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ITRE
Institute for Transportation Research and Education
North Carolina State University

Emission Measurement and Modeling: Transportation Planning and Operational Applications

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Triangle Clean Cities Stakeholders Meeting

Thursday January 28
RTP, North Carolina

Triangle Clean Cities Coalition

Acknowledgments

- The NCSU program is a team, not individual effort
  - **Dr. H. C. Frey, Professor of Environmental Engineering, NC State University**
  - Dr. Haibo Zhai, CMU
  - Dr. Kaishan Zhang, CARB
  - Dr. Alper Unal, World Resources Institute
  - Numerous graduate and undergraduate students

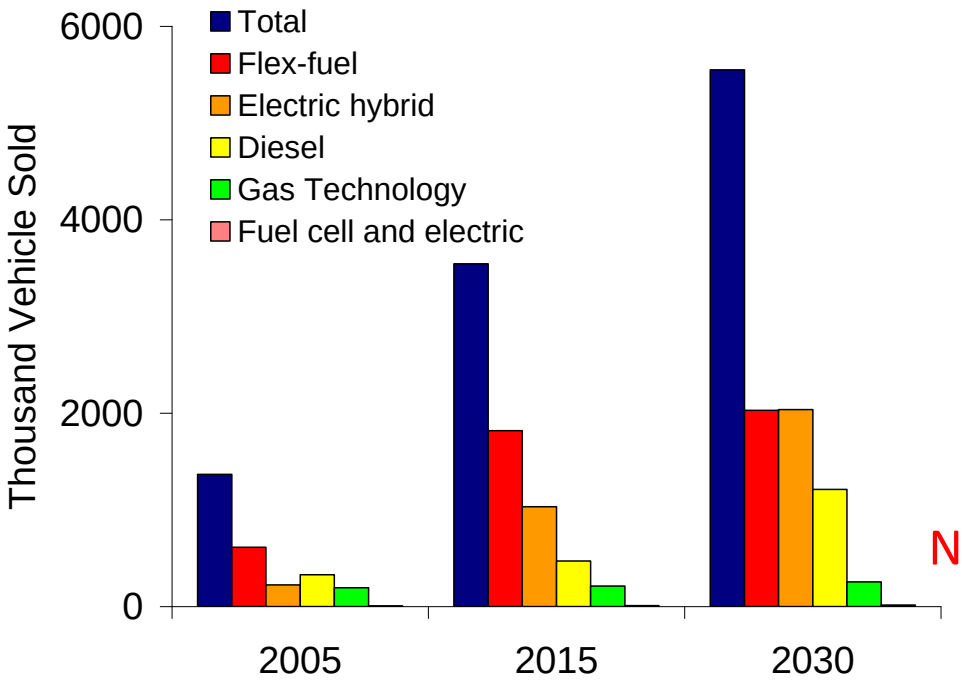
Presentation Outline

- Motivation
- Description of NC State Research Program / PEMS
- Application examples…
  I. Direct assessment of traffic signal control effectiveness
  II. Integration with TDM for quantifying impacts of transportation / air quality policies
- Questions / discussion

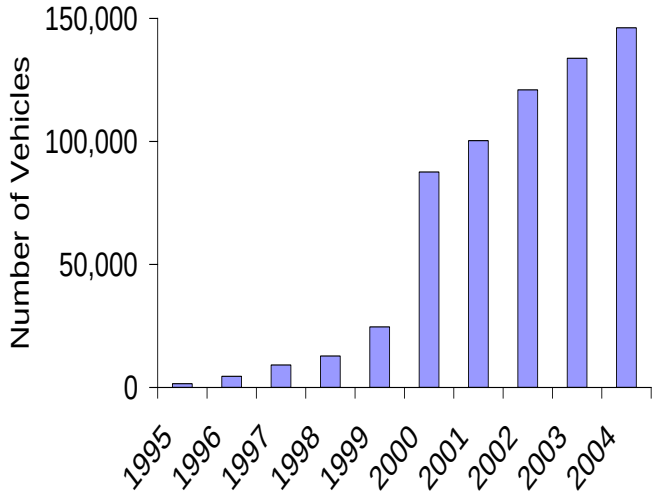
Motivation

- Addressing needs to quantify energy and emission consequences of transportation decisions at the project as well as regional levels.
  - Comparing different intersection controls (signals vs. roundabouts)
  - Comparing different road designs (i.e., grade, curvature effects) or improving one type of control (signals)
  - Contrasting different vehicles and fuels including trucks and buses
  - Comparing different routes and facility classes (freeways vs. arterials) by time of day
  - Setting congestion pricing policies

Motivation



Project MP of Alternative Vehicles



Number of E85-Fueled Vehicles in U.S.

From *Annual Energy Outlook 2007*, U.S. Department of Energy, alternative technologies are projected to exceed 27% of light-duty vehicle sales by 2030 in the national range.

Why not MOBILE / MOVES ?

- MOVES (**Mo**tor **V**ehicle **E**missions **S**imulator) just recently released

- U.S. EPA's MOBILE6 is currently used to address a wide variety of air pollution modeling needs.. but…
  - limited ability to represent real-world driving
  - one cycle used to represent driving on local roadways and freeway ramps.
  - CO_2 emission rates not adjusted by speed and facility type.
  - limited capability to model advanced technologies and alternative fuels.

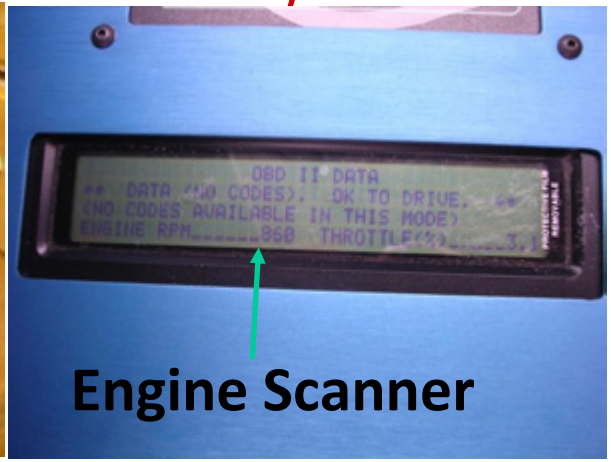
- Lacking **link-based emissions** estimators to couple with transportation models for high-resolution emission inventory estimates.
  - To estimate link-level average emission rates for all vehicle classes
  - To evaluate the sensitivity of average emission rates to average link-based speed and facility type.

Research Program at NC State

- Founded upon extensive, real-world data collection of vehicle dynamics, energy use and emissions
- Focused on assessing variability due to:
  - Vehicular factors (fuel, engine size, condition, mileage, etc.)
  - Infrastructure and control effects (grades, signals, curves, etc.)
  - Driver effects (traffic, level of agressiveness)
  - Ambient conditions (temp. , humidity, etc.)
- Data are also used to drive model development at the micro (sec by sec) and macro (mean speed) scales
- Fully compatible with the proposed MOVES binning method
- Uses in-vehicle instrumentation using **P**ortable **E**missions **M**easurement **S**ystems (PEMS)

PEMS / CATI

System Interface



Engine Scanner

OBD-II Adapter

Main Unit

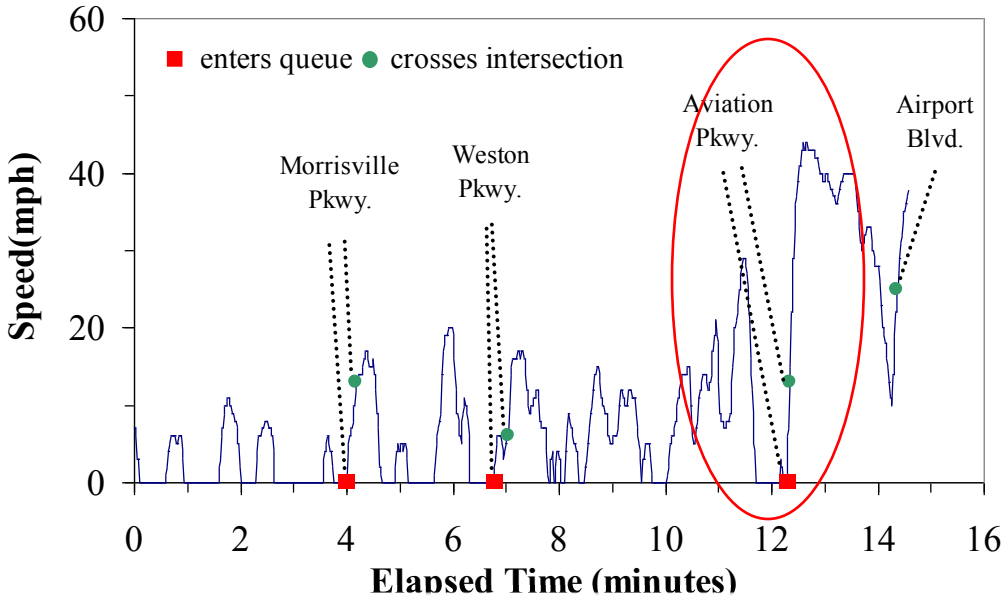
GPS

Sampling probe

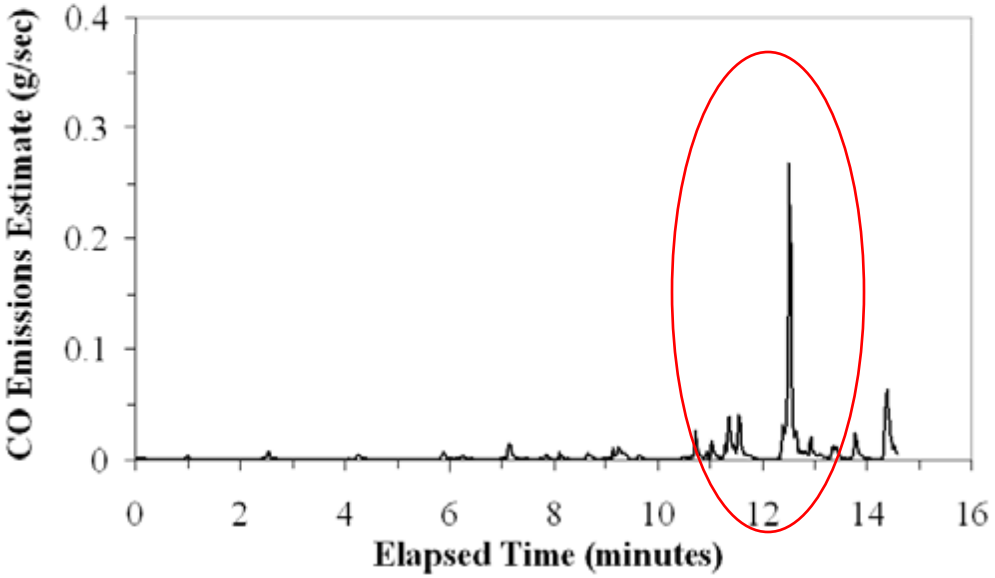
Frey, H.C., A. Unal, N.M. Rouphail, and J.D. Colyar, "On-Road Measurement of Vehicle Tailpipe Emissions Using a Portable Instrument," Journal of Air & Waste Management Assoc., 53(8):992-1002 (August 2003).

Sample Micro-scale Data -PEMS

Emissions episodes account for the majority of trip emissions,



Not necessarily Proportional to VMT



achieve!
NC STATE
Innovation in Action

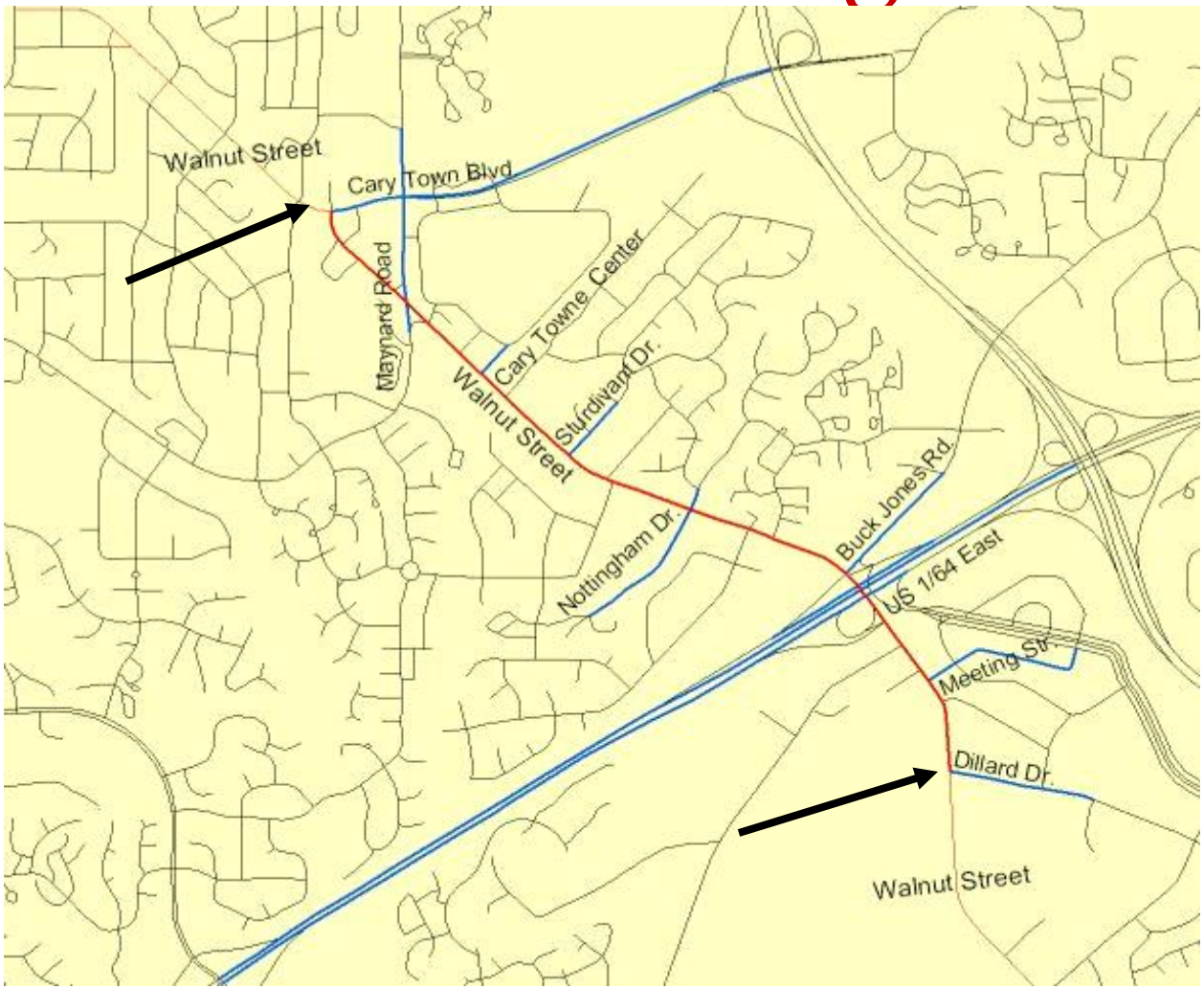
Direct Assessment of Traffic Signals on Emissions

Empirical Verification of Signal Timing Effects

- Eight light-duty gasoline vehicles
- 824 one-way on-road trips
- 2,020 miles traveled
- 100 vehicle-hours
- 4 different drivers
- Two arterial corridors: Chapel Hill Rd and *Walnut Street*

Unal, A., N.M. Rouphail, and H.C. Frey, "Effect of Arterial Signalization and Level of Service on Measured Vehicle Emissions," Transportation Research Record, Journal of the Transportation Research Board, No. 1842, pp. 47-56 (2003).

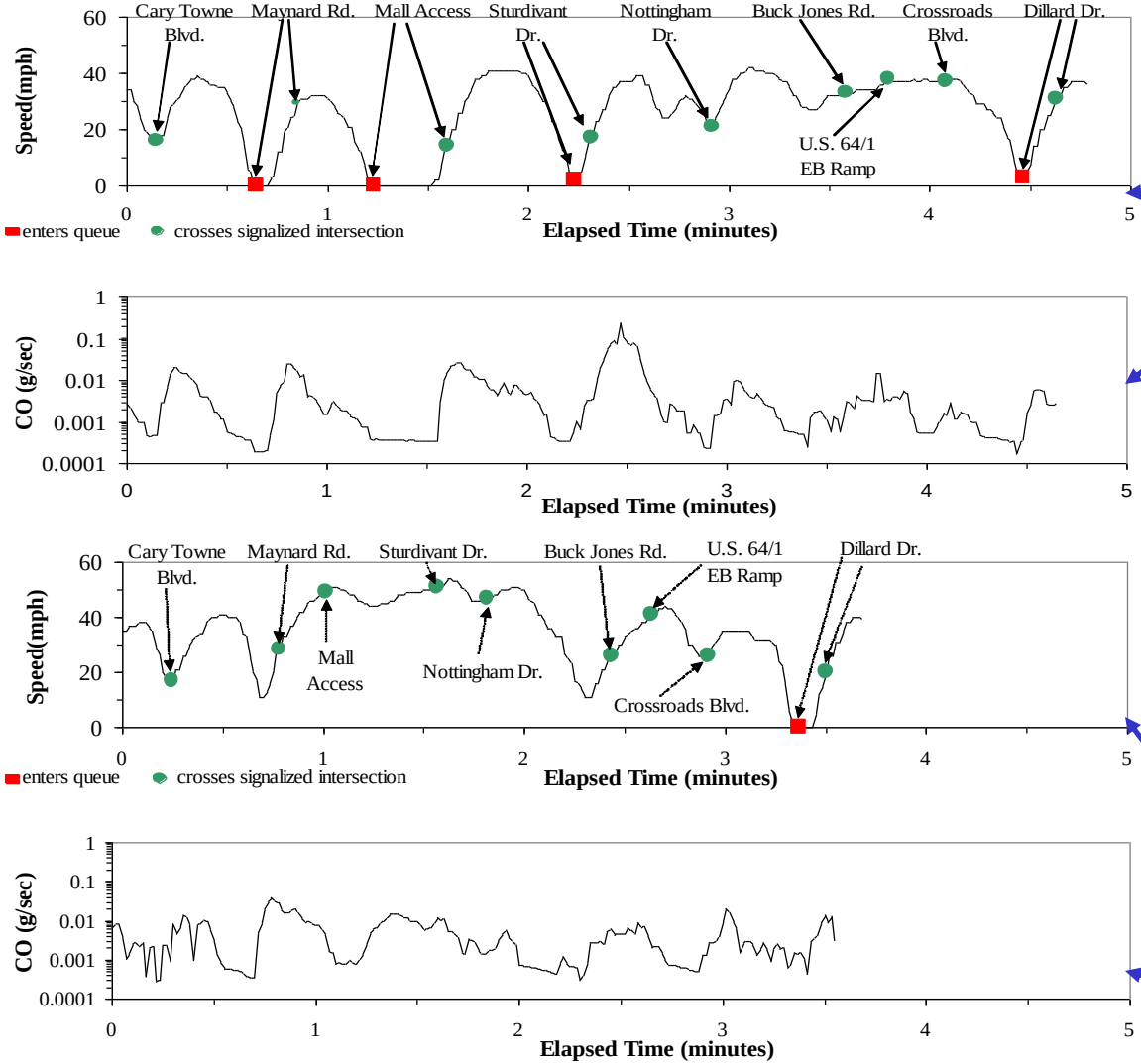
Walnut Street- Signal Coordination



Main Data Collection Corridor
Side Streets

Corridor Length: 2.3 mi
Speed Limit: 35,45 mph
Through Lanes: 4
No. of Signals= 8
LOS: C - AM North
C - AM South
D – PM North
C – PM South

Sample Walnut St. results from PEMS



REP. RUN BEFORE

Can measure second by second speeds, accelerations and Emissions- Calculate Corridor-Wide Emissions

REP. RUN AFTER

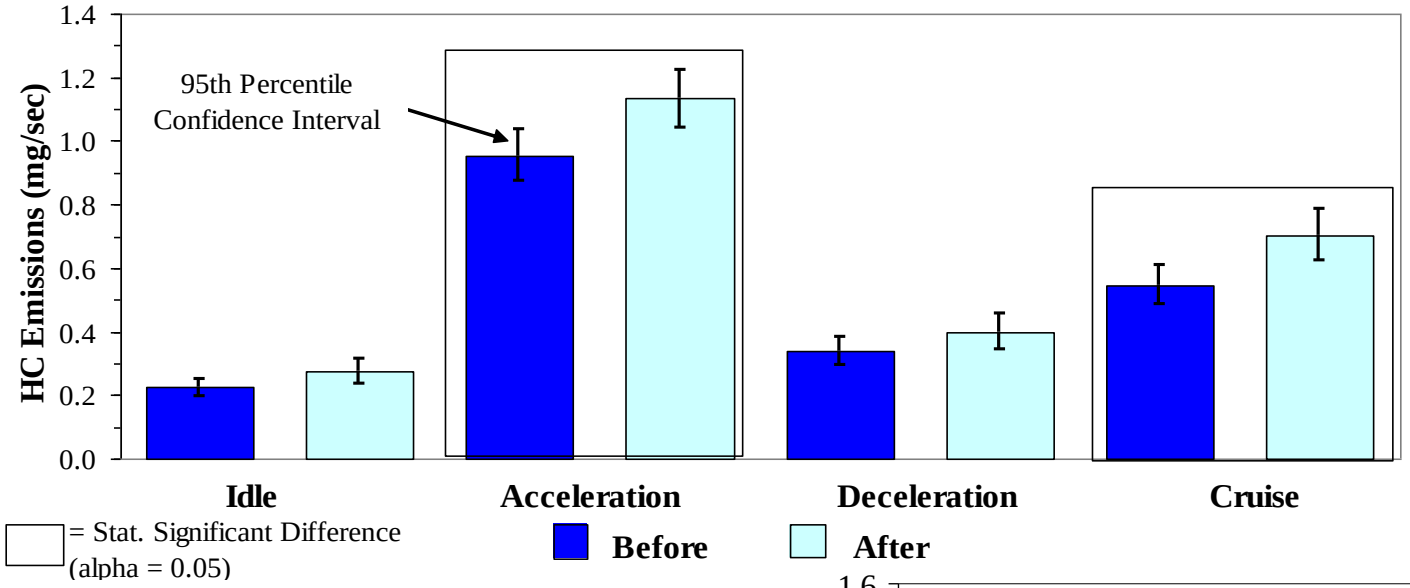
Signal Coordination Effects: Walnut St.

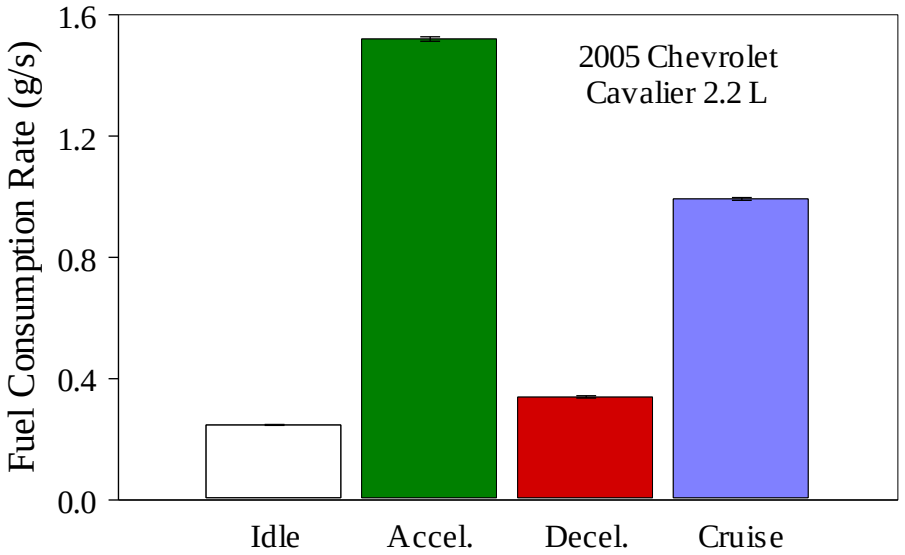
	Ford Taurus				Oldsmobile Cutlass			
Time Period	*Morning*		*Afternoon*		*Morning*		*Afternoon*	
Direction	*North*	*South*	*North*	*South*	*North*	*South*	*North*	*South*
Trip Duration (%)	-14	-24	-23	+0.3	-16	-17	-21	-0.9
Ave. Speed (%)	**+14**	**+32**	**+29**	-1.8	**+18**	**+20**	**+29**	-1.8
Control Delay (%)	**-40**	**-63**	**-55**	-4.6	**-38**	**-50**	**-56**	+8.5
Total Stops (%)	**-30**	**-60**	**-29**	-2.3	**-29**	**-46**	**-29**	-11
HC Emissions (%)	**-12**	**-18**	**-11**	+1	**-12**	**-13**	**-12**	-1
NO Emissions (%)	**-8**	**-12**	-1	+1	**-13**	**-14**	**-19**	-1
CO Emissions (%)	**-12**	**-19**	-5	+1	-4	**-9**	-1	-1

Understanding and Extending the Results: Modal Emissions models

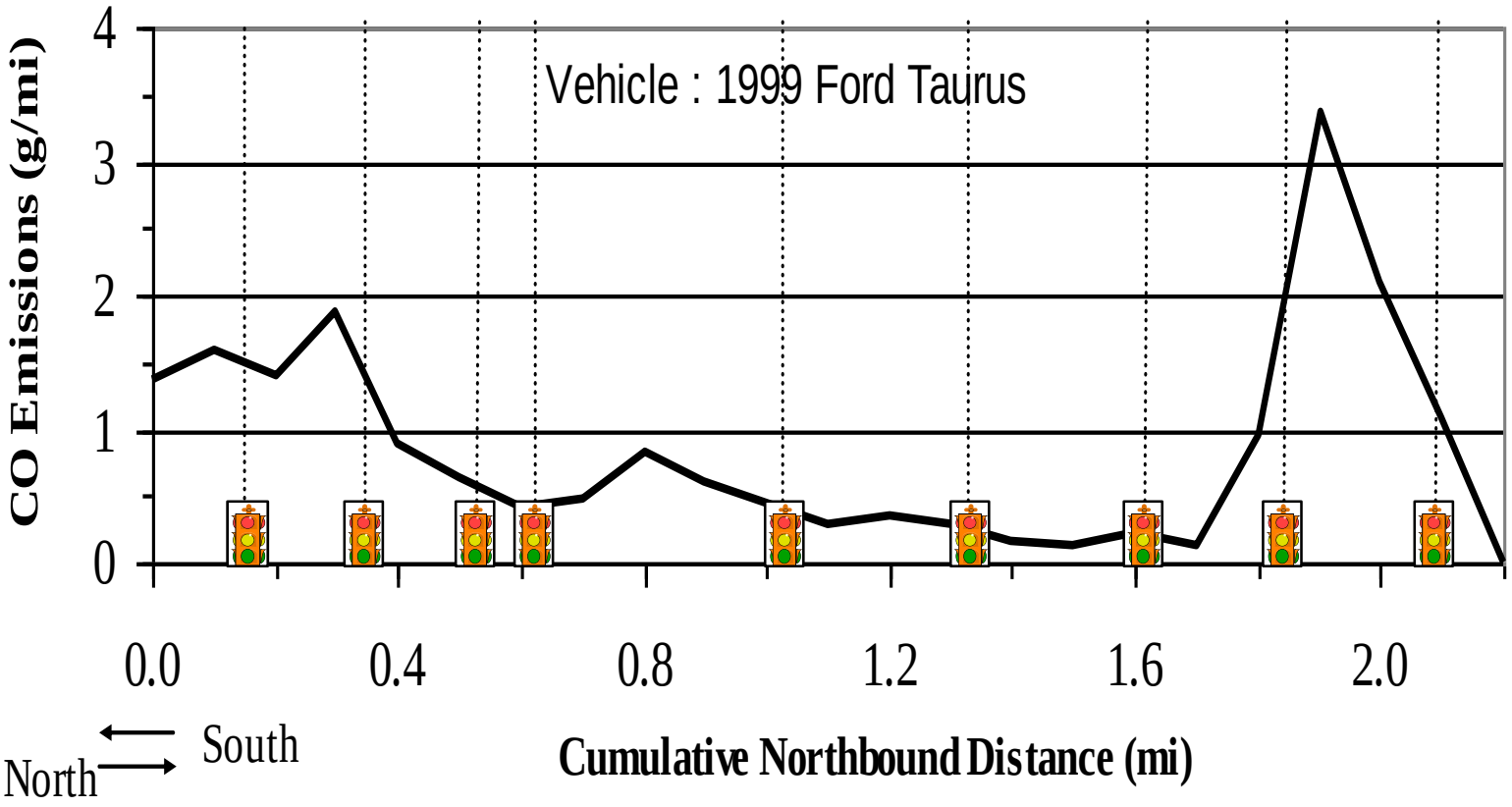
- **Modes** distinguish between power requirements and the resulting emission rates generated
- **Modes** can be defined at many resolution levels
  - Acceleration / Deceleration / Cruise / Idle (trip based)
  - Speed Range– consistent with most travel demand model (TDM) outputs (link based)
  - Vehicle Specific Power (MOVES paradigm- Second by second)– consistent with traffic micro-simulation models output (CORSIM, VISSIM, PARAMICS)

Example of 4 Mode Models: Fuel Use and HC Emission Rates

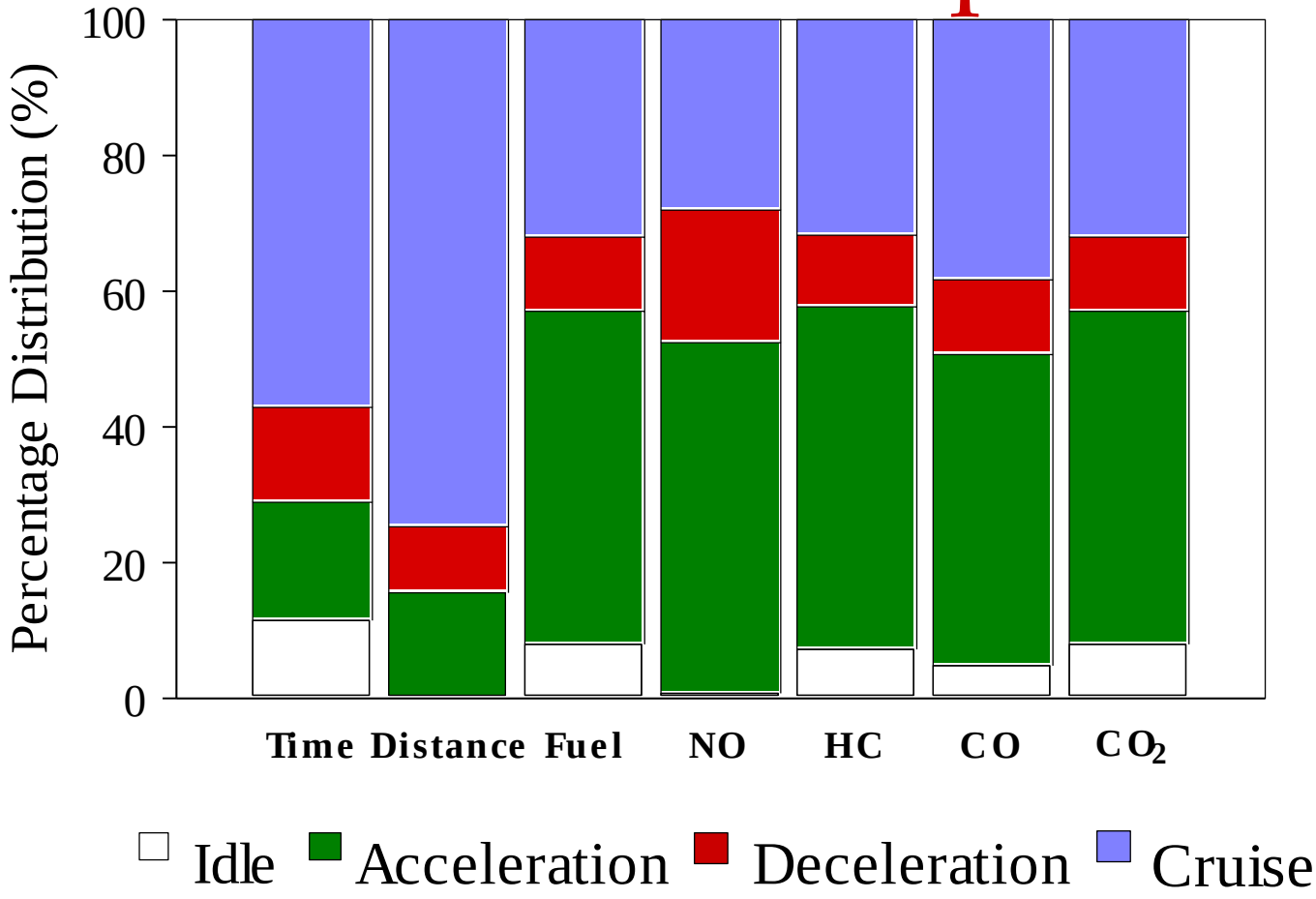




Example of Modal Emissions: Spatial Identification of Emission Hot Spots



Summary: Your average Urban Trip

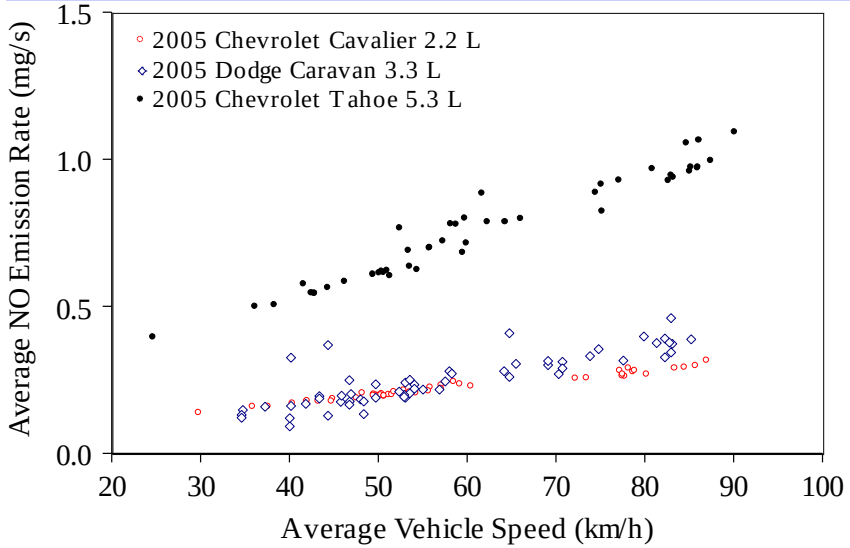


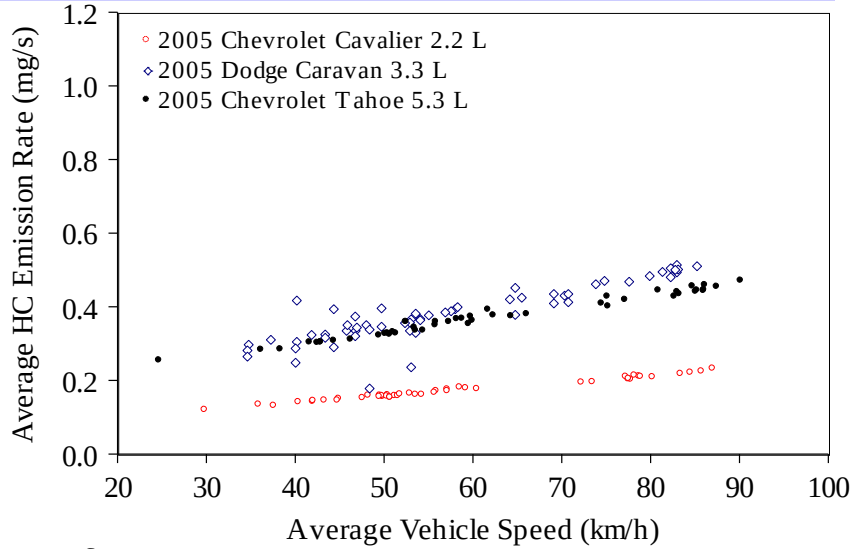
Integration with TDM's Emission Estimation at the Link / OD and Network Levels

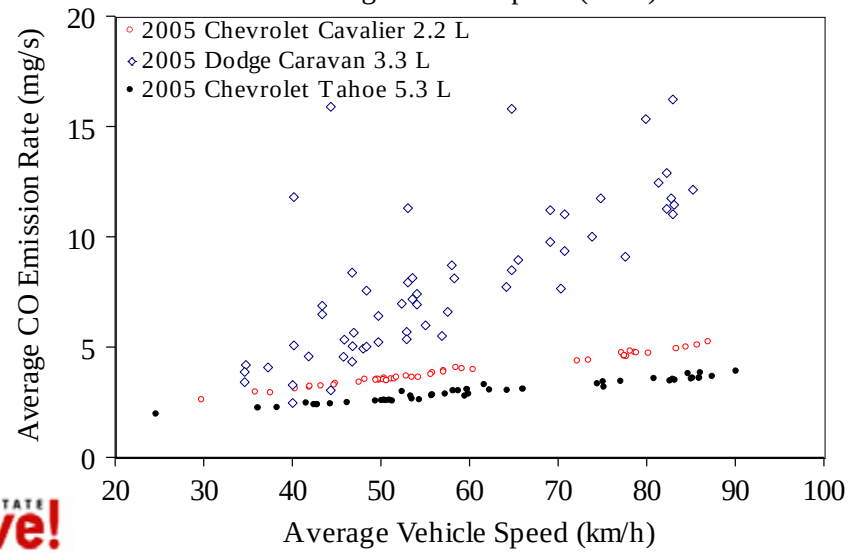
- Travel Demand Models typically produce link-based traffic volumes by vehicle class and average speeds
- We can take advantage of those outputs to generate energy / emission impacts to include the effects of:
  - Corridor – traffic engineering-- improvements
  - Changes in the vehicle fleet or alternative fuels
  - Changes in modal split
  - Changes in VMT due to growth, land use controls, pricing and other policies

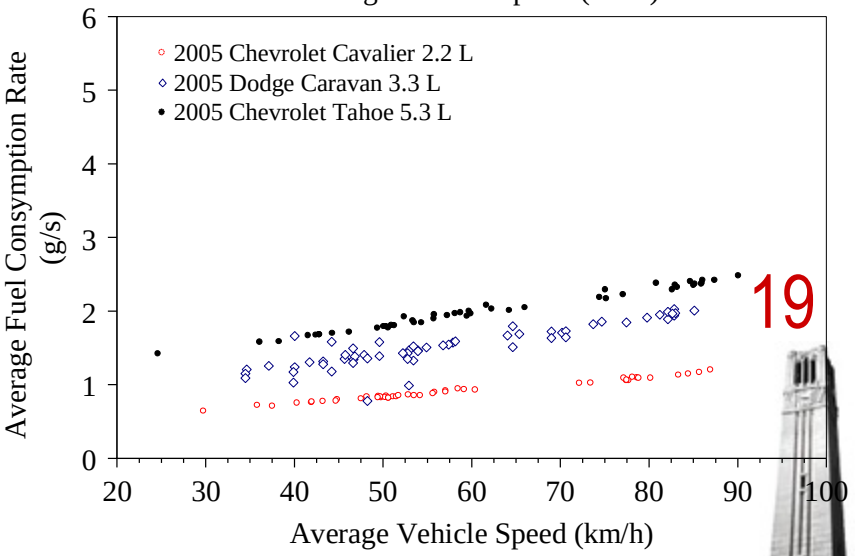
The good news: Association Between Emission Rates and Average Speeds

Sample: 588 runs covering 6 routes, 2TOD, 3 Primary Veh. (~ 195 hrs)

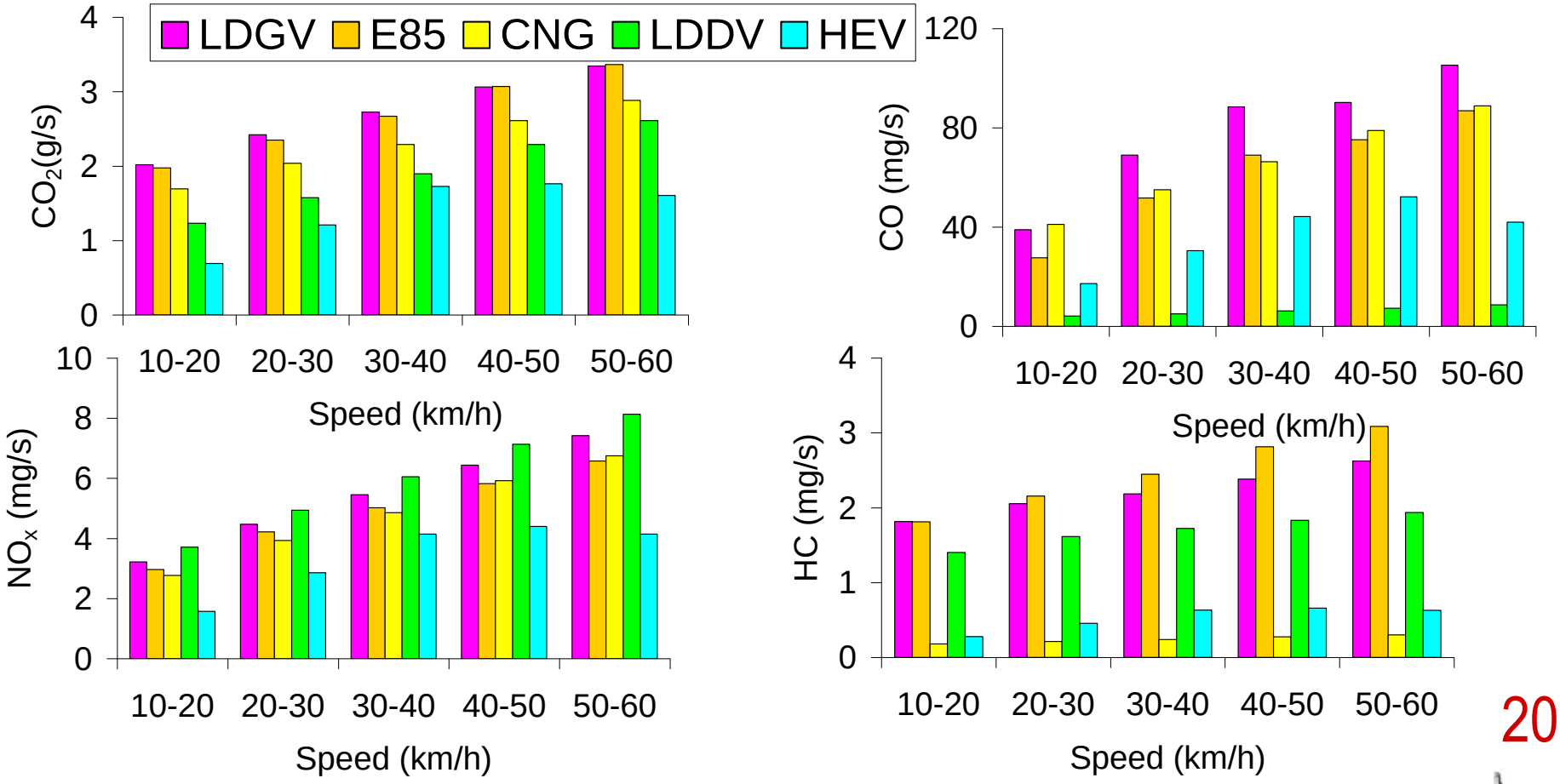








More Good News: Emission Factors by Speed and Vehicle Technology / Fuel Type

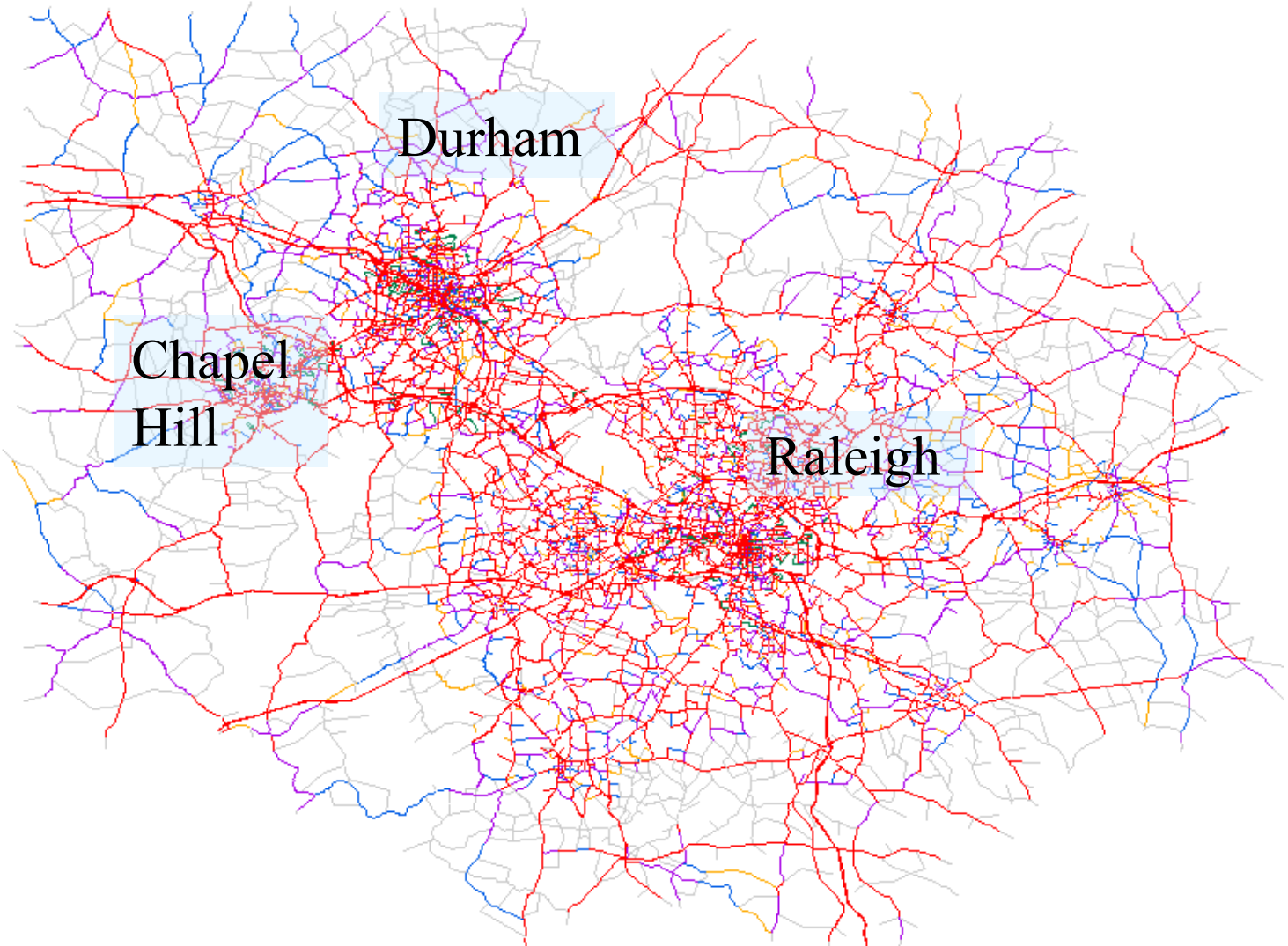


Frey, H.C., H. Zhai, and N.M. Rouphail (2009), "Regional On-Road Vehicle Running Emissions Modeling and Evaluation for Conventional and Alternative Vehicle Technologies," Environmental Science and Technology, 43(21):8449–8455

Armed with Both: Regional Mobile Emissions Inventory

- An emissions inventory is a database that lists, by source, the amount of air pollutants discharged into the atmosphere of a community during a given time period.
- Emission inventory data are used to:
  - calculate permit fees,
  - perform toxic air pollutant modeling evaluations,
  - conduct modeling for federally required criteria pollutant attainment and maintenance plans,
  - provide appropriate data to the public,
  - monitor progress and trends and
  - test the impact of regional mobility policies *(Source: EPA)*

Test bed: Triangle Regional Model Network AM Peak - Baseline Scenario



Triangle Regional Model Vehicle Activity

Summary 4-hour Morning Peak

Item	Vehicle Class [b]	Facility Type			Total
		Freeway / Ramp	Arterial	Local Collect.	
Link Average Speed (km/h)		92	68	47	
Number of Links in Model		1,580	3,990	9,510	15,080
Vehicle Kilometers Traveled (10^3 VKT)	Cars	3,589	3,775	3,185	10,548
	Trucks	1,687	1,060	997	3,744
	Buses	46	23	26	95
	Sum	5,322	4,858	4,208	14,388
Percentage of Total VKT (%)	Car	24.9	26.2	22.1	73.3
	Trucks	11.7	7.4	6.9	26.0
	Buses	0.3	0.2	0.2	0.7
	Sum	37.0	33.8	29.3	100.0

Scenarios

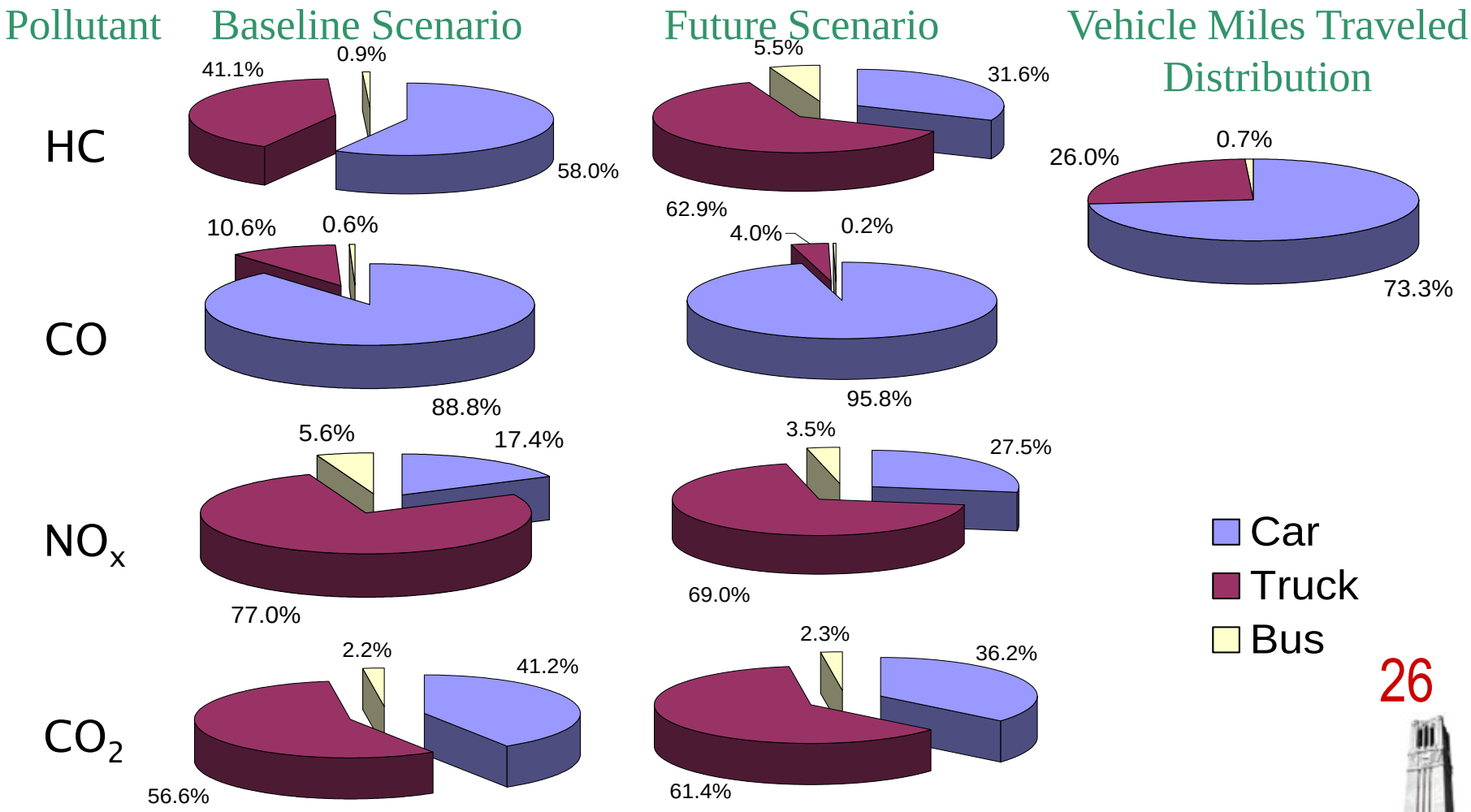
- **Baseline** Scenario: Considers only conventional vehicle technologies for 2005 base year
- **Alternative** Scenario: considers conventional technologies and 27% market penetration of alternative fleet technologies for the 2005 base year.
- **Future** Scenario: considers conventional and alternative vehicle technologies, emission control standards and programs for the calendar year and looks at VMT growth effects

Relative Emission Changes in the Morning Peak Hour (%)

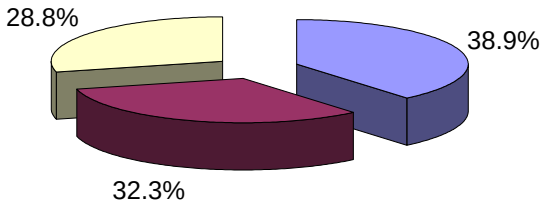
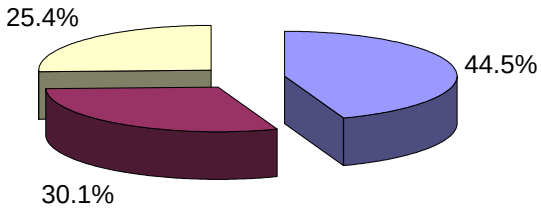
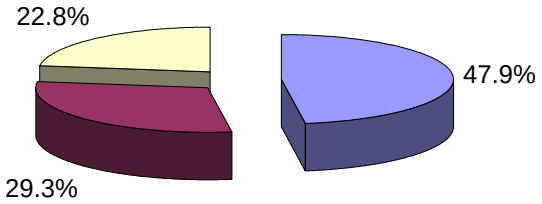
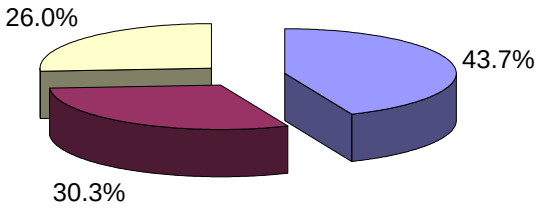
Scenarios and Pollutants Comparison	HC	CO	NO_x	CO_2
Alternative vs. Baseline	-7.7	-13.8	-3.1	-3.6
Future 2030 -- No VMT Growth vs. Baseline	-82.0	-71.9	-91.5	-12.8
Future 2030 -- VMT Growth vs. Baseline	-71.4	-58.0	-87.0	34.4

** Preponderance of Tier-2 Vehicle Standards in 2030*

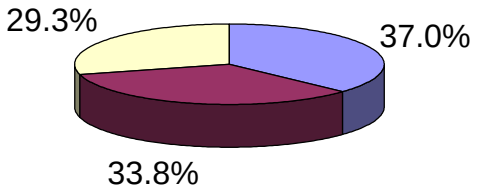
Network Emissions by Vehicle Type

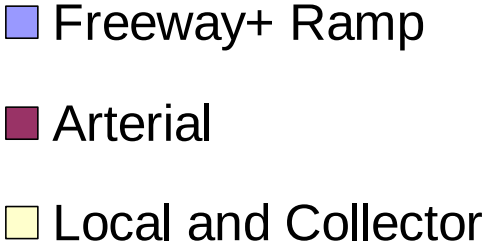


Network Emissions by Facility Type

Pollutant	Baseline Scenario
HC	
CO	
NO_x	
CO_2	

Vehicle Miles Traveled Distribution





Summary

- Ubiquitous use of PEMS data for direct or indirect assessment of transportation decisions related to road infrastructure or vehicles
- Our approach applies to any spatial or temporal scale, depending on the nature of the problem being looked at
- First, we need to characterize vehicle (or vehicle class) energy and emissions "signature" which requires 2-3 hrs of data collection using PEMS
- Models of data allows inferences into future scenarios combining effect of traffic (VMT), traffic controls, land use (Smart Growth) and vehicle technology.

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Thank you for your attention !!

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