Energy and Environmental Impacts of Personal Mobility

National Academy of Engineering
2006 U.S. Frontiers of Engineering Symposium

Matthew Barth
Professor, Electrical Engineering
Director, Center for Environmental Research and Technology
University of California, Riverside

Overview:

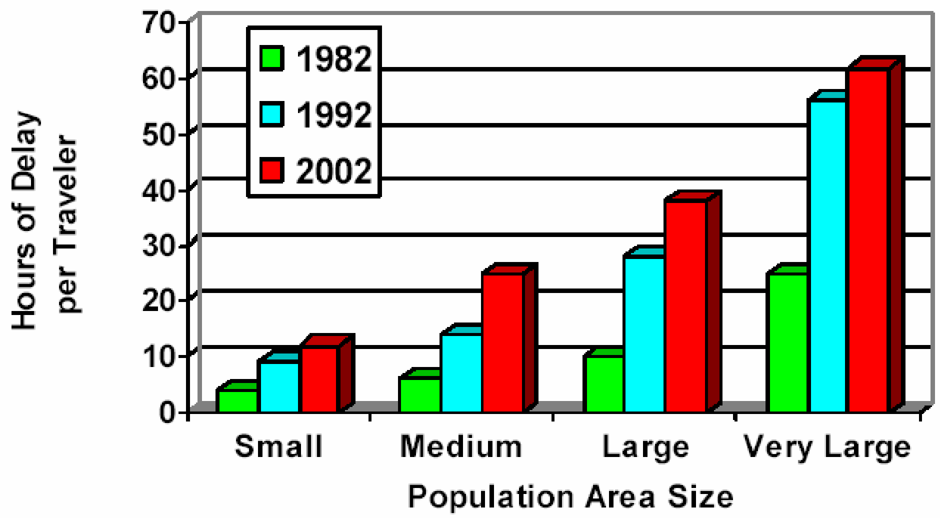
- personal mobility
- congestion
- vehicle emissions and fuel consumption
- intelligent transportation systems and examples
- other personal mobility options

Personal Mobility:

- personal mobility is an important part of a progressive society
- the automobile has become essential element of life
- our mobility is often restricted due to limitations in transportation infrastructure
- resource management problem:
    - if resources (transportation infrastructure) are limited and demand is high, congestion occurs

Roadway Congestion

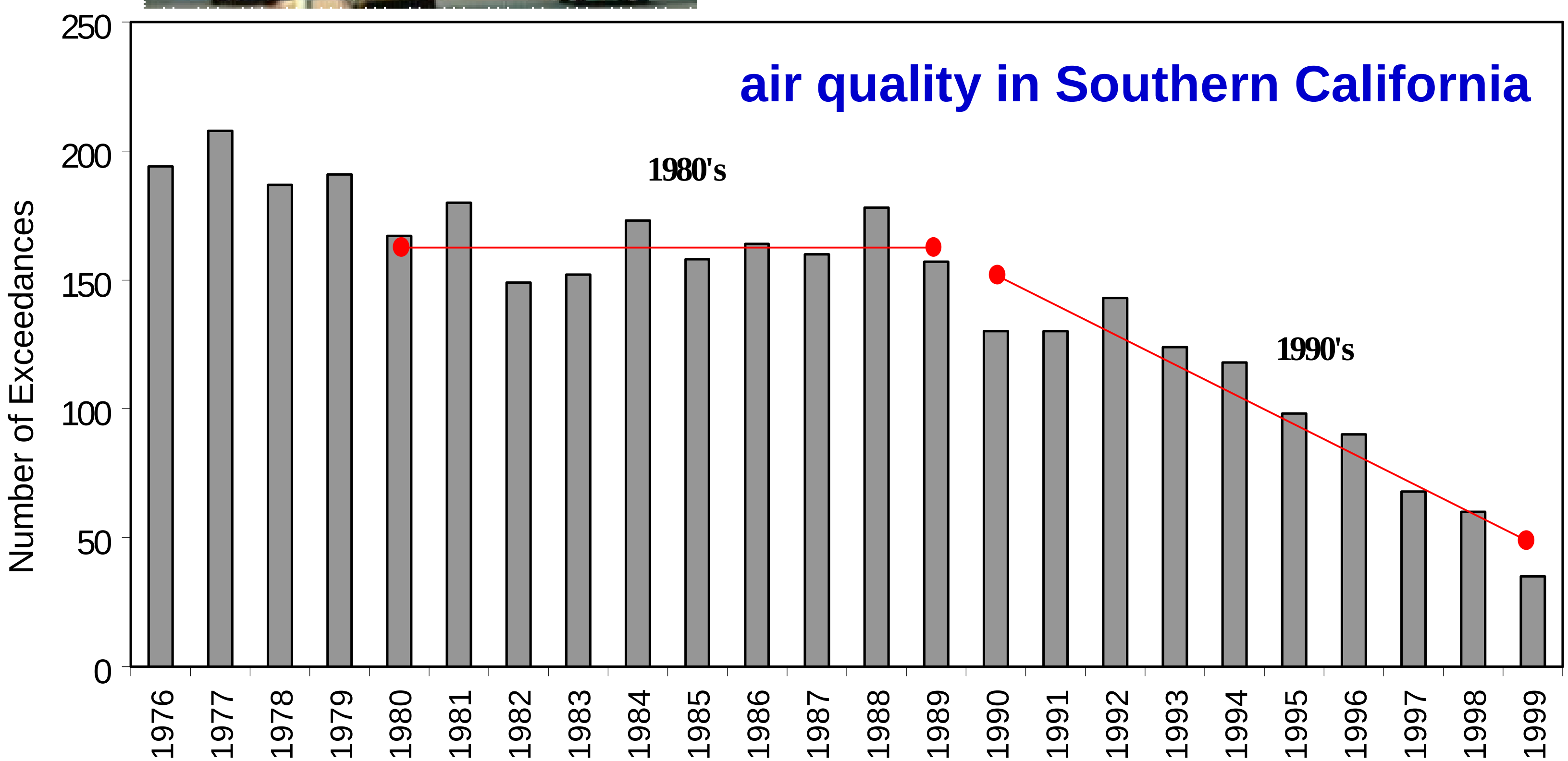
- Texas Transportation Institute Annual Mobility Study:
  - http://mobility.tamu.edu/ums
  - congestion has grown everywhere in areas of all sizes
  - congestion occurs during longer portions of the day and delays more travelers and goods than ever before
  - billions of gallons of fuel are wasted every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



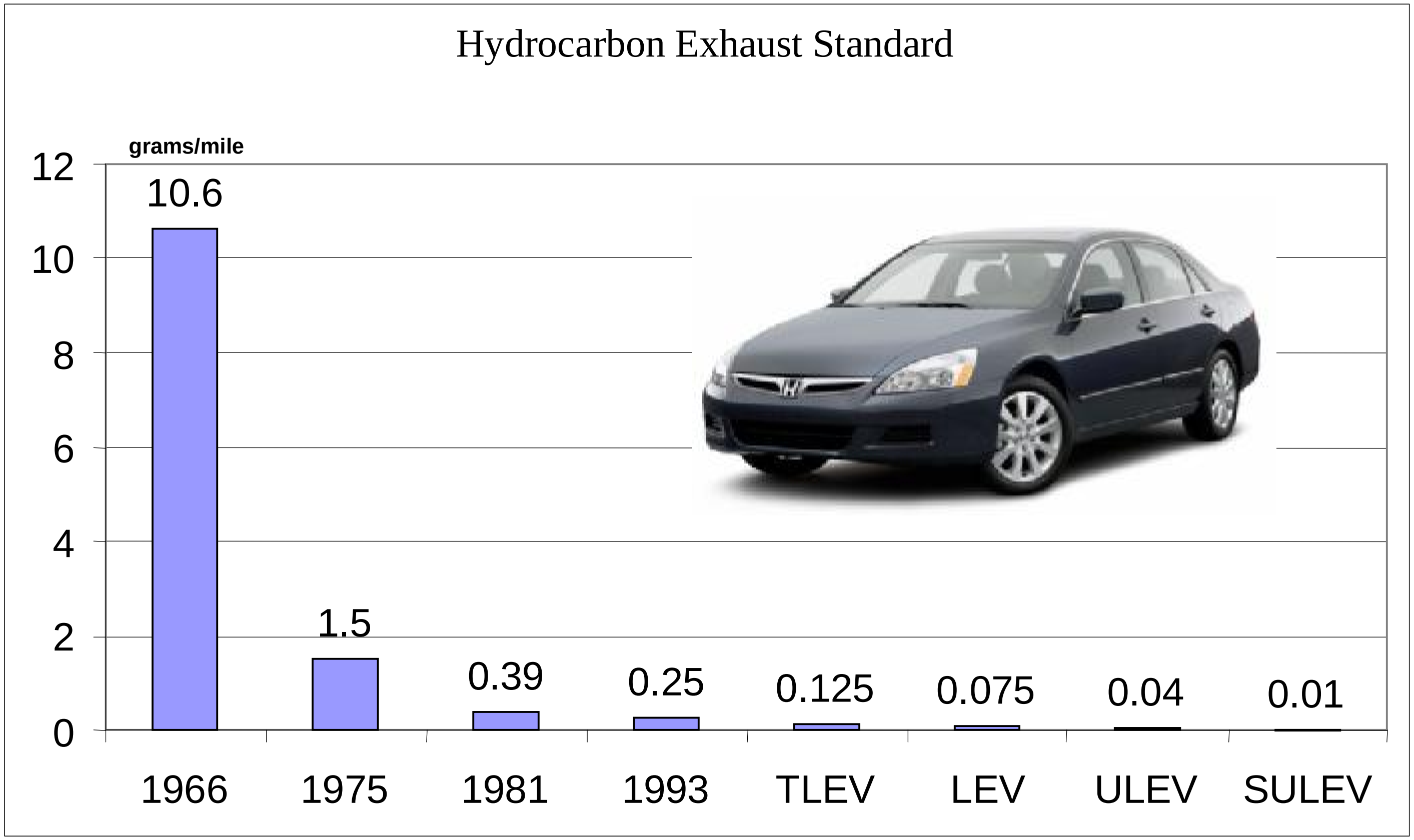
"slow speeds caused by heavy traffic and/or narrow roadways due to construction, incidents, or too few lanes for the demand"

Air Quality


KEEP
RIGHT


air quality in Southern California
Number of Exceedances
0
50
100
150
200
250
1980's
1990's
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999

key factor: emission certification standards



General Solutions to Congestion

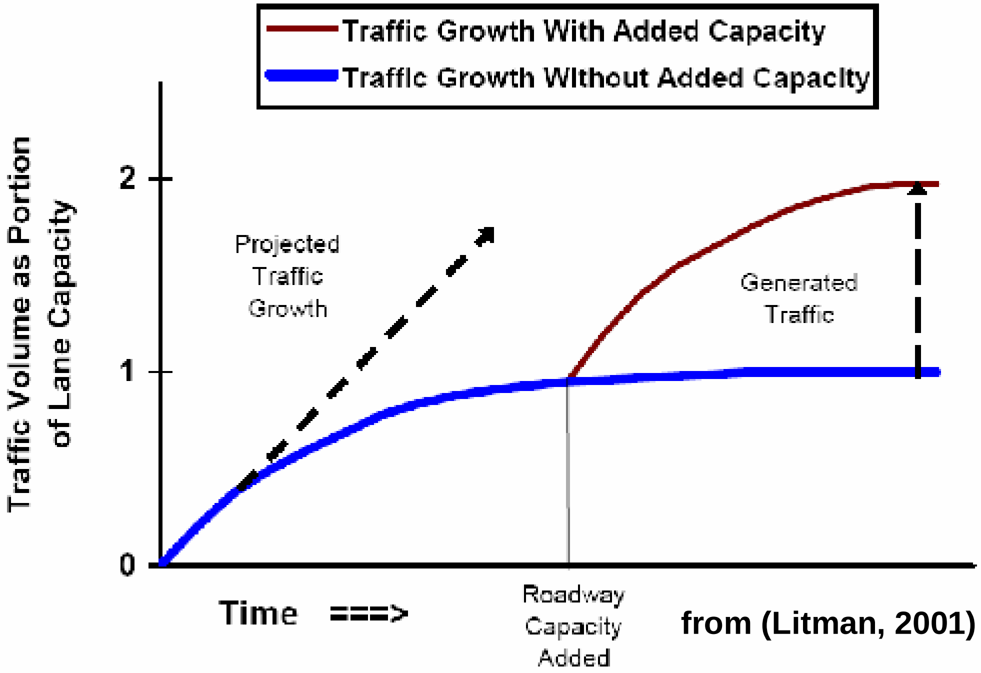
- ***Manage Supply:***
  - **build more lanes to increase roadway capacity**
  - **build more infrastructure for alternative modes (bike, rail, transit)**
    shown to be more cost effective (Lipman, 2006)
  - **improve system operations (e.g., respond quickly to incidents)**
  - **implement *intelligent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

United States Transportation Systems

- automobile-centric
- little demand and opportunity for alternative modes
- 1950's – 1990's: major build out of roadway network
- in many areas it is now difficult to construct new roadways:
    - higher population densities
    - land-use restrictions



from (Litman, 2001)

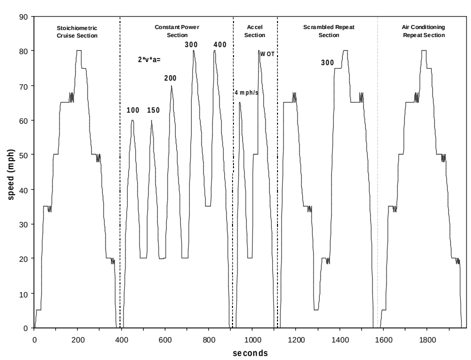
Transportation and Emissions Modeling

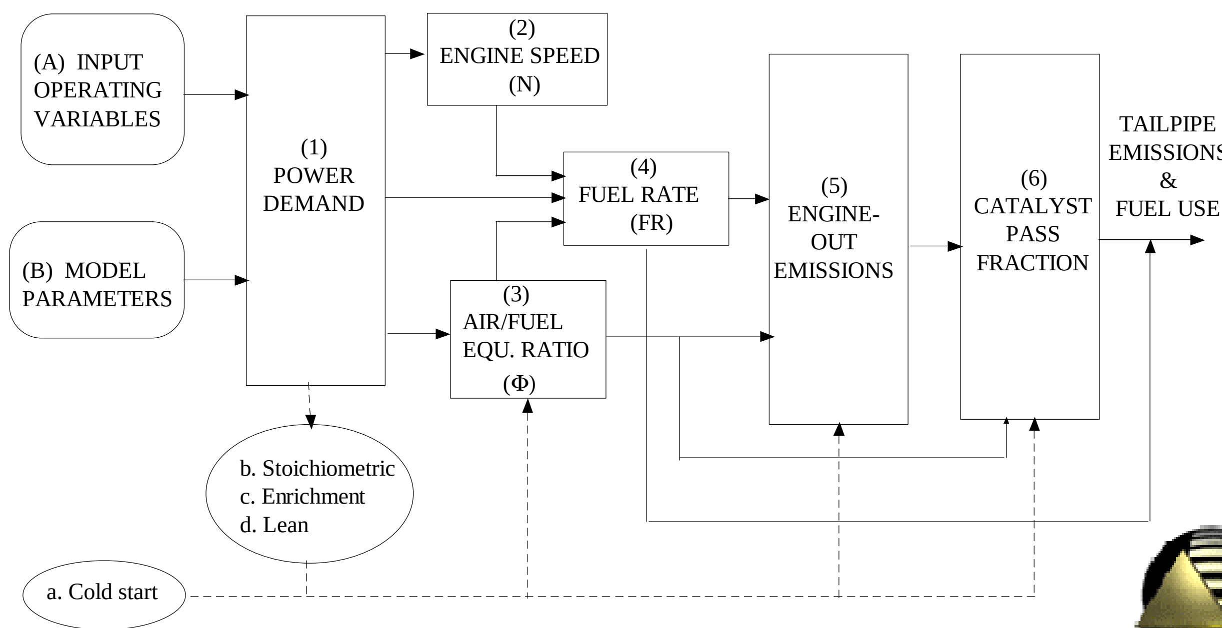
Transportation Modeling:

- **wide variety of tools: travel demand modeling, macroscale to microscale operational models**

Microscale Emissions and Fuel Consumption Modeling:

- **prediction of second-by-second emissions and fuel consumption from a wide variety of vehicles**
- **based on real-world emissions measurements using a large set of driving conditions**





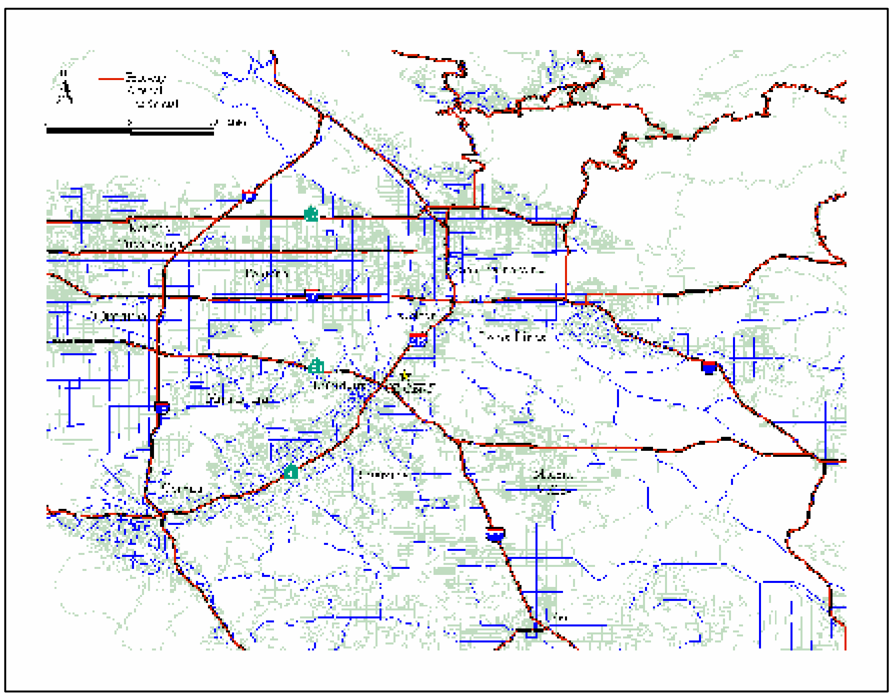
Microscopic Traffic Models

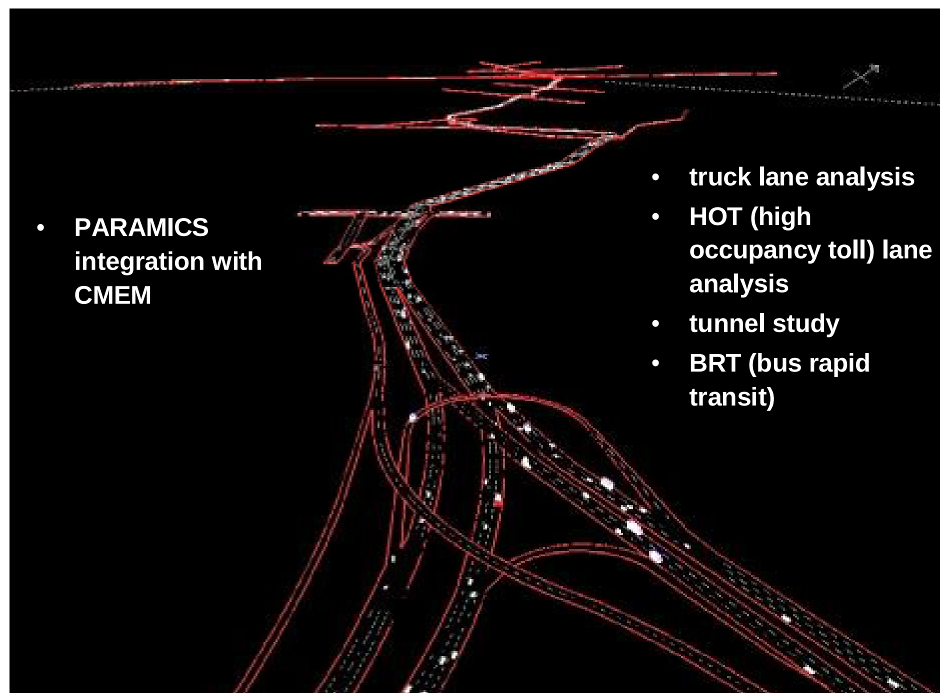
- models individual behaviors of vehicles:
  - car following behavior
  - lane-change behavior

$$\ddot{x}_{n+1}(t+\Delta t_{n+1}) = S_{n+1}\frac{[\dot{x}_n(t)-\dot{x}_{n+1}(t)]}{[x_n(t)-x_{n+1}(t)]}$$

$$\Delta t_{n+1} = reaction\,delay$$

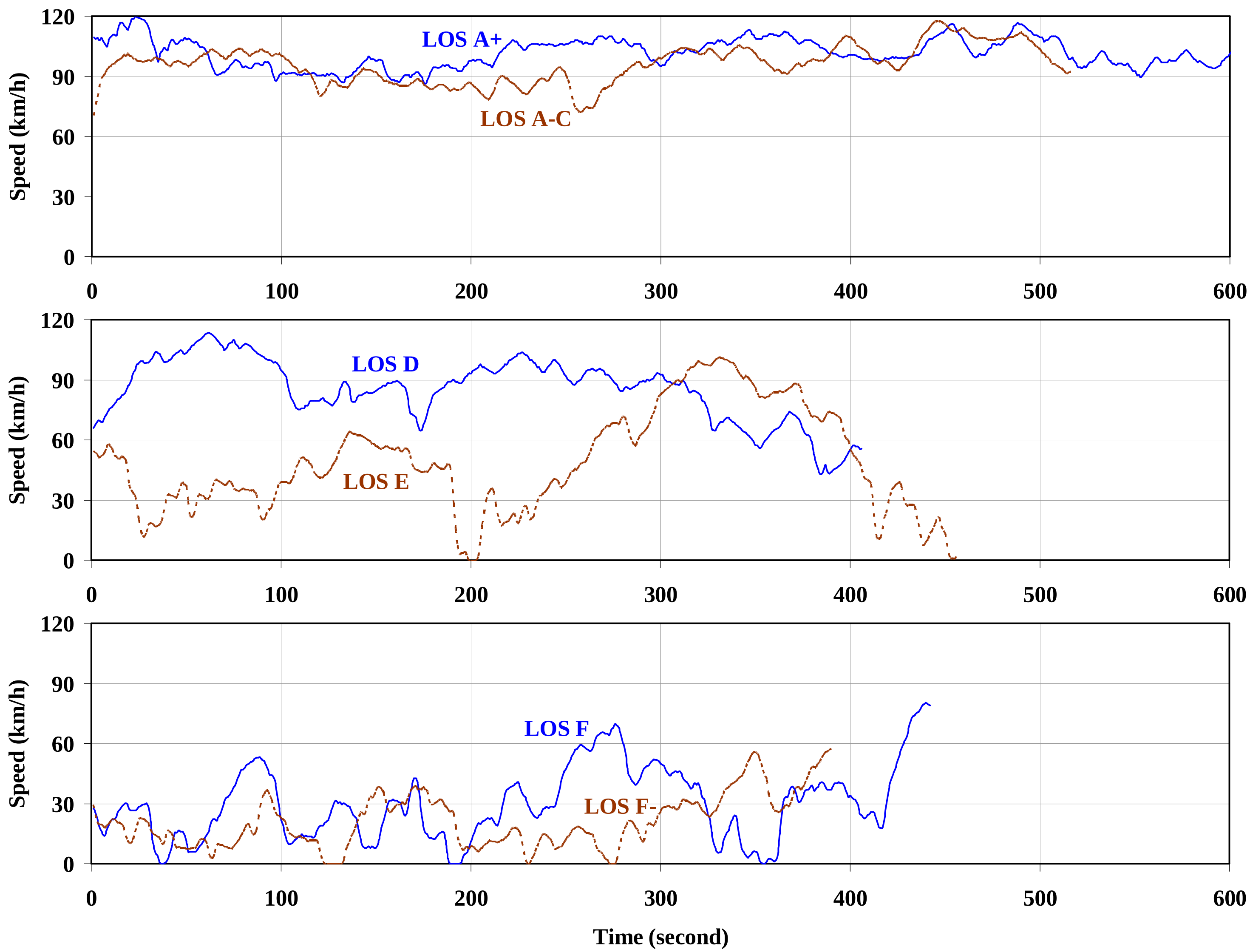
S_{n+1}: aggressive or passive behavior parameter





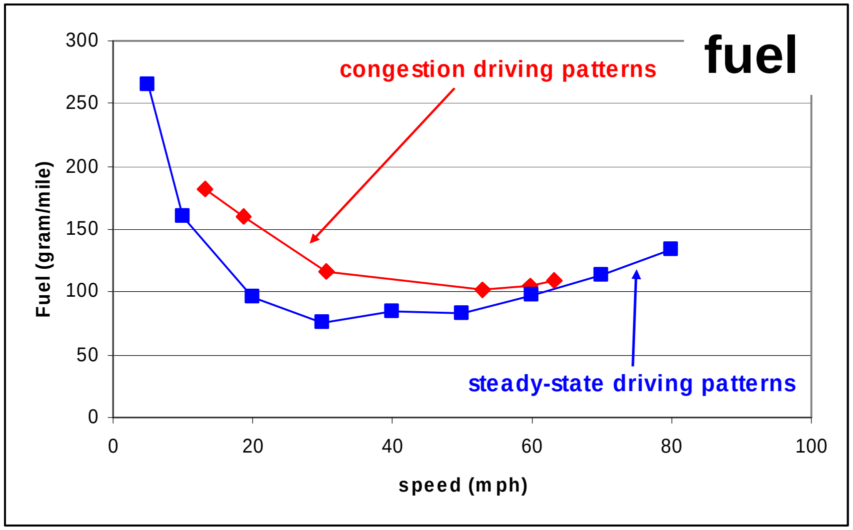
Roadway Congestion

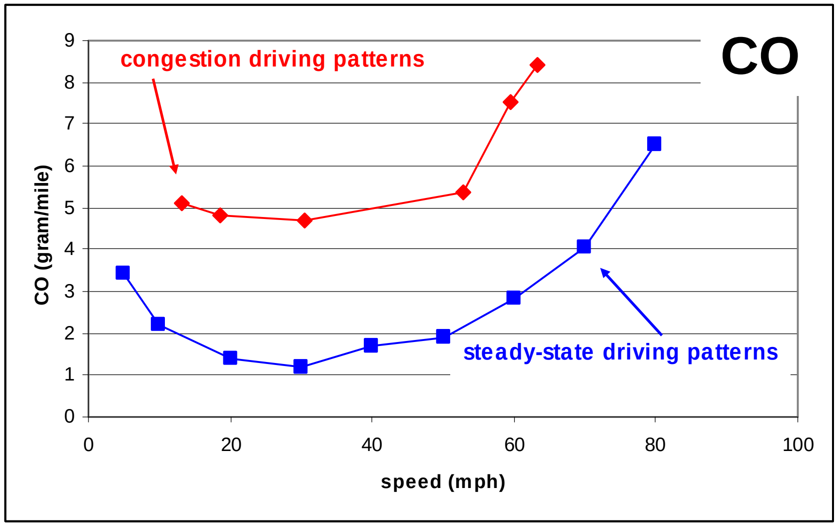
- Roadway congestion is often categorized as different "levels of service" (LOS)
- grades A – F: corresponds to traffic density

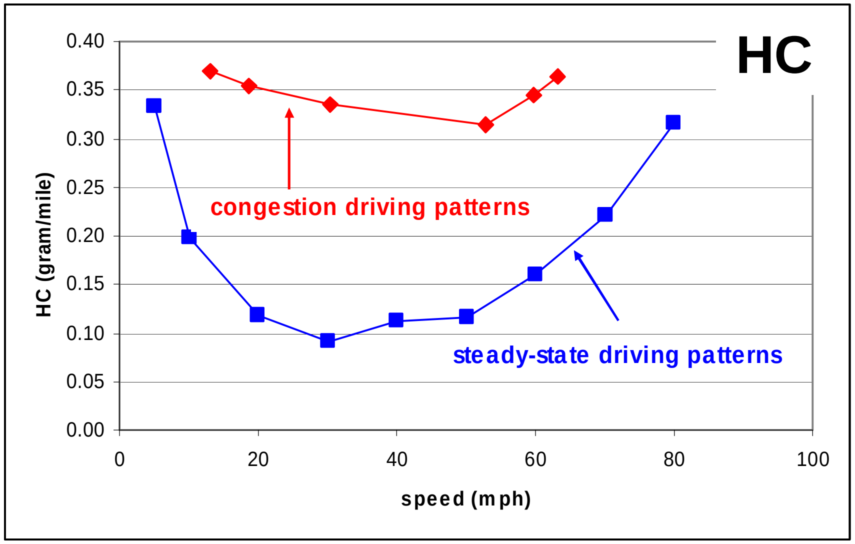


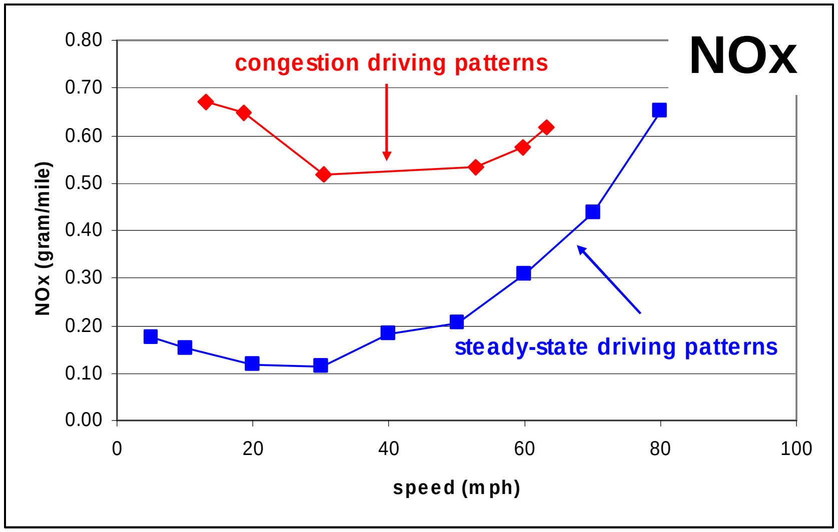
Congestion-Based Fuel Consumption and Emissions

- can plot as a function of average speed





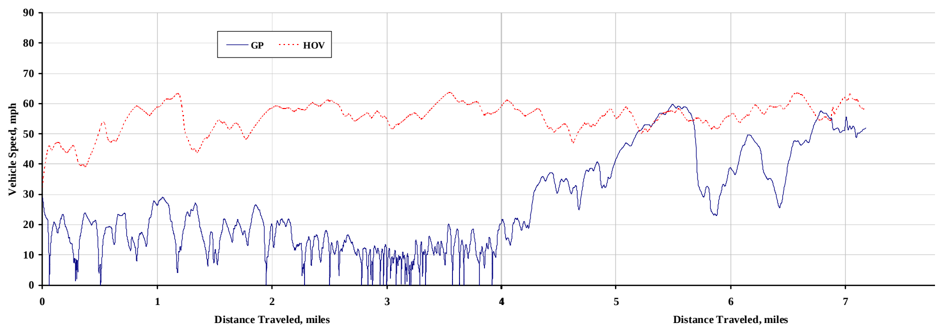


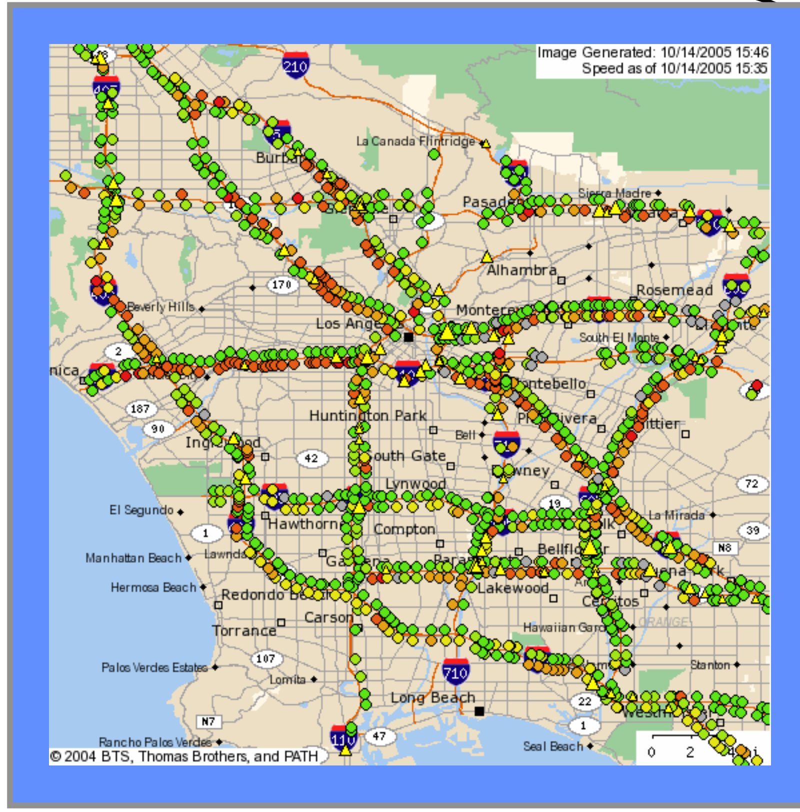


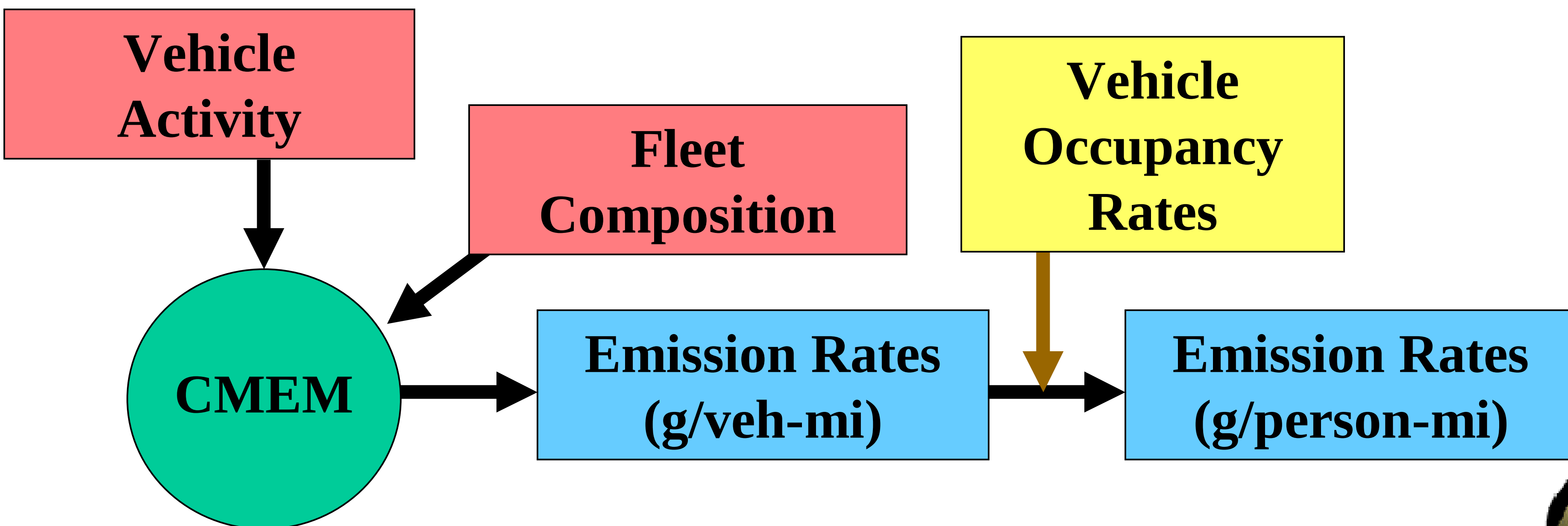
Congestion-Based Fuel Consumption and Emissions

- **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)**

Air Quality Impacts of HOV Lanes

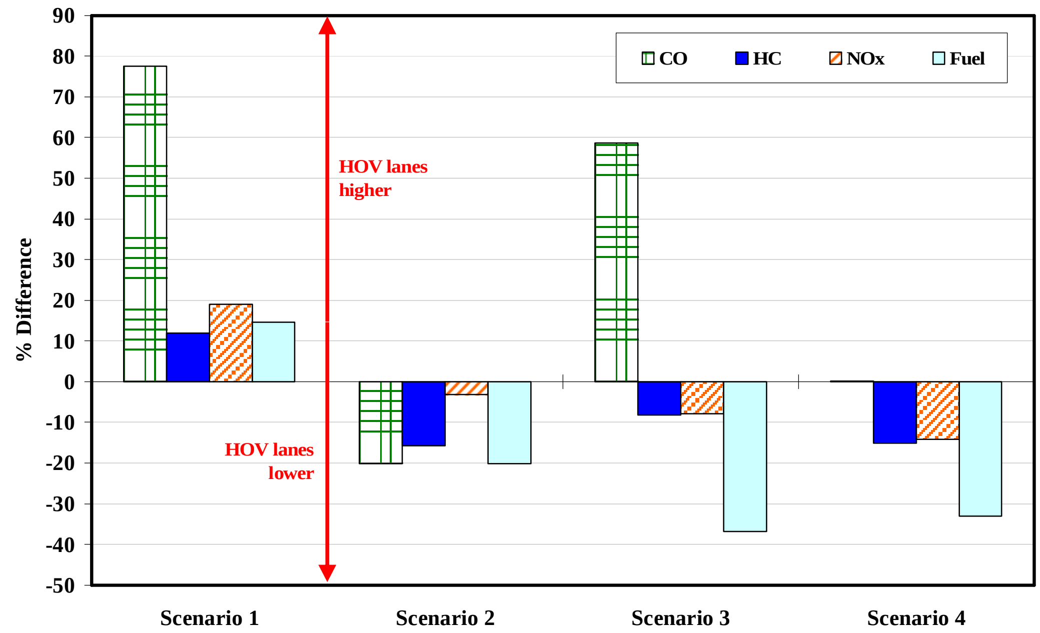




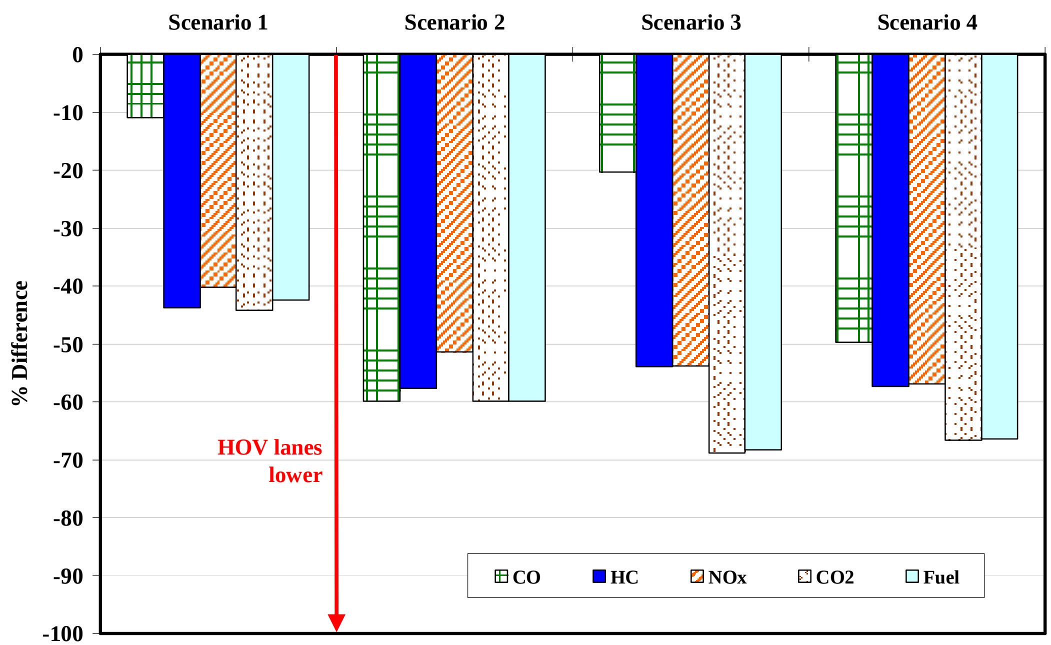


Emissions Comparison of HOV with Mixed Flow

Emissions & fuel per Vehicle Mile



Emissions & Fuel per Passenger Mile



Scenario	Condition
1	HOV under-utilized
2	typical conditions
3	HOV well-utilized
4	HOV over-utilized

HOV Lane Air Quality Findings

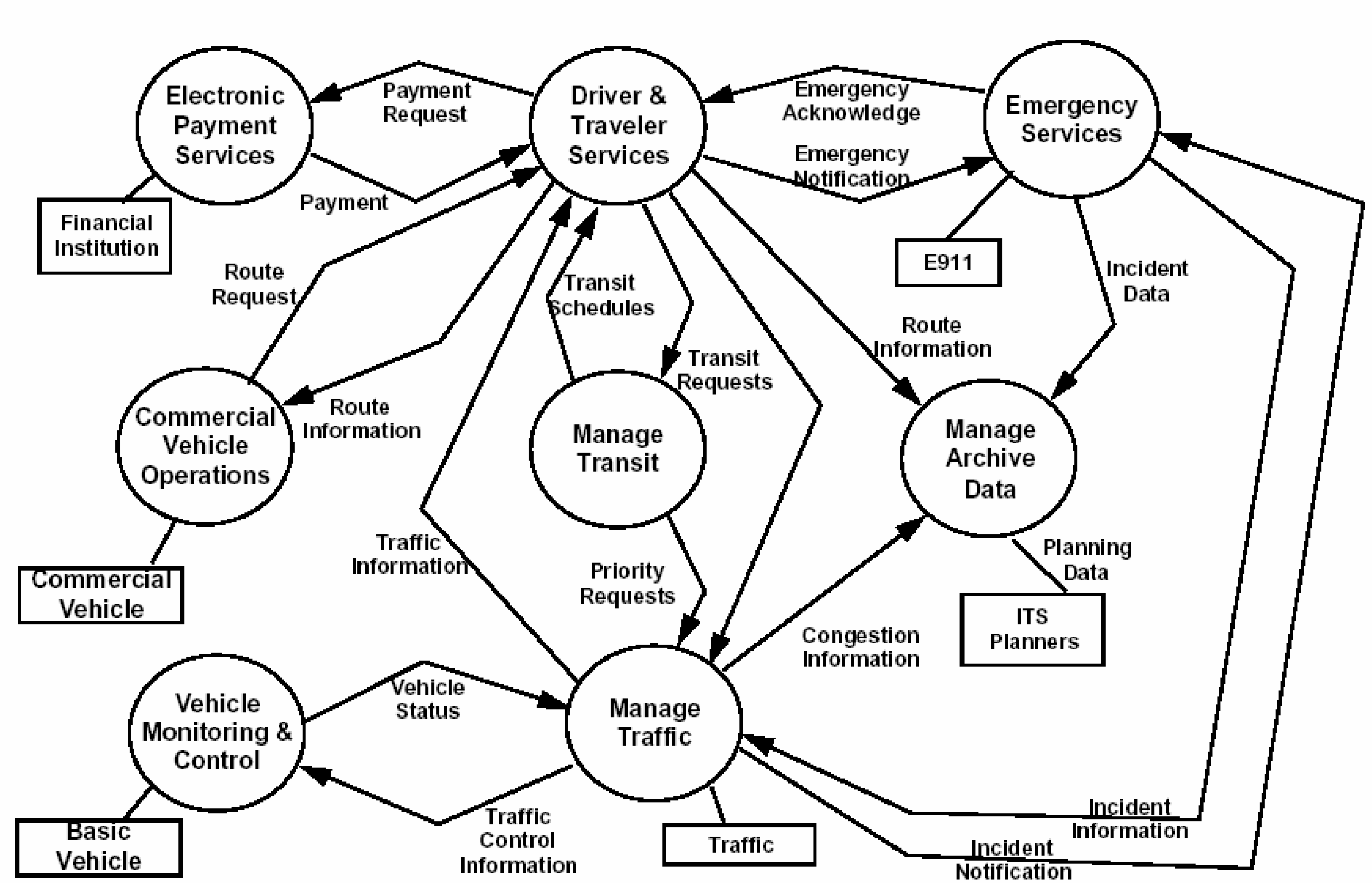
- Under the same traffic conditions, traffic dynamics in HOV lanes are not significantly different from those in mixed-flow lanes
- Travel speed in HOV lanes are relatively higher than that in MF lanes for most of the time.
- Under free-flow condition, extremely high speed travel in HOV lanes can result in higher emissions per vehicle-mile.
- With higher people-moving capacity, HOV lanes produce less emissions per person-mile across all scenarios.

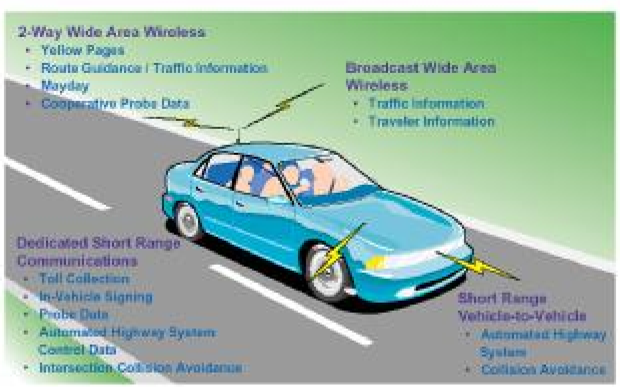
Intelligent Transportation Systems

- **improving capacity of existing infrastructure through the use of computers, communications, and control technology**

User Services Bundle	User Services
Travel and Transportation Management	• En-Route Driver Information • Route Guidance • Traveler Services Information • Traffic Control • Incident Management • Emissions Testing and Mitigation • Demand Management and Operations • Pre-trip Travel Information • Ride Matching and Reservation • Highway Rail Intersection
Public Transportation Operations	• Public Transportation Management • En-Route Transit Information • Personalized Public Transit • Public Travel Security
Electronic Payment	• Electronic Payment Services
Commercial Vehicle Operations	• Commercial Vehicle Electronic Clearance • Automated Roadside Safety Inspection • On-board Safety Monitoring • Commercial Vehicle Administration Processes • Hazardous Materials Incident Response • Freight Mobility
Emergency Management	• Emergency Notification and Personal Security • Emergency Vehicle Management
Advanced Vehicle Control and Safety Systems	• Longitudinal Collision Avoidance • Lateral Collision Avoidance • Intersection Collision Avoidance • Vision Enhancement for Crash Avoidance • Safety Readiness • Pre-Crash Restraint Deployment • Automated Highway System

Intelligent Transportation Systems





Example ITS Application: 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:

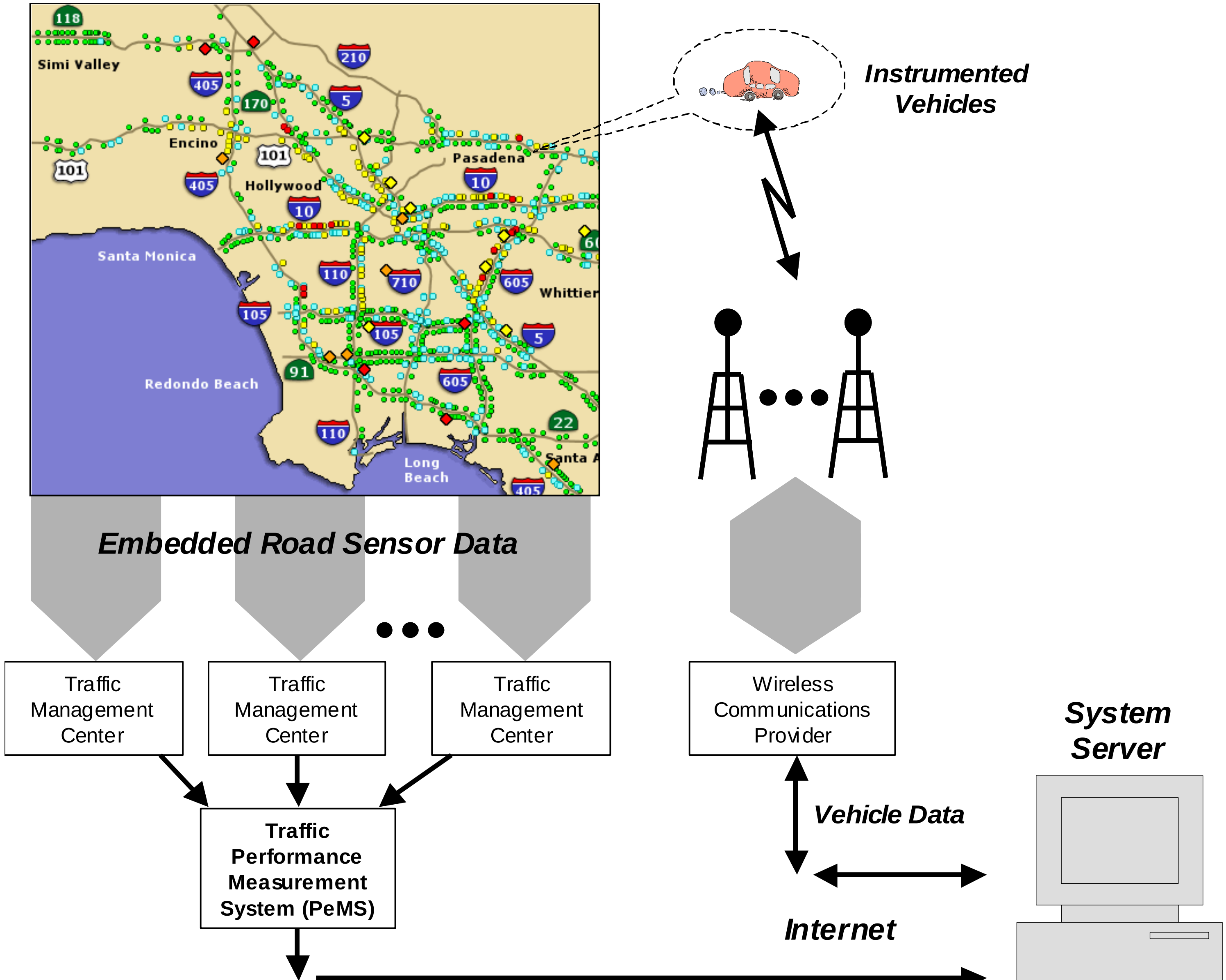
- ***fixed:*** **max permissible speed is set by the user; control system never exceeds this;**
- ***variable:*** **set speed is determined by vehicle location, where different speed limits are set spatially**
- ***dynamic:*** **speed is determined by time and location: temporal aspect varies based on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

Driving Behavior Intervention:

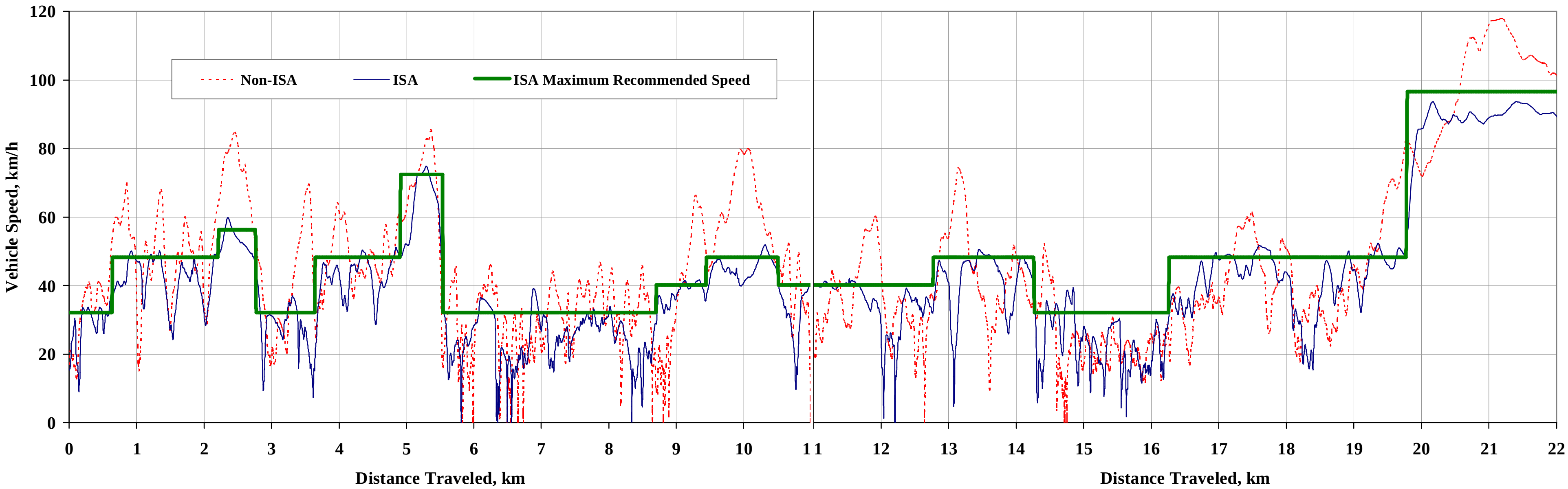
- **advisory, active support, and mandatory**

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

Intelligent Speed Adaptation Experimentation



Intelligent Speed Adaptation: Preliminary Results

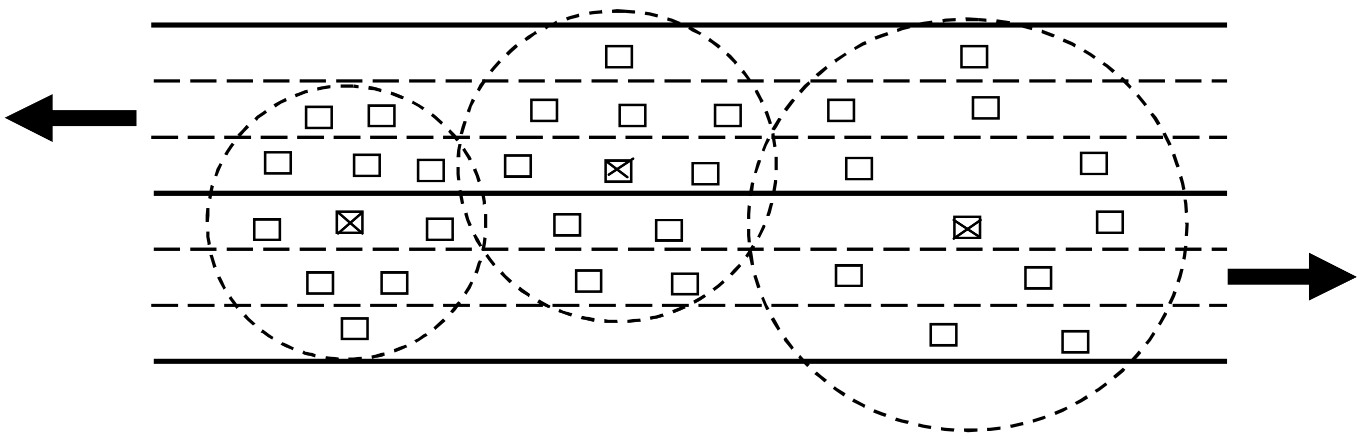


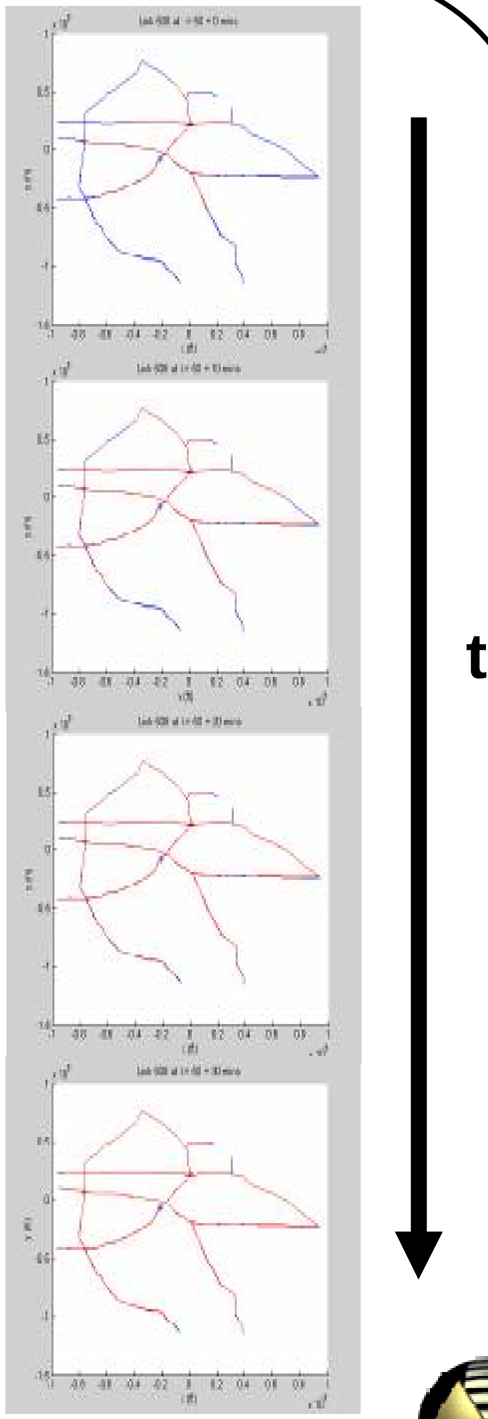
same travel time results:

Energy/Emissions	Non-ISA	ISA	Difference
CO2 (g)	5439	4781	-12%
CO (g)	97.01	50.47	-48%
HC (g)	3.20	1.90	-41%
NOx (g)	6.28	3.97	-37%
Fuel (g)	1766	1534	-13%

Vehicular Ad-Hoc Networks (VANET)

- **wireless communications vehicle-to-vehicle and vehicle-to-infrastructure is a hot research topic**
- **extension of wireless ad-hoc networking to mobile platforms**
- **many applications aimed at safety improvements**
- **other applications: self-organizing traffic information system**





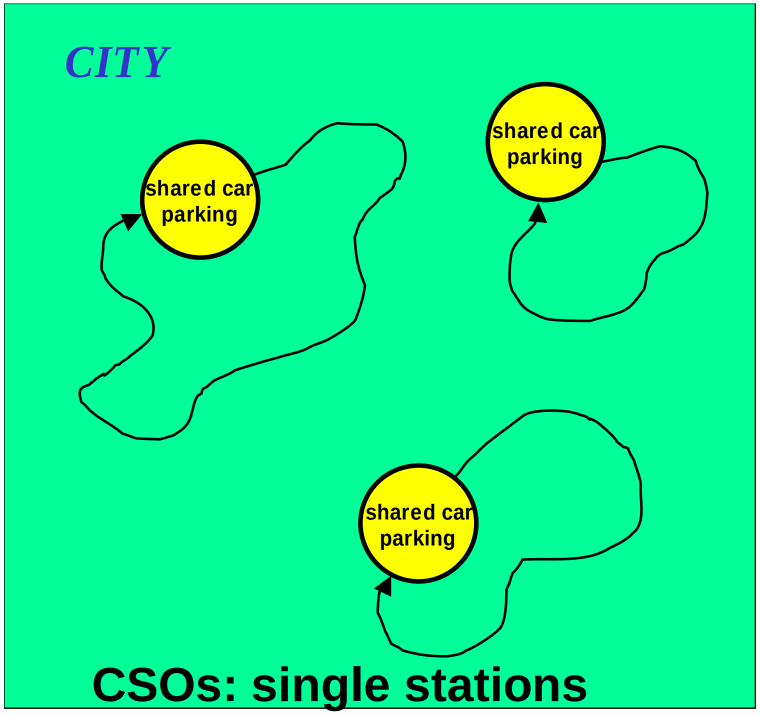
Shared-Use Vehicle Systems
(a.k.a. carsharing, station cars):

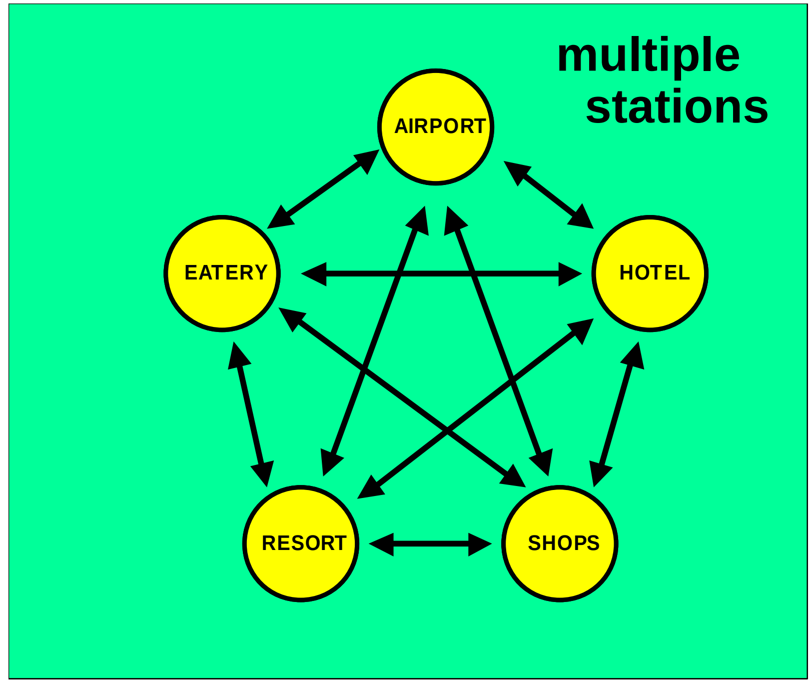
- organized short-term car rental
- joint access to a fleet of vehicles
- vehicles are used multiple times by multiple users

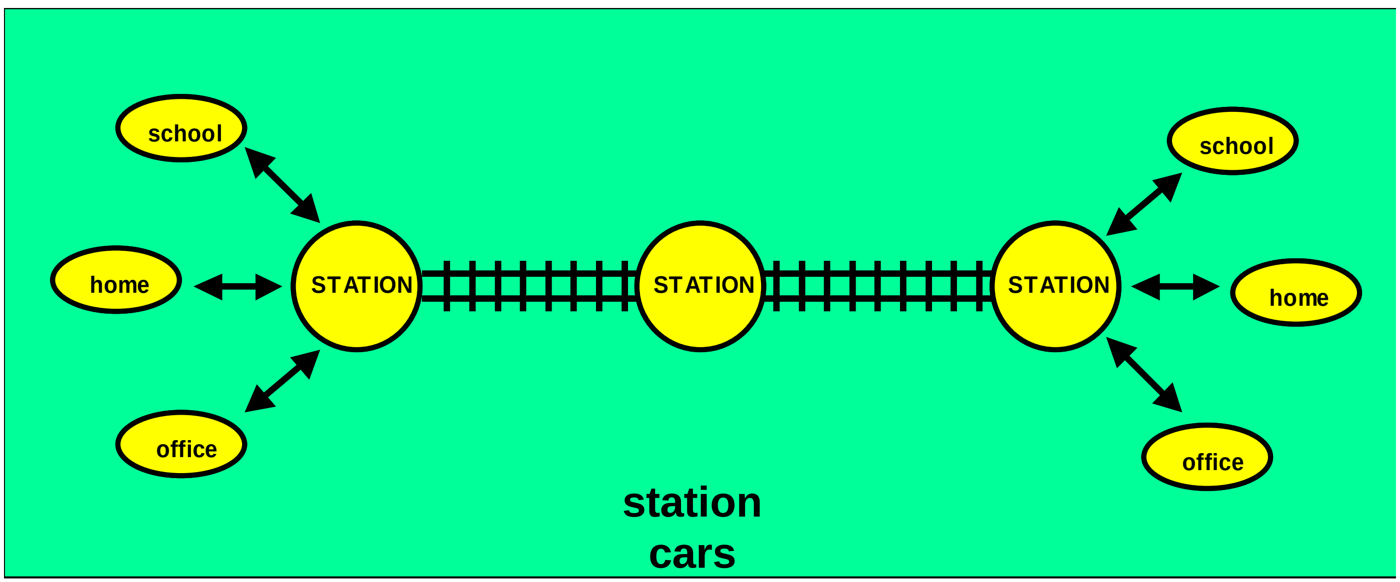
Key Benefits:

- improves transportation efficiency:
  - reduces number of vehicles to meet total travel demand
  - results in better land use
- user cost savings: vehicle payments, insurance, maintenance, etc.
- environmental benefit: lower vehicle emissions/energy
- transit ridership: improves access to transit

Primary Shared-Use Vehicle System Models







UCR Carsharing System:

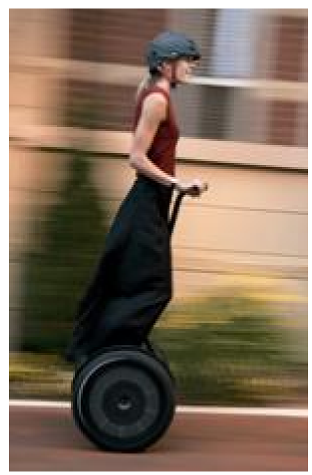
Smart Parking

- parking is costly and limited in almost every major city in the U.S., contributing to increased congestion, air pollution, and driver frustration
- ***Smart parking Management:***
  - use of advanced technologies to help direct drivers efficiently to available parking spaces
  - encourages transit ridership
  - lessens driver frustration
  - reduces congestion on roadways

- ***Approaches:***
  - dynamic displays on roadway signs informing drivers of location and parking lot capacity
  - the Internet, and cell phones: providing space availability, location, and pricing information

- ***Transit Oriented Developments:***
  - **promote transit use through the integration of multiple transit options in high-density developments consisting of residential, commercial, and retail entities**
- ***Bus Rapid Transit:***
  - **non-fixed rail transit system**
  - **significantly less expensive then light-rail**

- ***Innovative Mobility Modes:***



Summary and Future Directions

- Congestion will always be with us (induced demand effect)
- Necessity to go beyond an automobile-centric society
- Emissions: pollutant emphasis shift from cars to trucks to trains/ships
- Future Vehicles: hybrid electrics will continue to play an important role well into the future
- Application of Intelligent Transportation Solutions
- Increased automation in transportation