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

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For Presentation at:
U.S. Environmental Protection Agency
Ann Arbor, MI

March 5, 2014

Major Accomplishments

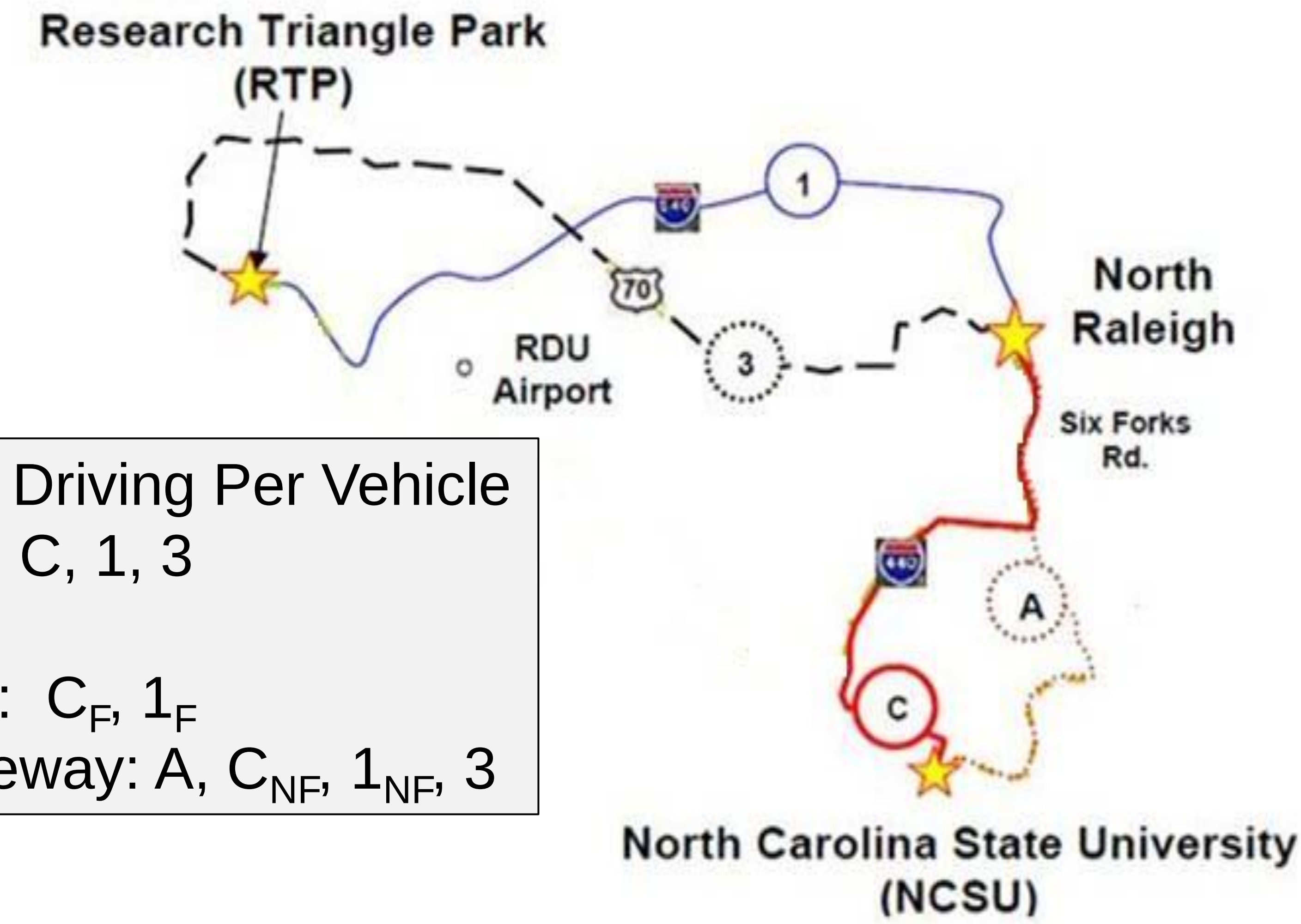
- Evaluation of MOVES model in comparison to independent empirical data
- Development of “MOVES Lite”
- Incorporation of “MOVES Lite” into DTALite dynamic traffic simulator
- Simulation experiments to test traffic management strategies and their effect on emissions

Model Evaluation

- MOVES has undergone some evaluation
  - Chassis dynamometer data: short duration, limited range of driving cycles
  - Remote sensing data: location-specific ‘snapshots’
  - Tunnel studies: location-specific, difficult to resolve for individual types of vehicles
- Approach here: use independent path-based data from in-use driving for 100 vehicles each measured over 110 miles

Portable Emission Measurement System

Test Routes



112 Miles of Driving Per Vehicle
4 Routes: A, C, 1, 3
6 Cycles
- Freeway: C_F, 1_F
- Non-Freeway: A, C_{NF}, 1_{NF}, 3

Vehicle Specific Power

Modal average fuel use and emission factors are estimated based Vehicle Specific Power (VSP).

$$VSP=v[1.1a+9.81(\sin(\arctan(r)))+0.132]+0.000302v^3$$

Where,

v = vehicle speed (km/h)

a = acceleration (km/h per sec)

r = road grade (%)

VSP = vehicle-specific power (kW/ton)

Vehicle Specific Power

Modal average fuel use and emission factors are estimated based Vehicle Specific Power (VSP).

Kinetic energy

$$VSP=v[1.1a+9.81(\sin(\arctan(r)))+0.132]+0.000302v^3$$

Where,

v = vehicle speed (km/h)

a = acceleration (km/h per sec)

r = road grade (%)

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Vehicle Specific Power

Modal average fuel use and emission factors are estimated based Vehicle Specific Power (VSP).

Road grade

$$VSP=v[1.1a+9.81(\sin(\arctan(r)))+0.132]+0.000302v^3$$

Where,

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a = acceleration (km/h per sec)

r = road grade (%)

VSP = vehicle-specific power (kW/ton)

Vehicle Specific Power

Modal average fuel use and emission factors are estimated based Vehicle Specific Power (VSP).

Rolling and rotational resistance

$$VSP=v[1.1a+9.81(\sin(\arctan(r)))+0.132]+0.000302v^3$$

Where,

v = vehicle speed (km/h)

a = acceleration (km/h per sec)

r = road grade (%)

VSP = vehicle-specific power (kW/ton)

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Vehicle Specific Power

Modal average fuel use and emission factors are estimated based Vehicle Specific Power (VSP).

Aerodynamic drag

$$VSP=v[1.1a+9.81(\sin(\arctan(r)))+0.132]+0.000302v^3$$

Where,

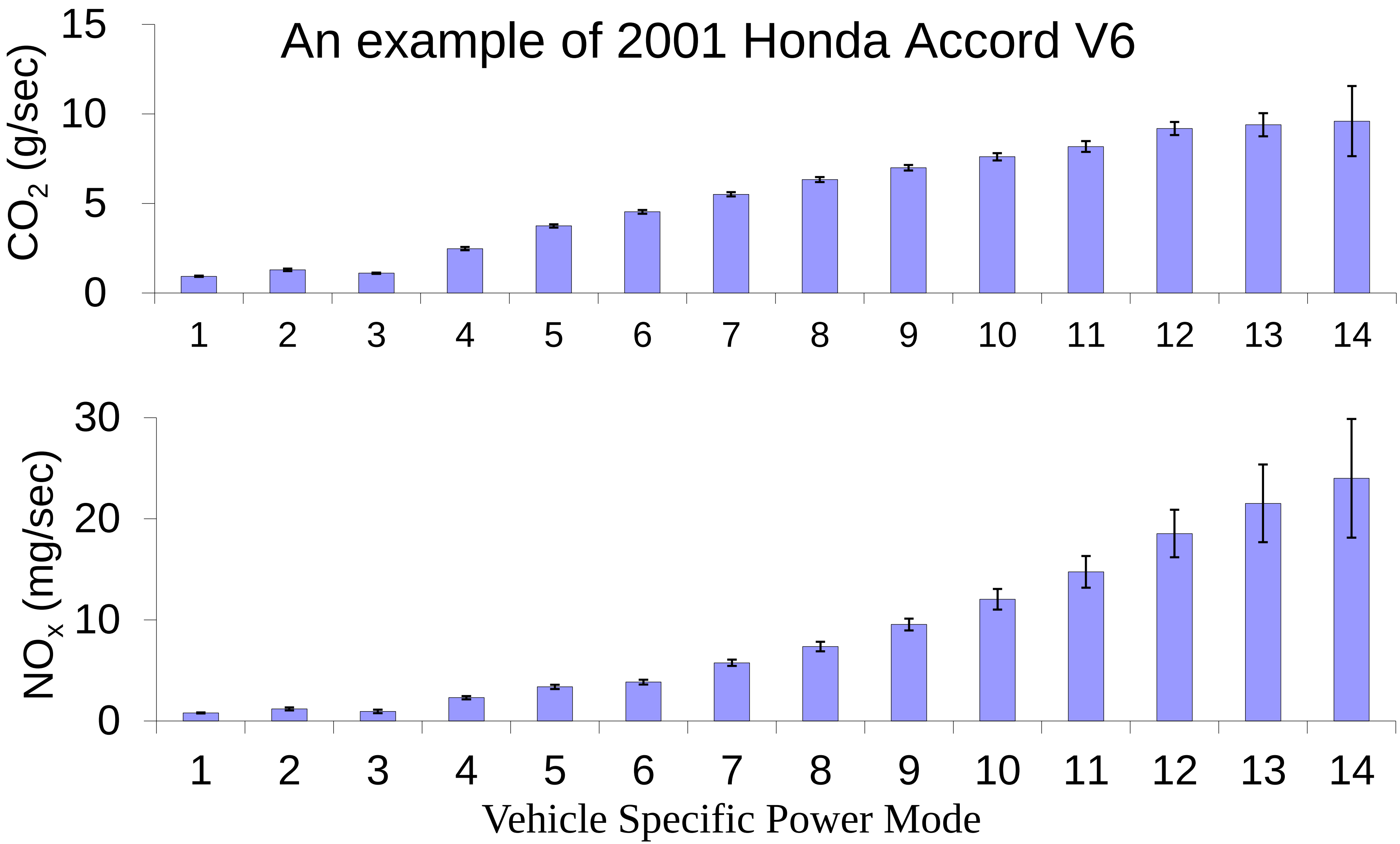
v = vehicle speed (km/h)

a = acceleration (km/h per sec)

r = road grade (%)

VSP = vehicle-specific power (kW/ton)

Example of VSP Modal CO_2 and NO_x Emission Rates



Characteristics of Measured Vehicles

- 100 Light Duty Gasoline Vehicles
- 63 Passenger Cars (PC)
- 37 Passenger Trucks (PT)
- 1996 to 2013 model years.
- 0 to 14 years of age
- 600 to 230,000 accumulated miles
- 1.3 to 5.4 L
- 1,700 to 7,400 lb GVW

Empirically-Based Emission Factors for Each Vehicle and Driving Cycle

$$EF_{v,c} = \frac{\left(\sum ER_{m,v} \bullet f_{m,c}\right) \bullet T_c}{L_c}$$

$EF_{v,c}$ = cycle average emission factor for vehicle *v* and cycle *c* (g/mi);

$ER_{m,v}$ = average emission rate for VSP mode *m* and vehicle *v* (g/s);

$F_{m,c}$ = fraction of time in VSP mode *m* for cycle *c;*

T_c = Total travel time for cycle *c* (sec);

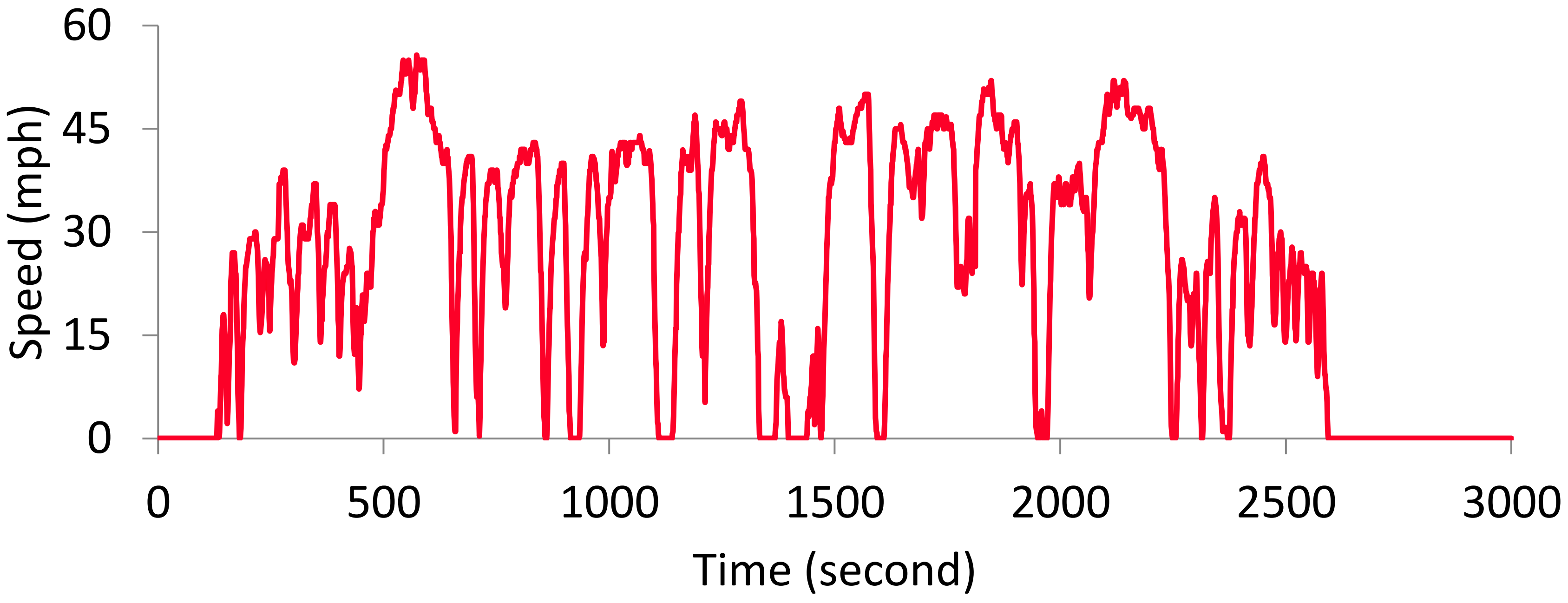
L_c = Total travel distance for cycle *c* (mi);

Project-level MOVES Emission Factors

- MOVES: vehicle emission factor model developed by U.S. Environmental Protection Agency.
- Evaluate consistency in emissions trends between MOVES and empirical data
- MOVES estimation methods:
  - National Level
  - County Level
  - **Project Level**

Project Level MOVES Emission Factors

- User enters a driving schedule.
- Based on second-by-second speed and road grade.



An example of 2000 Mitsubishi Galant on Route A

Example of MOVES Input Data

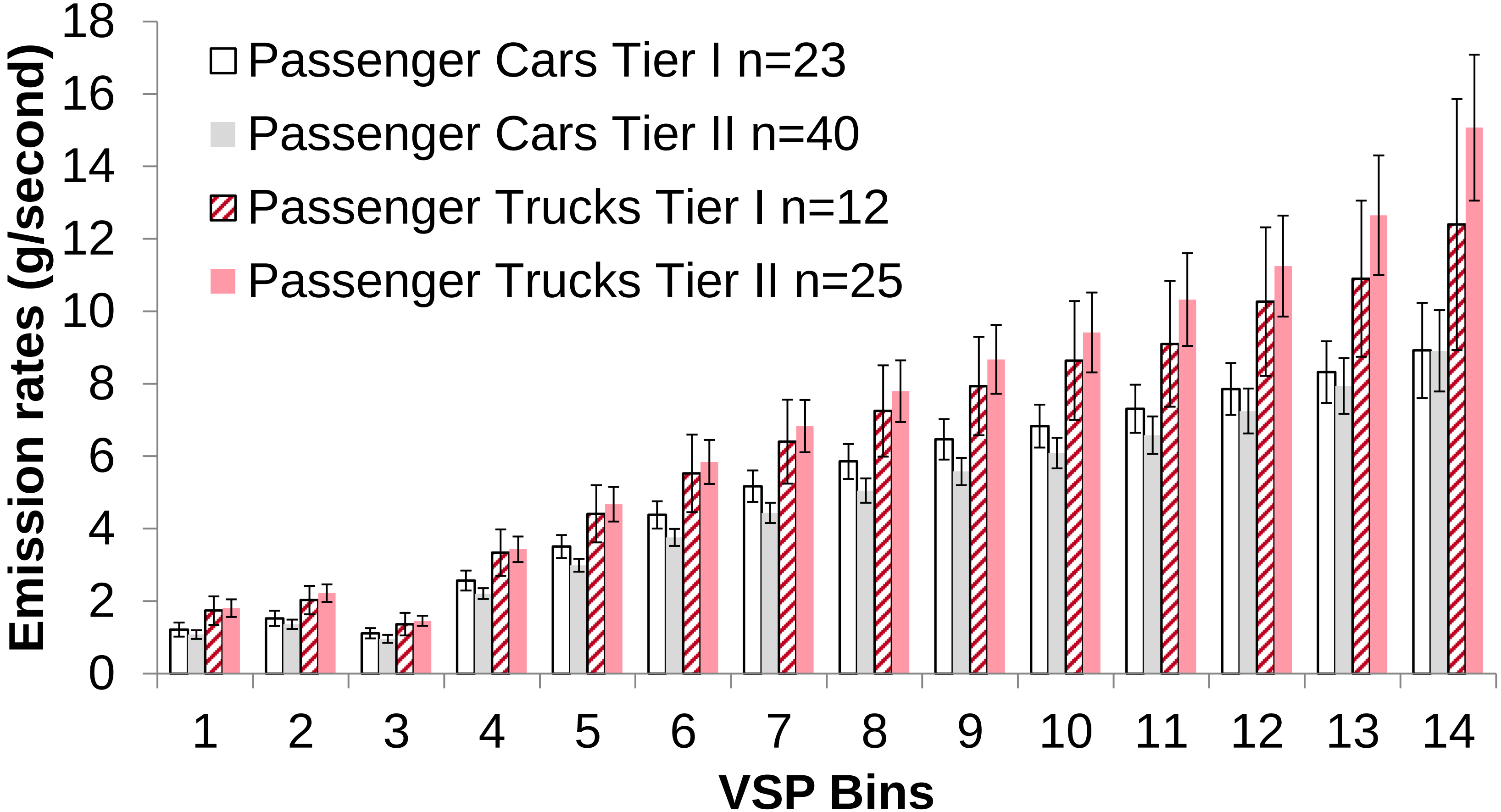
Example based on 2000 Mitsubishi Galant and Route A

Meteorological Data	97.3 ^{o}F; 32% Relative Humidity
Age Distribution	10 years, Calendar Year 2010
Driving Schedule	Empirical data: Route A
Link Source Type	100% passenger car
Link Length	20.3 miles
Fuel	Gasoline
I/M Program	Wake County, NC

Objectives for Model Evaluation

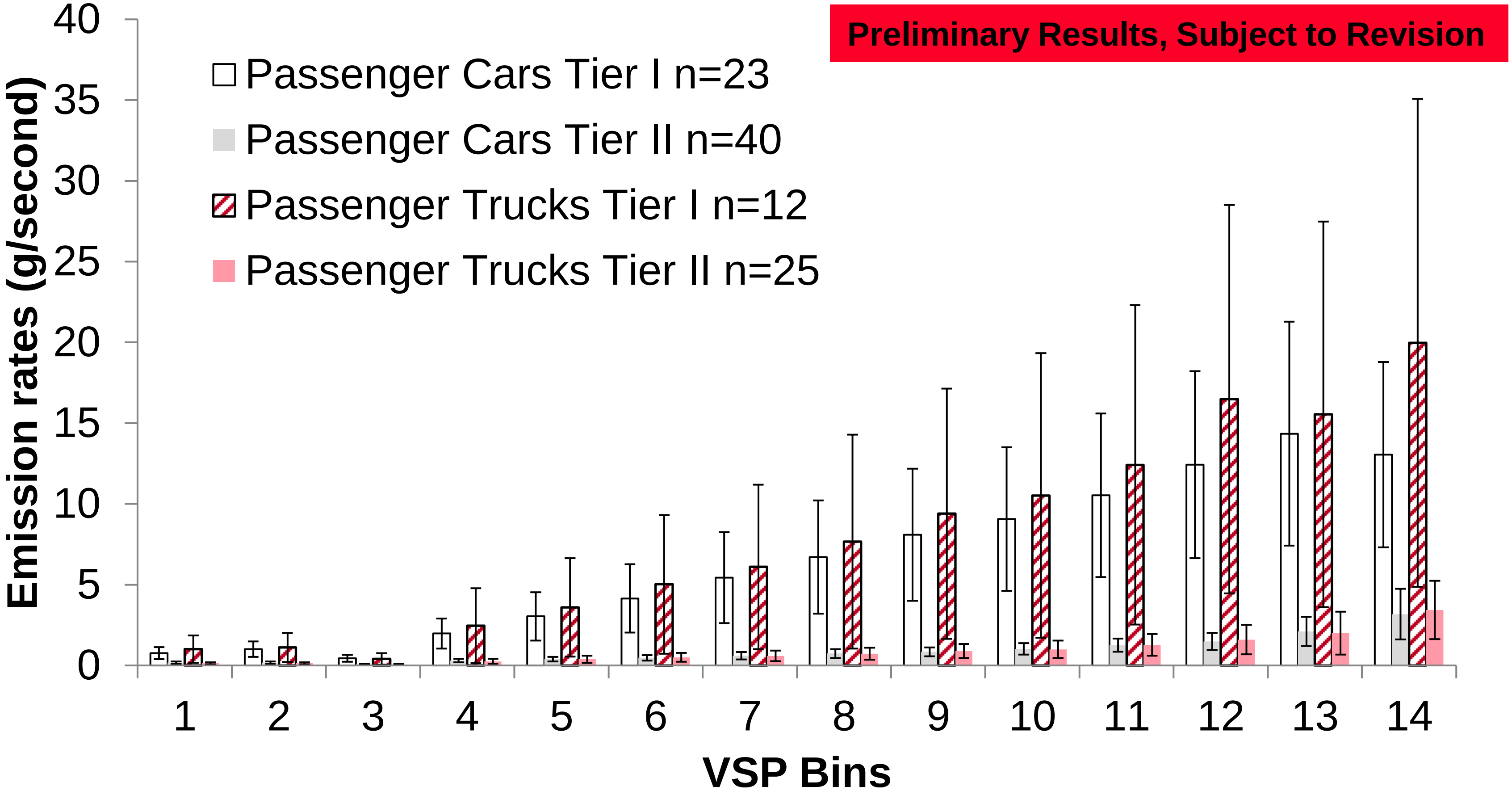
- Evaluate MOVES sensitivity to:
  - vehicle type
  - driving cycles
  - road types
  - model year
  - age and mileage
- Focus is on similarity in relative trends
- Results shown here are “preliminary” and undergoing some final data quality review

Summary of Empirical Data: CO_2 Emission Rates



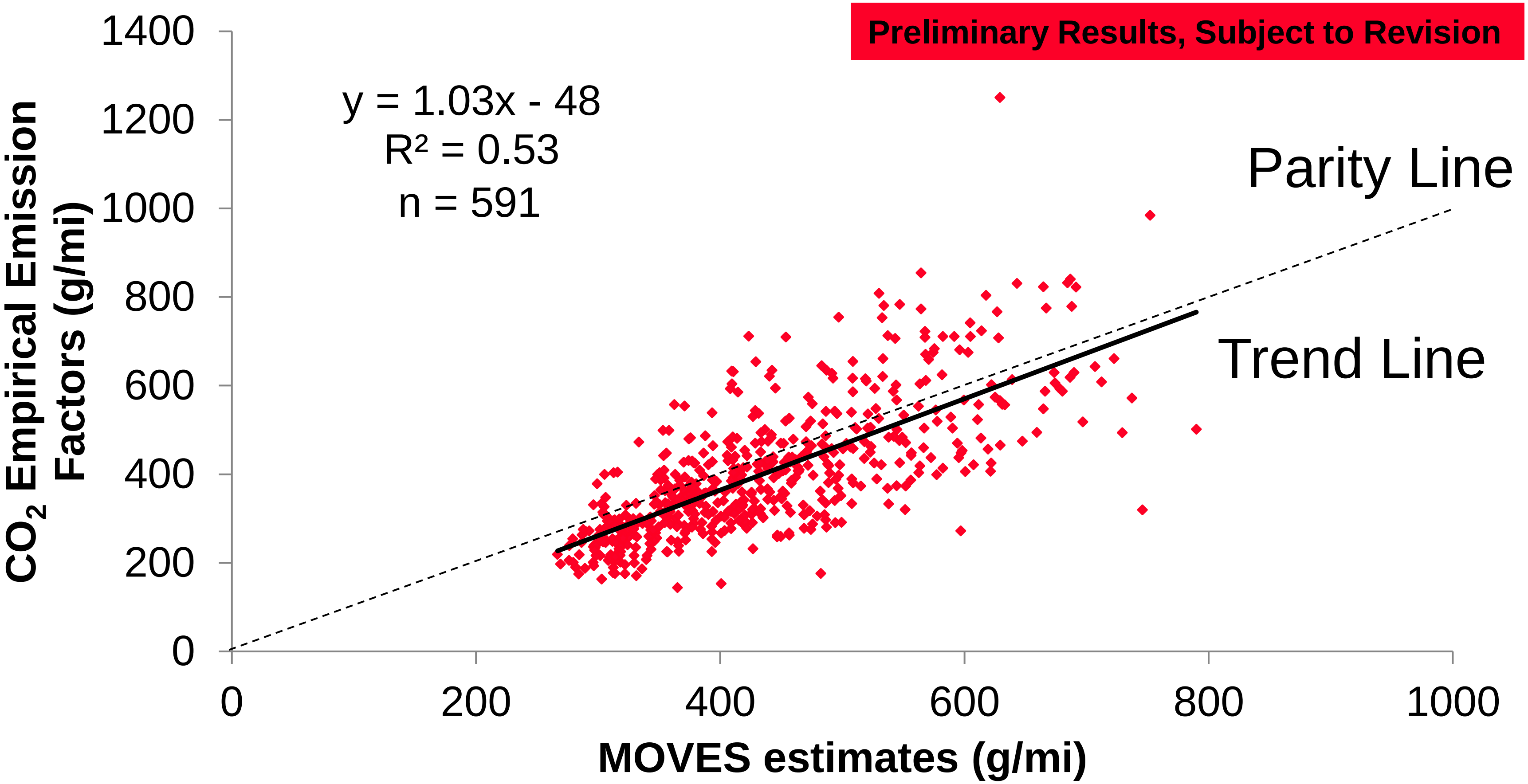
CO_2 Sensitive to Vehicle Type, Not Model Year

Summary of Empirical Data: NO_x Emission Rates



NO_x Sensitive to Vehicle Type & Model Year

Empirical vs. MOVES: CO_2



MOVES is a ***fleet*** model. Empirical data are individual vehicles

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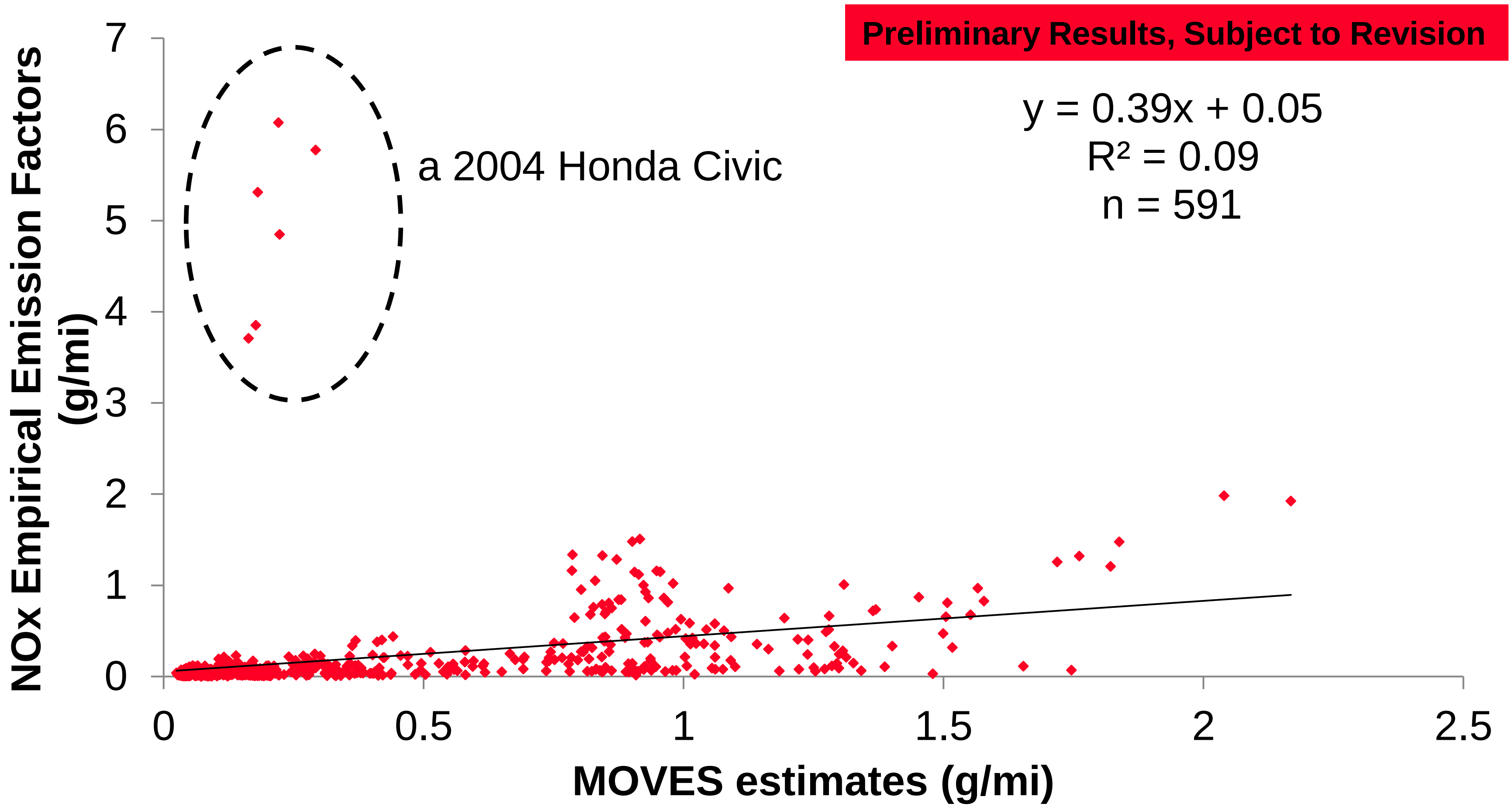
Empirical vs. MOVES: NO_x



MOVES is a ***fleet*** model. Empirical data are individual vehicles

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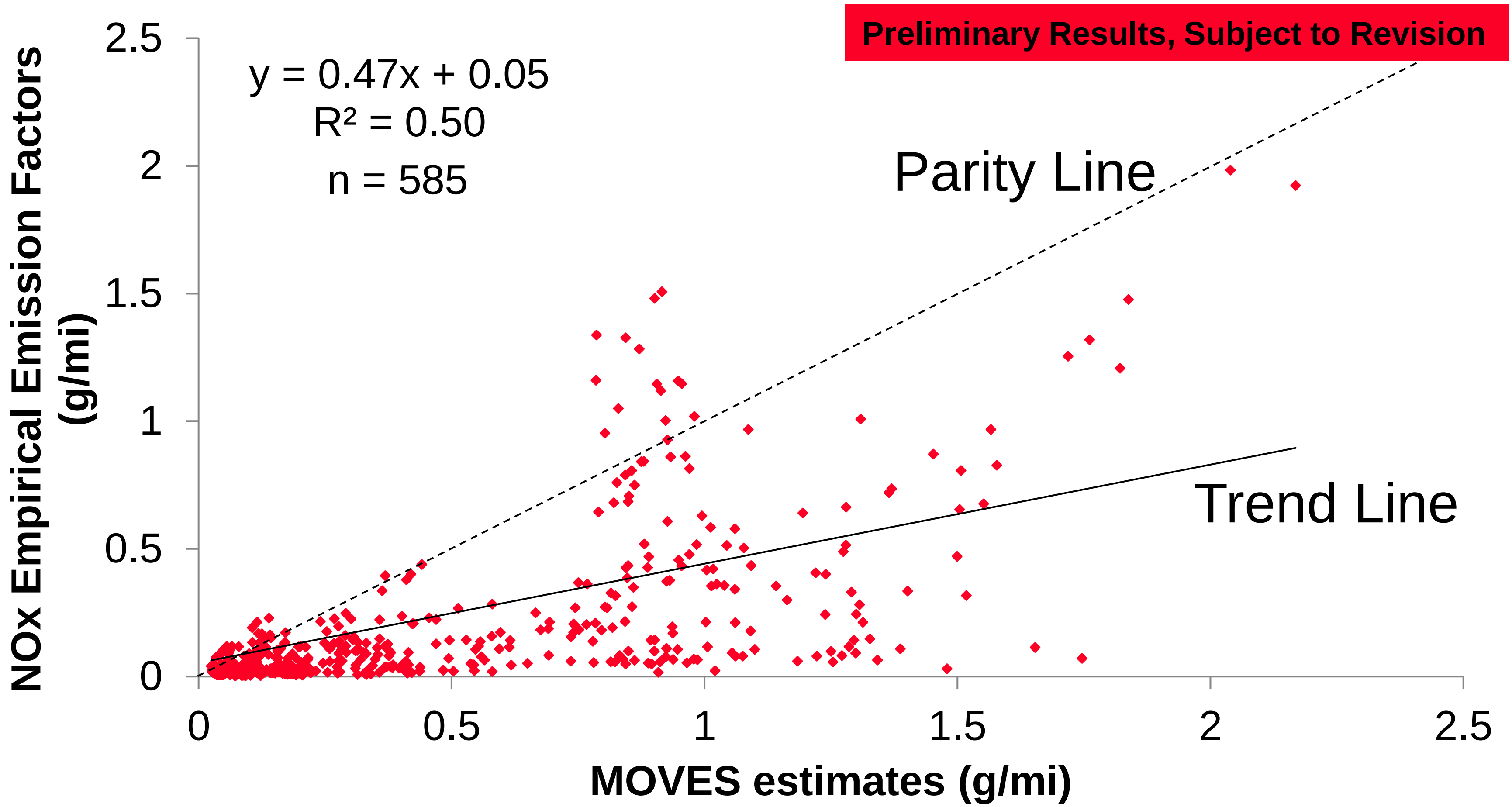
Empirical vs. MOVES: NO_x



MOVES is a ***fleet*** model. Empirical data are individual vehicles.

MOVES may better account for high emitters

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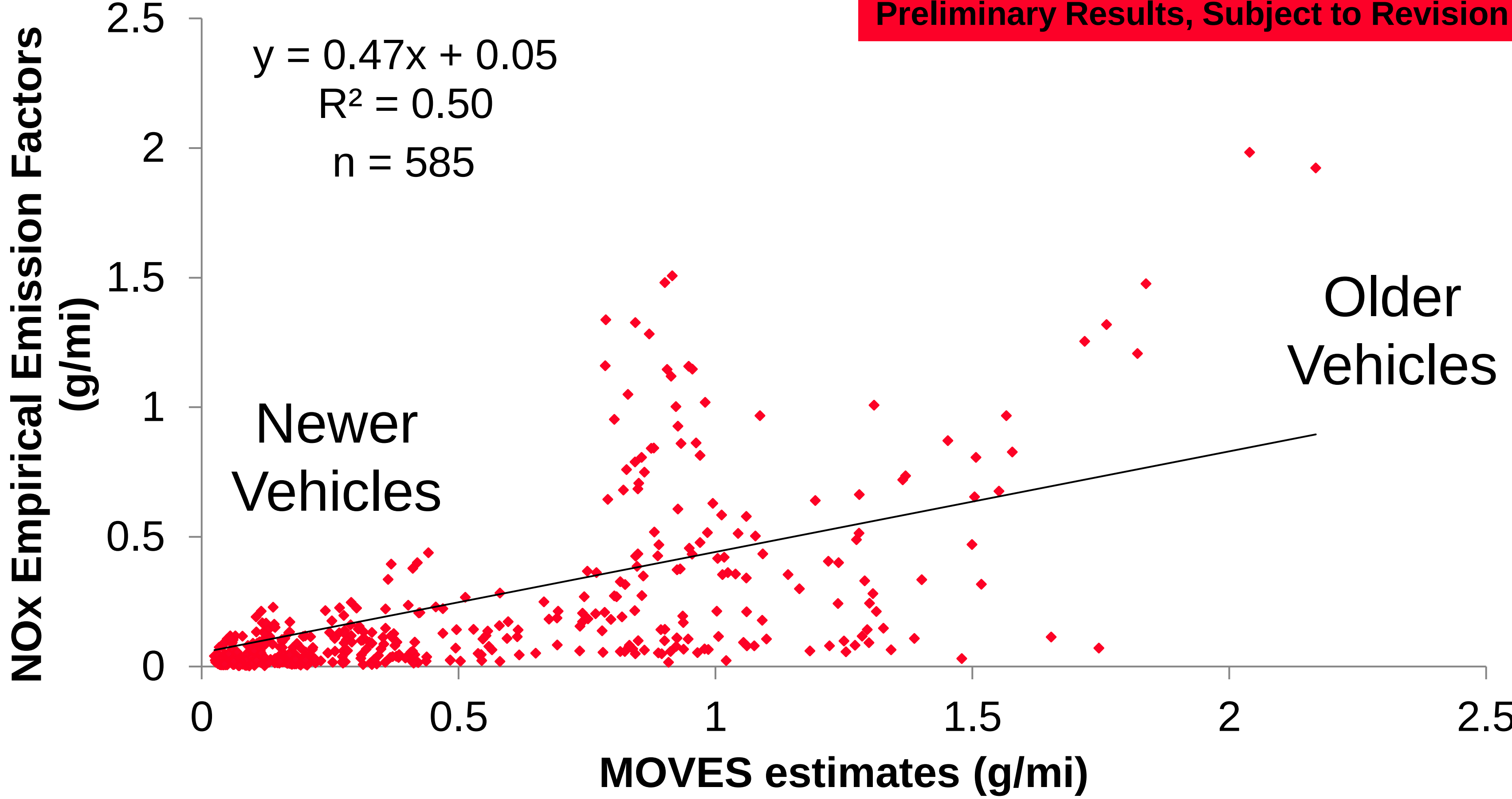
Empirical vs. MOVES: NO_x

Preliminary Results, Subject to Revision



MOVES is a ***fleet*** model. Empirical data are individual vehicles.

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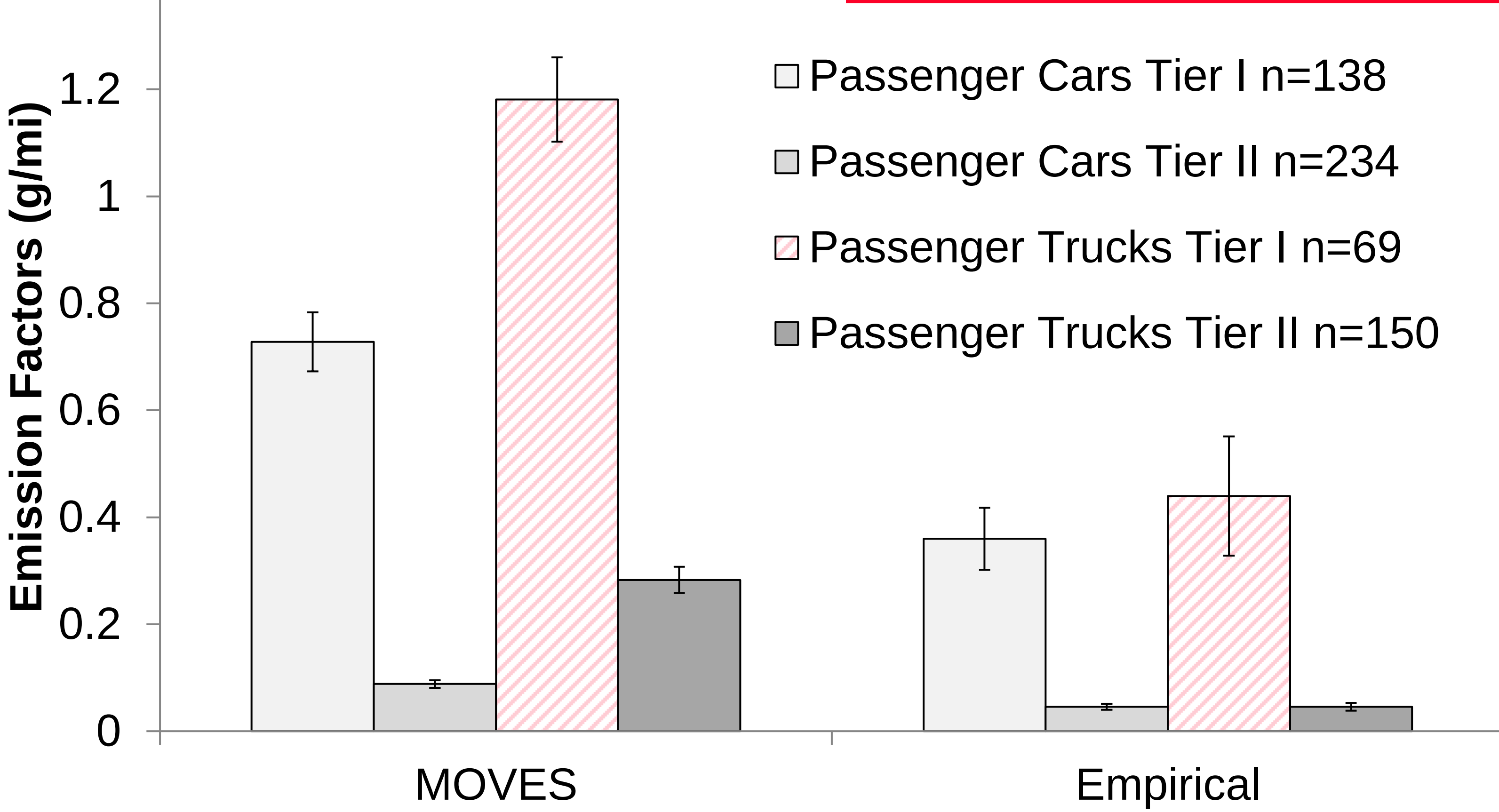
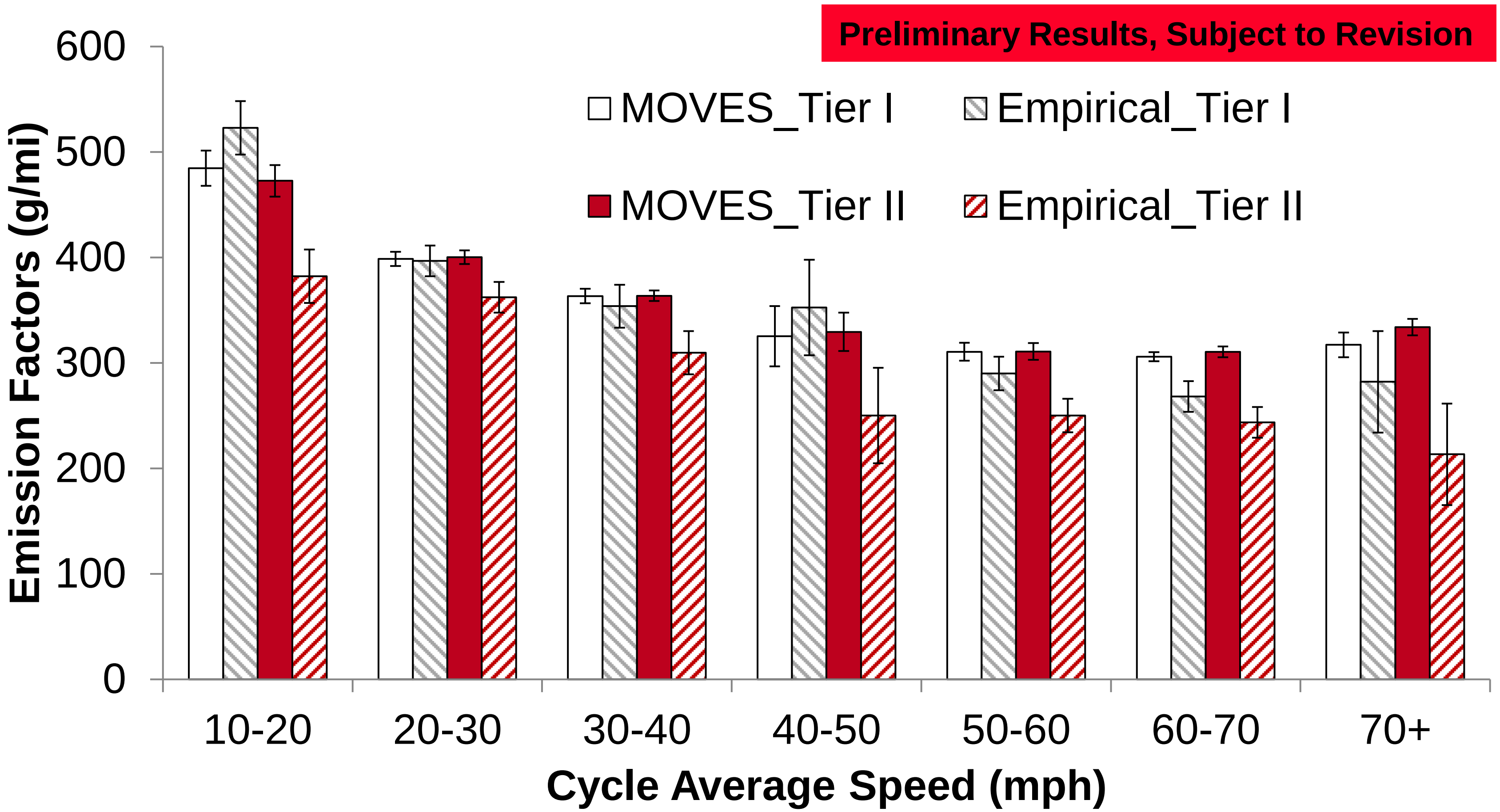
Average NO_x Emission Factors: PC and PT, Tier I and Tier II, MOVES and Empirical

Preliminary Results, Subject to Revision



Trends are similar: Tier II < Tier I, PC < PT. MOVES > Empirical

Comparisons of Empirical and MOVES CO_2 Emission Factors by Cycle Average Speed

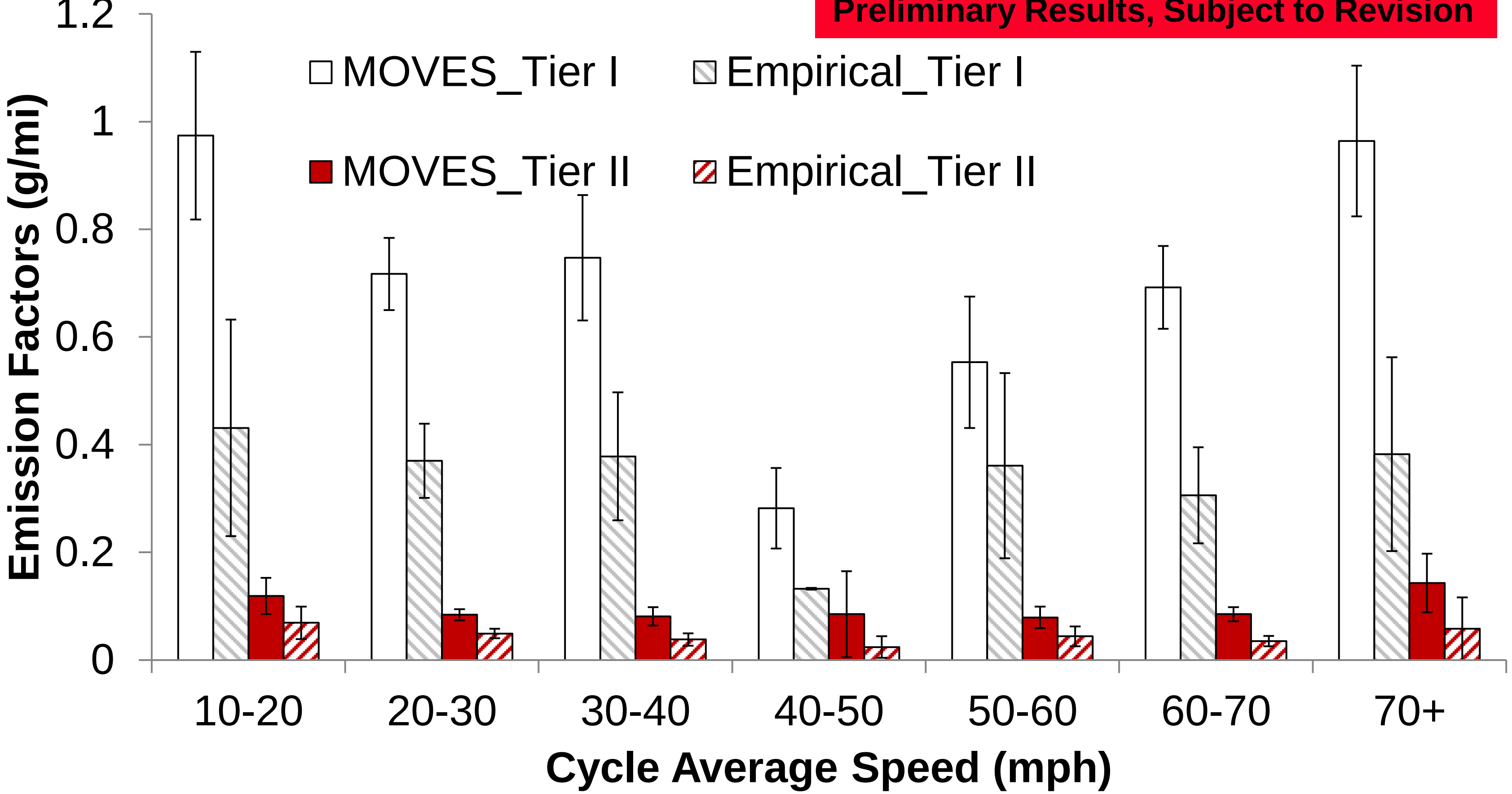


Tier 1 lowest rate at 60-70 mph

Tier 2 empirical includes some hybrid vehicles

Comparisons of Empirical and MOVES NO_x Emission Factors by Cycle Average Speed

Preliminary Results, Subject to Revision



Lowest Rate Typically at 40 to 50 mph for both MOVES and Empirical Data

Ongoing Work: MOVES vs. Empirical Data

- Road type: Freeway and Non-Freeway
- Mileage and Age: statistically significant trends for empirical data
- Distributions of inter-vehicle variation are often highly correlated when comparing one case to another (e.g., road type)

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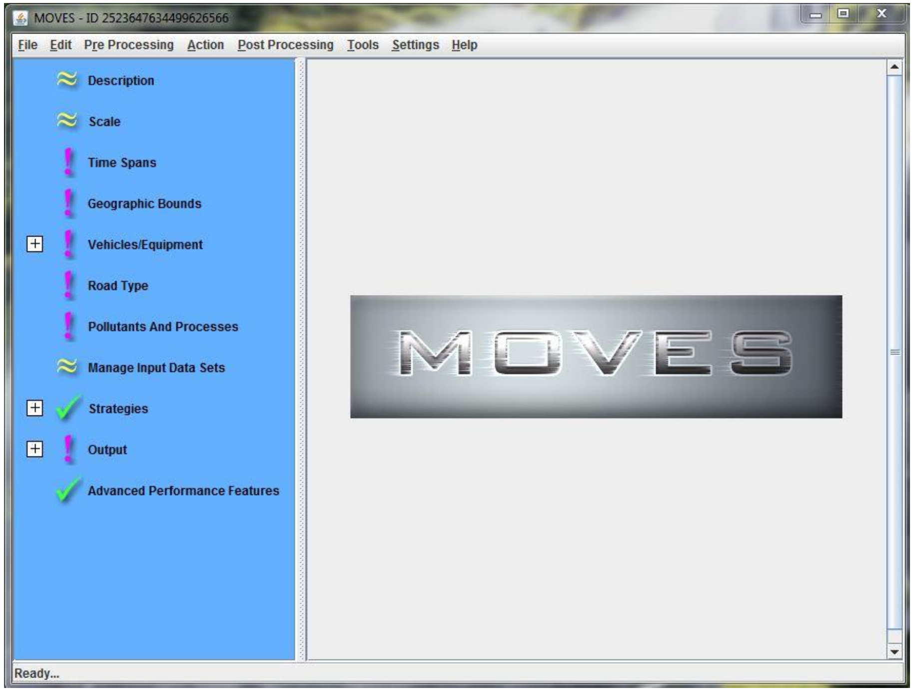
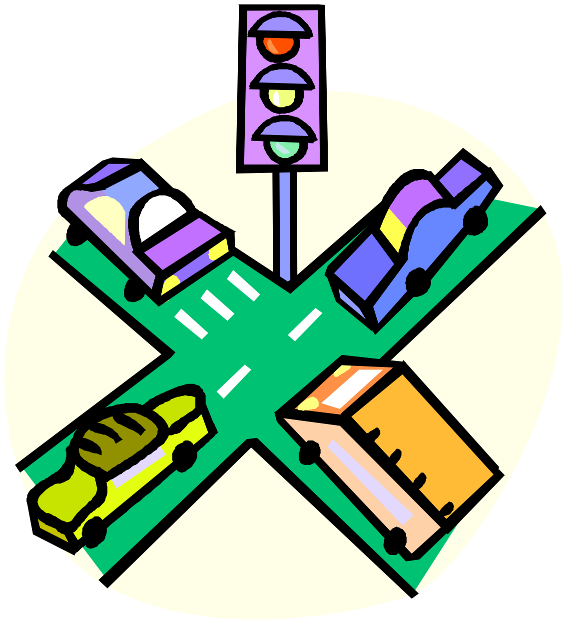
Development of "MOVES Lite"

- The U.S. EPA Motor Vehicle Emission Simulator (MOVES) is a computationally and data intensive model for estimating vehicle emission factors.

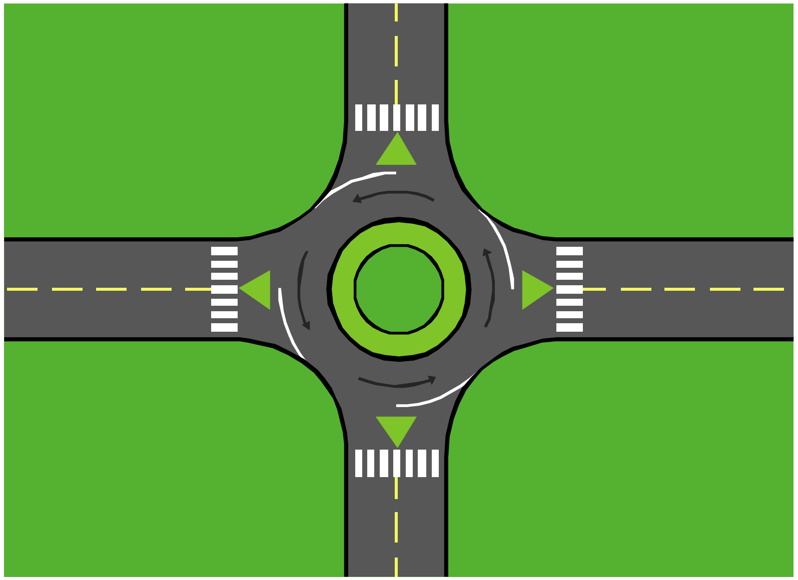


Motivation

- Traffic Simulation Models (TSMs) quantify the effect of infrastructure design and traffic control measures (TCMs) on vehicle dynamics (i.e. speed and acceleration of individual vehicles).

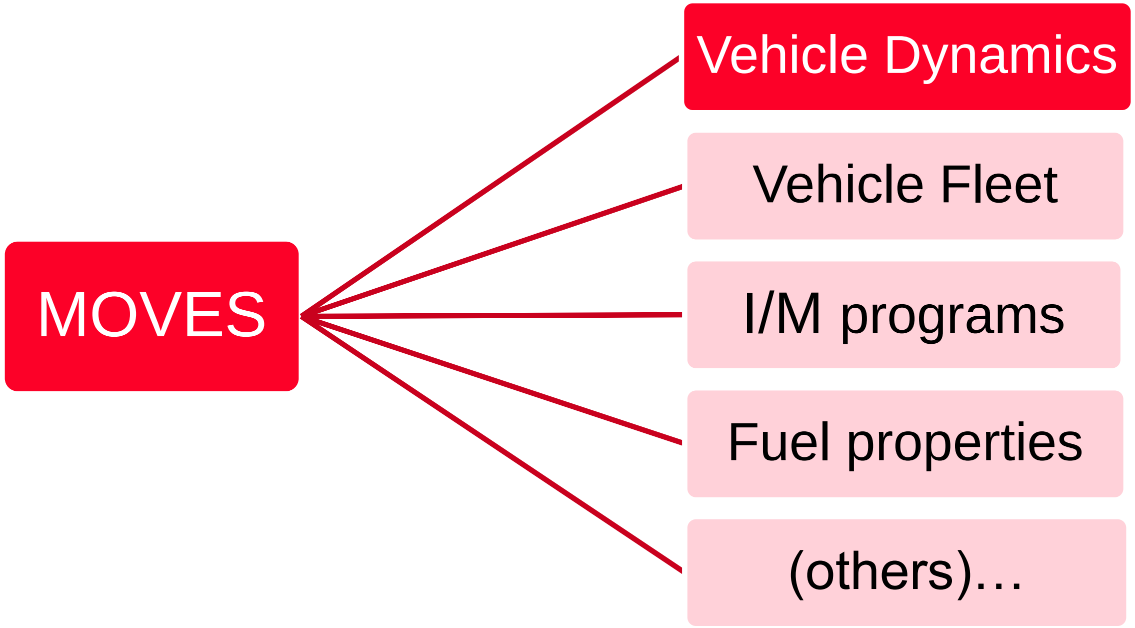


vs.



Motivation

- Because TSMs typically simulate only a few hours of vehicle activity, it is not necessary to dynamically simulate the effect of constant factors such as fuel properties and inspection/maintenance programs.



Objectives

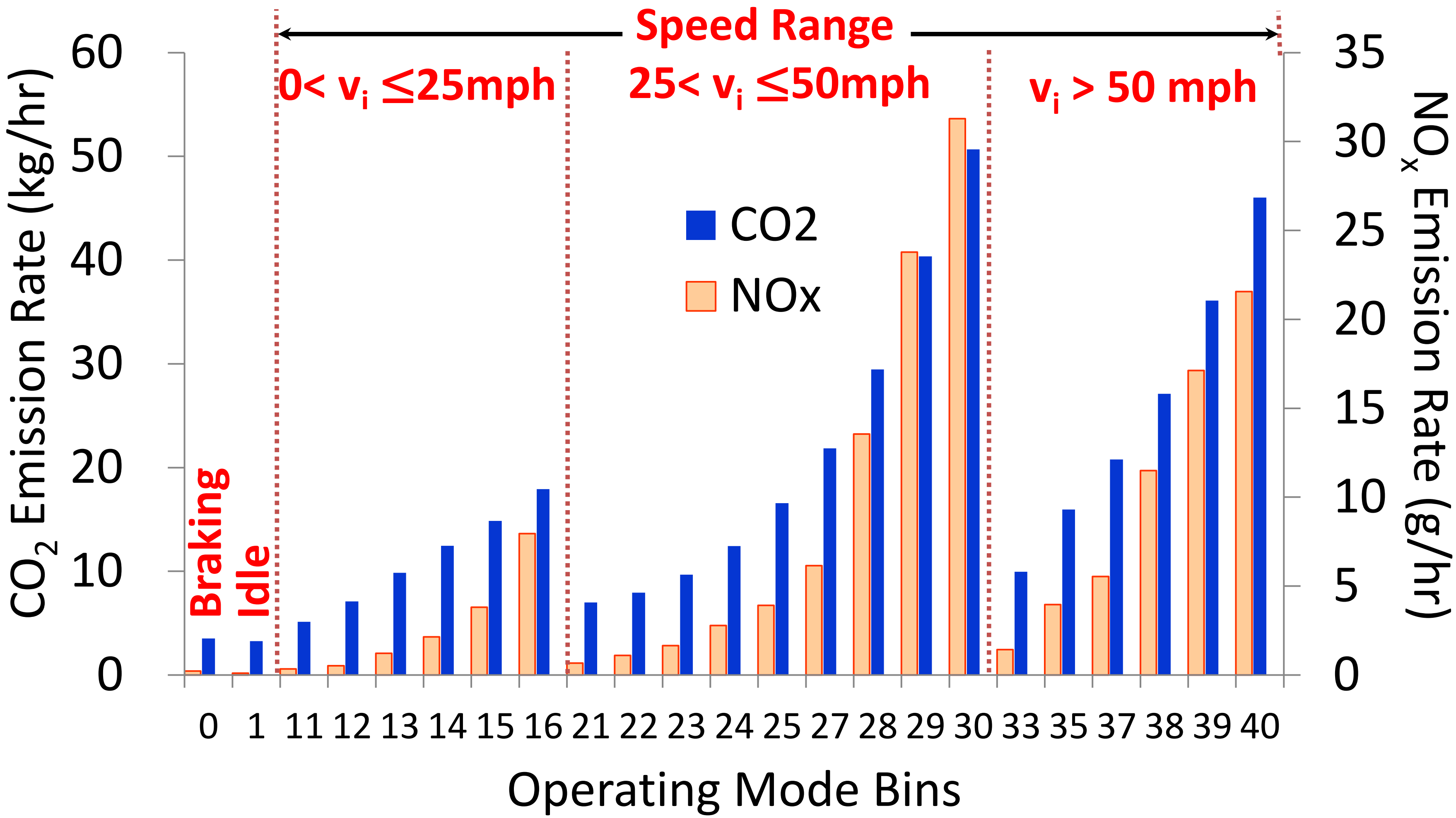
- Develop a simplified MOVES model that can be efficiently coupled with TSMs.
- Evaluate the accuracy of the simplified model.
- Evaluate the sensitivity of the simplified model to variations in driving cycles.

Definition of MOVES Operating Mode Bins by Speed and VSP Ranges

0 mph< $v_i \leq$25 mph		25 mph < $v_i \leq$50 mph		v_i >50 mph	
OpMode ID	Description	OpMode ID	Description	OpMode ID	Description
11	VSP< 0	21	VSP< 0		
12	0≤VSP< 3	22	0≤VSP< 3		
13	3≤VSP< 6	23	3≤VSP< 6	33	VSP< 6
14	6≤VSP< 9	24	6≤VSP< 9	35	6≤VSP<12
15	9≤VSP<12	25	9≤VSP<12		
16	12≤VSP	27	12≤VSP<18	37	12≤VSP<18
Other:		28	18≤VSP<24	38	18≤VSP<24
0	Braking	29	24≤VSP<30	39	24≤VSP<30
1	Idling	30	30≤VSP	40	30≤VSP

v_i: instantaneous speed of the ith second

Emission Rates for Operating Mode Bins in MOVES Default Database: 5 yr old Passenger Cars



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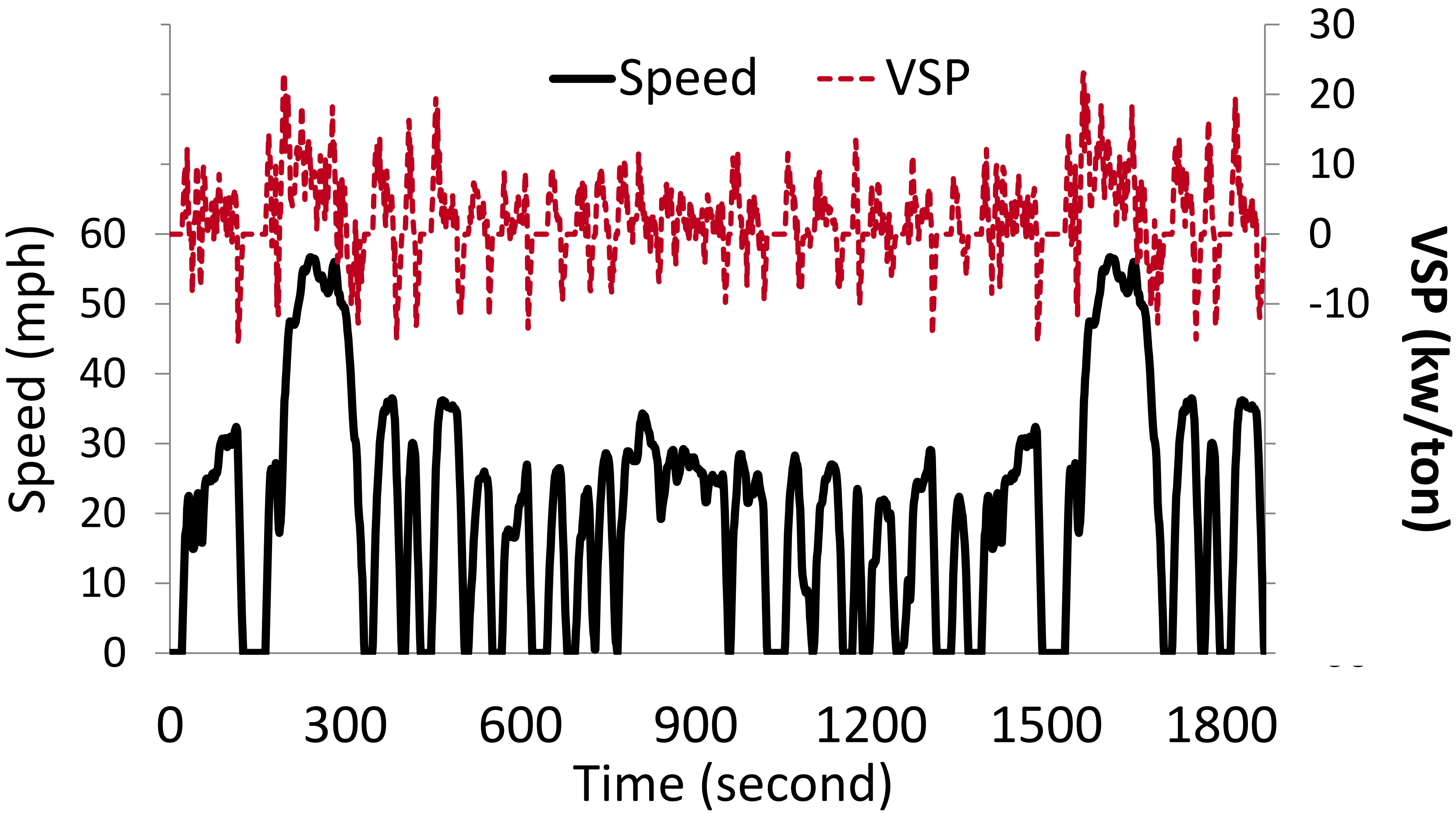
Speed and Vehicle Specific Power (VSP) for Federal Test Procedure (FTP)



Simplified Model
Cycle Average Emission Rate

- Simplified Model:

$$CE_{p,c} = \sum_{v} \left\{ \left[\sum_{a} \left(EF_{p,b,a,v} \times CCF_{p,c,a,v} \times f_{a,v} \right) \right] \times f_v \right\} \quad (1)$$

$CE_{p,c,}$	=	cycle average emission factor for pollutant p, for any arbitrary driving cycle c, for a fleet of vehicles with mixed types and ages, gram/mi
$EF_{p,b,a,v}$	=	base emission rate for pollutant p, for base cycle b, age a, vehicle type v, gram/mi
$CCF_{p,c,a,v}$	=	cycle correction factor for pollutant p, driving cycle c, age a, vehicle type v
$f_{a,v}$	=	age fraction for age a and vehicle type v
f_v	=	vehicle type fraction for vehicle type v

Simplified Model
Base Emission Rate From MOVES

Emission rate for a base cycle estimated using MOVES

$$CE_{p,c} = \sum_{v} \left\{ \left[\sum_{a} \left(\boxed{EF_{p,b,a,v}} \times CCF_{p,c,a,v} \times f_{a,v} \right) \right] \times f_v \right\} \quad (1)$$

$CE_{p,c,}$	=	cycle average emission factor for pollutant p, for any arbitrary driving cycle c, for a fleet of vehicles with mixed types and ages, gram/mi
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$f_{a,v}$	=	age fraction for age a and vehicle type v
f_v	=	vehicle type fraction for vehicle type v

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Simplified Model
Cycle Correction Factor

CCF for any arbitrary cycle c calculated by Eq. 2

$$CE_{p,c} = \sum_{v} \left\{ \left[\sum_{a} \left(EF_{p,b,a,v} \times \boxed{CCF_{p,c,a,v}} \times f_{a,v} \right) \right] \times f_{v} \right\} \quad (1)$$

$CE_{p,c,}$	=	cycle average emission factor for pollutant p, for any arbitrary driving cycle c, for a fleet of vehicles with mixed types and ages, gram/mi
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$f_{a,v}$	=	age fraction for age a and vehicle type v
f_{v}	=	vehicle type fraction for vehicle type v

Simplified Model: Distribution of Fleet Age

- Conceptual Model:

$$CE_{p,c} = \sum_{v} \left\{ \left[\sum_{a} \left(EF_{p,b,a,v} \times CCF_{p,c,a,v} \times \boxed{f_{a,v}} \right) \right] \times f_v \right\} \quad (1)$$

Distribution of vehicle type ***v*** fleet by age ***a***

$CE_{p,c,}$	=	cycle average emission factor for pollutant p, for any arbitrary driving cycle c, for a fleet of vehicles with mixed types and ages, gram/mi
$EF_{p,b,a,v}$	=	base emission rate for pollutant p, for base cycle b, age a, vehicle type v, gram/mi
$CCF_{p,c,a,v}$	=	cycle correction factor for pollutant p, driving cycle c, age a, vehicle type v
$f_{a,v}$	=	age fraction for age a and vehicle type v
f_v	=	vehicle type fraction for vehicle type v

Simplified Model: Distribution of Vehicle Types

- Conceptual Model:

$$CE_{p,c} = \sum_{v} \left\{ \left[\sum_{a} \left(EF_{p,b,a,v} \times CCF_{p,c,a,v} \times f_{a,v} \right) \right] \times f_{v} \right\} \quad (1)$$

Distribution of vehicle type ***v***

$CE_{p,c,}$	=	cycle average emission factor for pollutant p, for any arbitrary driving cycle c, for a fleet of vehicles with mixed types and ages, gram/mi
$EF_{p,b,a,v}$	=	base emission rate for pollutant p, for base cycle b, age a, vehicle type v, gram/mi
$CCF_{p,c,a,v}$	=	cycle correction factor for pollutant p, driving cycle c, age a, vehicle type v
$f_{a,v}$	=	age fraction for age a and vehicle type v
f_{v}	=	vehicle type fraction for vehicle type v

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Estimating the Cycle Correction Factor

$$CCF_{p,c,a,v} = \left(\frac{\left(\sum_m f_m^c \times ER_{p,a,v,m}\right)}{\left(\sum_m f_m^b \times ER_{p,a,v,m}\right)} \right) \left(\frac{V^b}{V^c} \right) \quad (2)$$

$ER_{p,a,v,m}$	=	default emission rate for pollutant p, age a, vehicle type v, in operating mode bin m, g/hr
$f_m^{\ c}$	=	fraction of time in OpMode bin m in cycle c
$f_m^{\ b}$	=	fraction of time in OpMode bin m for base cycle b
V^c	=	cycle average speed for cycle c, mph
V^b	=	cycle average speed for base cycle b, mph

Estimating the Cycle Correction Factor

$$CCF_{p,c,a,v} = \left(\frac{\left(\sum_m f_m^c \times ER_{p,a,v,m}\right)}{\left(\sum_m f_m^b \times ER_{p,a,v,m}\right)} \right) \left(\frac{V^b}{V^c} \right) \quad (2)$$

$ER_{p,a,v,m}$	=	default emission rate for pollutant p, age a, vehicle type v, in operating mode bin m, g/hr
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$f_m{}^b$	=	fraction of time in OpMode bin m for base cycle b
V^c	=	cycle average speed for cycle c, mph
V^b	=	cycle average speed for base cycle b, mph

Distribution of <u>time</u> in OpMode bin ***m*** for base cycle ***b***

Estimating the Cycle Correction Factor

$$CCF_{p,c,a,v} = \left(\frac{\left(\sum_m f_m^c \times ER_{p,a,v,m}\right)}{\left(\sum_m f_m^b \times ER_{p,a,v,m}\right)} \right) \left(\frac{V^b}{V^c} \right)$$

$ER_{p,a,v,m}$	=	default emission rate for pollutant p, age a, vehicle type v, in operating mode bin m, g/hr
$f_m^{\ c}$	=	fraction of time in OpMode bin m in cycle c
$f_m^{\ b}$	=	fraction of time in OpMode bin m for base cycle b
V^c	=	cycle average speed for cycle c, mph
V^b	=	cycle average speed for base cycle b, mph

Distribution of time in OpMode bin ***m*** for any user-specified cycle ***c***

Estimating the Cycle Correction Factor

$$CCF_{p,c,a,v} = \left(\frac{\left(\sum_m f_m^c \times ER_{p,a,v,m}\right)}{\left(\sum_m f_m^b \times ER_{p,a,v,m}\right)} \right) \left(\frac{V^b}{V^c} \right) \quad (2)$$

$ER_{p,a,v,m}$	=	default emission rate for pollutant p, age a, vehicle type v, in operating mode bin m, g/hr
f_m^c	=	fraction of time in OpMode bin m in cycle c
f_m^b	=	fraction of time in OpMode bin m for base cycle b
V^c	=	cycle average speed for cycle c, mph
V^b	=	cycle average speed for base cycle b, mph

Default "OpMode Bin" mode ***m*** Emission Rates for Pollutant ***p***, vehicle Age ***a***, and Vehicle type ***v***.

Estimating the Cycle Correction Factor

$$CCF_{p,c,a,v} = \left(\frac{\left(\sum_m f_m^c \times ER_{p,a,v,m}\right)}{\left(\sum_m f_m^b \times ER_{p,a,v,m}\right)} \right) \left(\frac{V^b}{V^c} \right) \quad (2)$$

$ER_{p,a,v,m}$	=	default emission rate for pollutant p, age a, vehicle type v, in operating mode bin m, g/hr
f_m^c	=	fraction of time in OpMode bin m in cycle c
f_m^b	=	fraction of time in OpMode bin m for base cycle b
V^c	=	cycle average speed for cycle c, mph
V^b	=	cycle average speed for base cycle b, mph

Ratio of average speeds for base and user-specific cycles to convert from ‘per time’ to ‘per distance’

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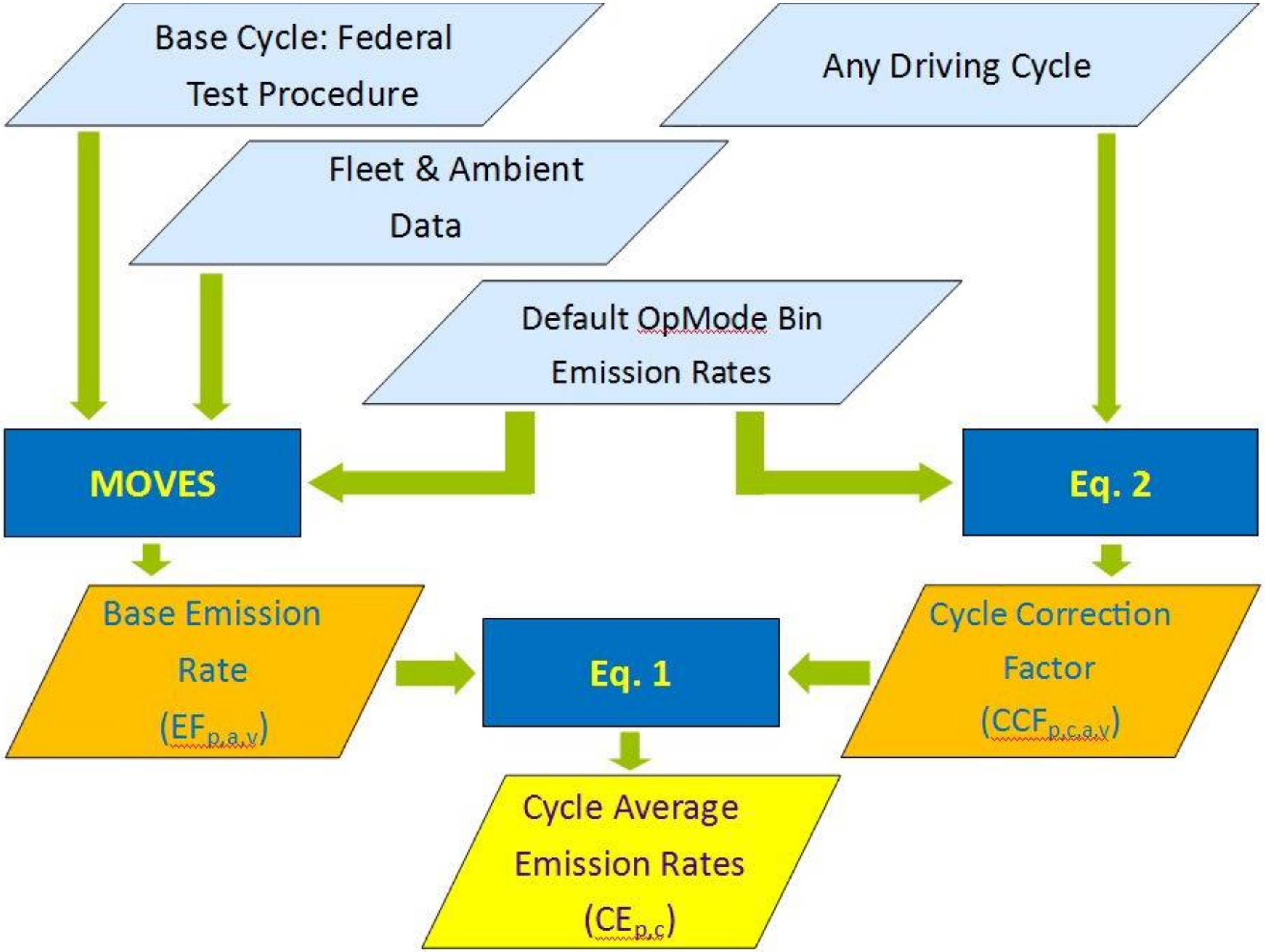
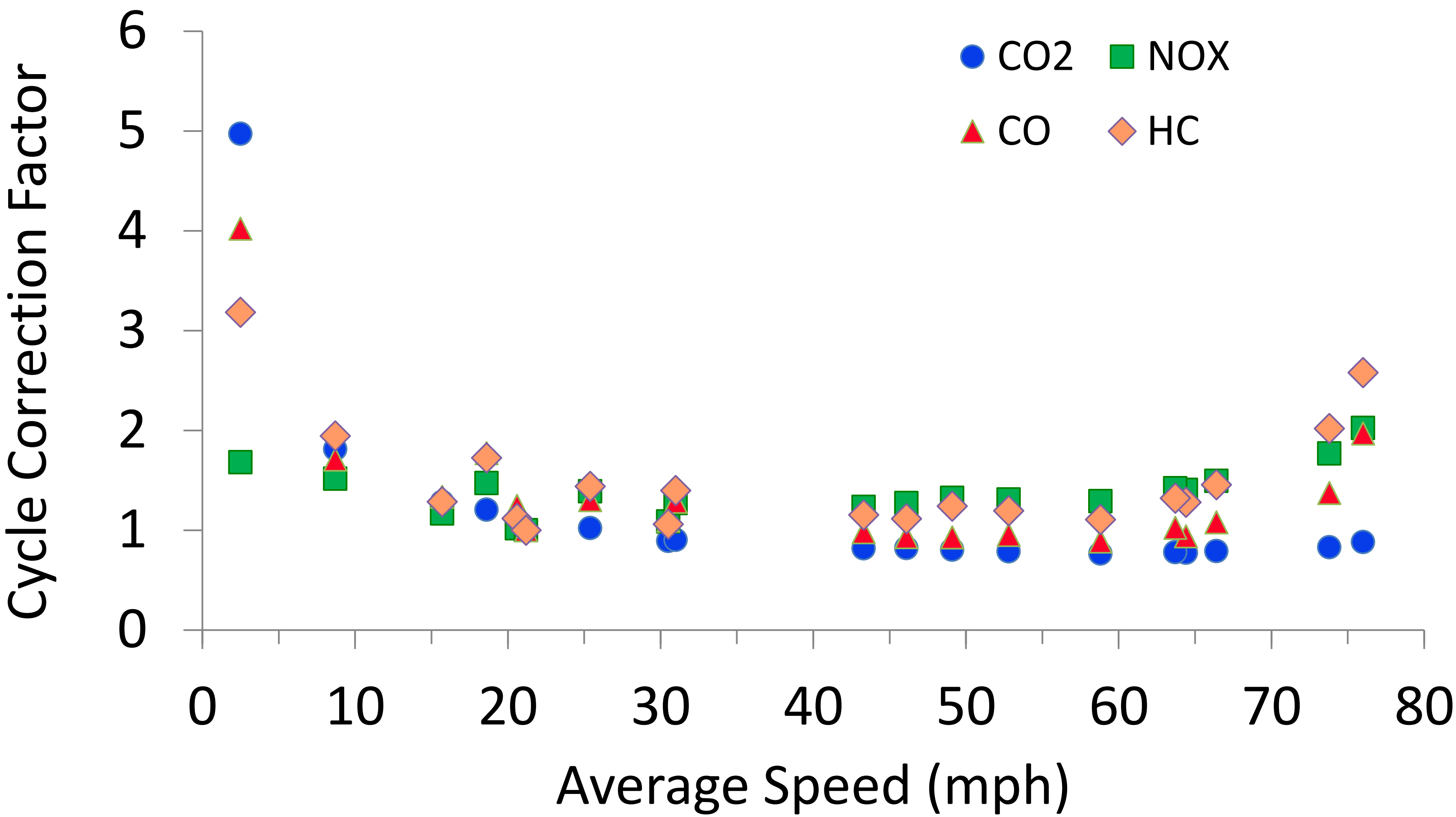
Flow Chart of the Conceptual Model



Emission Factor Case Study

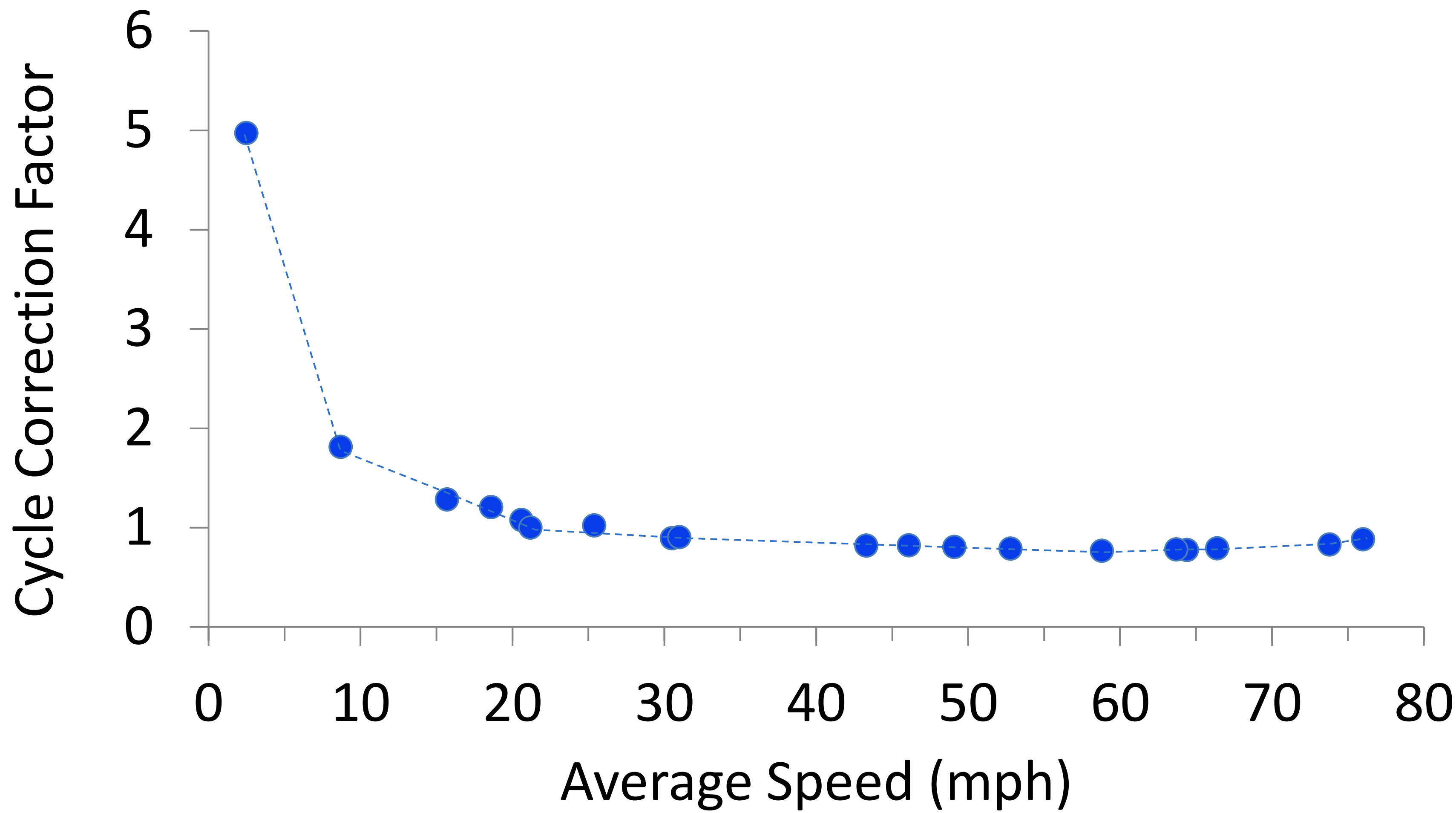
- Passenger Cars, 5 years old, Gasoline, Calendar year 2011
- 18 MOVES default driving cycles
- Base Cycle: Federal Test Procedure (FTP)
- Scenario Assumptions:
  - Ambient Temperature: 65 ^{o}F
  - Gasoline
- Estimate cycle average emission factors using simplified model
- Evaluate the accuracy of the simplified model compared to MOVES results

Cycle Correction Factors for 18 Driving Cycles



Calendar year 2011, 5 year old gasoline passenger car

Cycle Correction Factors for CO_2



Calendar year 2011, 5 year old gasoline passenger car

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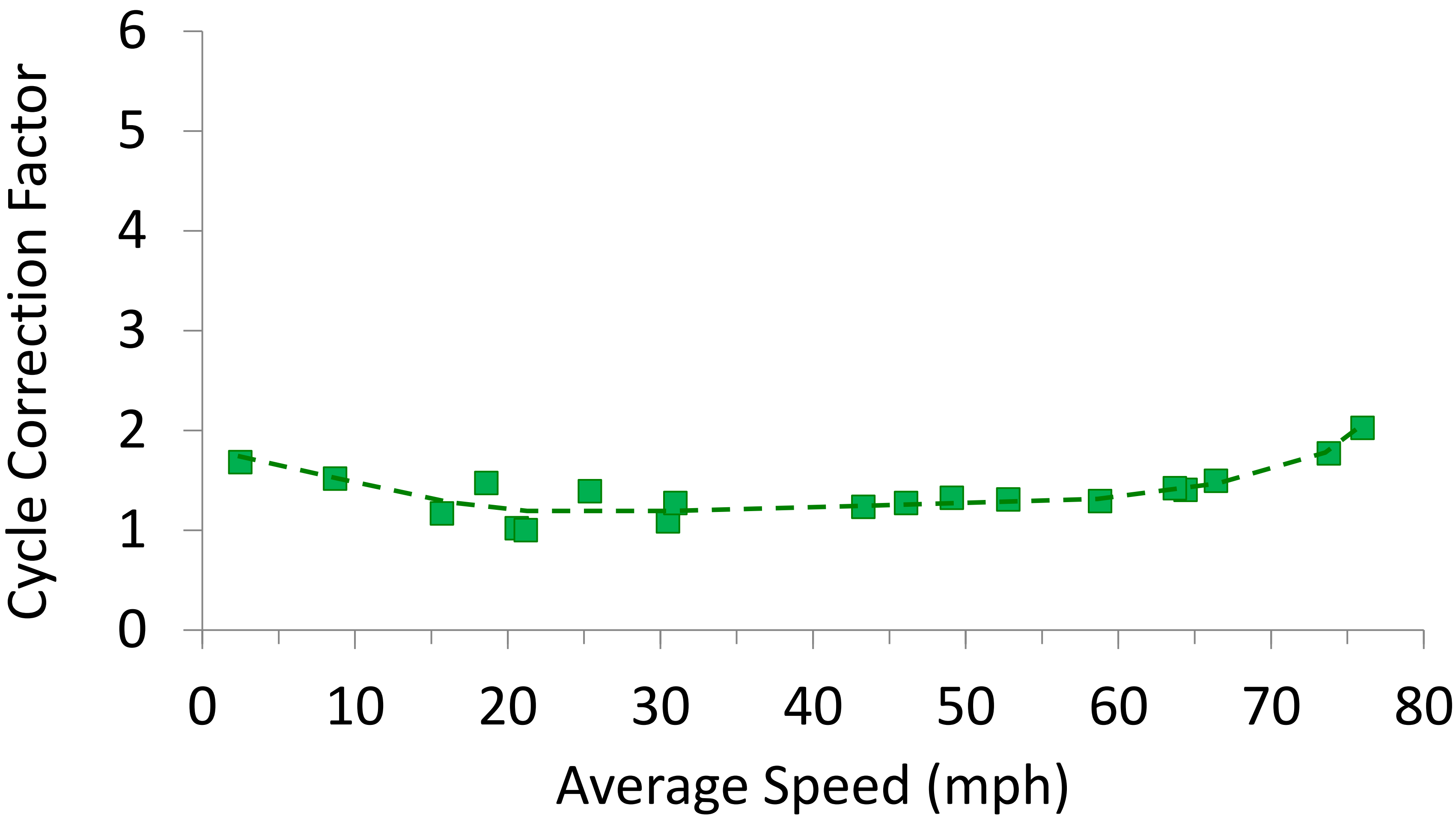
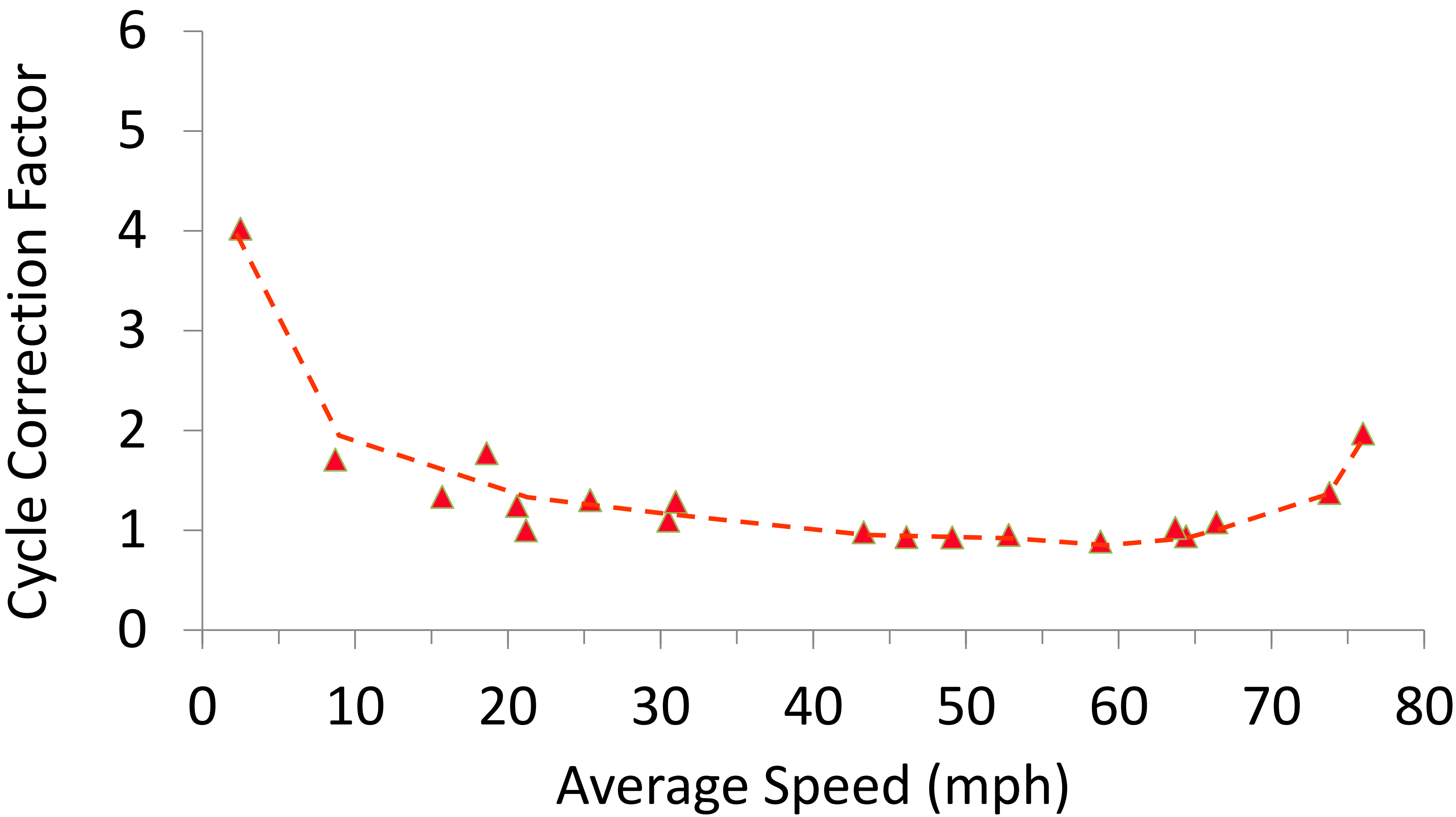
Cycle Correction Factors for NO_x



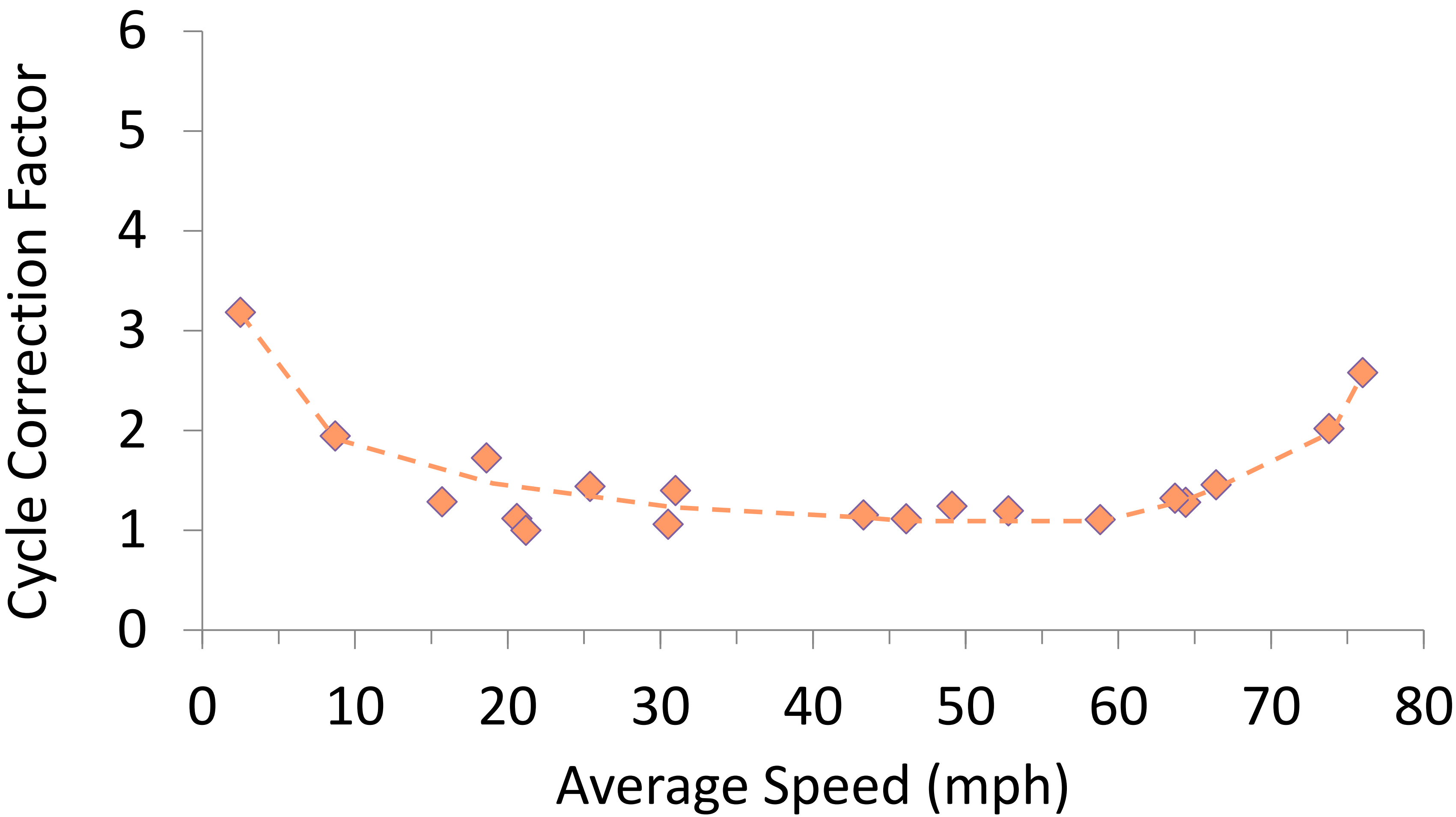
Calendar year 2011, 5 year old gasoline passenger car

Cycle Correction Factors for CO



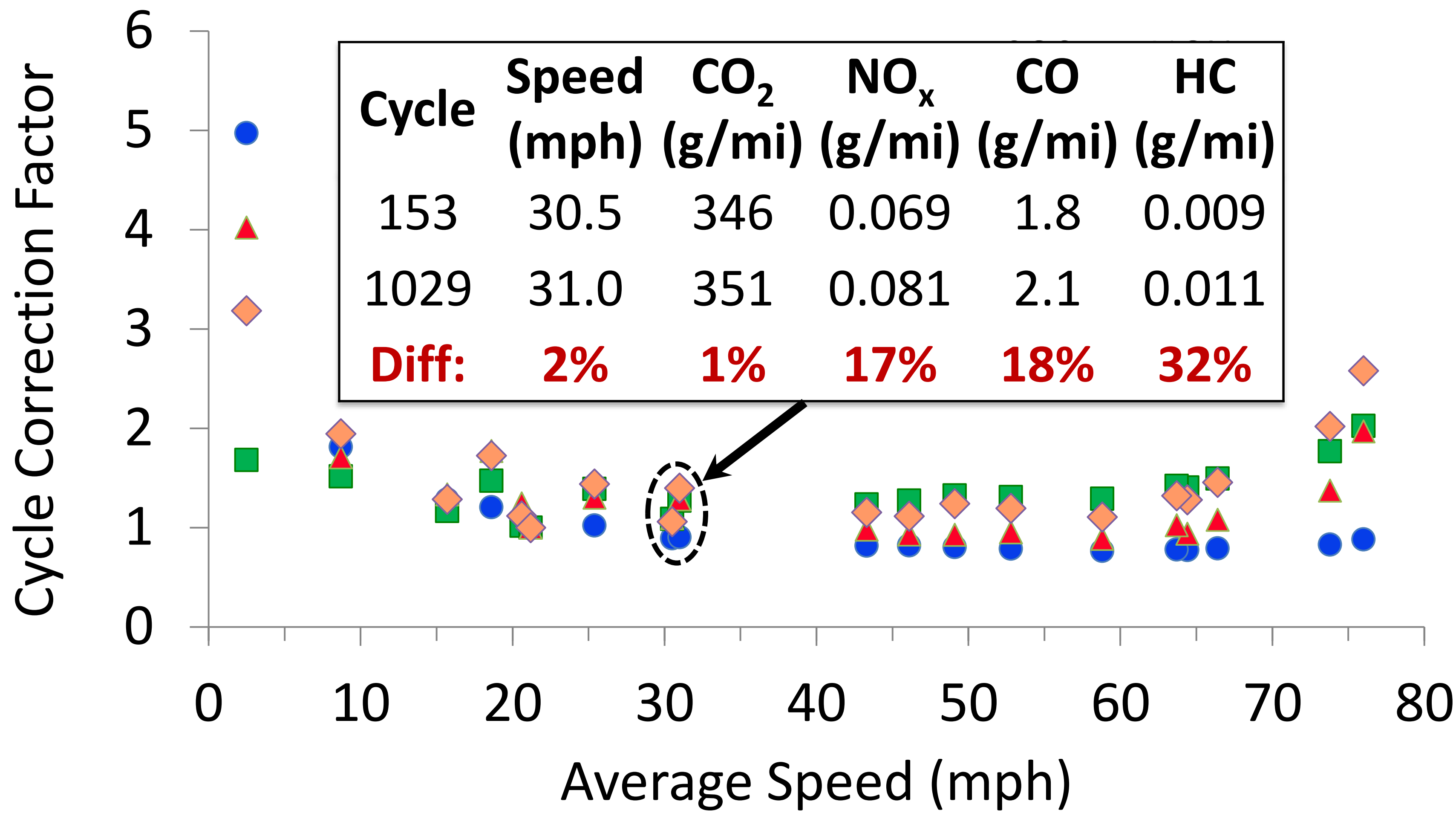
Calendar year 2011, 5 year old gasoline passenger car

Cycle Correction Factors for Hydrocarbons



Calendar year 2011, 5 year old gasoline passenger car

Different Emission Rates for Cycles with Similar Average Speeds



Cycle	Speed (mph)	CO_2 (g/mi)	NO_x (g/mi)	CO (g/mi)	HC (g/mi)
153	30.5	346	0.069	1.8	0.009
1029	31.0	351	0.081	2.1	0.011
Diff:	**2%**	**1%**	**17%**	**18%**	**32%**

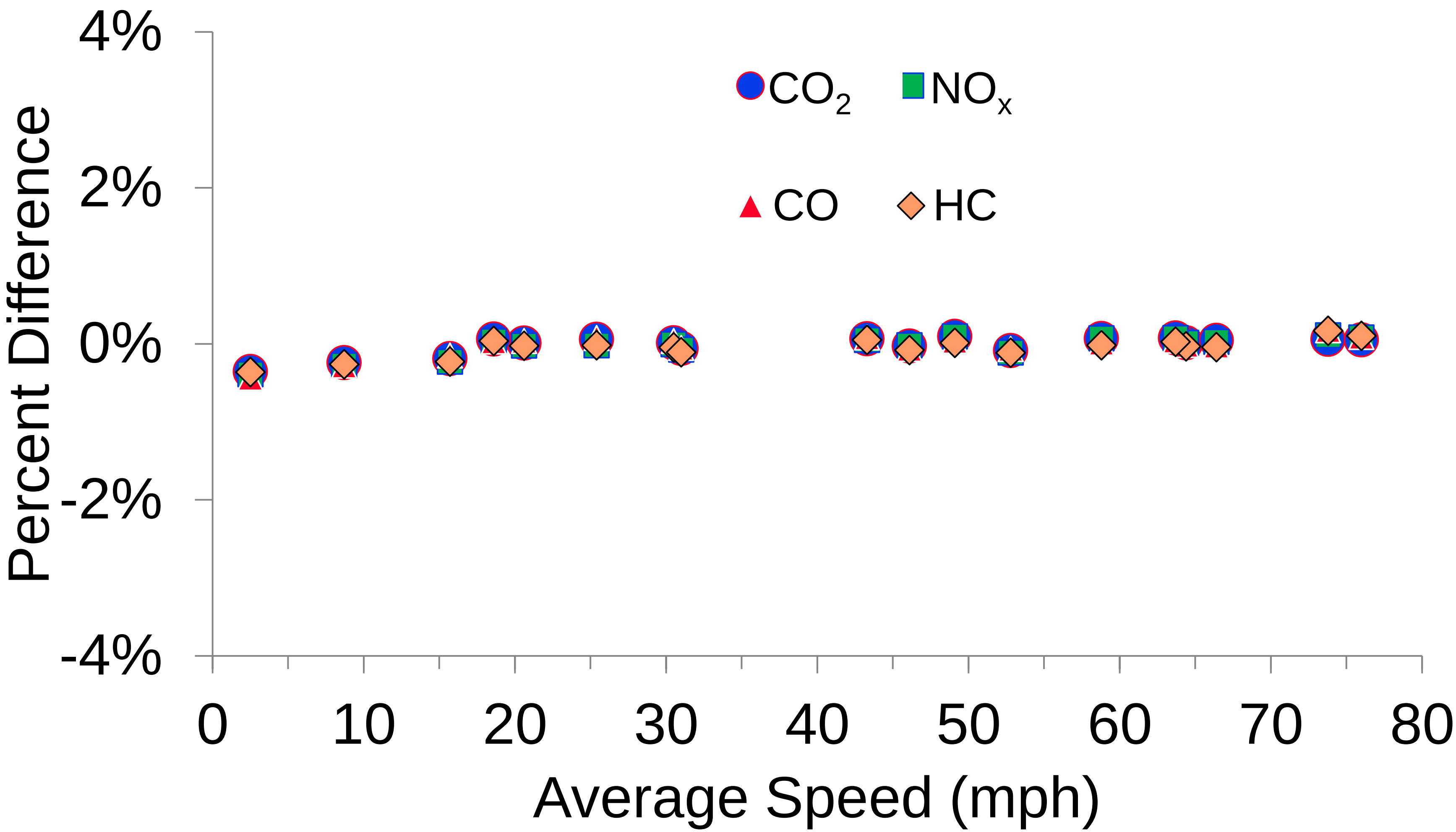
Calendar year 2011, 5 year old gasoline passenger car

Comparing Simplified Model and MOVES

Cycle Ave. Speed (mph)	CO_2			NO_x		
	MOVES (g/mi)	Simplified Model (g/mi)	% Diff.	MOVES (mg/mi)	Simplified Model (mg/mi)	% Diff.
2.5	1930	1930	0.35	39	39	0.39
30.5	347	347	-0.01	28	28	0.02
46.1	319	319	0.03	36	36	0.04
66.4	308	308	-0.05	47	47	0.00
73.8	323	323	-0.06	60	60	-0.14

Calendar year 2011, 5 year old gasoline passenger car

Errors of the Simplified Model



Calendar year 2011, 5 year old gasoline passenger car

Average of Errors of the Simplified Model

Vehicle Types	Average Percent Error: Simplified vs. MOVES Models, All Selected Cycles			
	CO_2	NO_x	CO	HC
Passenger Car (PC)	0.02	0.03	0.02	0.04
Passenger Truck (PT)	0.01	-0.22	-0.07	0.17
Light Commercial Truck (LCT)	0.46	-0.35	0.28	-0.09
Single Unit Short Haul Truck (SHT)	-0.35	-0.43	-0.11	-0.09
Combination Long Haul Truck (LHT)	0.06	-0.41	0.06	0.20

18 driving cycles each for PC, PT, and LCT

11 driving cycles each for SHT and LHT.

These five vehicle types comprise more than 95% of the fleet.

Ages: 0, 5, 10, 15 years (2011 calendar year).

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Processing Time of the Simplified Model

- Simplified Model is implemented using MATLAB
- Estimating emission factors for 18 driving cycles

Simplified Model	MOVES
0.2 seconds	10 minutes

3,000 times faster

Ongoing Work: Integrated MOVES Lite and DTALite Packages for Emission Analysis

Microscopic Vehicle Trajectory Reconstruction

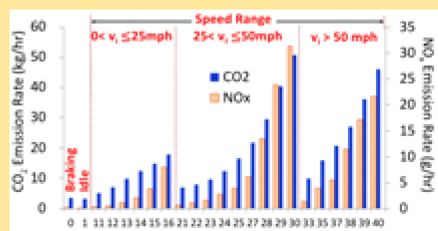
Emission Aggregation

DTALite

Large-scale Dynamic Traffic Assignment & Simulator

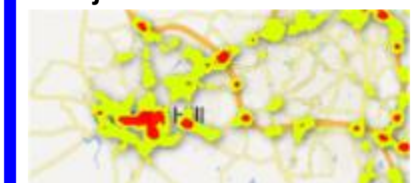
MOVES Lite

Simplified Emission Estimation Method

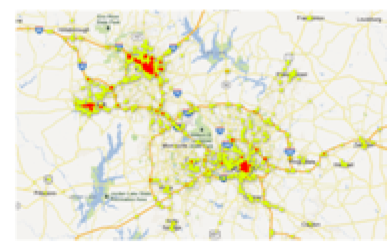


Emission Estimates

Project level



Network level



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Linking Traffic and Emissions Simulation

- DTALite is a computationally efficient “mesoscopic” model
- DTALite simulates 1 Hz trajectories for individual vehicles with realistic combinations of speed and acceleration
- MOVES Lite is directly incorporated into DTALite – no need for time consuming data file writing and use of MOVES
- DTALite with MOVES Lite enables assessment of a wide breadth of traffic management strategies, and their effect on emissions

DTALite at a glance

- **Open-source** DTA (Dynamic Traffic Assignment) Model
- Vehicle movements on links are governed by macroscopic (flow based) relationship of speed versus density
- However, vehicles are modeled individually (agents) from their origin to destination
- Can model large networks very efficiently (e.g., the case study network ~ 10 minutes per iteration).
- Using a specialized car following algorithm, micro-scale vehicle activity data are generated as input to emission calculations (based on MOVES Lite implementation within DTALite)
- Model can assess the impact of many control measures:
  - Changing the vehicle fleet or age composition
  - Changing level of traveler information available (pre-trip, en route, etc.)
  - Incorporating tolled links or toll or HOV lanes
  - Improved incident response
  - And more…
- Access at: https://sites.google.com/site/dtalite/

Basic DTALite Inputs

- Detailed network geometry (link type, # of lanes, free flow speed or speed limit, capacity, toll rate, etc.)
- Time-dependent Origin-Destination trip matrix (15 min res.)
- *Much of the above can be directly imported from a travel demand model (e.g. TransCad)*
- Link traffic model (relationship between speed, flow and density)
- Distribution of vehicle types (cars, SUV's, short and long haul trucks, etc.) and demand types (SOV/ HOV / Trucks)
- Distribution of drivers with information types (% with access to no info., pre-trip, en-route, or dynamic congestion information)
- Detailed incident data (when applicable)
- Location of variable message signs and other control devices (when applicable)
- Tolling protocols (Time of Day, other) and value of time distribution

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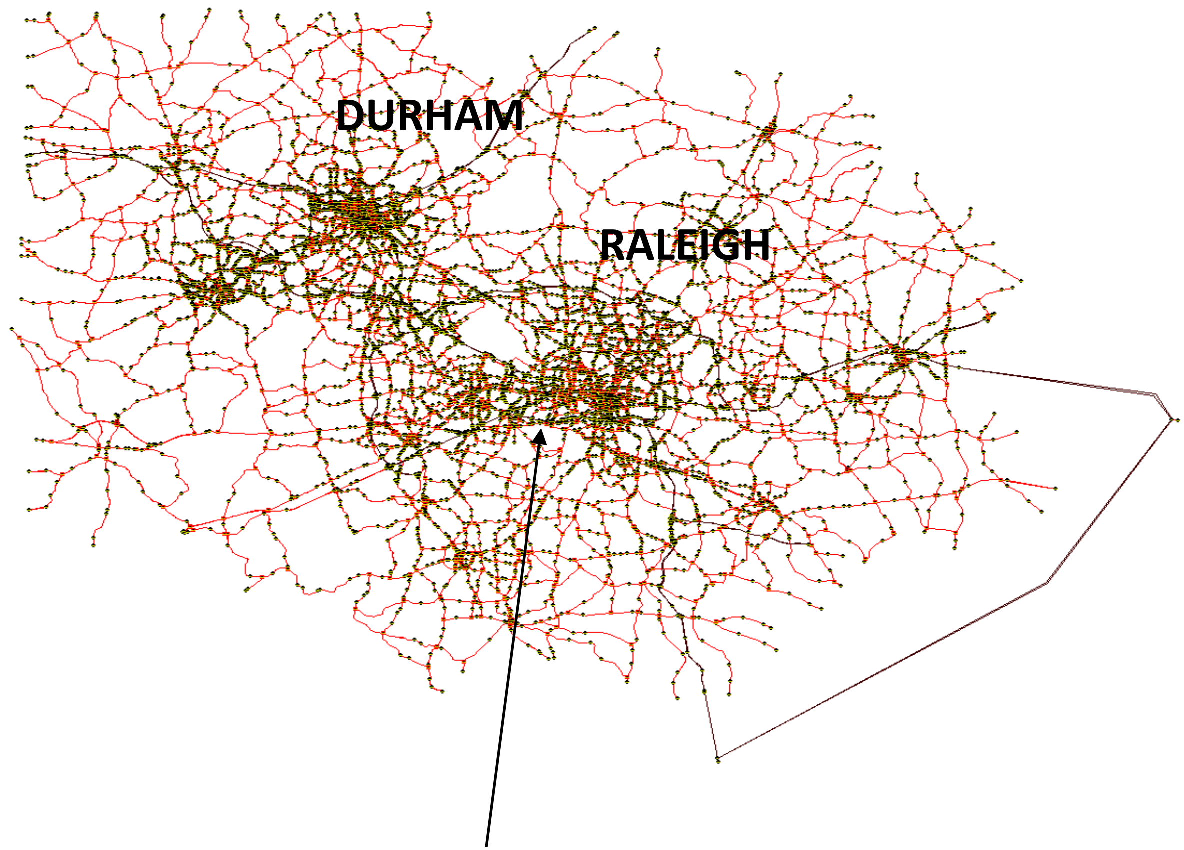
Case Study Network

- **Triangle Regional Model** (TRM) network in Research Triangle Region, NC
- Contains **9,528 nodes, 20,258 links** and **7,193 origin-destination pair**s
- Baseline case study:
  - Weekday
  - 6 am to 11 am
  - **1,051,469 vehicles** enter the network
- 87% Single Occupant Vehicle (SOV) and 13% High Occupancy Vehicle (HOV)
- Vehicle age distribution as given by NC DENR for Wake County, NC



Major roadways indicated in green

Case Study: Scenarios

Scenario	Label	Explanation	Motivation
Baseline*	BASE	Running the model with default demand and network data as calibrated for the region	Benchmark
Mode Shift*	MS	Switching 10% of travelers from SOV→ HOV, keeping total person travel the same– effect is to reduce total vehicle demand	Emissions Saved due vehicle reduction
Fleet Replacement*	FR	Substituting older vehicles with newer ones, by altering the default vehicle age distribution	Emissions Saved due to fleet replacement
Peak Spreading*	PS	Smoothing the arrivals in the peak hour to reduce the level of concentrated peaking	Emissions Saved due demand flattening
Special Study**: Incident No-Info	INC	Creating an incident on a major highway, where drivers have no access to information	Emissions impacts of major incident
Special Study**: Incident with VMS	VMS	Assessing how information disseminated to drivers via Variable Message Signage (VMS) can reduce congestion and emissions	Emission mitigation effects of VMS / Incident

**Analysis at the network and I-40 path level **Analysis at the incident path level only*

Preliminary Results, Subject to Revision

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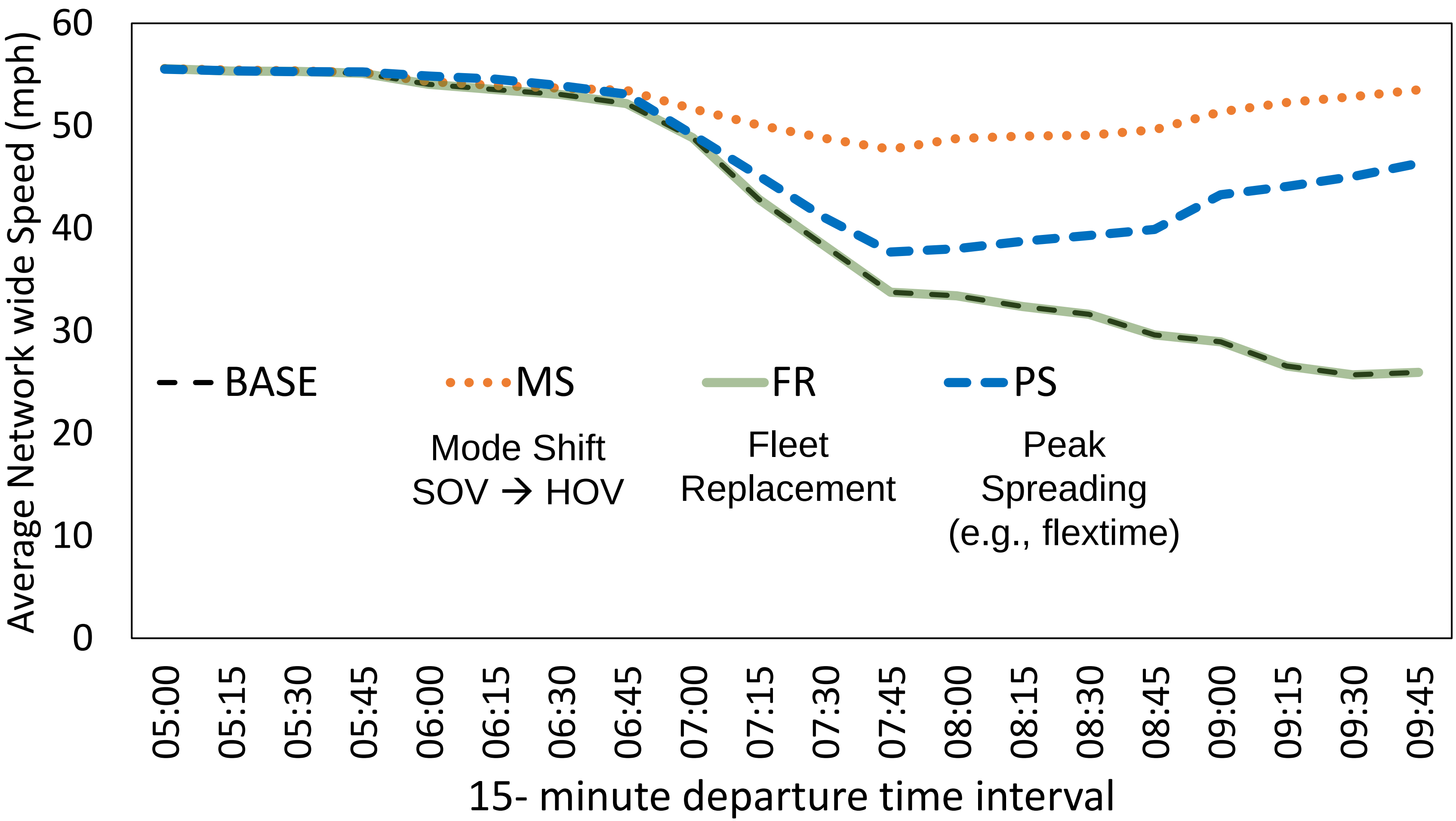
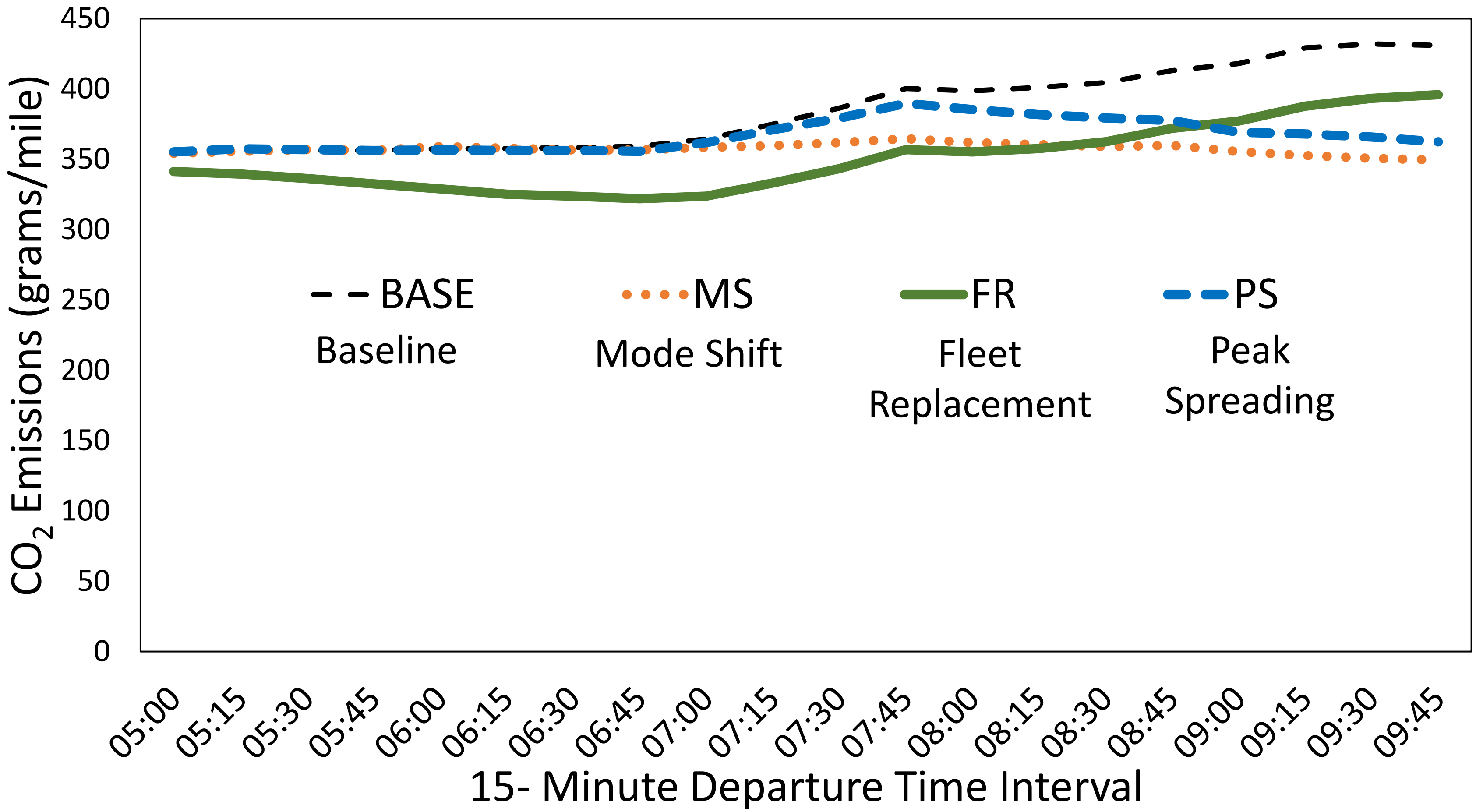
Evaluating Strategies: Network Average Speed



The fleet replacement scenario (FR) changes only the vehicle age distribution.

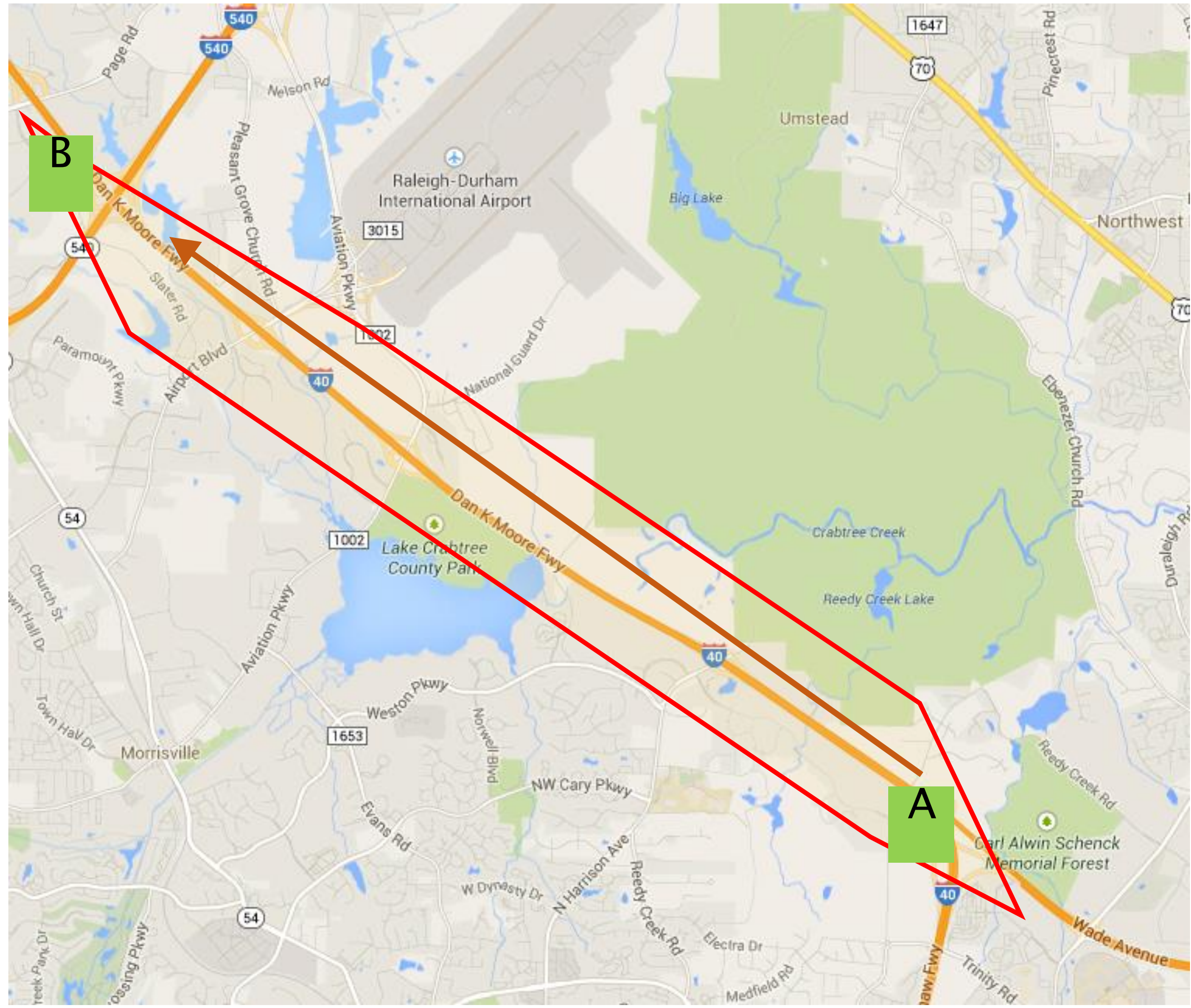
Preliminary Results, Subject to Revision

CO_2 Emissions per Mile over Network



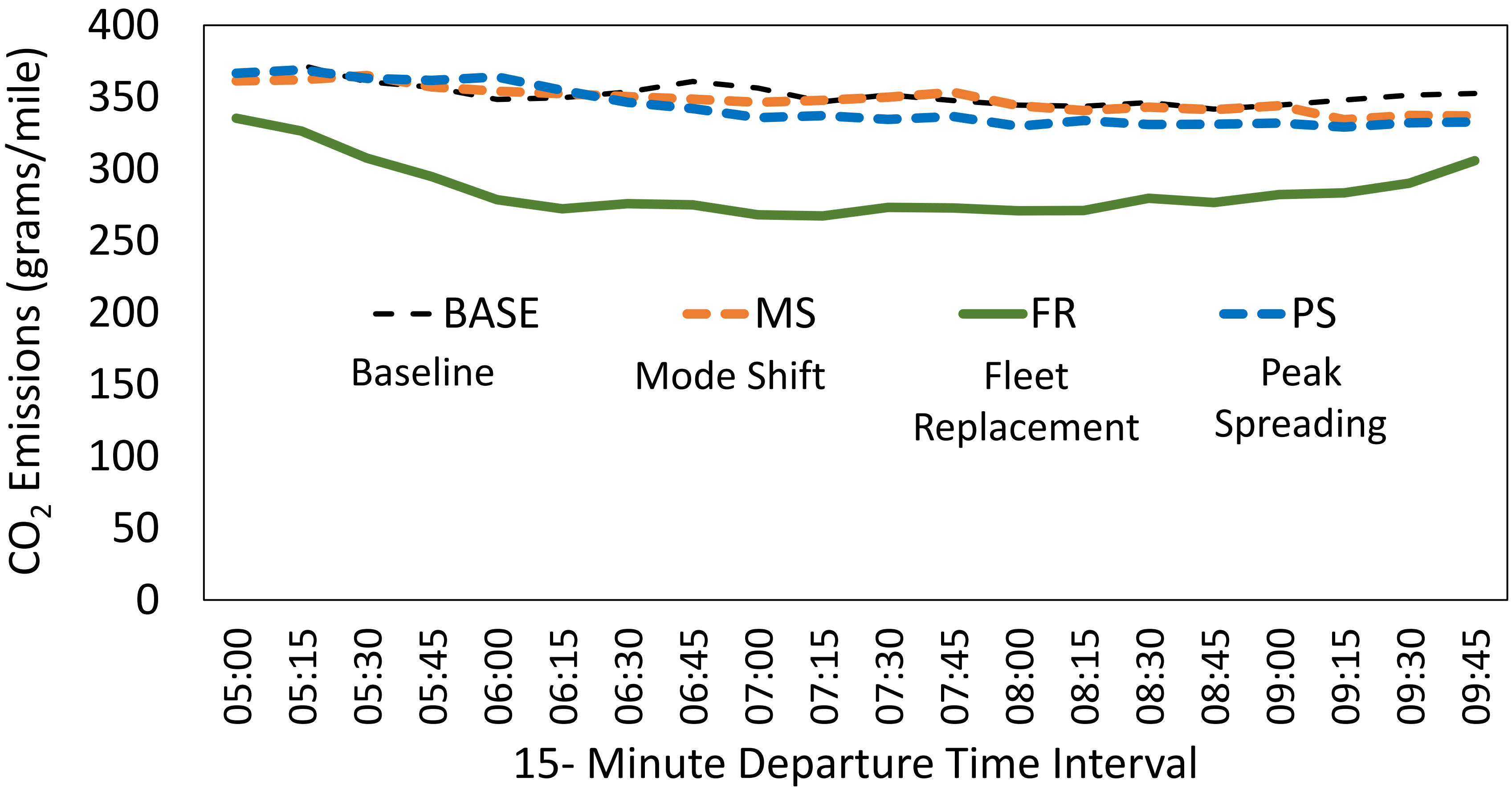
I-40 Path for MS, FR and PS Strategies

- 5.89 mile section on I-40 in Wake County
- Free-flow travel time ~ 5 minutes (A→B)
- WB- from Merge point of Wade Avenue to I-40 at Exit 283B (I-540)
- Comprises Node #8938 to Node #9449, total of 17 model links



Preliminary Results, Subject to Revision

Average CO_2 Emissions Per Mile along I-40 Path



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Summary Comparison:

Pollutant: CO_2						
Strategy	Network-wide			I-40 Path-based		
	Average Speed (mph)	Vehicle Miles Traveled (VMT) miles	Emissions g/mi	Average Speed (mph)	Vehicle Miles Traveled (VMT) miles	Emissions g/mi
BASE	38	12,474,022	386	55	348,868	351
Mode Shift	51	11,587,945	358	58	323,346	348
Peak Spread.	45	12,543,660	369	56	356,538	341

Example:

MS vs. BASE reduces network emissions by 14%

PS vs. BASE reduces network emissions by 4%

Preliminary Results, Subject to Revision

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Summary Comparison:

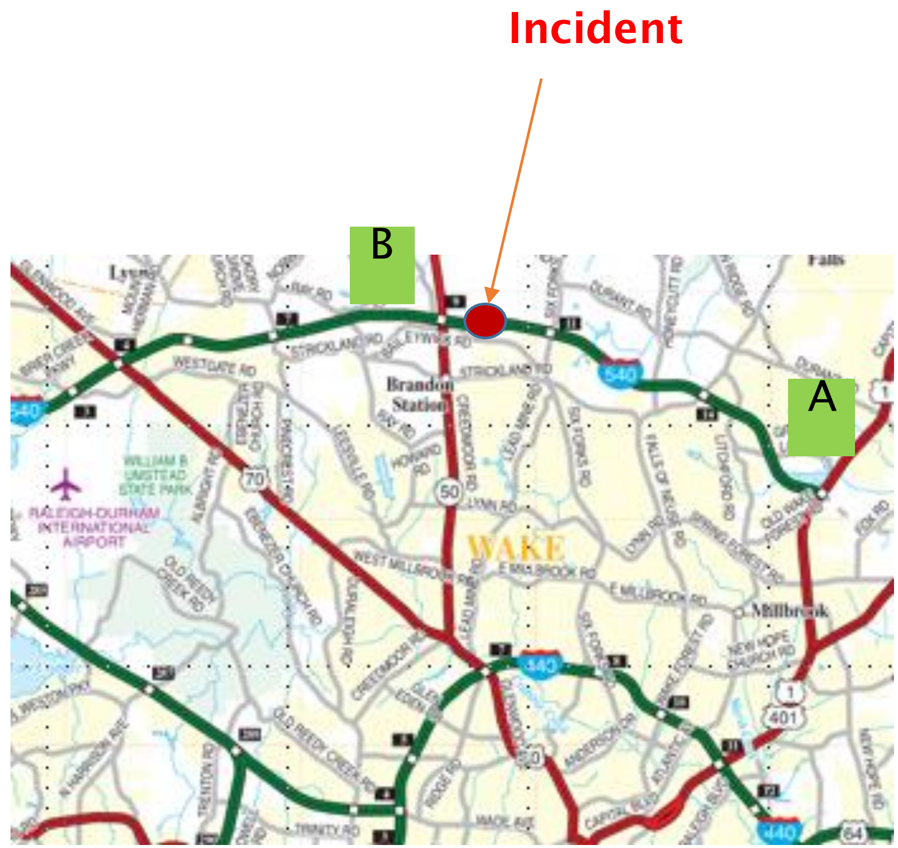
Pollutant: NO_x						
Strategy	Network-wide			I-40 Path-based		
	Average Speed (mph)	Vehicle Miles Traveled (VMT) miles	Emissions g/mi	Average Speed (mph)	Vehicle Miles Traveled (VMT) miles	Emissions g/mi
BASE	38	12,474,022	0.72	55	348,868	0.69
MS	51	11,587,945	0.70	58	323,346	0.69
FR	38	12,474,022	0.07	55	348,868	0.06
PS	45	12,543,660	0.71	56	356,538	0.68

Example:

MS vs. BASE reduces network emissions by 10%
PS vs. BASE reduces network emissions by 1%
FR vs. BASE reduces network emissions by 90%

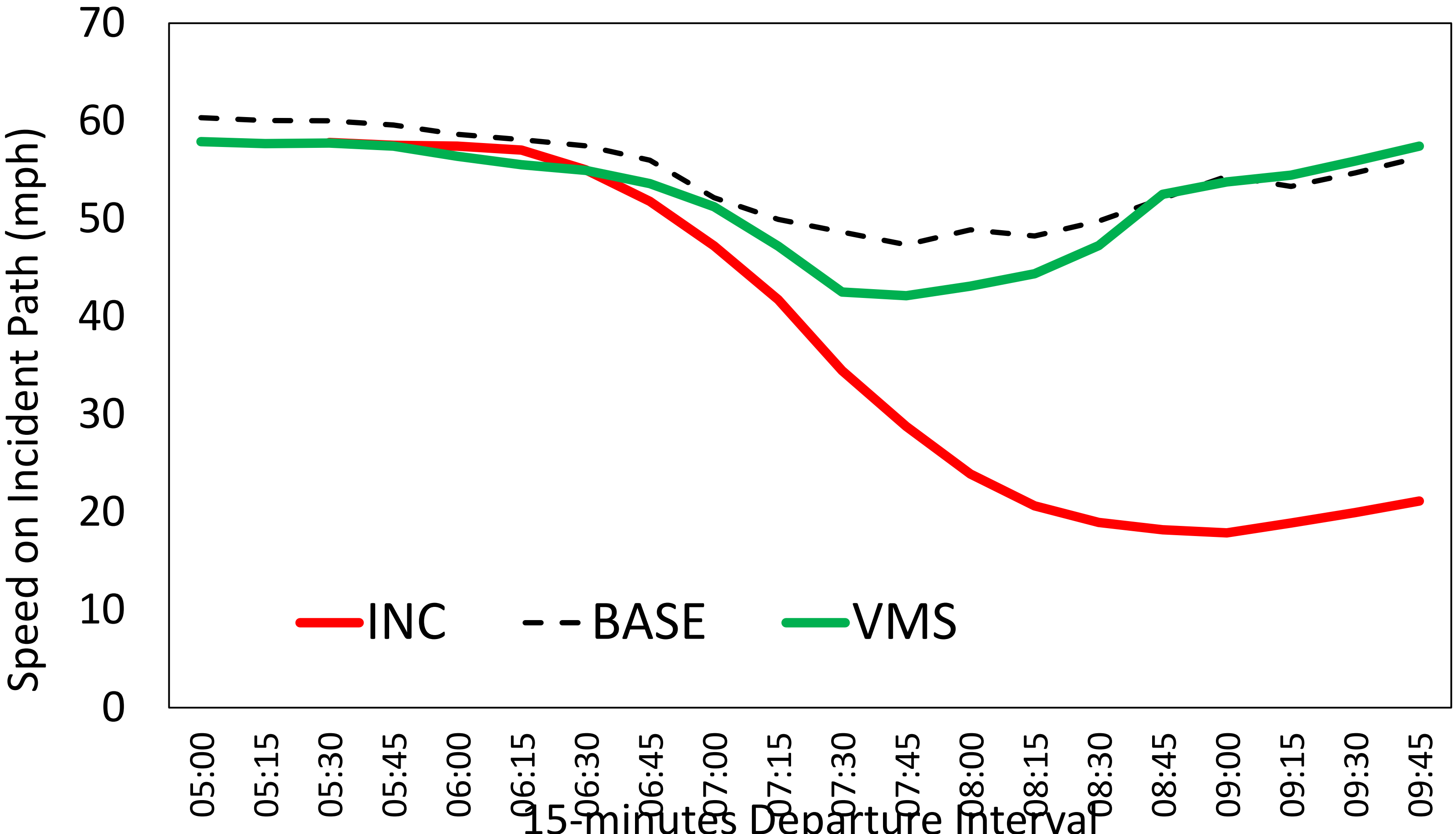
Special Study: Incident Impacts

- BASE: Selected Path A→ B , comprising 22 Links, 9.54 miles, free-flow travel time 8.37 min
- INC: An incident is simulated from 5 AM to 10:40 AM with
  - 50% capacity reduction
  - and 30 mph speed limit
- VMS: Activate several upstream Variable Message Signs (VMS) to motivate diversion away from the incident site



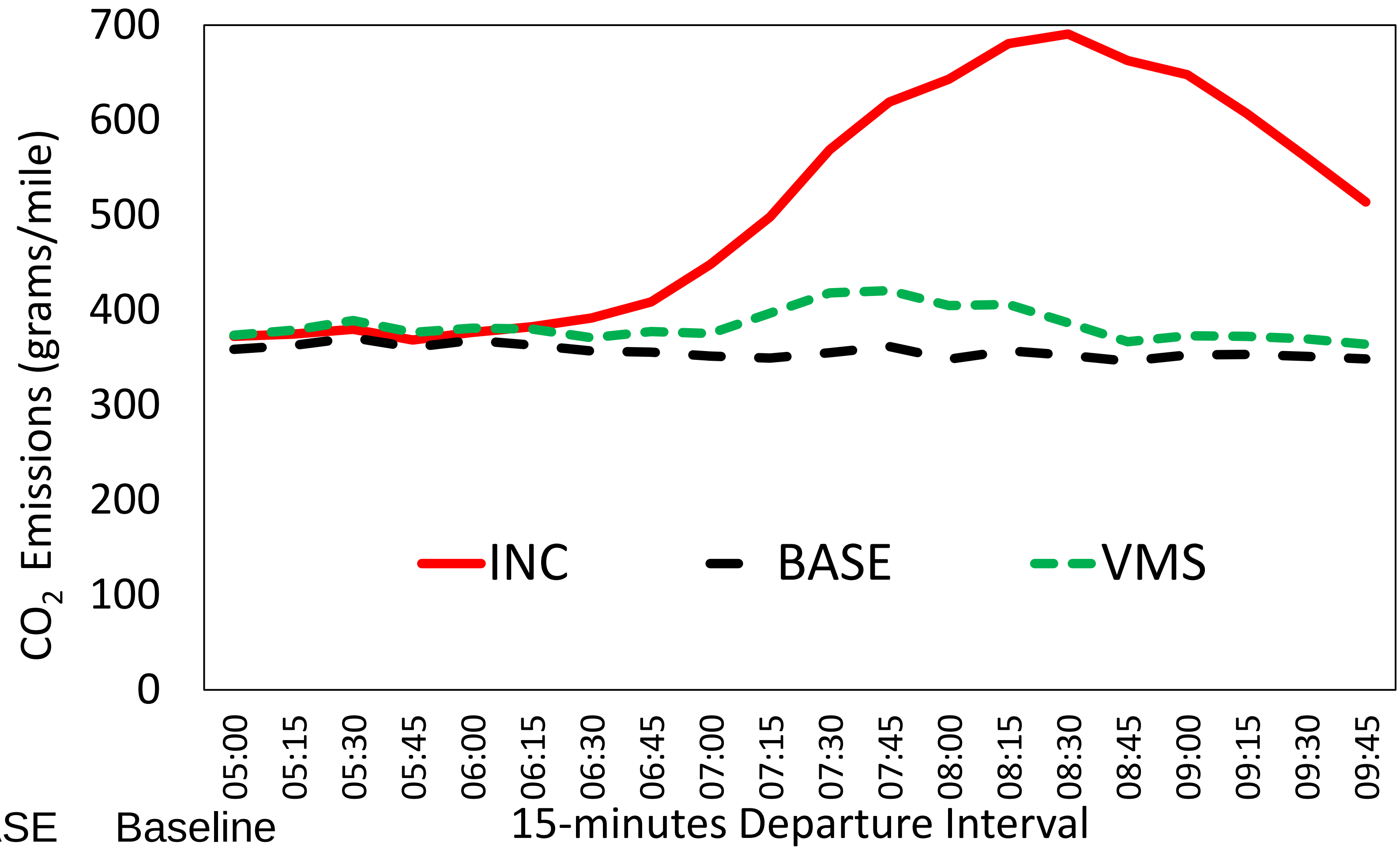
For VMS, assume 20% of drivers will consider diversion if they can find a faster path

Strategy VMS: Average Speed on Incident Path I-540



BASE Baseline
INC Incident Only
VMS Incident with VMS

Strategy VMS: Avg. CO_2 emission on Incident Path I-540



BASE	Baseline
INC	Incident Only
VMS	Incident with VMS

Preliminary Results, Subject to Revision

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Comparing Incident-Related Impacts

Strategy	VMT	Average Speed (mph)	Path-based Emissions in grams/mile			
			CO_2	NO_x	CO	HC
BASE	189,189	55	351	0.69	7.2	0.20
INC	189,189	27	528	1.00	11.1	0.34
VMS	138,910	52	383	0.78	7.8	0.22

Although not shown here, can also analyze a portion of the network that includes diversion paths, or the entire network

DTALite Work in Progress

- Refinement of the case studies and details of the methods for specification of model input
- Testing additional strategies including capacity improvements, tolling, ramp metering and work zone strategies
- Developing additional applications, such network evacuation modeling (due to weather or special events)
- Calibrating the simulated trajectories with second by second observations
- Applications to different network configurations
- Developing training material and user guides
  - e.g. www.learning-transportation.org

Key Contributions

- Evaluation of MOVES based on PEMS data
- Simplified version of MOVES: sensitive to vehicle dynamics, vehicle type, and age distribution
- Incorporation of MOVES Lite into an open source dynamic traffic assignment model, DTALite.
- Capability to test, via simulation, traffic management strategies at multiple scales (i.e. network, corridor).
- Traceability of the method: DTALite → MOVES Lite → MOVES → Empirical evaluation

Acknowledgements

- Although the research described here has been funded wholly or in part by the U.S. Environmental Protection Agency's STAR program through EPA Assistance ID No. RD-83455001, it has not been subjected to any EPA review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

This research is funded by

U.S. EPA - Science To Achieve Results (STAR) Program

Grant # RD-83455001