of speed changes



Potential CO_2 reduction as a result of smoother traffic flow



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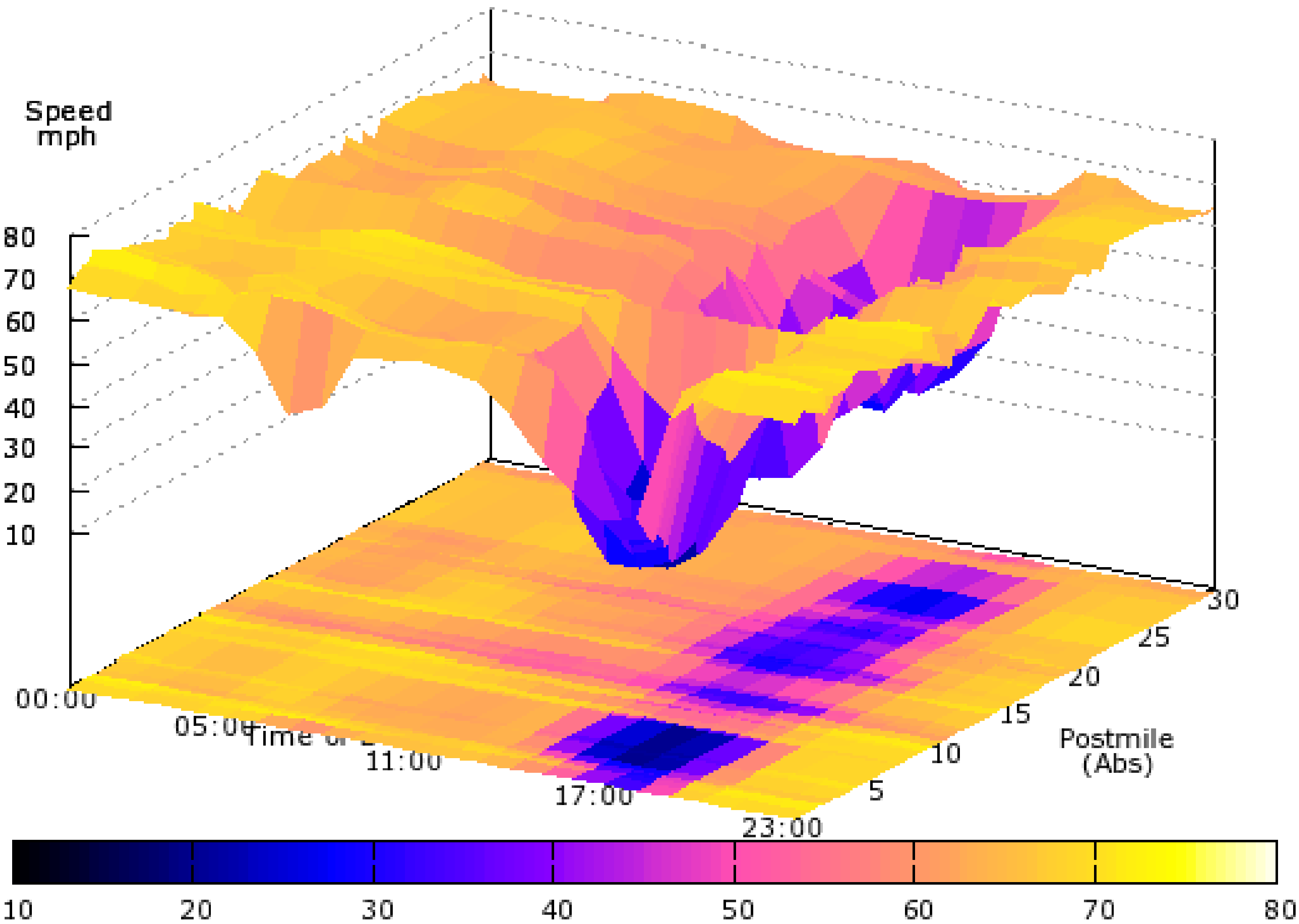
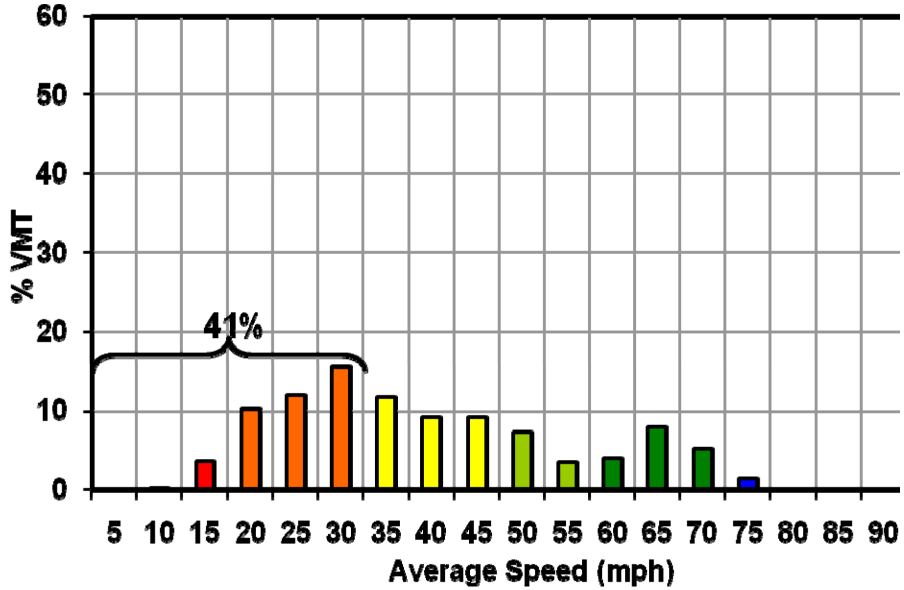
Real World Congestion: Average traffic speed along the SR-60 eastbound corridor by time-of-day (x-axis) and distance (y-axis)

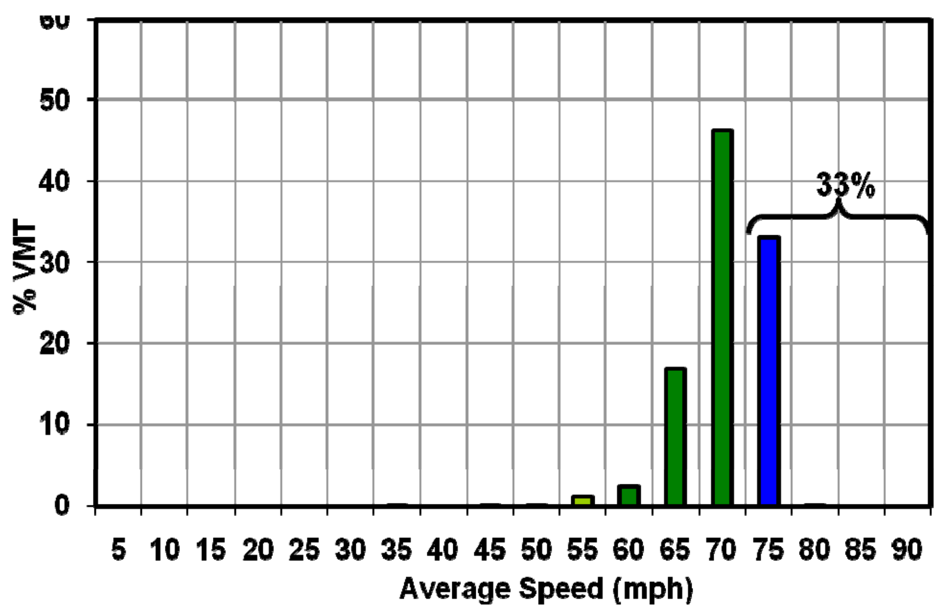




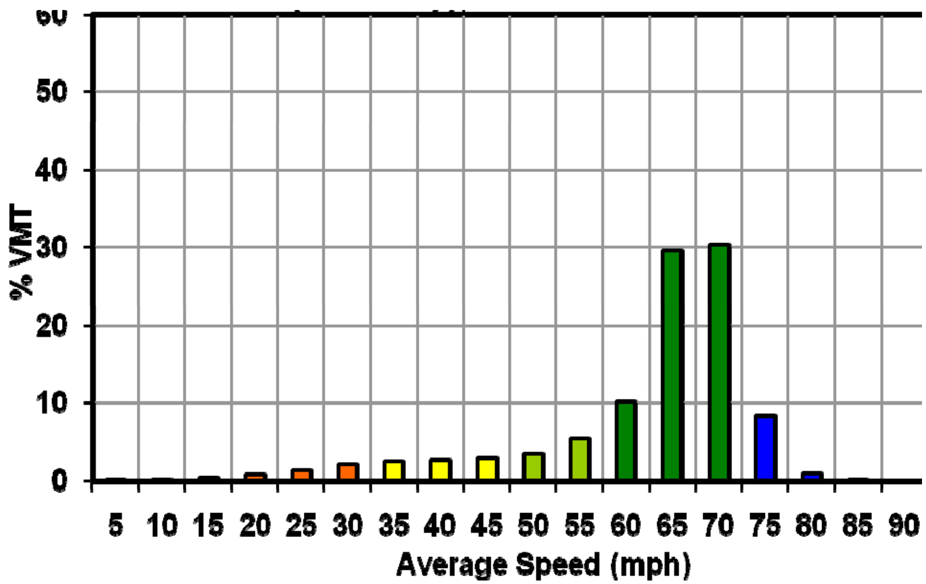
%VMT-speed distribution for SR-60E for the month of June 2007 during the PM peak hour

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

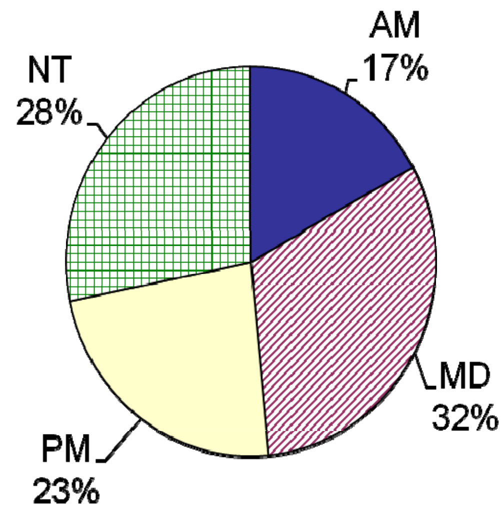


conversion to steady-state 60 mph: 8% CO_2 savings



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

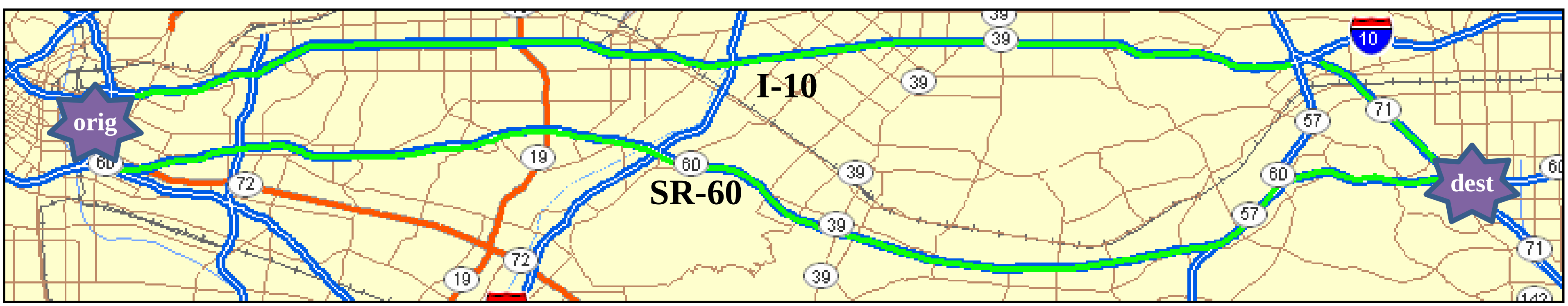
fraction of total daily VMT for different time periods



Environmentally-Friendly Navigation Case Studies:

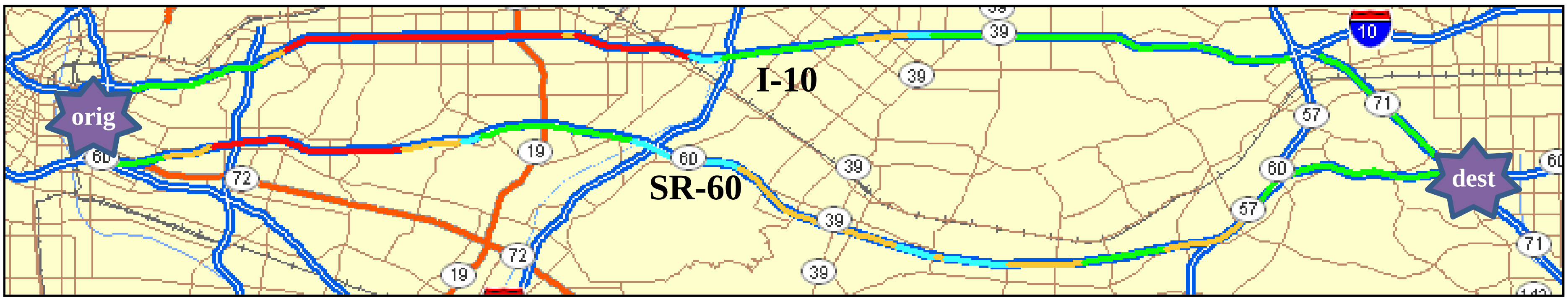
- **shortest-distance or shortest-duration path will often be the path that minimizes energy use or emissions**
- **roadway congestion and other factors (e.g. grade) create scenarios where minimum-energy and minimum-emissions path may be different than shortest duration or distance**
- **four case studies, where total fleet energy and emissions are considered**
- **Case Study 1): freeflow conditions**

Performance Measure	I-10 path	SR-60 path	% Diff
Distance (km)	43.97	44.86	-1.97
Travel time (minutes)	22.65	23.55	-3.82
Fuel consumption (g)	3,766.62	3,780.03	-0.35
CO_2 (g)	11,530.54	11,600.42	-0.60
CO (g)	143.10	133.82	6.93
HC (g)	3.99	3.90	2.31
NO_x (g)	9.82	9.80	0.20

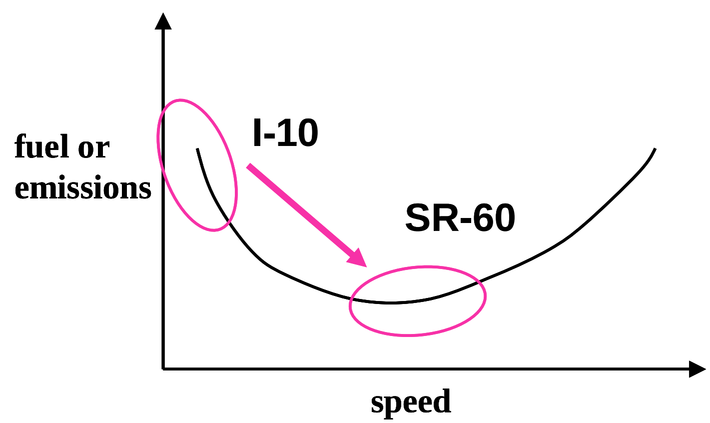


Environmentally-Friendly Navigation Case Studies:

- **Case Study 2): moderate congestion along one route, heavy congestion on other**
- **actual study date: March 16, 2007 at 2PM**

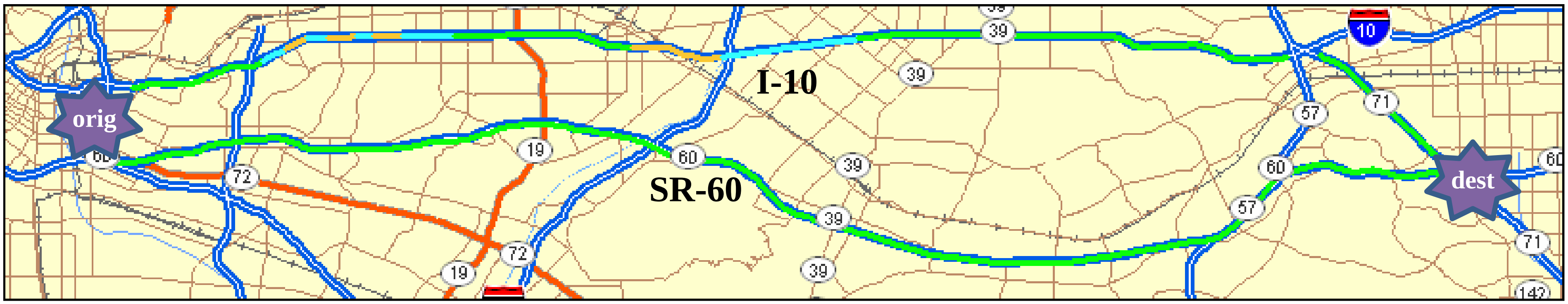


Performance Measure	I-10 path	SR-60 path	% Diff
Distance (km)	43.97	44.86	-1.97
Travel time (minutes)	93.40	41.01	127.75
Fuel consumption (g)	4,770.07	3,360.50	42.15
CO_2 (g)	14,917.86	10,505.36	42.00
CO (g)	62.98	46.34	35.91
HC (g)	2.83	2.36	19.92
NO_x (g)	9.24	8.09	14.22

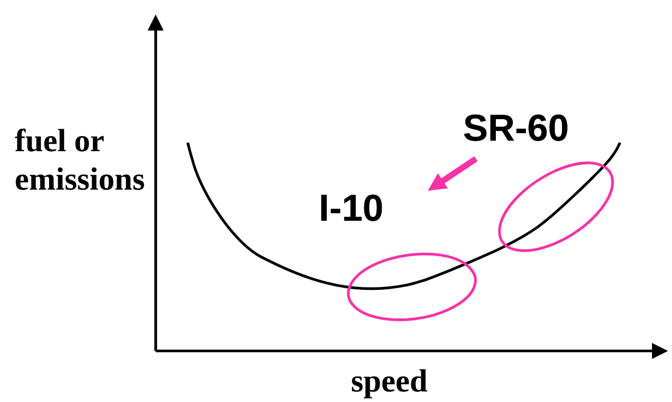


Environmentally-Friendly Navigation Case Studies:

- **Case Study 3): freeflow along one route, moderate congestion on other**
- **actual study date: February 12, 2007 at 10AM**

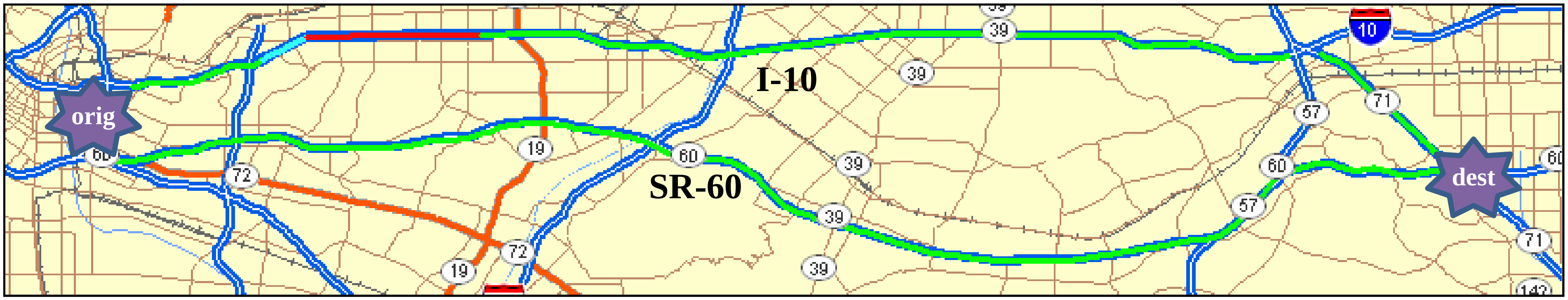


Performance Measure	I-10 path	SR-60 path	% Diff
Distance (km)	43.97	44.86	-1.97
Travel time (minutes)	29.23	23.55	24.12
Fuel consumption (g)	3,458.90	3,799.68	-8.97
CO_2 (g)	10,703.61	11,645.16	-8.09
CO (g)	88.01	141.15	-37.65
HC (g)	3.09	3.97	-22.17
NO_x (g)	8.77	9.90	-11.41

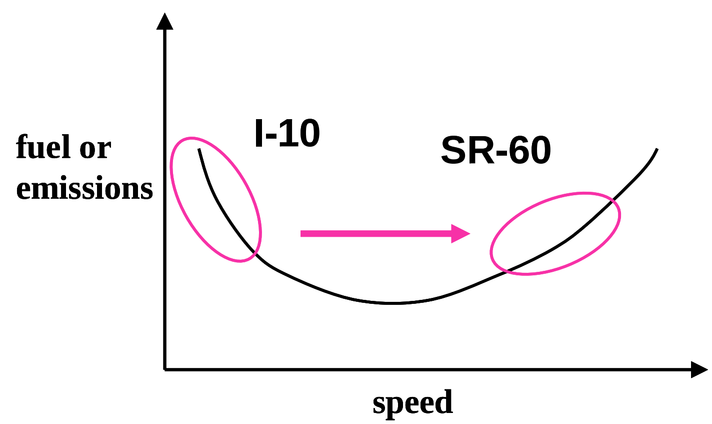


Environmentally-Friendly Navigation Case Studies:

- Case Study 4): freeflow along one route, heavy congestion on other
- actual study date: February 6, 2007 at noon



Performance Measure	I-10 path	SR-60 path	% Diff
Distance (km)	43.97	44.86	-1.97
Travel time (minutes)	41.07	24.00	71.13
Fuel consumption (g)	4,042.54	3,717.99	8.73
CO_2 (g)	12,479.80	11,437.82	9.11
CO (g)	119.05	122.41	-2.74
HC (g)	3.58	3.73	-4.02
NO_x (g)	9.57	9.59	-0.21



Intelligent Speed Adaptation

- **process that monitors the current speed of a vehicle, compares it to an externally defined set speed, and takes corrective action**

Different Forms:

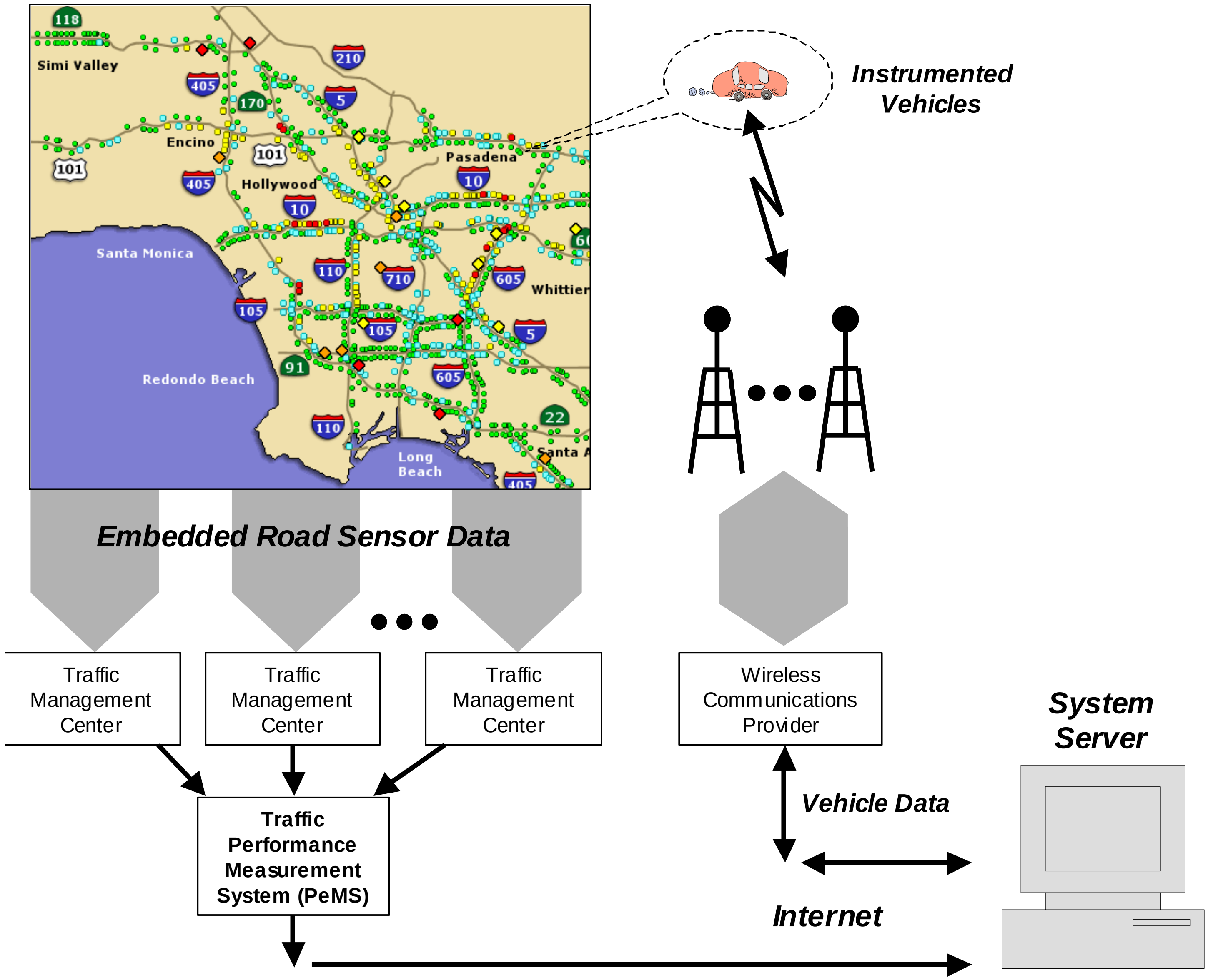
- ***fixed:*** **max permissible speed is set by the user; control system never exceeds this;**
- ***variable:*** **set speed is determined by vehicle location, where different speed limits are set spatially**
- ***dynamic:*** **speed is determined by time and location: temporal aspect varies based on road network conditions or weather**

Driving Behavior Intervention:

- **advisory, active support, and mandatory**

Benefits: **safety, lower congestion, lower environmental impacts**

Intelligent Speed Adaptation Experimentation



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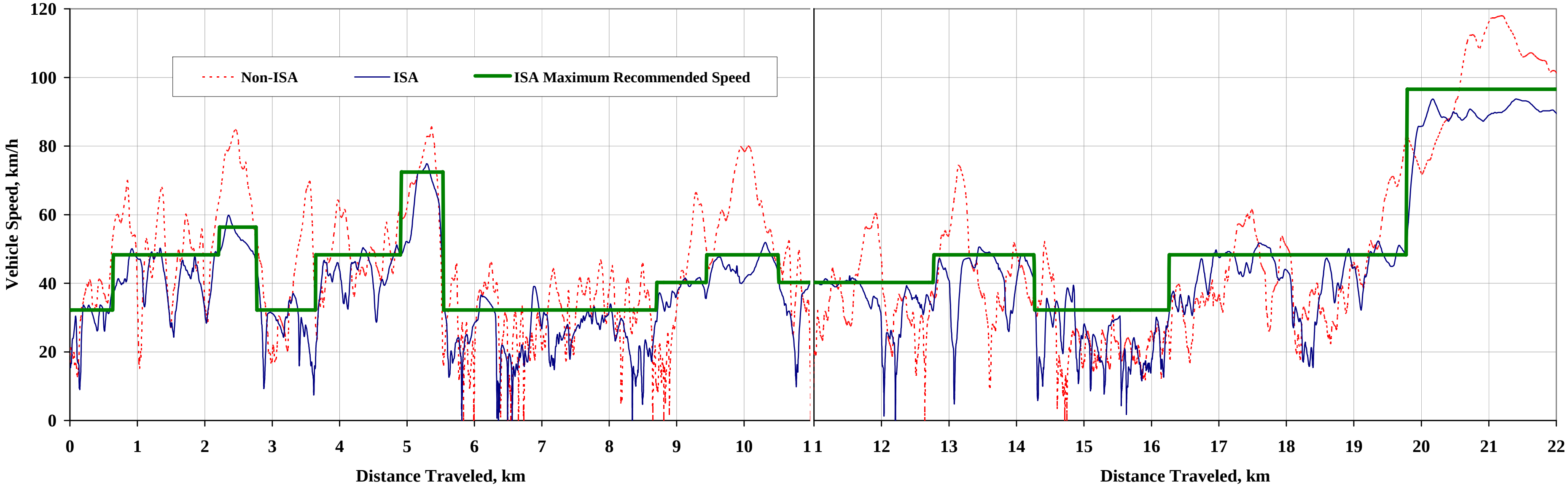
Intelligent Speed Adaptation: Preliminary Results



same travel time results:

Energy/Emissions	Non-ISA	ISA	Difference
CO_2 (g)	5439	4781	-12%
CO (g)	97.01	50.47	-48%
HC (g)	3.20	1.90	-41%
NO_x (g)	6.28	3.97	-37%
Fuel (g)	1766	1534	-13%

Summary and Conclusions:

- Traffic congestion has a significant impact on fuel consumption and 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 60 mph (e.g. enforcement, ISA); 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)
- CO_2: Each can save 5 – 12%, can be additive for greater savings
- EFNav: Extending work to arterials and surface streets; road grade
- ISA: increased simulation scenarios, real-world experimentation