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Framework for Context-Sensitive Spatially- and Temporally-Resolved Onroad Mobile Source Emission Inventories

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Needs for a Real-World Emission Inventory

Under ***actual and local conditions***, what is the effect of…?

Infrastructure
- Land-use
- Network: Road, Transit
- Roadway type
- Road grade
- Traffic control
- Fuel and energy availability

Behavior
- Traffic conditions (e.g., congestion)
- Choice of mode
- Choice of vehicle
- Choice of route
- Driver behavior

Vehicle Technology
- Vehicle size and weight
- Propulsion (e.g., combustion, hybrid, electric, fuel cell)
- Fuel (e.g., biofuels, additives)
- Lubricants

Ambient conditions
- Temperature
- Humidity
- Ambient Pressure

Accurate quantification of real-world emissions is the first step toward effective real-world management of emissions

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Research Objectives

1. Develop a robust, multi-scale methodology for estimating highway vehicle emission inventories at various spatial and temporal scales.

2. Evaluate the utility of mesoscopic and microscopic transportation simulation models to predict vehicle activity at a sufficient resolution, or in analyzing future vehicle, control or network design scenarios.

3. Quantify the relative contribution of vehicle type, vehicle activity and traffic control measures on the magnitude and variability in regional emission estimates.

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Research Tasks

1. Compile and Catalogue “Legacy” Activity and Emissions Data for the Study Region
2. Select and Construct the Test-Bed Network
3. Develop a Data Collection Plan to Fill Key Gaps
4. Conduct Field Data Collection
5. Identify, Review, and Characterize Expanded Traffic Control Measures
6. Develop and Validate Fuel Use and Emissions Models
7. Quantify Uncertainty
8. Demonstrate Methodology

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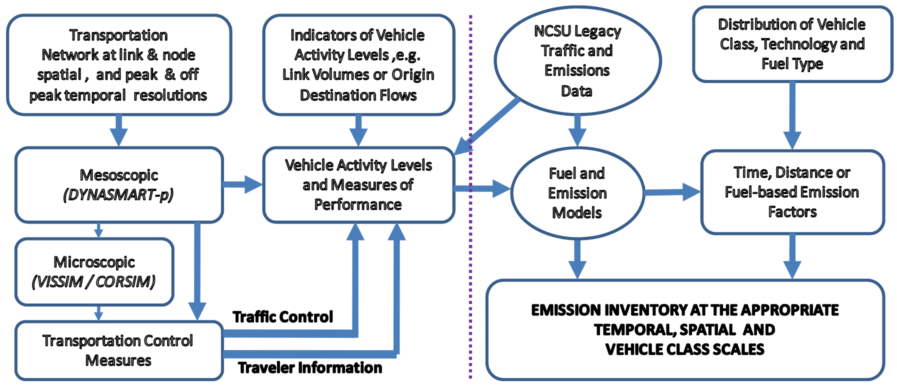
Research Framework



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TASK 1: Compile and Catalog "Legacy" Activity and Emissions Data for the Study Region

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Portable Emission Measurement System

- **OEM-2100 Montana System**
  - **Clean Air Technologies International, Inc.**
  - **Carry-on Luggage shape**
  - **Weight: 35 *lbs.***
  - **13.8 *volt* with 5~18 *amps.***
  - **2 gas analyzers**
  - **Global Positioning System (GPS)**

- **Gas Analyzer**
  - **NO and O_2 from electro-chemical sensors**
  - **HC, CO, and CO_2 from non-dispersive infrared (NDIR)**
- **Global Positioning System (GPS)**
  - **GPS system measures vehicle location**

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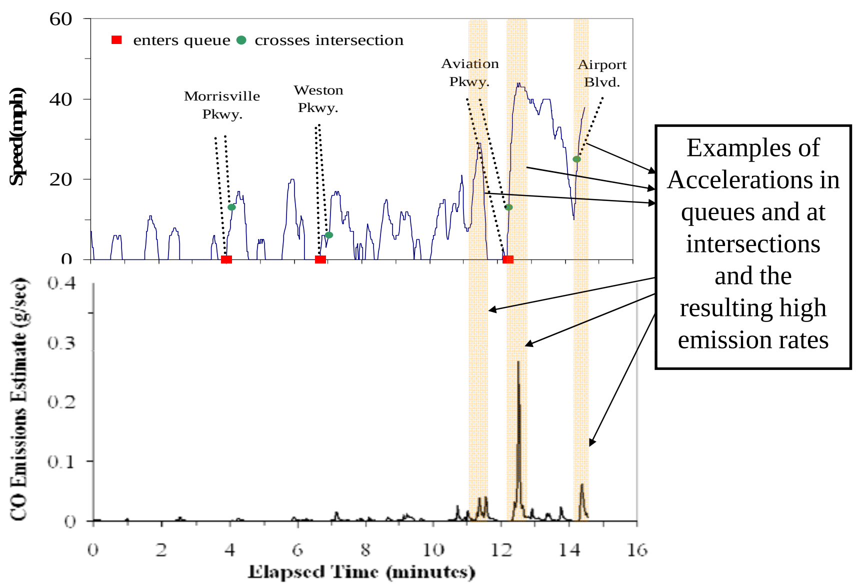
Example of Variablity in Real-World Emissions for a Signalized Arterial



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Quantifying Fuel Use and Emission Rates Versus Estimated Engine Load for a Light Duty Vehicle

Vehicle Specific Power (VSP):

- Power demand
- Gravity and road grade
- Rolling resistance
- Aerodynamic drag

$$VSP = v(1.1a + 9.81r + 0.132) + 3.02 \times 10^{-4} v^3$$

Where:

v = velocity
a = acceleration
r = road grade

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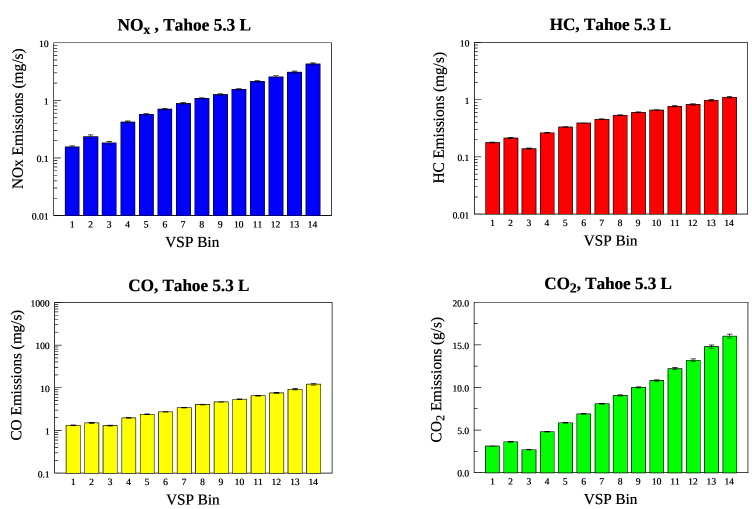
Example of Vehicle Specific Power Modes for Emissions of a 2005 Chevrolet Tahoe



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NCSU Legacy Data

Database	Study Date	Study Location	Vehicles	Runs	Hours of Data	Vehicle Type
Traffic Signal Study (NCDOT)	1999-2001	Wake County, NC	12	1123	135	LDGV
Dump Trucks (NCDOT)	2004	Wake and Durham, NC	12	48	288	HDDV: Diesel, B20
Vehicle Info. System (NSF)	2005-2007	Raleigh and RTP, NC	13	146	232	LDGV
Cement Mixers (Lafarge)	2007	Atlanta, Vancouver	8	16	136	HDDV: Diesel, B20
School Bus (Unsponsored)	2007	Raleigh	2	2	10	PHEV and Conventional
Tractor-Trailer Trucks (NCDOT)	2007-2009	North Carolina	4	9	60	HDDV: Diesel, B20
Microscale Variability (NSF)	2008-2010	Raleigh and RTP, NC	22	26	68	LDGV (includes HEVs)
Plug-In Hybrid Electric (NSF)	2009-2010	Raleigh	2	60	51	Retrofitted Prius

TASK 2: Construct the Test-Bed Network

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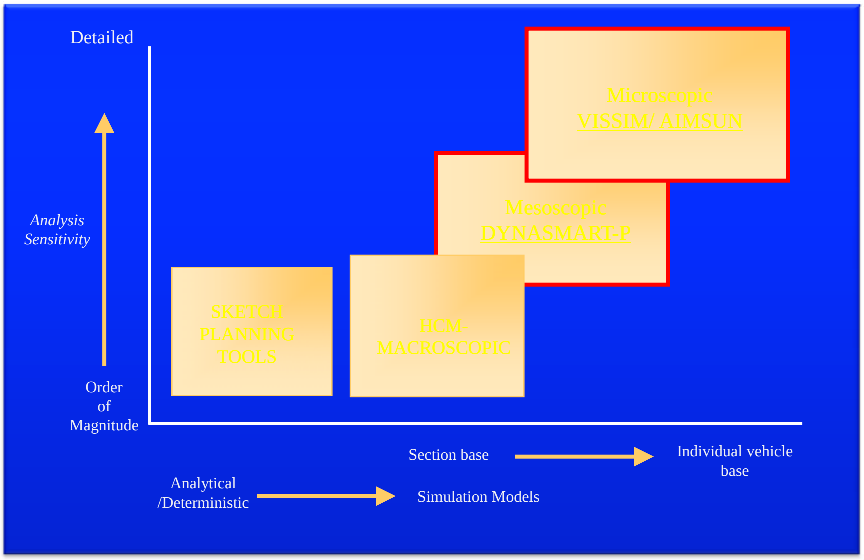
Traffic Analysis Tools- Hierarchy



DYnamic Network Assignment and Simulation Model for Advanced Road Telematics for Planning Applications (DYNASMART-P or DS-P)

http://www.fhwa.dot.gov/crt/lifecycle/dynasmart.cfm

- Network assignment model, used primarily in conjunction with demand forecasting procedures for strategic (long-term) planning applications
- Traffic simulation model, used primarily for traffic operational studies
- Resolution: Mesoscopic.. individual vehicles (micro) retain path information but use link speed-density function (macro)
- Applications: Assessing infrastructure investments, Determining congestion pricing schemes, Evaluating ITS alternatives, Evaluating work zone management strategies, Bus priority or BRT schemes, Evacuation modeling and much more…

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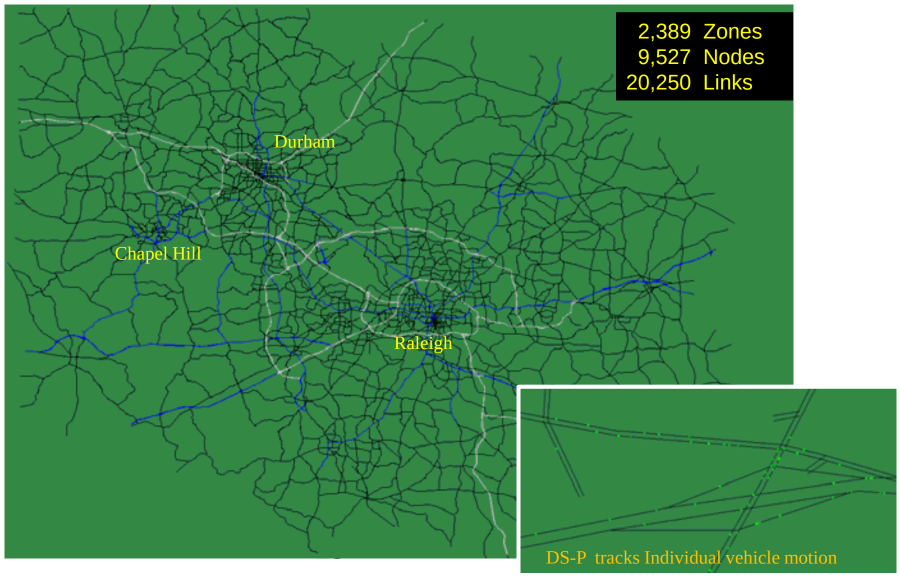
DS-P Network-Triangle Regional Network

(ongoing NCDOT funded Project 2009-05)



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Performance Measures Available from Various Simulation tools

DYNASMART-P (min. by min.)

- Volume
- Speed and travel time
- Density
- Queue length
- Delay
- Vehicle mix
- Moving and stopping times
- Vehicle diversion
- Driving Schedule (aggregated)

VISSIM/AIMSUN (sec. by sec.)

- Volume
- Speed and travel time
- Density
- Queue length
- Delay
- Vehicle mix
- Moving and stopping times
- Driving Schedule
- Fuel and Emissions

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Task 3: Develop a Data Collection Plan to Fill Key Gaps

Real-World Vehicle Activity, Fuel Use and Emissions Measurement Capability

- Portable Emission Measurement System (PEMS)
  - **Infrastructure Data**: Vehicle location (GPS), road grade (via altimeter and GPS)
  - **Vehicle Technology and Fuels**: Engine size, fuel properties
  - **Behavior** (Vehicle Dynamics): Speed, Acceleration, Engine RPM
  - **Ambient conditions**: temperature, humidity, pressure
  - **Vehicle Fuel Use and Emissions**: Gas analyzers for NO, HC, CO, CO_2 and opacity (Particulate Matter)

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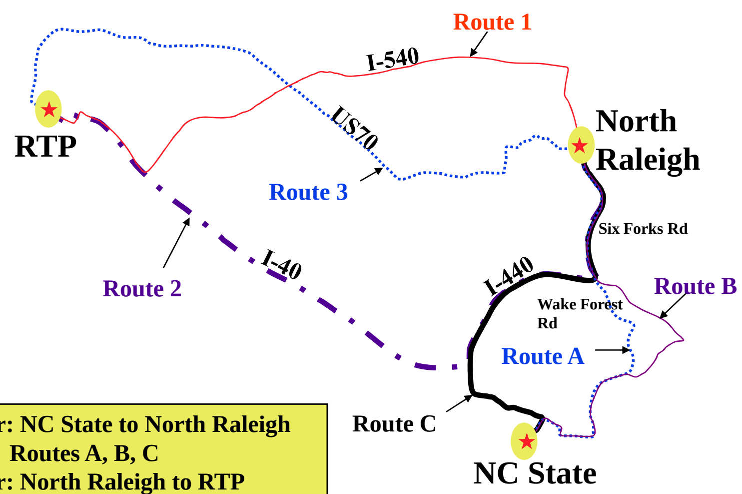
Real World Field Studies: Multiple Routes and Roadway Types



O/D Pair: NC State to North Raleigh
Routes A, B, C
O/D Pair: North Raleigh to RTP
Routes 1, 2, 3

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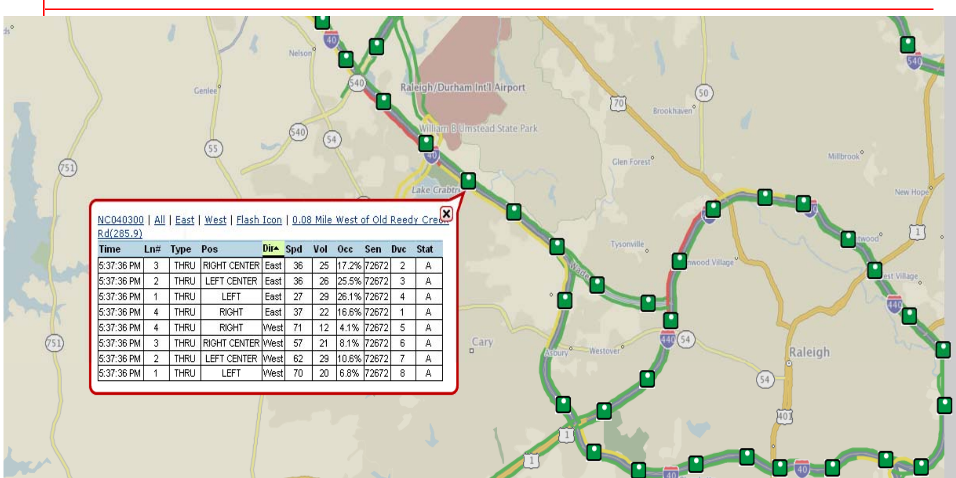
Point Activity Data : An Example of Fixed Sensors - TRAFFIC.COM



Time	Ln#	Type	Pos	Dir	Spd	Vol	Occ	Sen	Dvc	Stat
5:37:36 PM	3	THRU	RIGHT CENTER	East	36	25	17.2%	72672	2	A
5:37:36 PM	2	THRU	LEFT CENTER	East	36	26	25.5%	72672	3	A
5:37:36 PM	1	THRU	LEFT	East	27	29	26.1%	72672	4	A
5:37:36 PM	4	THRU	RIGHT	East	37	22	16.6%	72672	1	A
5:37:36 PM	4	THRU	RIGHT	West	71	12	4.1%	72672	5	A
5:37:36 PM	3	THRU	RIGHT CENTER	West	57	21	8.1%	72672	6	A
5:37:36 PM	2	THRU	LEFT CENTER	West	62	29	10.6%	72672	7	A
5:37:36 PM	1	THRU	LEFT	West	70	20	6.8%	72672	8	A

RTMS Technology

http://stakeholder.traffic.com/mainmenu/stakeholder/index.html

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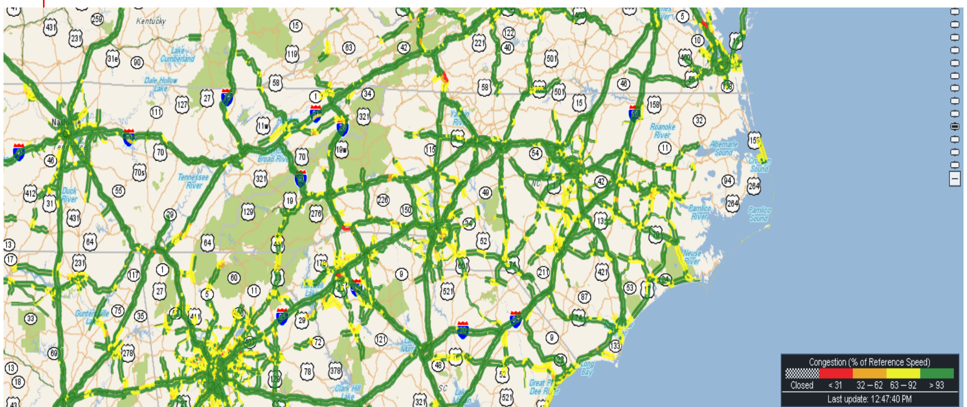
Segment Partial Activity Data using Mobile Sensors: INRIX (North Carolina)



Mostly probe vehicles (commercial, taxi, etc + individual commuters)

http://i95.inrix.com/I95/Traffic.aspx

ITRE

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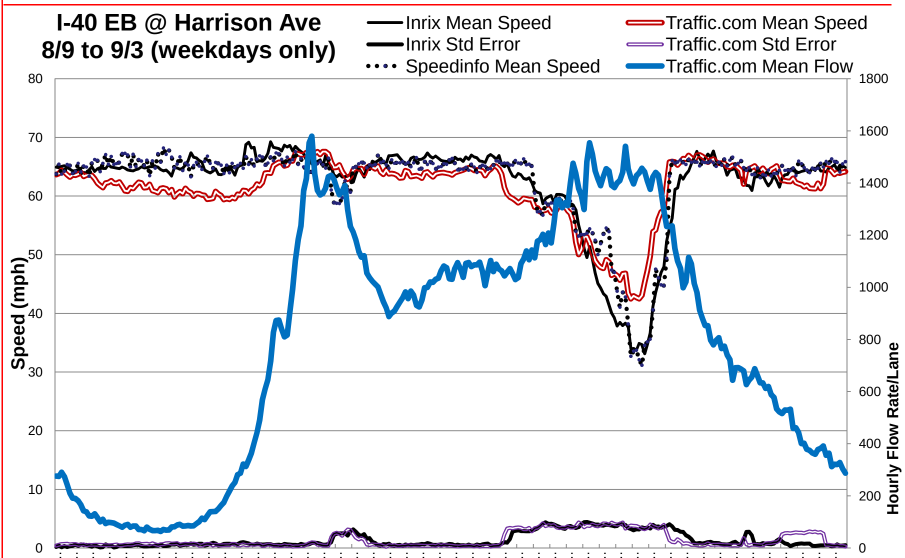
Sensor Data Comparisons- 3 Sources, Same Location



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Task 4: Field Data Collection

Recent Data Collection Activity to Fill Data Gaps

Date Of Measurement	Vehicle		
	Year	Make	Model
10/15	2002	Lexus	RX300
10/16	2004	Honda	Civic
10/17	2000	Mitsubishi	Galant
10/18	2006	Toyota	Corolla
10/20	1997	Toyota	Camry
10/22	2003	Nissan	Frontier
10/28	2006	Honda	Civic Hybrid
10/30	2000	Honda	Civic
10/31	2000	Nissan	Altima
11/1	2006	Toyota	Prius (Hybrid)
11/5	1998	Ford	Expedition
11/6	2005	Buick	LaCrosse
11/10	1997	Honda	Accord
11/14	1996	Toyota	Tacoma

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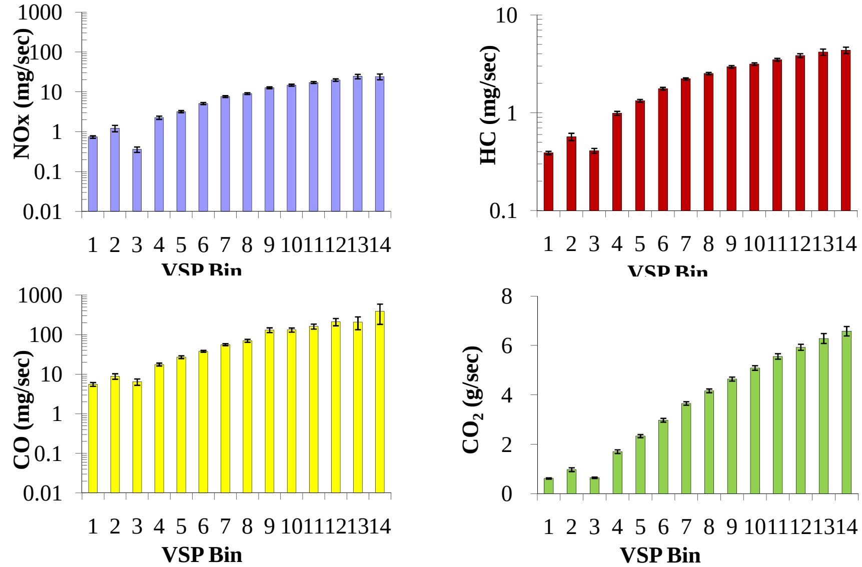
Vehicle Specific Power (VSP) Mode-Based Emissions Model for 2000 Honda Civic



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Task 5: Identify, Review, and Characterize Expanded Traffic Control Measures

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Potential Traffic Control Measures

Inventory of TCM for achieving improvements in sustained service rates for freeways and/or arterial segments

Freeway	Arterial	Both
HOV / HOT Lanes	Signal Retiming	Narrow Lanes
Ramp Metering	Signal Coordination	Reversible Lanes
Ramp Closures	Adaptive Signals	Variable Lanes
Congestion Pricing	Queue Management	Truck Only Lanes
Pricing by Distance	Raised medians	Truck Restrictions
Weaving Section Improvement	Access Points	Pre-Trip Information
Frontage Road Construction	Right/Left Turn Channelization	In-Vehicle Information
Interchange Modifications	Alternative Left Turn Treatments	Variable Message/Dynamic Message Signs
Incident Management		Inter-Vehicle (V2V) Communications

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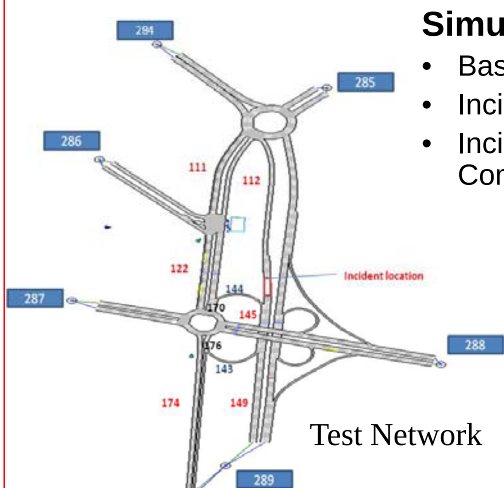
TCM Environmental Impact Example
Vehicle to Vehicle (V2V) Communications
Using Augmented Micro-Simulation (AIMSUN) Tool



Test Network

Simulation Scenarios:

- Baseline Scenario (no incident)
- Incident Scenario (no V2V)
- Incident with enabled V2V Communications Scenario

Measures of Effectiveness (MOE)

1- *Mobility* : speed, travel time, delay time, stop time and number of stops

2- *Environmental:*

Fuel consumption and NO_x, HC and CO emission rates

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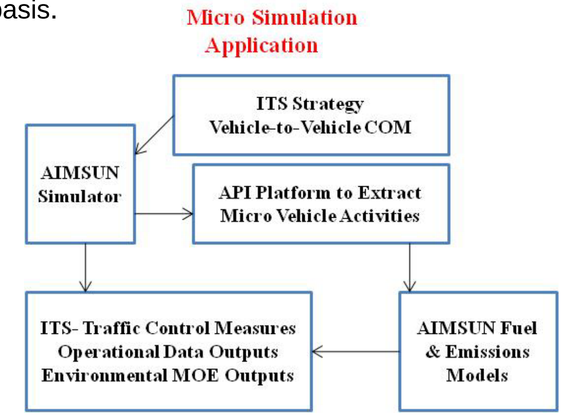
Methodology for assessing effect of Vehicle-to-Vehicle (V2V) Communication for Incident Avoidance

- Linking transportation activity and vehicle fuel use and emissions models
- Generate an applications program interface (API) extracting micro vehicle activity in terms of speed, acceleration, and road grade on a second-by-second basis.



Changes in Traffic Flow, Fuel Use, and Emissions Associated With Vehicle-to-Vehicle Communication During an Incident

Measure of Performance	Baseline	Incident - No V2V	Incident - V2V
Travel Time (sec/km)	82	103	95
Fuel (ml/veh)	29	36	33
NO_x (mg/veh)	4.0	6.5	5.5
HC (mg/veh)	11	16	14
CO (mg/veh)	20	29	25

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Task 6: Develop and Validate Fuel Use and Emissions Models

Evaluation of Real-World Emission Rates via Comparison to MOVES (Example)

Location	Wake County, NC
Time	Oct 5, 2009, Weekday, 2pm-3pm
Vehicle	Light Duty Gasoline Vehicle
Links	Link 1: High Speed, Interstate Link 2: Moderate Speed, Local and Arterial Roads Link 3: Low Speed, Local Roads

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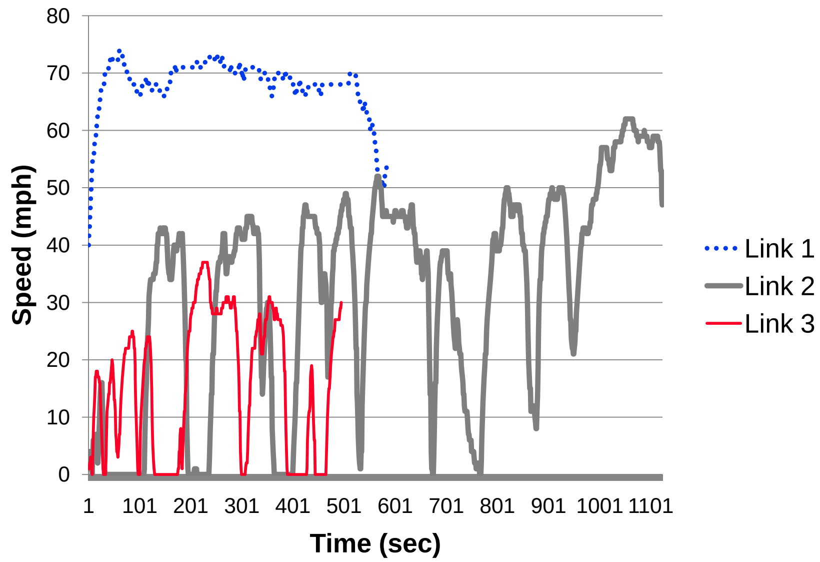
Real World Speed Profiles Input to MOVES



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Example Speed Profile Emission Average Rates from MOVES

Variable	Link 1	Link 2	Link 3
Average Speed (mph)	68	32	15
Total Energy Consumption (MJ/mile)	4.3	5.0	6.5
CO_2 (g/mile)	310	360	470
NO_x (g/mile)	0.22	0.21	0.18
CO (g/mile)	1.5	1.7	1.6
HC (mg/mile)	21	24	27

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Benchmarking

- Use MOVES to provide fleet average emission factors for the selected geographic area for a baseline driving cycle
- Compare real-world data to predictions for fuel/vehicle technology combinations represented in MOVES
- Assess relative trends in emission rates associated with variability in link-based speed profiles for both PEMS and MOVES
- Improve representation of PHEVs based on recent and ongoing field data collection

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Task 7: Quantify Uncertainty

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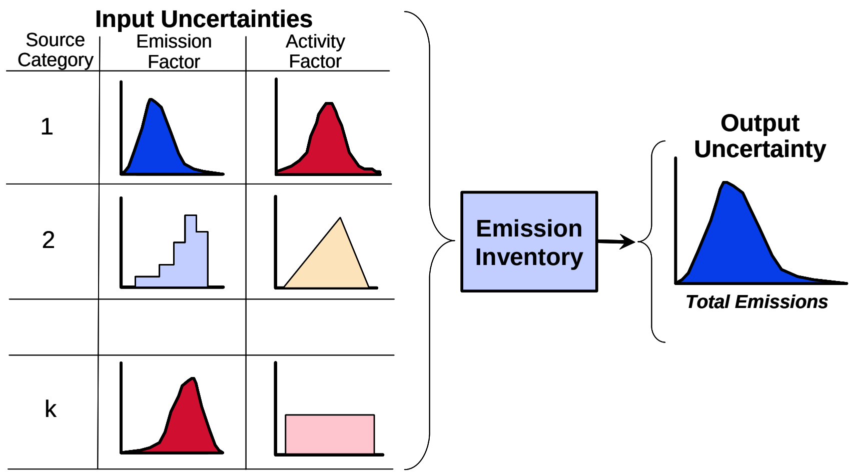
Uncertainty in Emission Inventories



Source: Chapter 8, NARSTO (2005)

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Examples of Key Factors Influencing Uncertainty in Vehicle Emissions

- Modal emission rates
- Inter-vehicle variability
- Vehicle operation (driving cycles)
- Vehicle volume
- Incidents
- Averaging Time
- Geographic Area

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TASK 8: Demonstration of Integrated Methodology

- Link state-of-the-art traffic models with vehicle fuel-use and emissions models using second-by-second VSP and speed.
- Demonstrate linkage for the Triangle Regional Network
- Demonstrate the sensitivity of the regional on road vehicle EI to alternative
  - Traffic Control Measures
  - Fuels
  - Vehicle Technology
  - Transportation Improvements
- Evaluate the high resolution activity-emissions framework.
- Quantify uncertainty in link-based emissions and the total emission inventory.
- Multi-pollutant emissions of CO_2, CO, NO_x, volatile organic compounds, and PM.
- Identify factors that reduce real-world fuel use and emissions.
- Compare model predictions with real-world data

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