Vehicle Emissions Modeling in the U.S.A.

February 21, 2002

3rd Japan Clean Air Program Conference
Tokyo, Japan

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Presentation Outline

- Conventional Vehicle Emissions Modeling
  - U.S. EPA's MOBILE Model
  - California Air Resources Board's EMFAC Model
- Vehicle Emissions Modeling Across Different Scales
- Modal Emission Modeling
- Integrating Transportation and Emission Models:
  - TRANSIMS
  - MEASURE
  - ITEM
  - MOBILE6
- Supporting Data Collection
- U.S. EPA's New Generation Model

Conventional Vehicle Emission Models in the U.S.

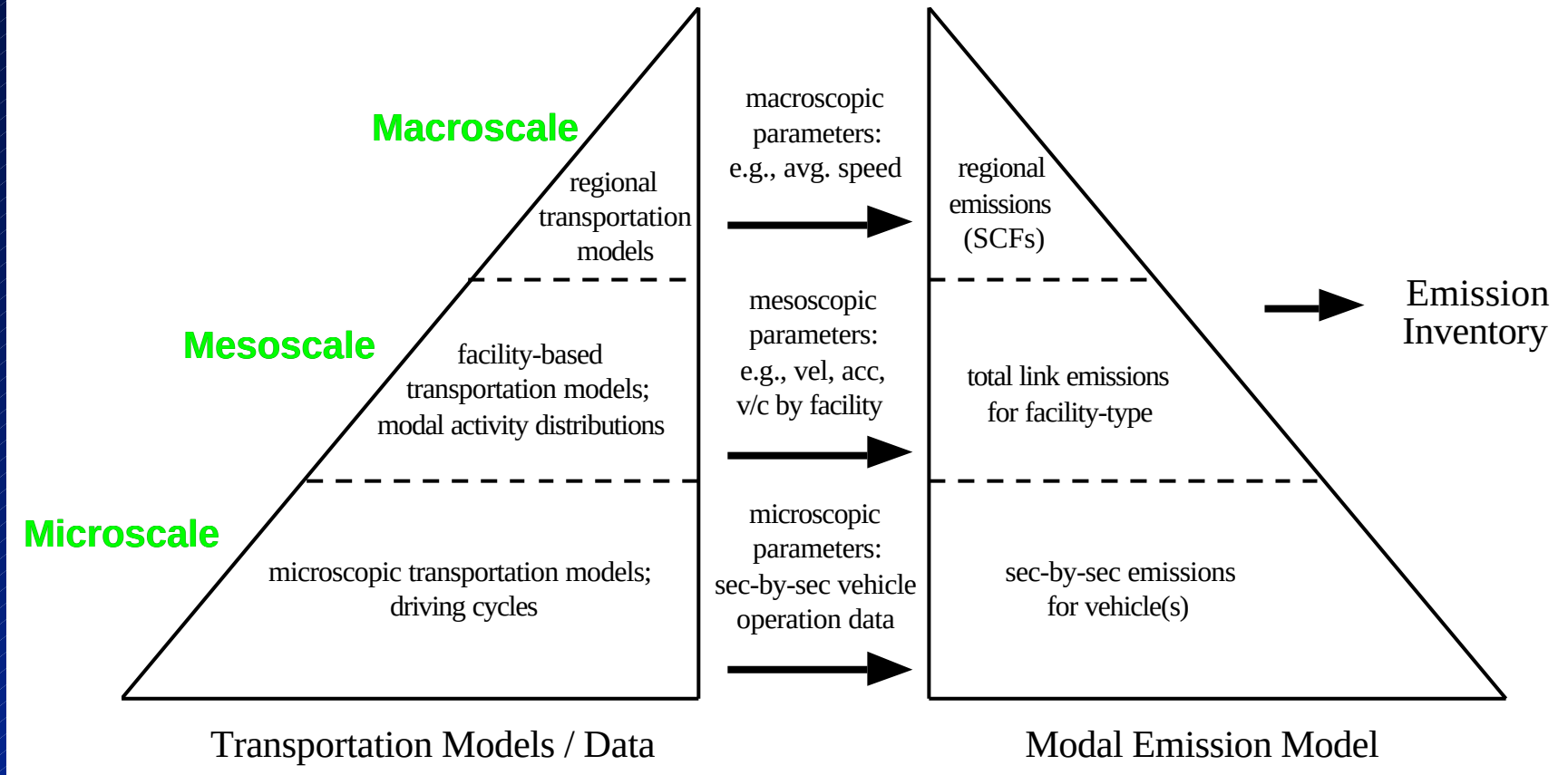
- MOBILE Model
  - developed in the late 1970's by U.S. Environmental Protection Agency
  - has undergone significant expansion, improvements over the years
  - uses method of base emission rates and correction factors
  - latest version is MOBILE6, just released (2/02)
- California Air Resources Board's EMFAC Model
  - developed separately from MOBILE by CARB
  - based on stricter standards and fuels used in California
  - uses similar methodology as MOBILE
  - recent version is EMFAC2000

EPA MOBILE model

- Originally designed to estimate mobile source emission inventories to compare impact of control strategies
- Over the years, an increasing number of requirements have been placed on MOBILE (CAAA, ISTEA, NEPA,…)
- MOBILE now has six general application areas:
  - *National/Regional Regulatory Strategies*
  - *Evaluation of Control Strategies/Emission Inventory/Rate of Progress*
  - *State Implementation Plan Demonstration of Attainment*
  - *Transportation Conformity/Evaluation of Transportation Impacts in non-attainment areas*
  - *Transportation Control Measure Effectiveness*
  - *National Environmental Policy Act/Evaluation of Capital Investments*
- Applications at various temporal and spatial resolutions

Emissions Modeling Framework

- MOBILE (and EMFAC) have some significant deficiencies for what it is being asked to do
- A set of models (with a guidance document) is a better approach:
  - *Macroscale Aggregated Regional Emissions Model*
    - used to perform comparisons of some control strategies
    - determine significance of mobile source vs. other source emissions
  - *Mesoscale Integrated Transportation/Emissions/Air Quality Model*
    - tightly integrates transportation/emissions/air-quality models
    - handles higher level of detail in traffic operating conditions, etc.
  - *Microscale Instantaneous or Modal Emissions Model*
    - can be combined with microscale traffic simulation models
    - can serve as foundation of other emission models



Transportation/Emissions Modeling Framework

Other Vehicle Emission Modeling Methods

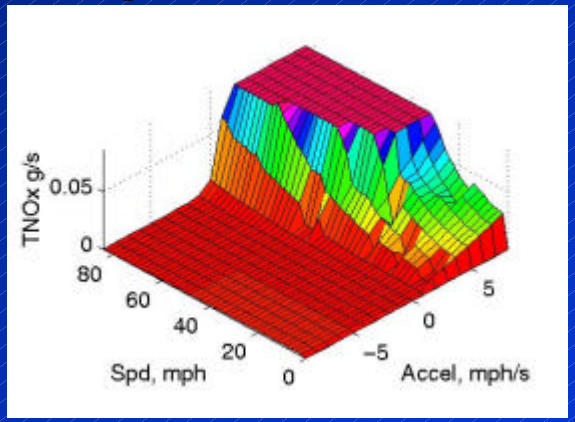
- Array of new modeling techniques developed in late 1990's:

- Fuel-Based Emission Inventories
  - normalizes vehicle emissions to fuel consumption, not VMT
  - requires estimates of fuel use, e.g., from fuel tax
  - generates reasonable emission inventories for large databases

- Modal and instantaneous vehicle emission models:
  - concerned with estimating emissions as a function of vehicle operating mode, (e.g., idle, acceleration, cruise, deceleration)
  - predicts emissions second-by-second

- Integrated Transportation and Emission Models:
  - microscale and mesoscale

Modal Emissions Modeling Techniques



- **Speed Lookup Tables:**

- **Neural-Network-Based Vehicle Emissions Models**
  - uses neural network architecture
  - trains network using emissions data
  - results are only as good as what has been trained

- **Aggregate Modal Emission Models**
  - uses statistical techniques to predict emissions from database
  - hierarchical tree-based regression analysis applied to database
  - predicts total emissions for integrated driving cycle
  - basis of Georgia Tech's MEASURE model

Modal Emissions Modeling Techniques (cont.)

- Physical Instantaneous Emissions Models
  - divides emissions creation process into physical phenomena
  - models each phenomena as separate modules
  - modules are calibrated with empirically-derived parameters
  - basis of Comprehensive Modal Emissions Model (CMEM)

- Other Issues:
  - Validation: some models have undergone rigorous validation, others haven't
  - History Effect: instantaneous emissions depend on previous vehicle operation

The Development of the Comprehensive Modal Emissions Model (CMEM)

- began as National Cooperative Highway Research Program Project: (1995 - 2000)
- currently being enhanced and improved (2000 – present) with EPA funding
- based on significant amount of emissions data from a wide range of vehicles
- over 100 other groups now using CMEM for specific analysis

Objective:

to develop and verify a modal emissions model that accurately reflects light-duty vehicle emissions produced as a function of the vehicle's operating mode.

CMEM Major Development Tasks:

- collect existing data and literature from related work
- define vehicle/technology groups
- develop dynamometer emission testing protocol
- conduct testing on large, representative vehicle sample (~350 vehicles)
- develop working model
- perform validation
- integrate developed modal emissions model into various transportation modeling frameworks
- beta test model at other institutions
- develop graphical user interface to model
- hold national symposium for potential model practitioners

CMEM Categories:

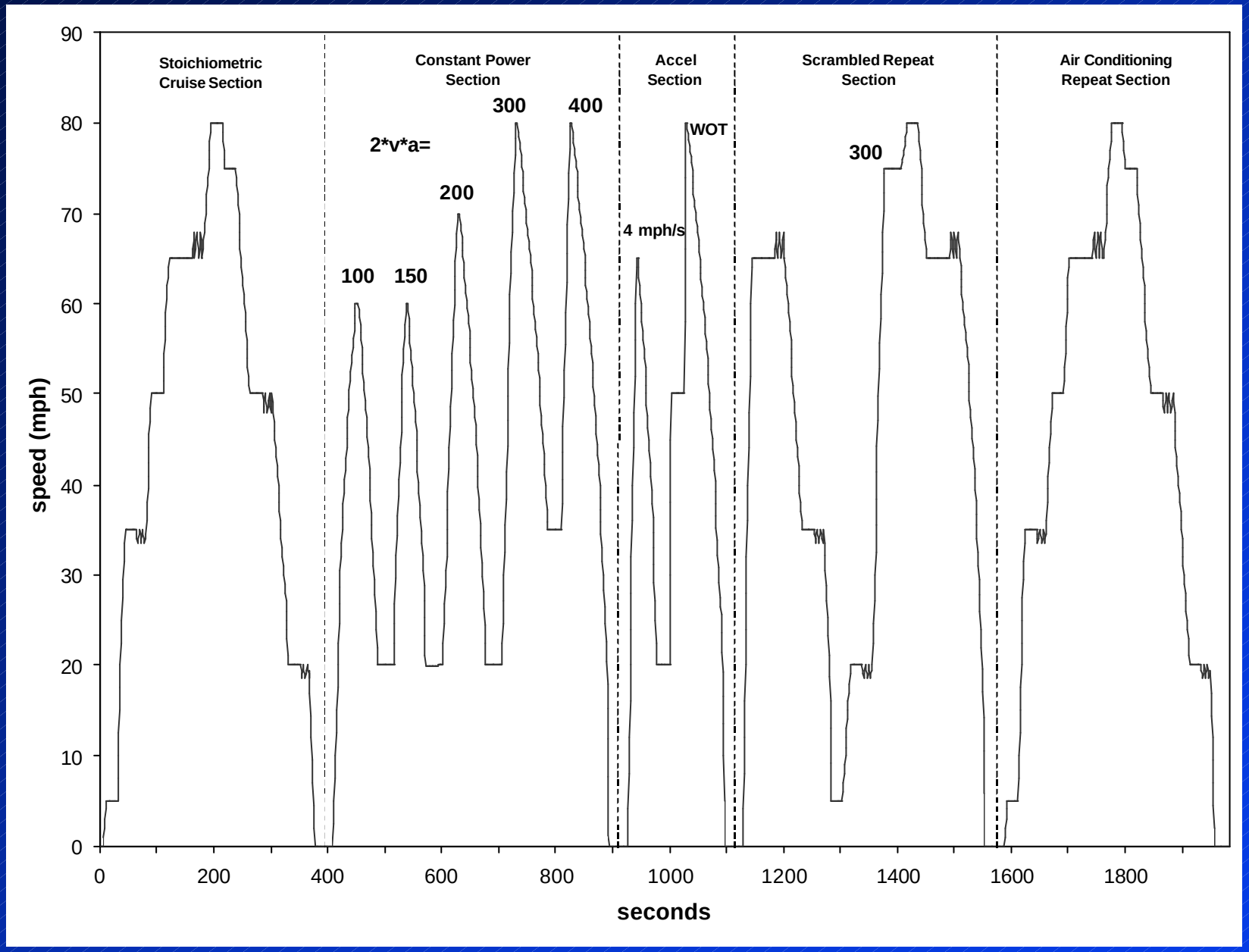
Category #	Vehicle Technology Category
	Normal Emitting Cars
1	No Catalyst
2	2-way Catalyst
3	3-way Catalyst, Carbureted
4	3-way Catalyst, FI, >50K miles, low power/weight
5	3-way Catalyst, FI, >50K miles, high power/weight
6	3-way Catalyst, FI, <50K miles, low power/weight
7	3-way Catalyst, FI, <50K 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
	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, >8500 GVW
40	Diesel powered (>8500 GVW)
	High Emitting Vehicles
19	Runs lean
20	Runs rich
21	Misfire
22	Bad catalyst
23	Runs very rich

Vehicle Testing Procedure:

- Complete 3-bag FTP test
- high-speed US06 cycle
- modal emissions cycle (MEC01)

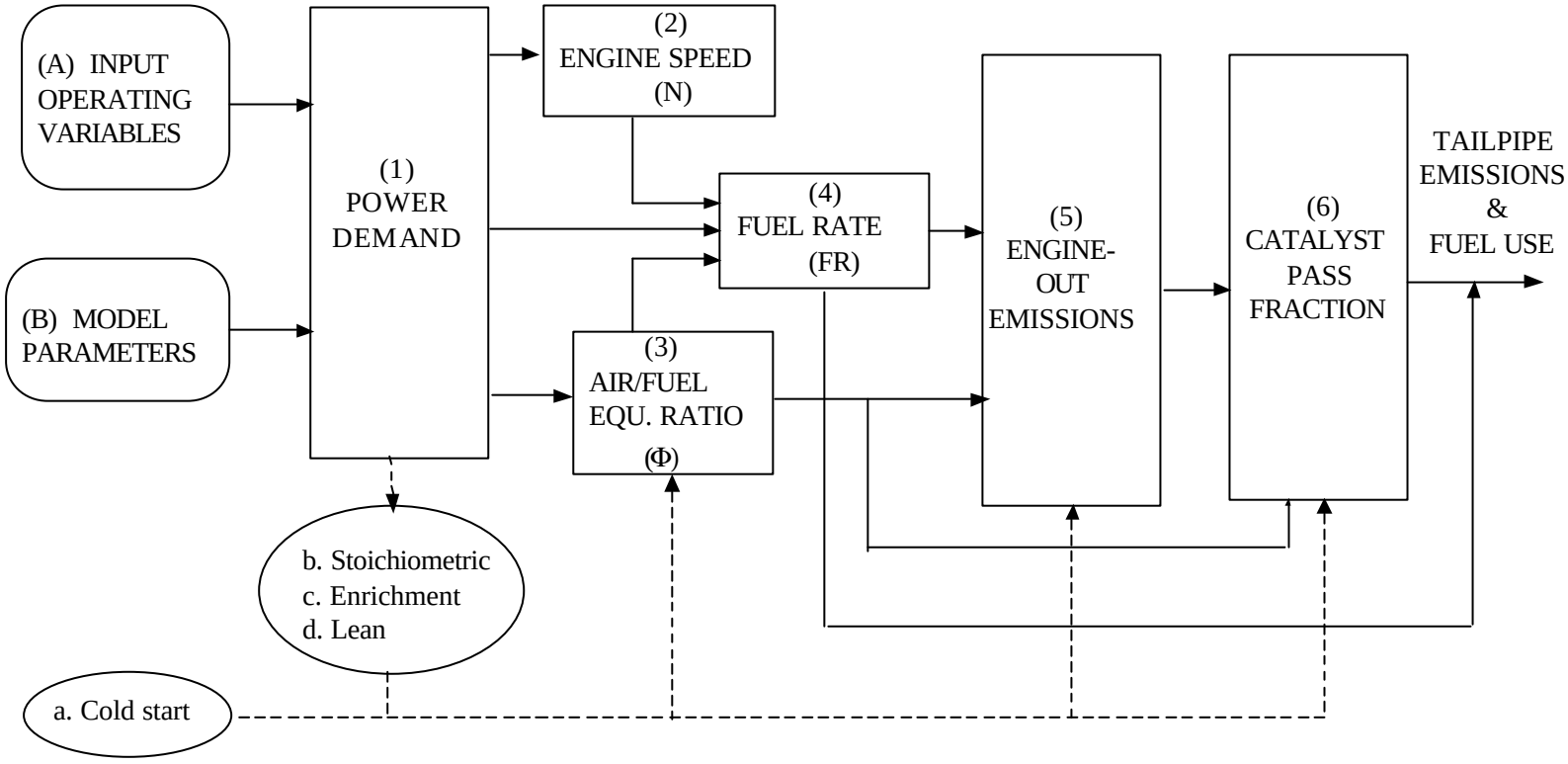
Testing Sequence:

Operation	Duration (sec)	Comments
12-hour soak		
equipment prep	1,200	20 minutes to prepare equipment
FTP Bag 1	505	cold start
FTP Bag 2	866	hot running
10 minute soak	600	engine is off
FTP Bag 3	505	warm start
FTP bag analysis	1,800	engine is off, bag gases analyzed
equipment prep	1,200	20 minutes to prepare equipment
IM240	240	bring vehicle to hot stabilized operation
US06	600	high speed driving
1 minute idle	60	allow vehicle to stabilize
MEC01	1,160	modal events
AC & Repeat Hill	760	AC and repeatability checks
bag analysis	1,800	bag gases run through analyzers
Total	11,296 (188 min)	



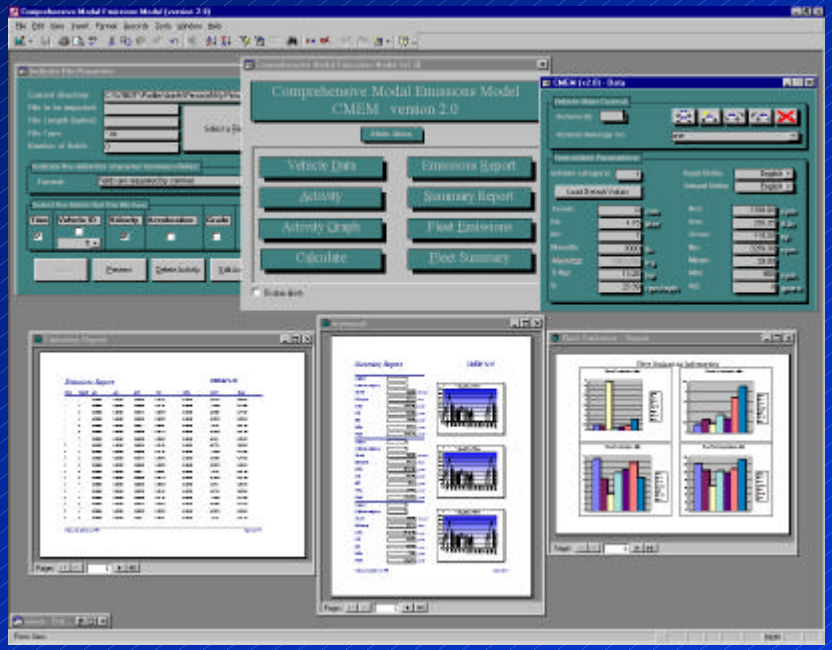
MEC01v7 driving cycle

MODEL EMISSIONS MODEL ARCHITECTURE



$$\text{tailpipe emissions} = FR \bullet \left(\frac{g_{emission}}{g_{fuel}}\right) \bullet CPF$$

Forms of the Model:



Core Model:

- command line
- UNIX, PC

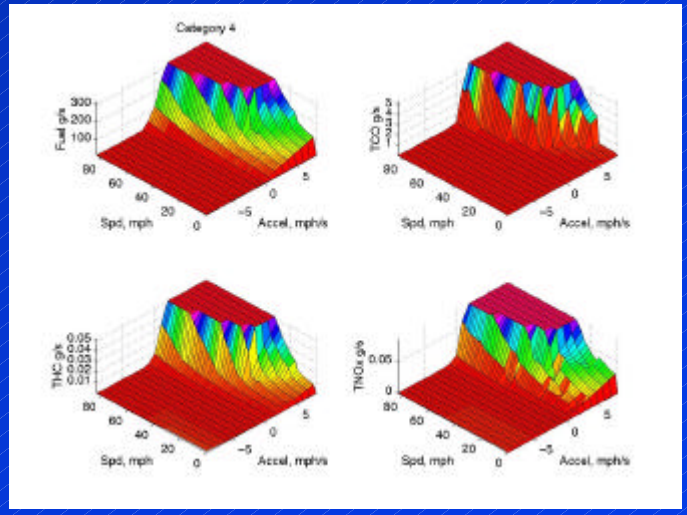
Batch Model:

- command line
- UNIX, PC

Graphical User Interface:

- MS ACCESS

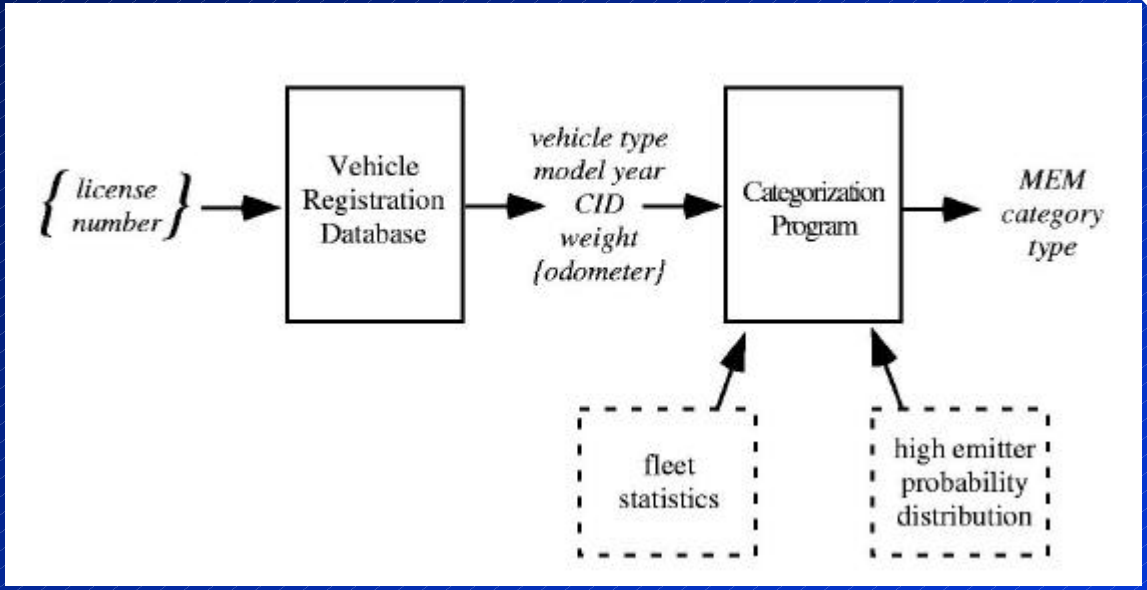
Velocity/Acceleration-indexed Lookup Tables



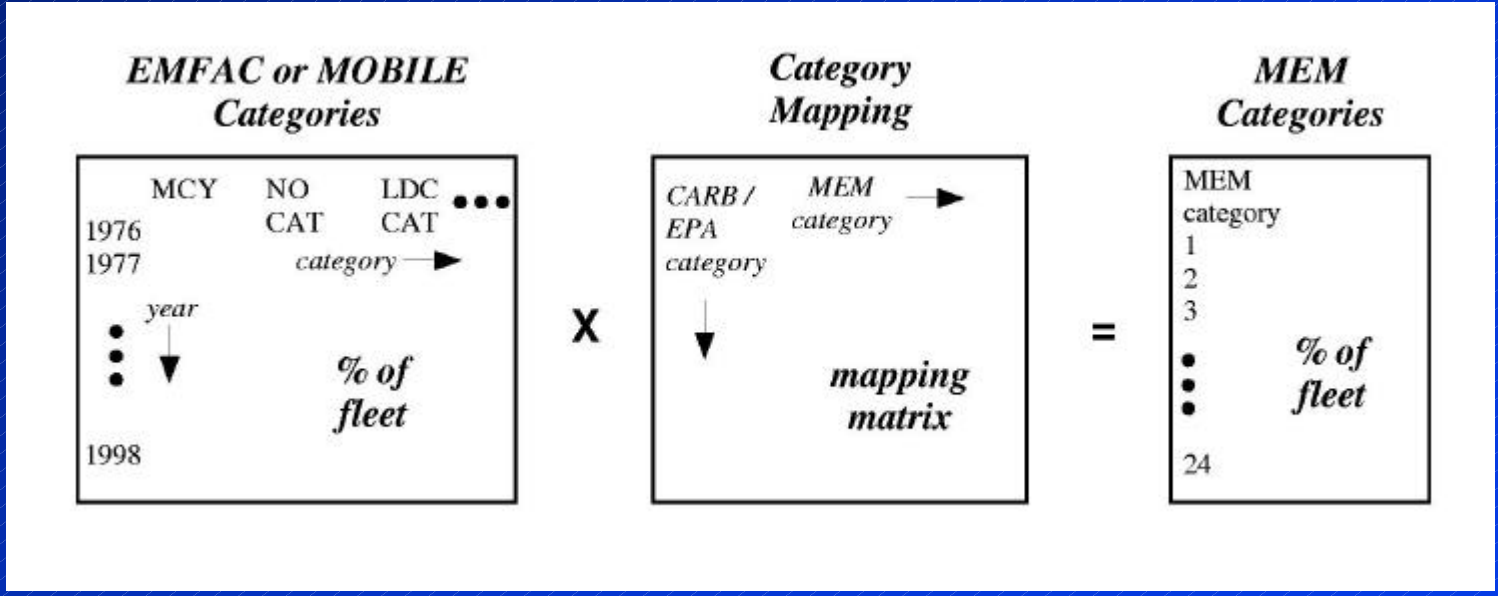
- based on core model, interpolated
- can be used by microscopic traffic simulation models

http://www.cert.ucr.edu/cmem

Vehicle Categorization:



Registration database to CMEM category type:



Integration of Transportation and Emissions Models

Key Components:

- Vehicle operating parameters (activity)
- Vehicle fleet distributions (category mappings)

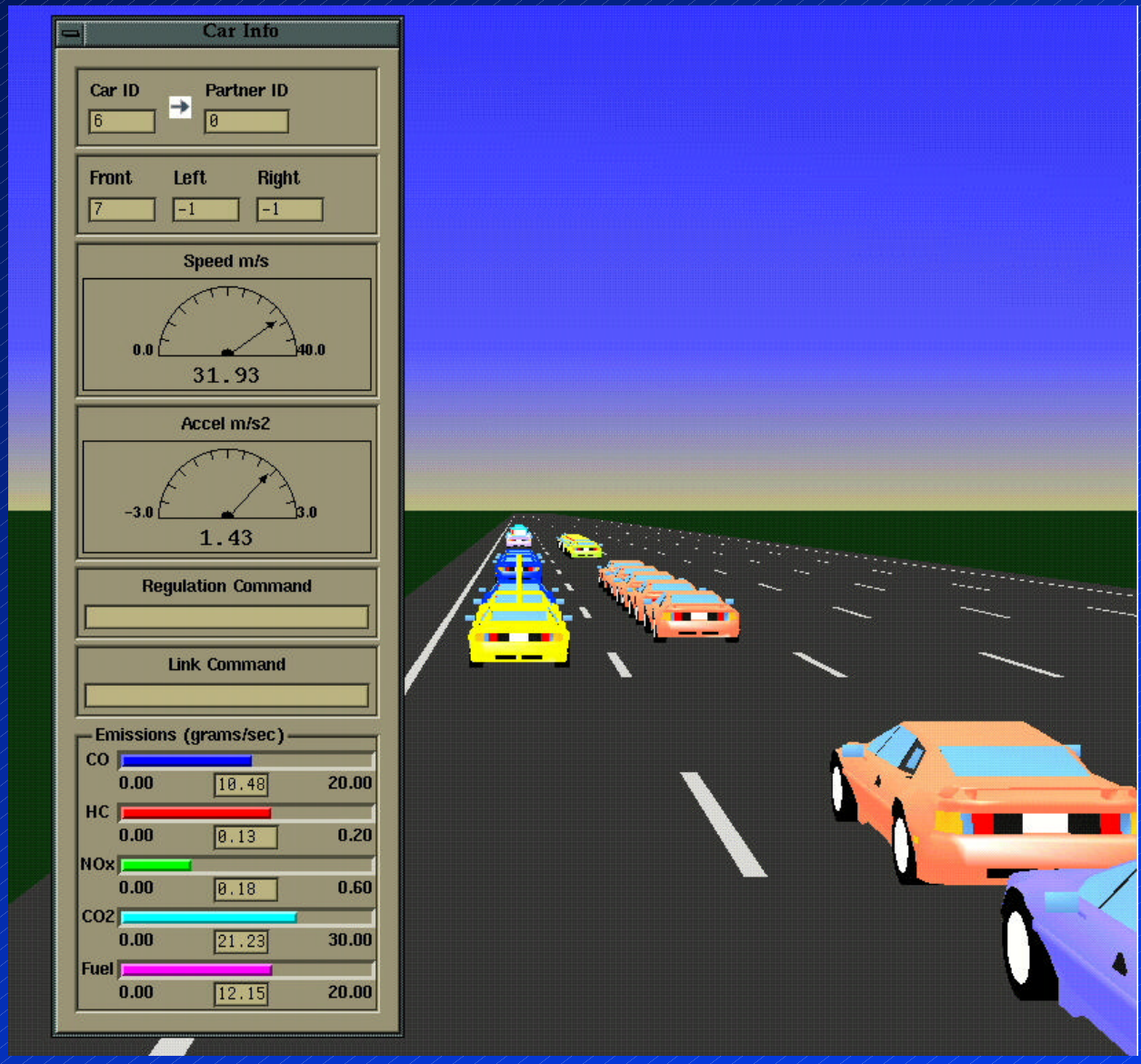
Microscale Traffic Simulation:

- Can use V/A–indexed LUTs (or specific power LUTs)
- Can use trajectory output and post-processes through core model
- Can integrate emissions module directly in traffic simulation

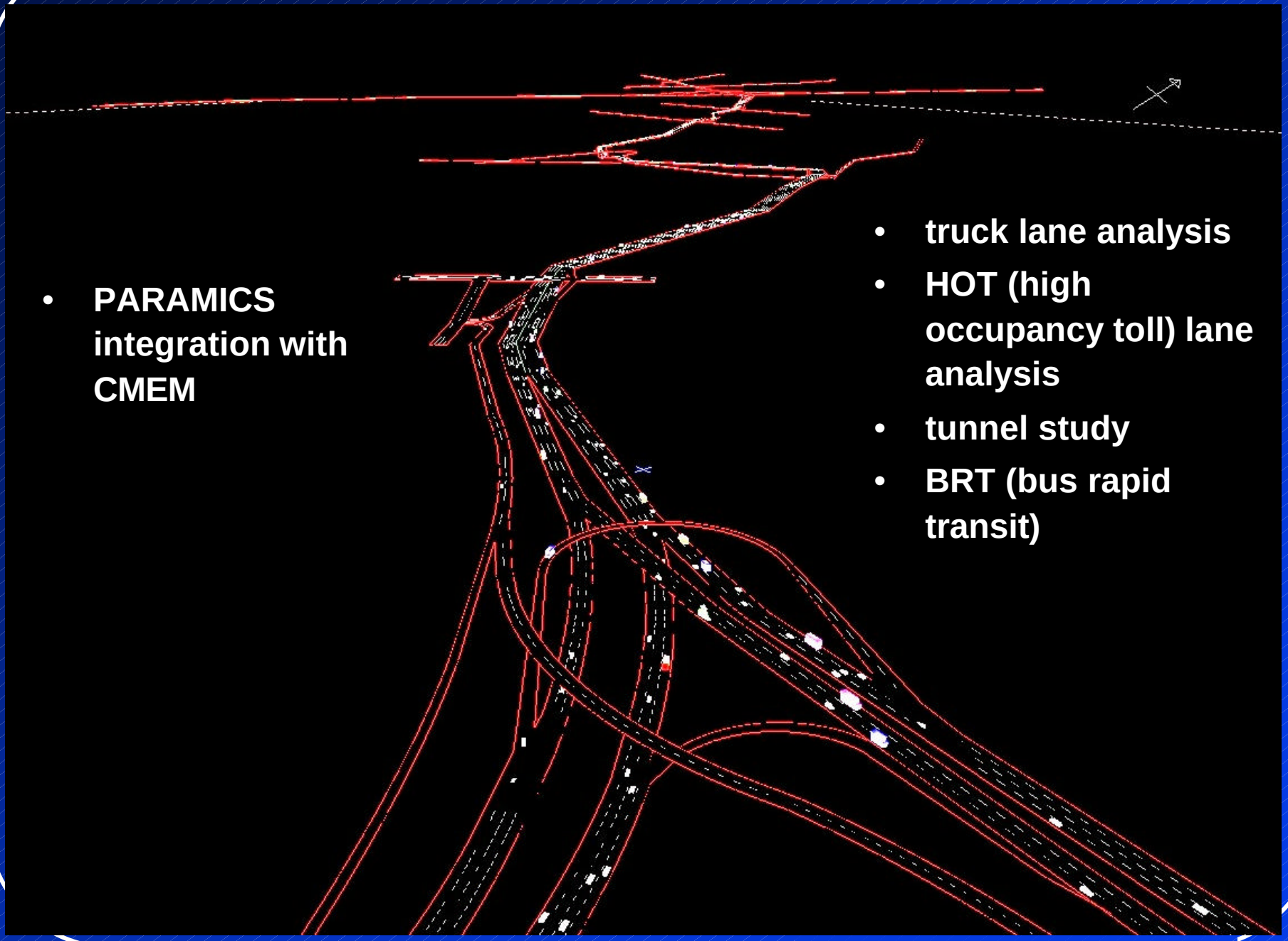
Microscale Examples:

- FHWA family: NETSIM, FRESIM, CORSIM
- Higher fidelity: Paramics, MITSIM, VISSIM
- applications: intersections, corridors, transportation control measures, intelligent transportation system projects

Example Microscale Integration:



CMEM integrated with SmartAHS/SHIFT simulator

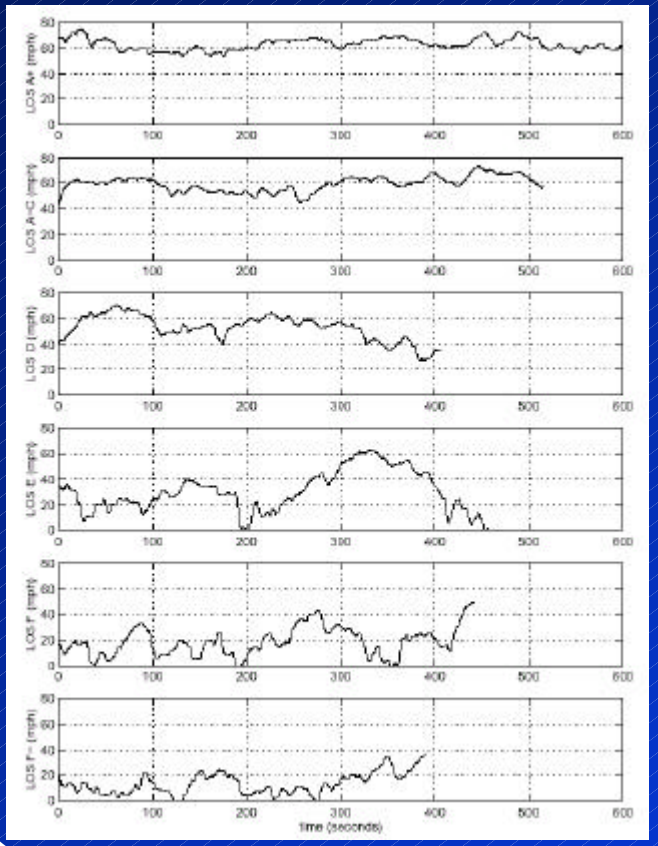


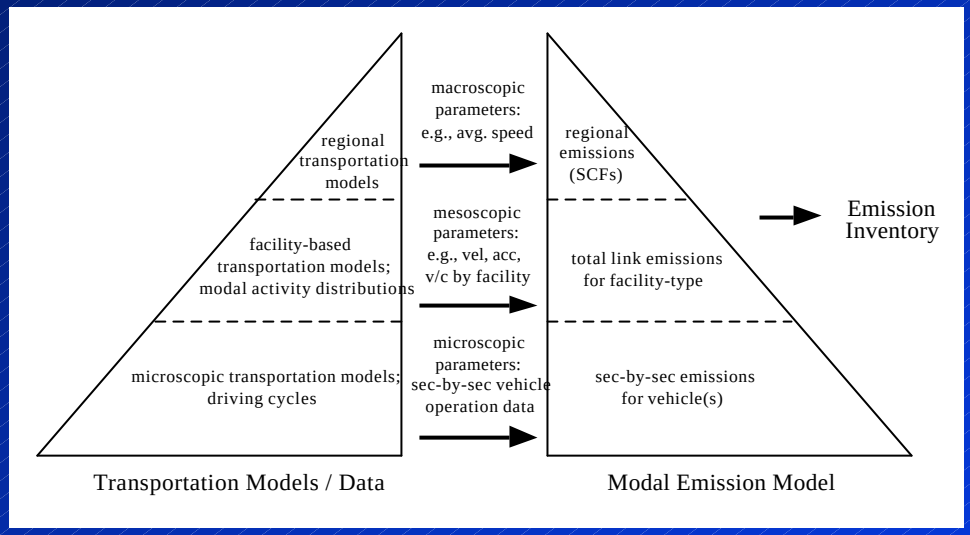
- PARAMICS integration with CMEM

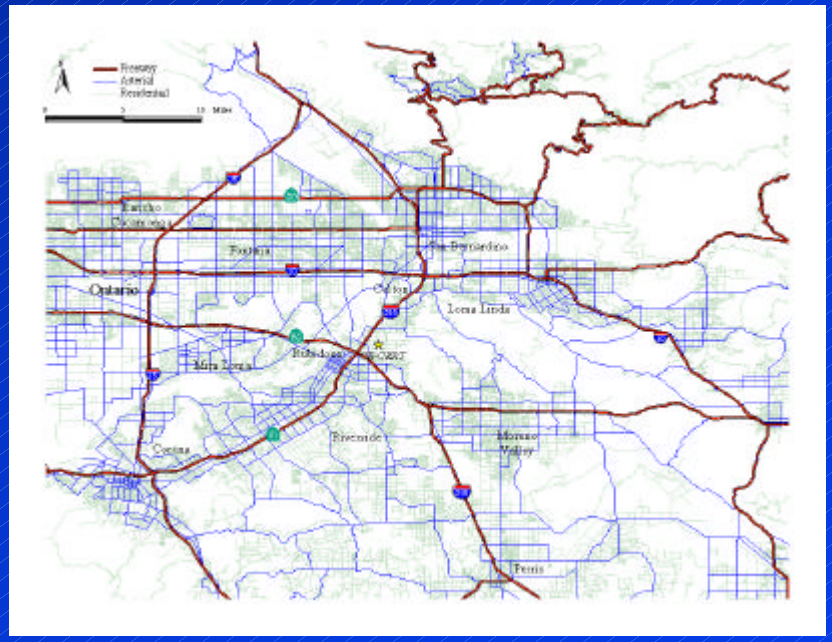
- truck lane analysis
- HOT (high occupancy toll) lane analysis
- tunnel study
- BRT (bus rapid transit)

Mesoscale Integration of Transportation and Emission Models

- Deriving “link-based” or “trip-based” emission factors
- Using specific facility-congestion cycles



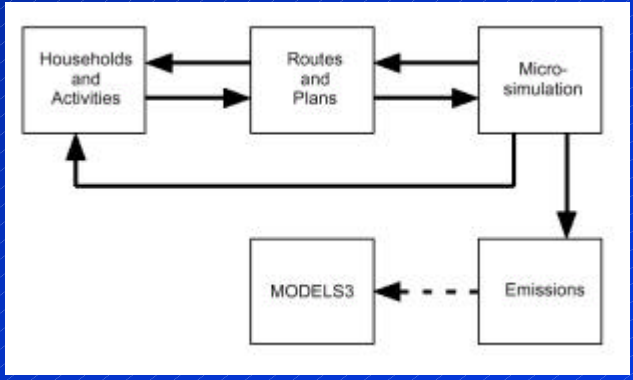




Mesoscale Integration of Transportation and Emission Models

TRANSIMS:

- Major effort aimed at fully integrating transportation and emissions modeling; considered micro- or mesoscale model
- Developed at Los Alamos National Laboratory, under Transportation Model Improvement Program (FHWA, EPA, DOE)
- Integrated components:
  - Activity based travel demand
  - Intermodal trip planning
  - Traffic microsimulation
  - Air-quality and other macro analyses



- CMEM is basis for LDV emission prediction
- Major Research issue: how to estimate emissions based on “quantum-step” velocities: use additional V/A probability distributions
- developed incrementally, latest application is Portland, Oregon
- currently transitioning from research to commercial model

Mesoscale Integration of Transportation and Emission Models

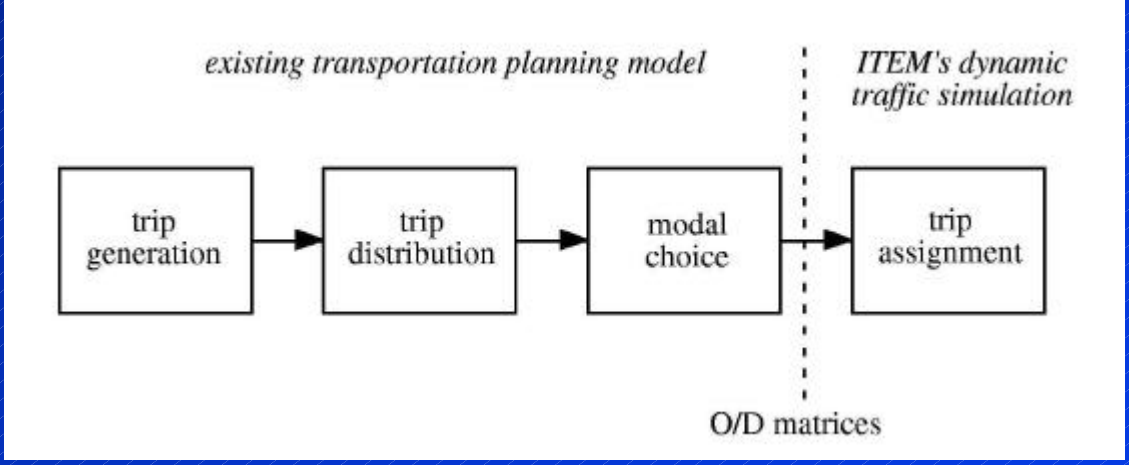
MEASURE:

- Mobile Emissions Assessment System for Urban and Regional Evaluation
- Developed at Georgia Institute of Technology
- Geographical Information System (GIS)–based System
- Allows for micro and macroscale modeling
- uses aggregate modal emission technique
- current focus is focused on developing vehicle activity and fleet parameters
- high versatility

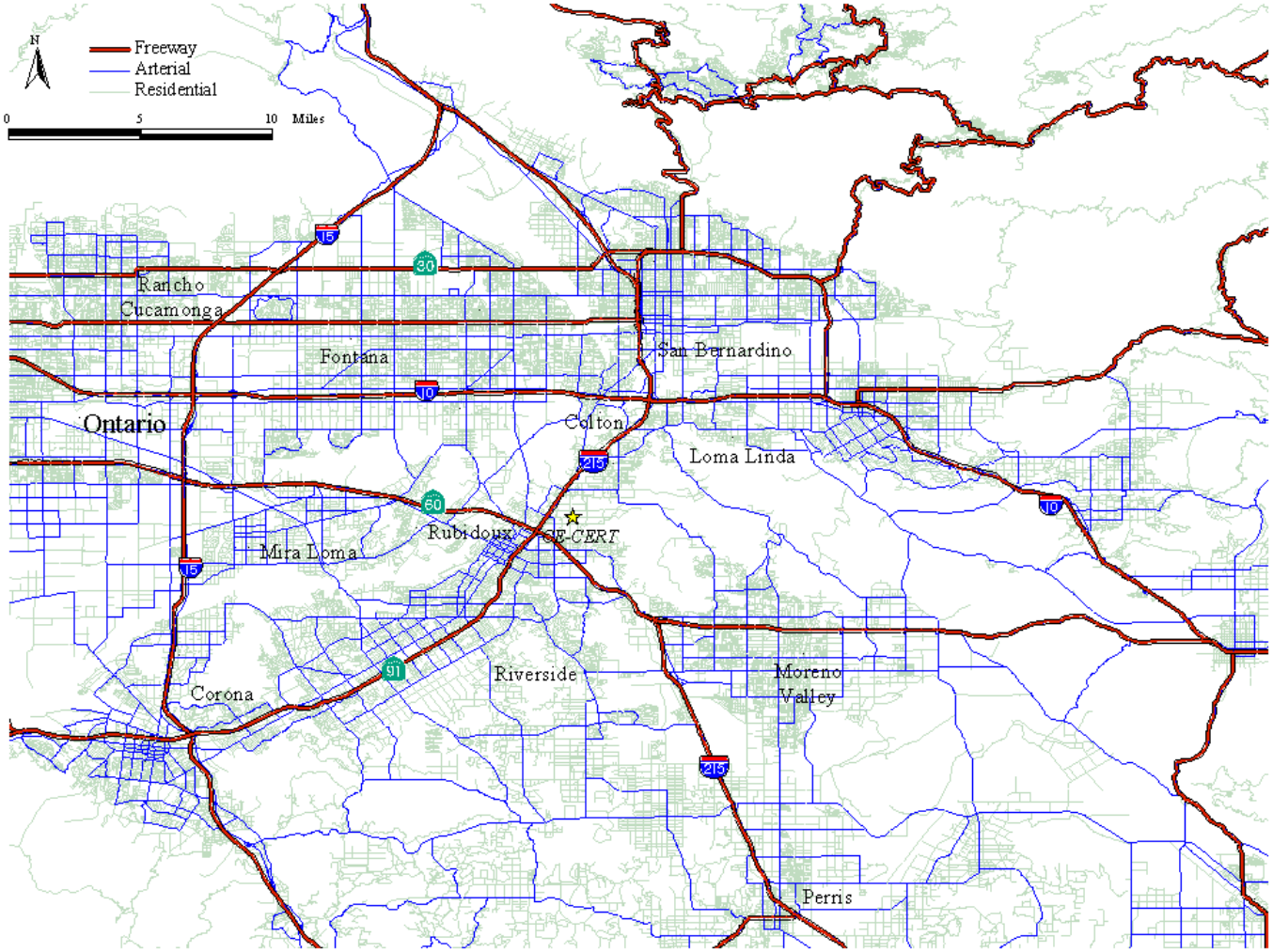
Mesoscale Integration of Transportation and Emission Models

ITEM:
Integrated Transportation/Emissions Modeling Framework

- Developed at UCR CE-CERT
- *Sponsor:* South Coast Air Quality Management District (SCAQMD)
- implemented for Inland region of South Coast Air Basin (SCAB) in Southern California
- link-based emissions modeled built up from CMEM
- replaced traffic assignment component with dynamic traffic simulation module



ITEM Mesoscale Model of Southern California Inland Empire



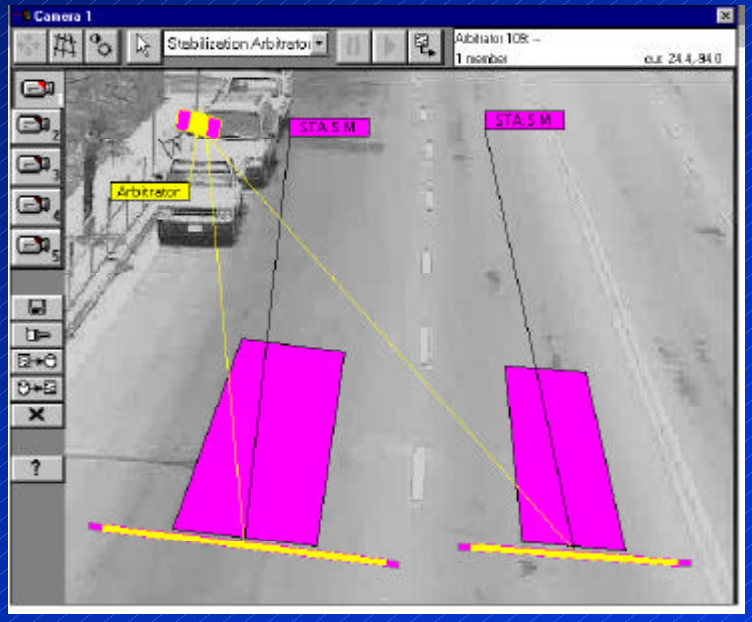
U.S. EPA MOBILE-6

- Recent release of MOBILE model (February 2002)
- major revision after many years
- still considered macroscopic, but allows facility-specific emission factors (based on larger activity and emissions database)
- Start emissions have been improved
- better modeling of air-conditioning
- better representation of high emitting vehicles
- has better documentation
- http://www.epa.gov/otaq/m6.htm

Supporting Emissions and Vehicle Activity Data Collection

Emissions:

- Laboratory Dynamometer
- On-Board Emissions Testing
- Heavy Duty Diesel Emissions Research Laboratory



Vehicle Activity:

- individual vehicle activity
- vehicle fleet category data
- traffic data

On-Board Vehicle Emission Measurements

The Sample Conditioning System
Is Placed In The Trunk Of The Test Vehicle

FTIR Occupies The Rear Seat Of The Vehicle

CE-CERT's HDD Mobile Research Lab

- major effort sponsored by US EPA, diesel engine manufacturers, California Air Resources Board
- 53 foot insulated trailer can be pulled by a variety of tractors
- equipped with state-of-the-art analytical equipment
- intelligent drivers aid

- **sound structure**
- **adequate air conditioning**
- **multiple power sources (115, 220 & 440 volts)**
- **mobile analytical bench & dilution tunnel**

Vehicle Activity Research Tasks

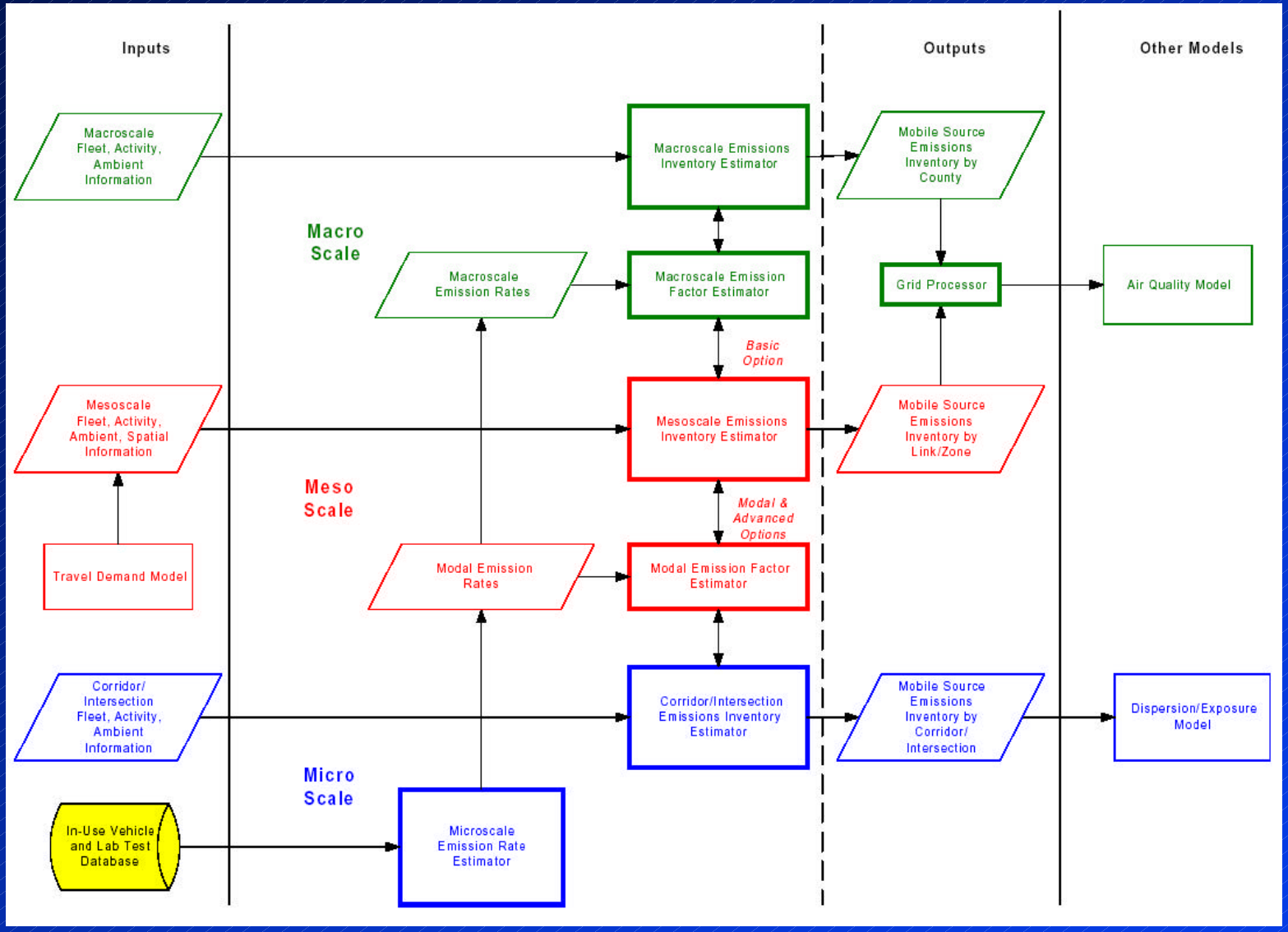
- collect large-scale vehicle activity data (vehicle counts, average speed, car/truck proportions) via Autoscope and Caltrans Performance Monitoring System (PeMS)
- collect detailed vehicle fleet data (license plate sample) via video imaging
- collect detailed vehicle driving traces via GPS, OBD II, and Doppler sensors

- OBD-II bus interface
- carrier phase DGPS aided INS
- Doppler speed sensor

U.S. EPA New Generation Model (NGM)

- Recent effort by U.S. EPA spawned by NRC Report on mobile source emissions modeling
- viewed more as a suite of integrated models to handle many types of situations at micro-, meso-, and macroscale levels
- will be based heavily on on-board emission measurements, rather than dynamometer testing
- the model will encompass all pollutants including CO, CO_2, HC, NO_x, PM, air toxics, and greenhouse gases
- the software design should be efficient and flexible
- the model will be implemented in a coordinated, clear, and consistent manner
- web-site: http://www.epa.gov/otaq/ngm.htm

Proposed New Generation Model Framework



Conclusions and Future Directions

- On-board emission measurements will play a much more important role compared to dynamometer testing
- vehicle emission models are getting more detailed and require more detailed data: vehicle activity
- several vehicle activity studies are underway
- New generation models will cover all “levels” of vehicle emissions modeling
- Vehicles:
  - vehicles are getting cleaner and cleaner and thus are more difficult to measure
  - high emitters are still an important issue
  - Heavy Duty Diesel vehicles are another key contributor to emissions inventory