The MOVES Approach to Modal Emission Modeling

John Koupal, Ed Nam, Bob Giannelli, Chad Bailey
EPA Office of Transportation & Air Quality
CRC On-Road Vehicle Emission Workshop
March 29, 2004

MOVES

MOVES

Additional Collaborators

- Jim Warila
- Ed Glover
- Larry Landman

MOVES

MOVES2004 Emission Rate Sources

Pollutant/Process	Running	Start	Extended Idle	Well-To-Pump	Manufacture/ Disposal
Total Energy	MSOD Second-By-Second Data	MSOD Bag Data	EPA Testing	GREET (version produced for EPA by Argonne National Lab)	
Petroleum Energy	Calculated from Total Energy				
Fossil Energy					
Atmospheric CO_2					
CH_4	MSOD Bag Data		Not Estimated		
N_2O	MSOD Bag Data				
CO_2 Equivalent	Calculated from CO_2, CH_4, N_2O				

MOVES

Modal Emission & Activity Approach

- **Applies only to running energy consumption for MOVES 2004**
  - Plan to use for HC, CO, PM, NOx, Toxics for later versions
- **Basis of MOBILE models is average speed**
  - Aggregate approach “averages out”
  - Appropriate for larger modeling domains
  - Does not separate out differences in acceleration
- **Transportation community has pushed for approach which accounts for speed & acceleration**
  - Intersection modeling, Hot-spot analysis, TRANSIMS
- **NRC recommended a modeling approach applicable to multiple analysis scales but internally consistent**

MOVES

MOVES "Binning" Approach

- **Group activity and emissions into "Bins"**
  - Vehicle Specific Power (VSP) & Speed
    - VSP accounts for speed, acceleration, grade, road load
- **Any driving pattern can be modeled based on distribution of time spent in bins**
  - Adds major flexibility compared to MOBILE
- **Provides common emission rates for all scales**

Binning Approach - Background

- **Initially looked at binning by VSP only**
  - On-Board Shootout (CRC 2002)
  - NC State analysis of modal approaches (Frey, CRC 2003)
- **Concluded VSP alone not sufficient** (Koupal, CRC 2003)
  - Would produce bias at low and hi speeds
  - Initially proposed binning by VSP and average speed
- **Conducted further assessment to find improved binning approach**
  - "Engine Specific Power" (Nam, CRC 2003)
  - Revised binning assessment results presented today

Goals Of Binning Assessment

- **Improve prediction over VSP-only approach**
- **Define bins in such as way as to:**
  - Use readily-available activity parameters
    - Binning by RPM or engine friction fails this test
  - Allow bin definition based on what the vehicle is doing in that moment
    - Binning by average speed fails this test
- **Define common set of bins for all vehicles and pollutants**
- **Allow bins to be filled across a broad range of vehicles (source bins) using available data**

Binning Assessment

- **Chose instantaneous speed as second binning variable**
  - Also looked at RPM, acceleration
- **Used HTBR to show important VSP and speed breakpoints**
- **Assessed 5 different combinations of VSP & speed**
- **Decided on bin structure that performed well and could be filled with data from IM240 cycle**
  - Large portion of light-duty data for MOVES2004 will be from New York State I/M evaluation program (not an in-use I/M program)

“Bin Option 5” (17 bins)

Braking (Bin 0)			
Idle (Bin 1)			
VSP \ Speed	**0-25mph**	**25-50**	**>50**
< 0 kw/tonne	Bin 11	Bin 21	
0 to 3	Bin 12	Bin 22	
3 to 6	Bin 13	Bin 23	
6 to 9	Bin 14	Bin 24	
9 to 12	Bin 15	Bin 25	
12 and greater	Bin 16	Bin 26	Bin 36
6 to 12			Bin 35
< 6			Bin 33

Binning Proof-Of-Concept

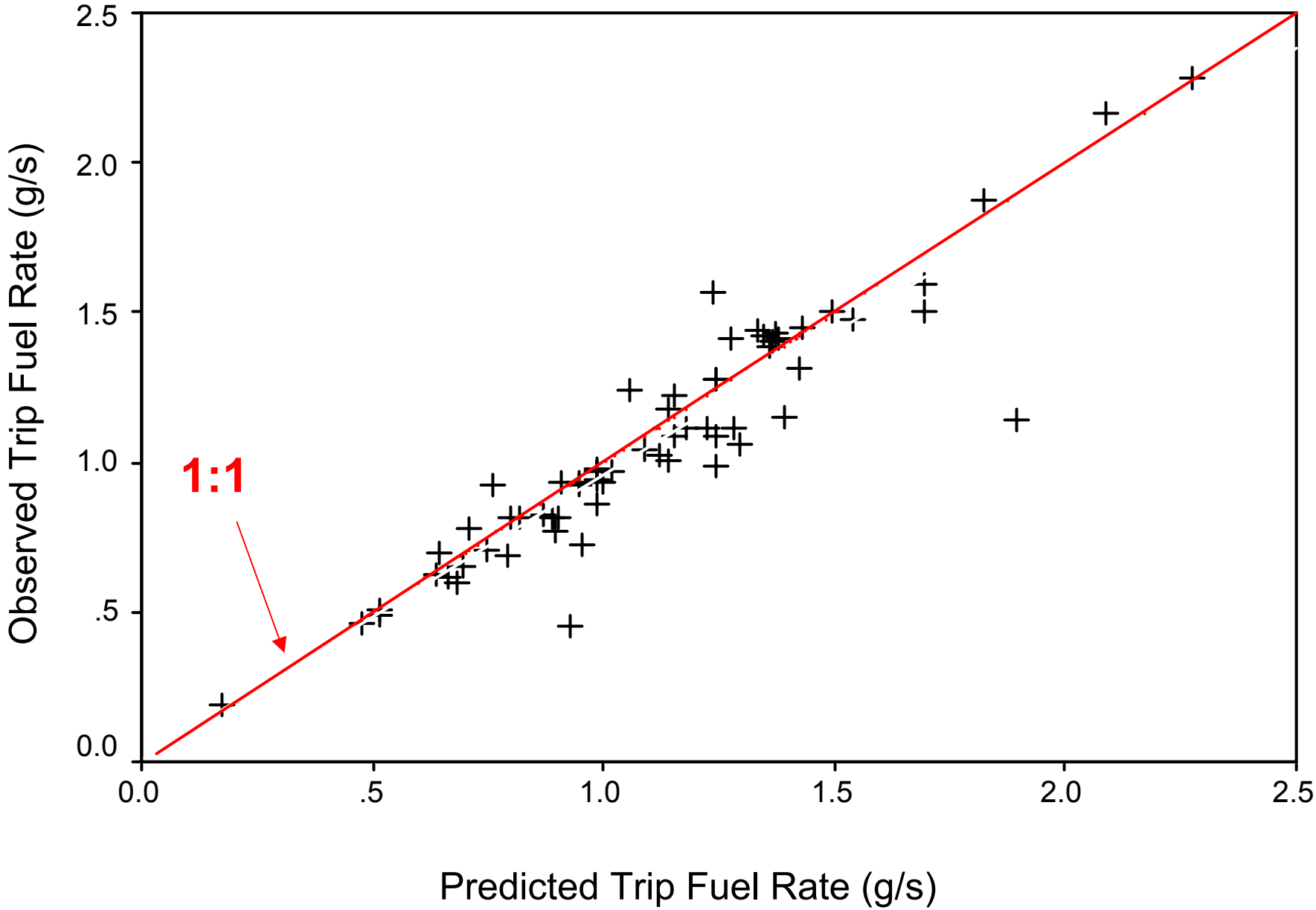
- **Can binning approach independently predict aggregate emission results?**
- **Analysis sample**
  - Light-duty: ARB UCC Dataset, EPA On-Board Shootout
  - Heavy-duty: CE-CERT Trailer Data, EPA Shootout
- **Random sample of trips removed**
- **Binned rates developed from remaining trips**
- **Emissions of removed trips independently predicted based on distribution of time in bins**

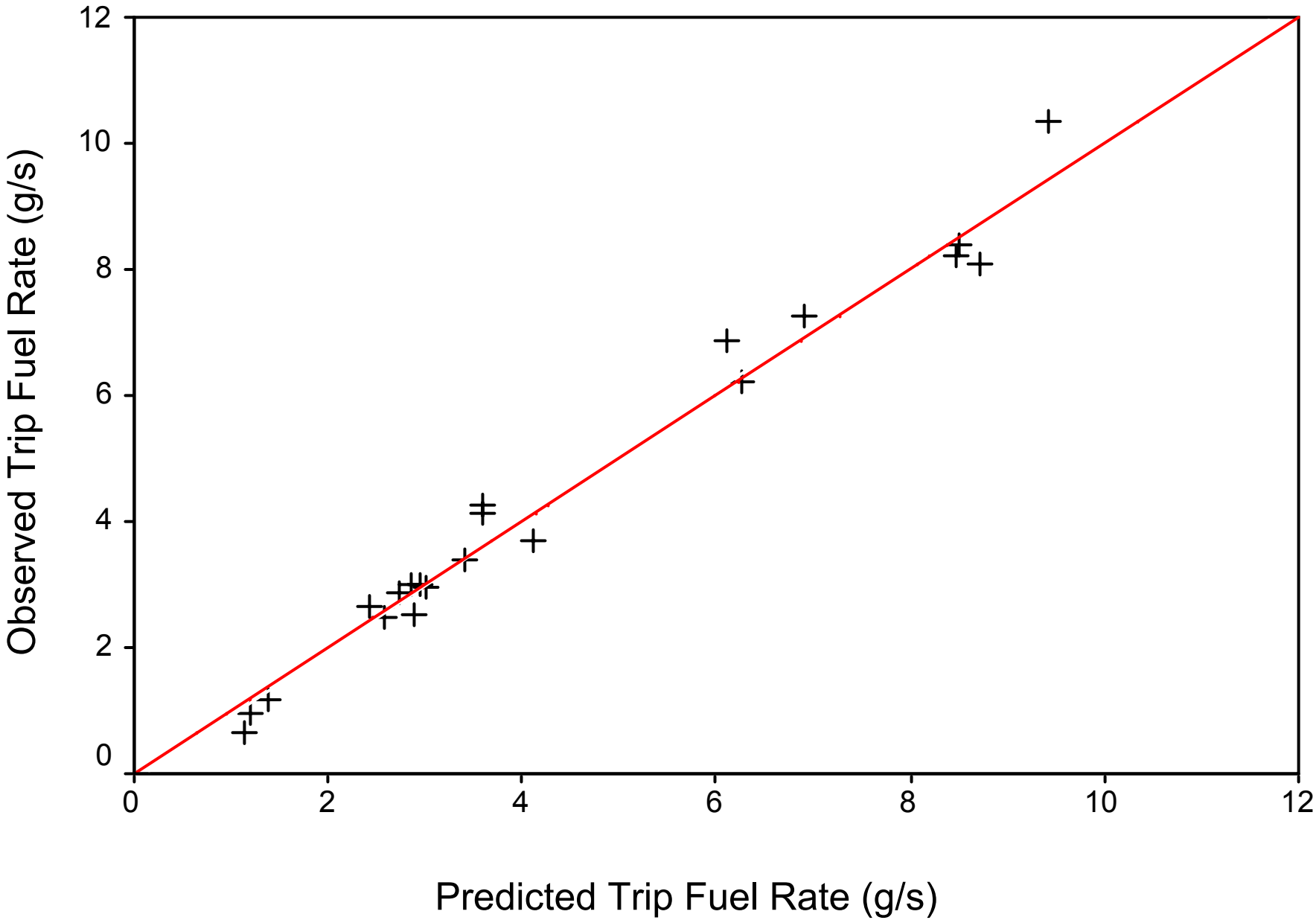
Validation Results: Bin Option 5 and VSP-Only Approaches

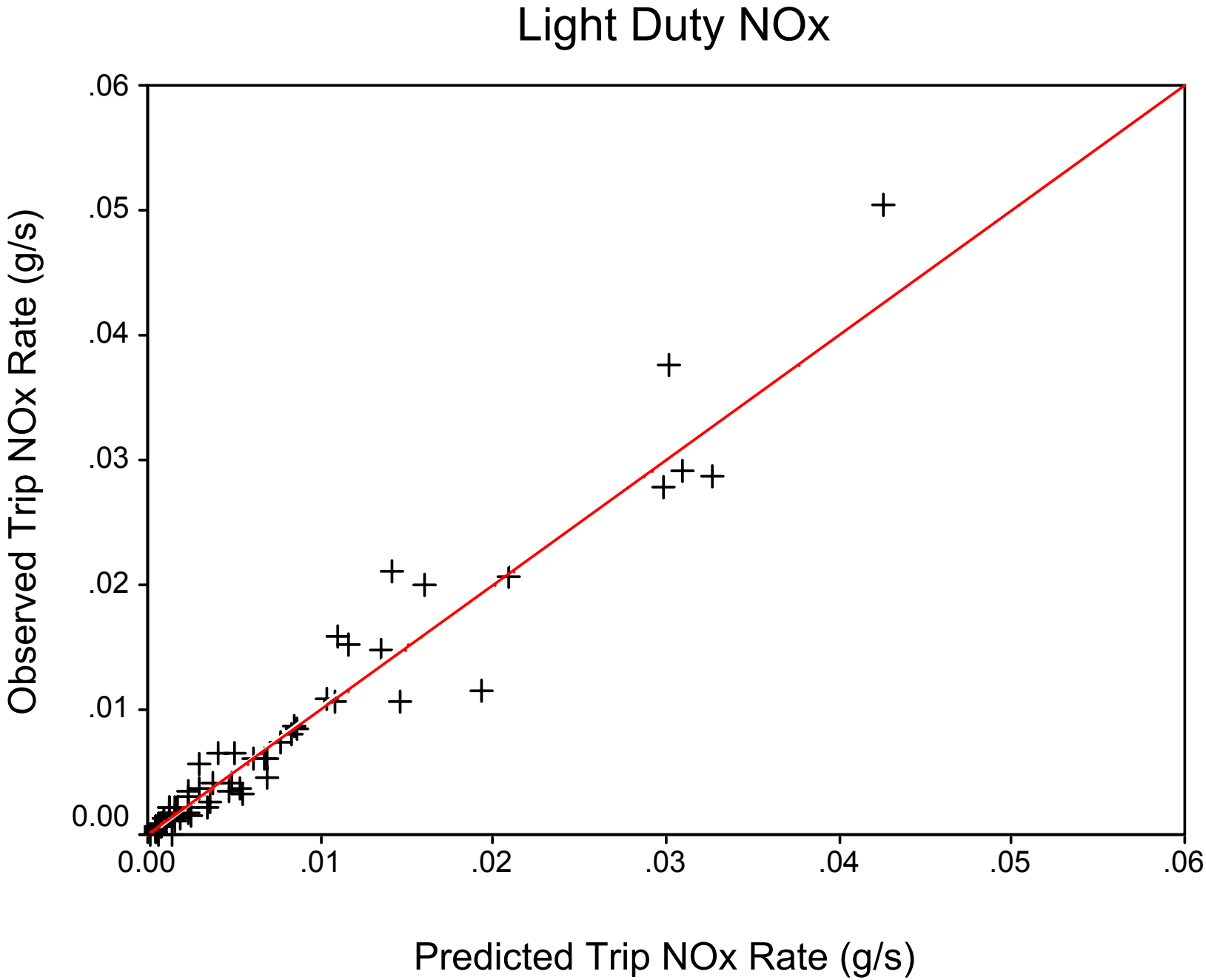
Percent Difference From Observed Average Trip Fuel/Emission Rates

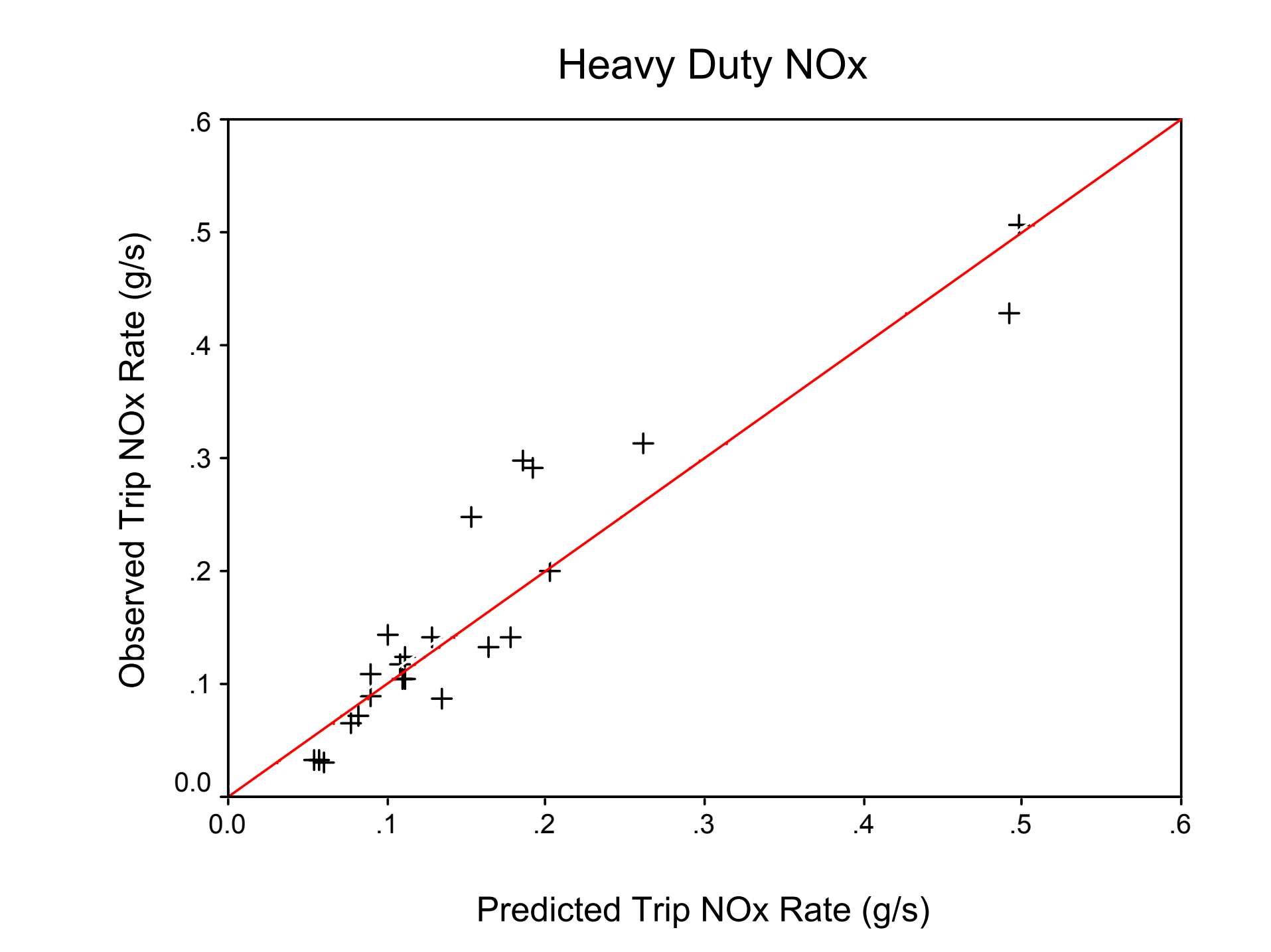
All Trips								
	Light-Duty				Heavy-Duty			
	Fuel	HC	CO	NOx	Fuel	HC	CO	NOx
VSP	9%	1%	6%	5%	1%	15%	13%	-3%
BO5	4%	1%	3%	-3%	-1%	10%	14%	-4%
Trips w/ Average Speed < 30								
	Light-Duty				Heavy-Duty			
	Fuel	HC	CO	NOx	Fuel	HC	CO	NOx
VSP	22%	14%	8%	14%	10%	36%	25%	19%
BO5	8%	6%	4%	-7%	0%	23%	21%	7%
Trips w/ Average Speed > 30								
	Light-Duty				Heavy-Duty			
	Fuel	HC	CO	NOx	Fuel	HC	CO	NOx
VSP	-1%	-6%	6%	1%	-6%	-15%	-4%	-16%
BO5	1%	-2%	3%	-1%	-2%	-9%	3%	-11%

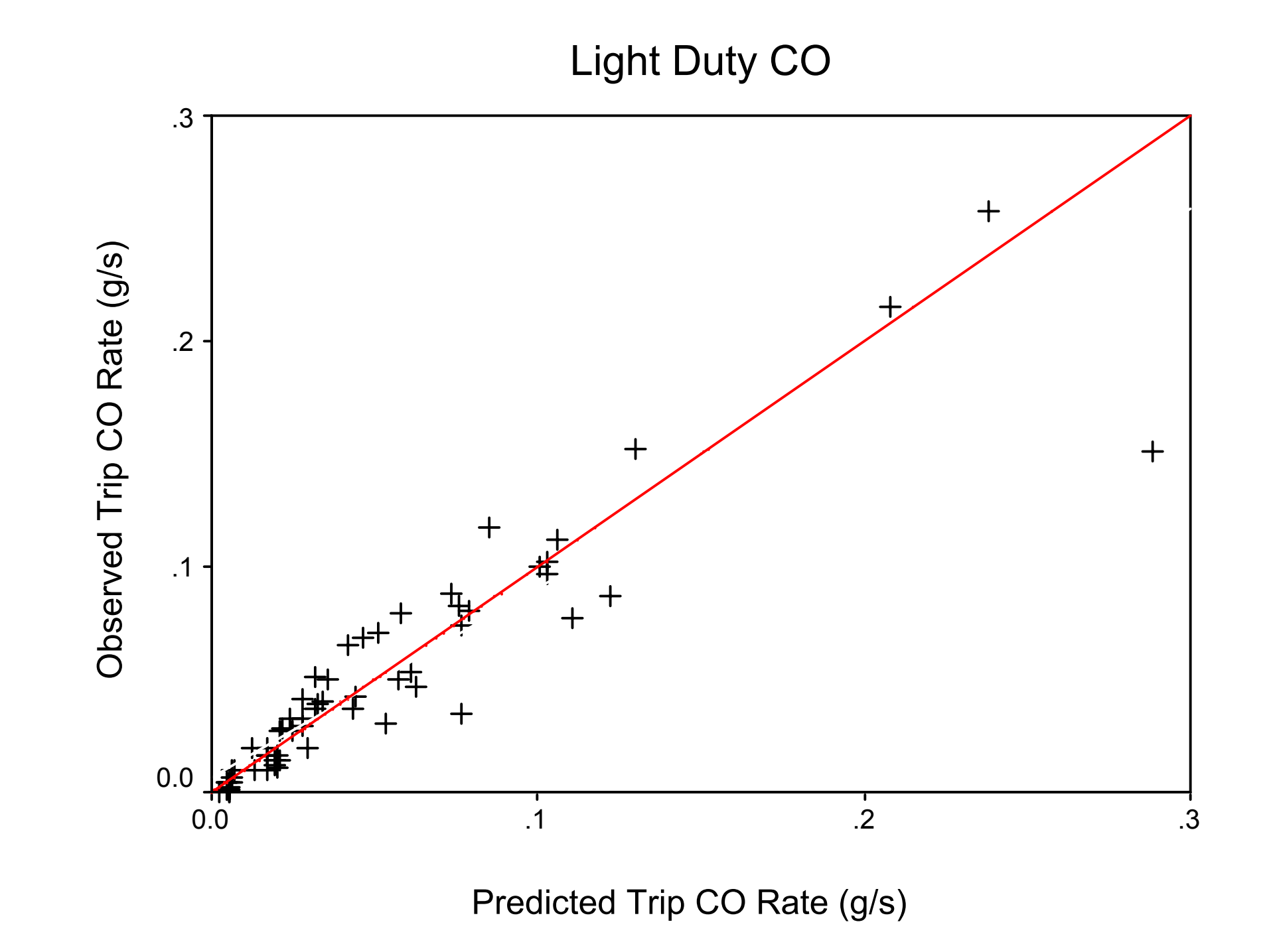
Per-Trip Results for BO5 In Following Slides

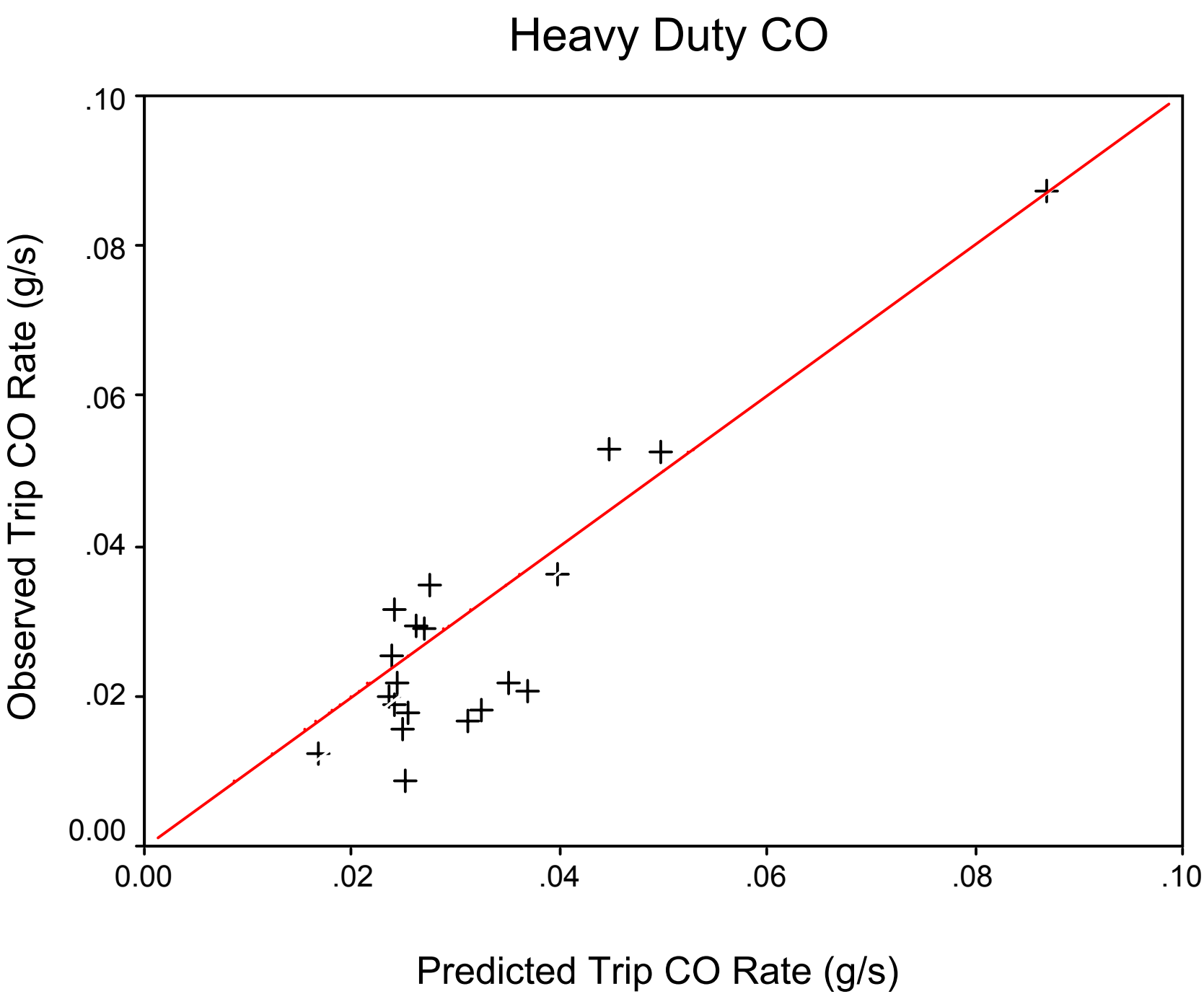

Observed Trip Fuel Rate (g/s)
Predicted Trip Fuel Rate (g/s)
1:1
2.5
2.0
1.5
1.0
.5
0.0
0.0
.5
1.0
1.5
2.0
2.5

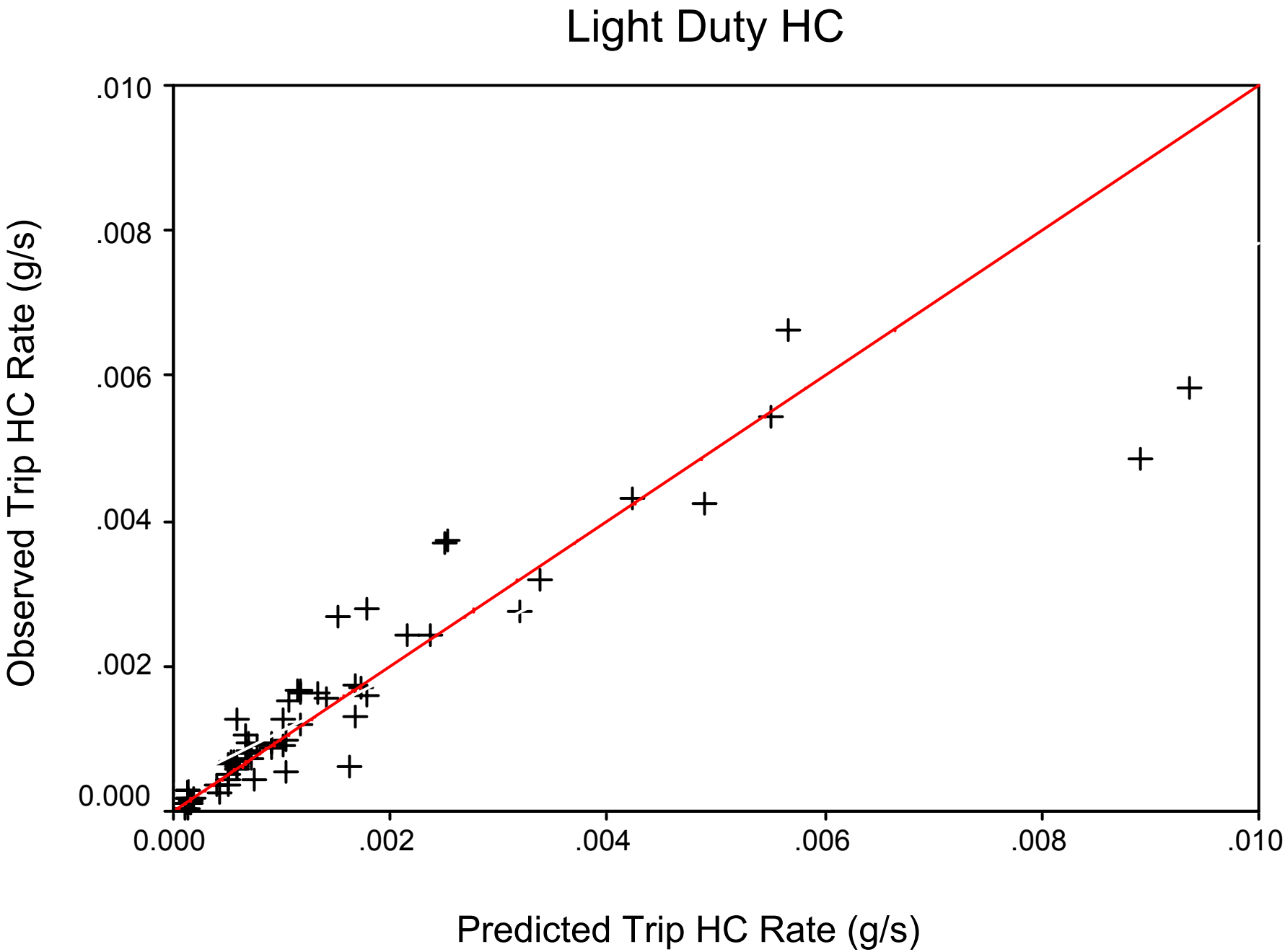

Observed Trip Fuel Rate (g/s)
Predicted Trip Fuel Rate (g/s)
0
2
4
6
8
10
12

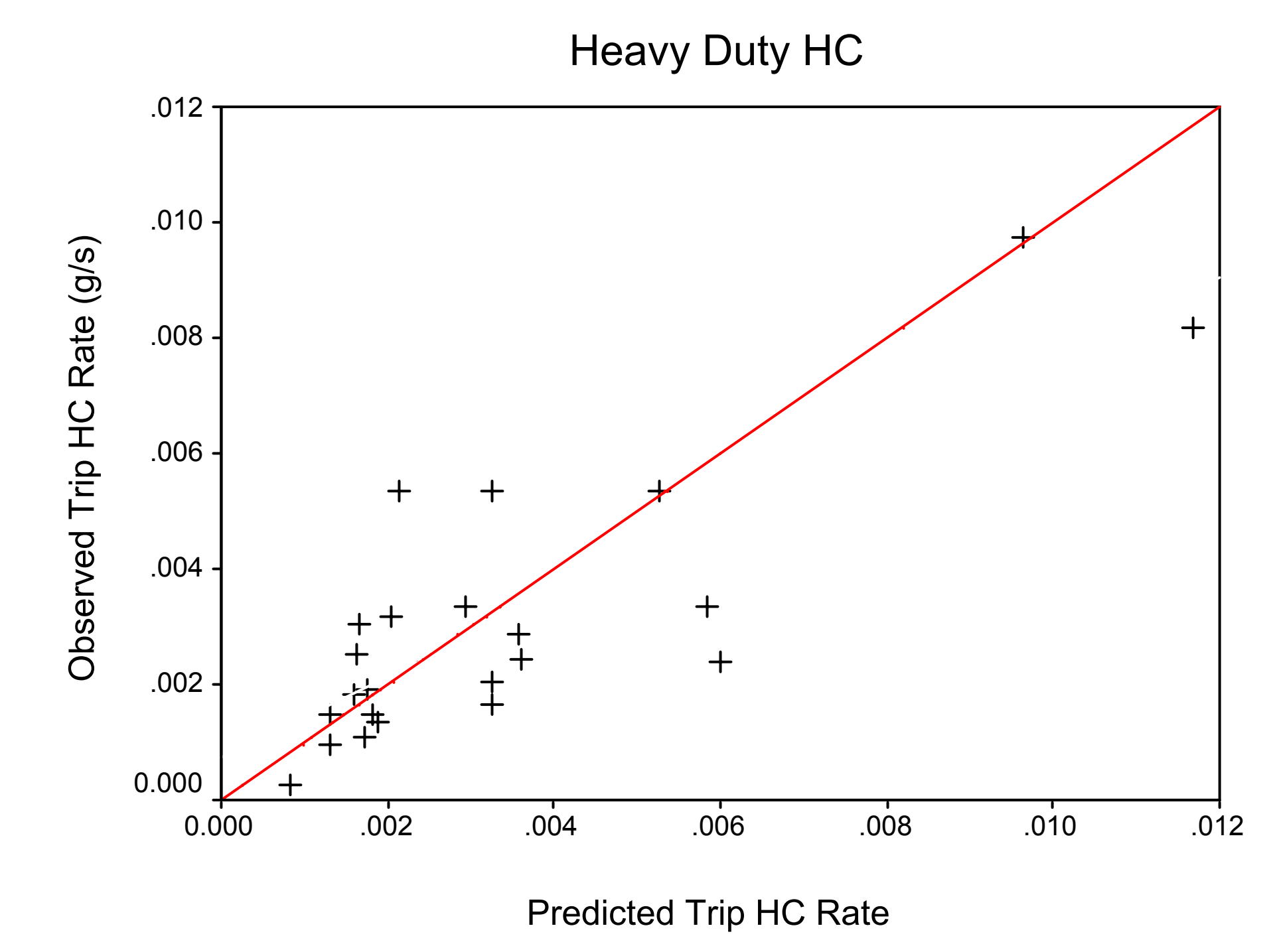

Light Duty NOx
Observed Trip NOx Rate (g/s)
Predicted Trip NOx Rate (g/s)
.06
.05
.04
.03
.02
.01
0.00
0.00
.01
.02
.03
.04
.05
.06

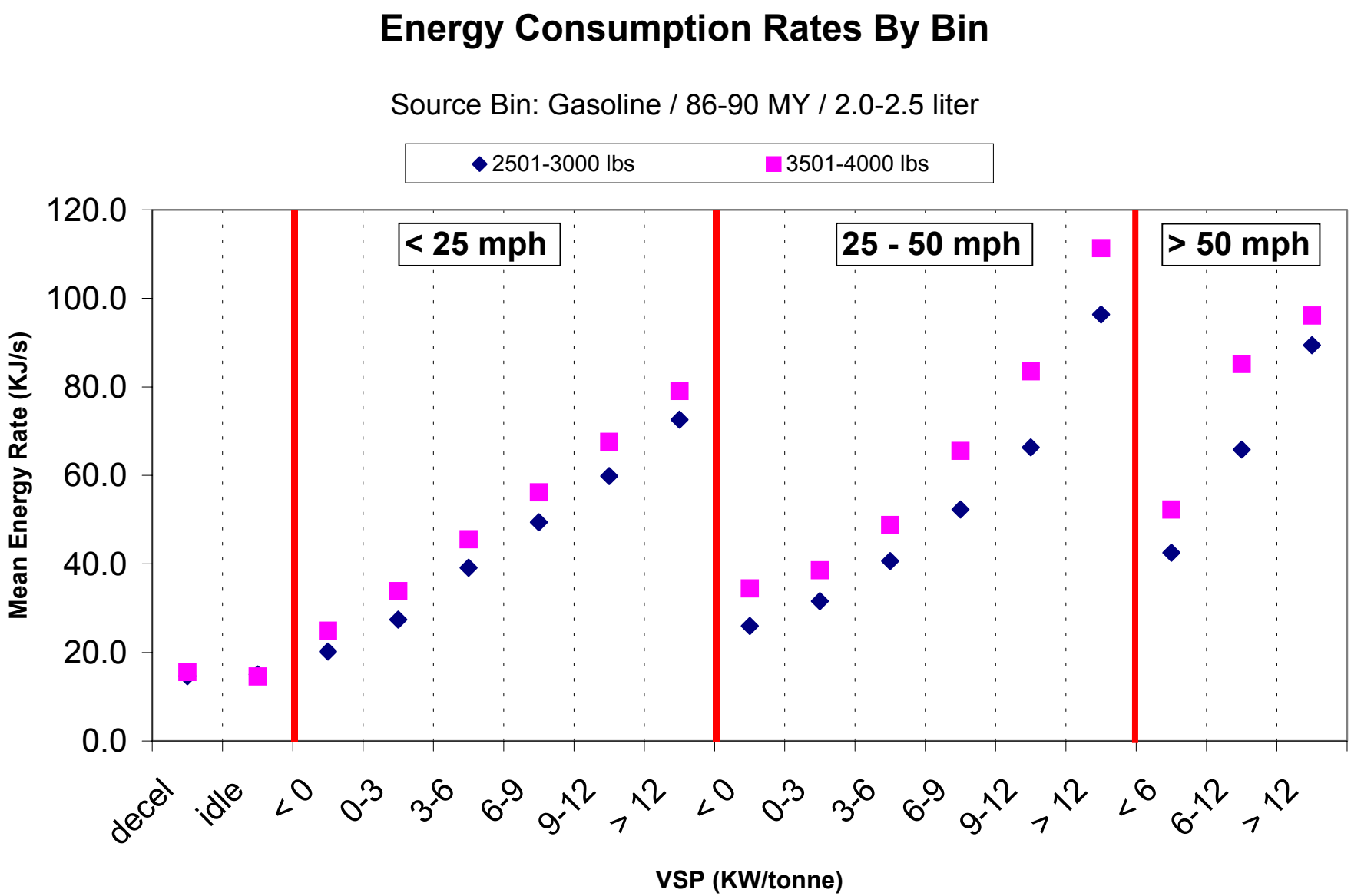

Heavy Duty NOx
Observed Trip NOx Rate (g/s)
Predicted Trip NOx Rate (g/s)
0.0
.1
.2
.3
.4
.5
.6


Light Duty CO
Observed Trip CO Rate (g/s)
Predicted Trip CO Rate (g/s)
.3
.2
.1
0.0
0.0
.1
.2
.3


Heavy Duty CO
Observed Trip CO Rate (g/s)
.10
.08
.06
.04
.02
0.00
0.00
.02
.04
.06
.08
.10
Predicted Trip CO Rate (g/s)

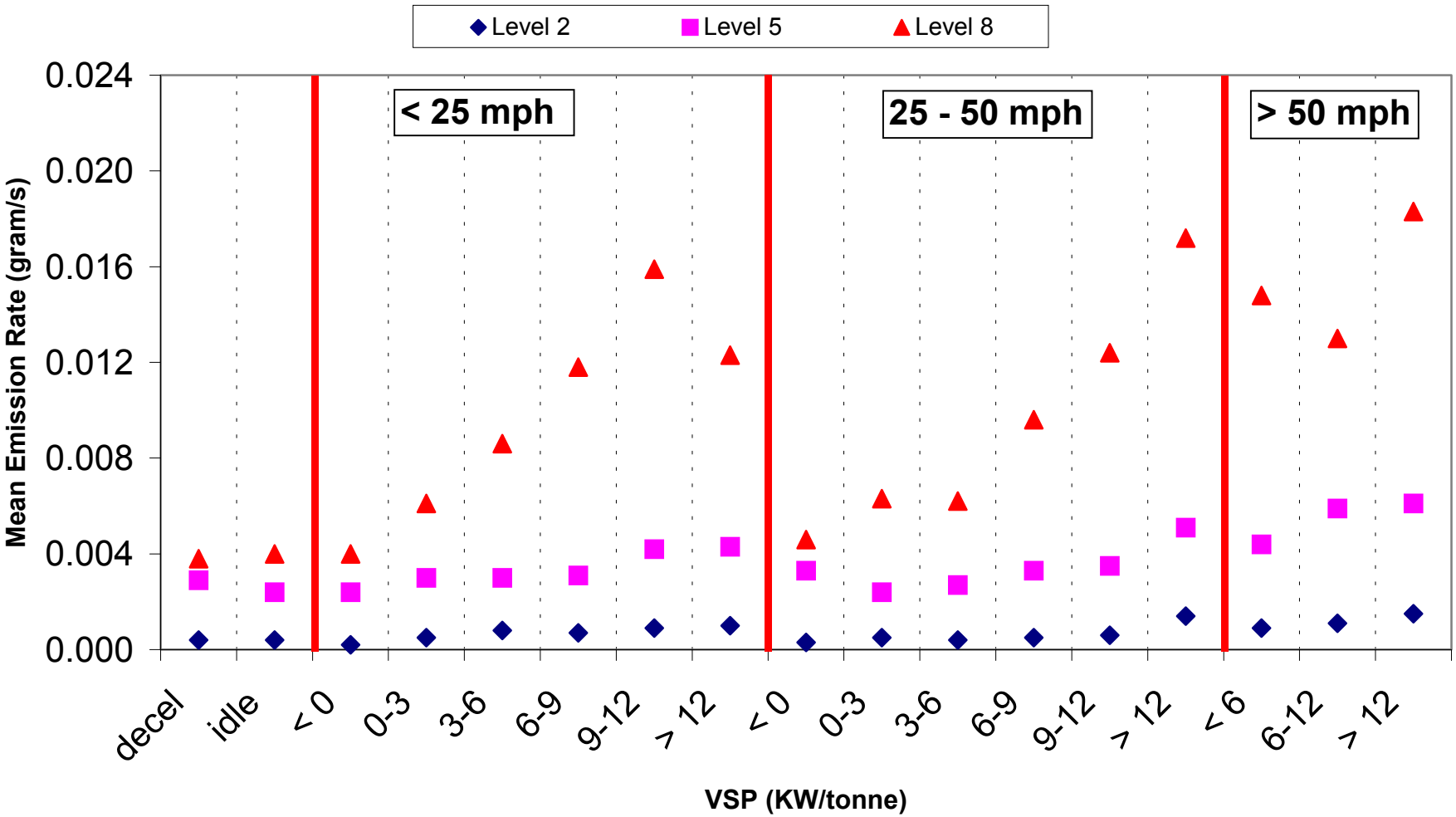

Light Duty HC
Observed Trip HC Rate (g/s)
.010
.008
.006
.004
.002
0.000
0.000
.002
.004
.006
.008
.010
Predicted Trip HC Rate (g/s)


Heavy Duty HC
Observed Trip HC Rate (g/s)
Predicted Trip HC Rate
.012
.010
.008
.006
.004
.002
0.000
0.000
.002
.004
.006
.008
.010
.012


Energy Consumption Rates By Bin
Source Bin: Gasoline / 86-90 MY / 2.0-2.5 liter
2501-3000 lbs
3501-4000 lbs
< 25 mph
25 - 50 mph
> 50 mph
Mean Energy Rate (KJ/s)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
decel
idle
< 0
0-3
3-6
6-9
9-12
> 12
< 0
0-3
3-6
6-9
9-12
> 12
< 6
6-12
> 12
VSP (KW/tonne)

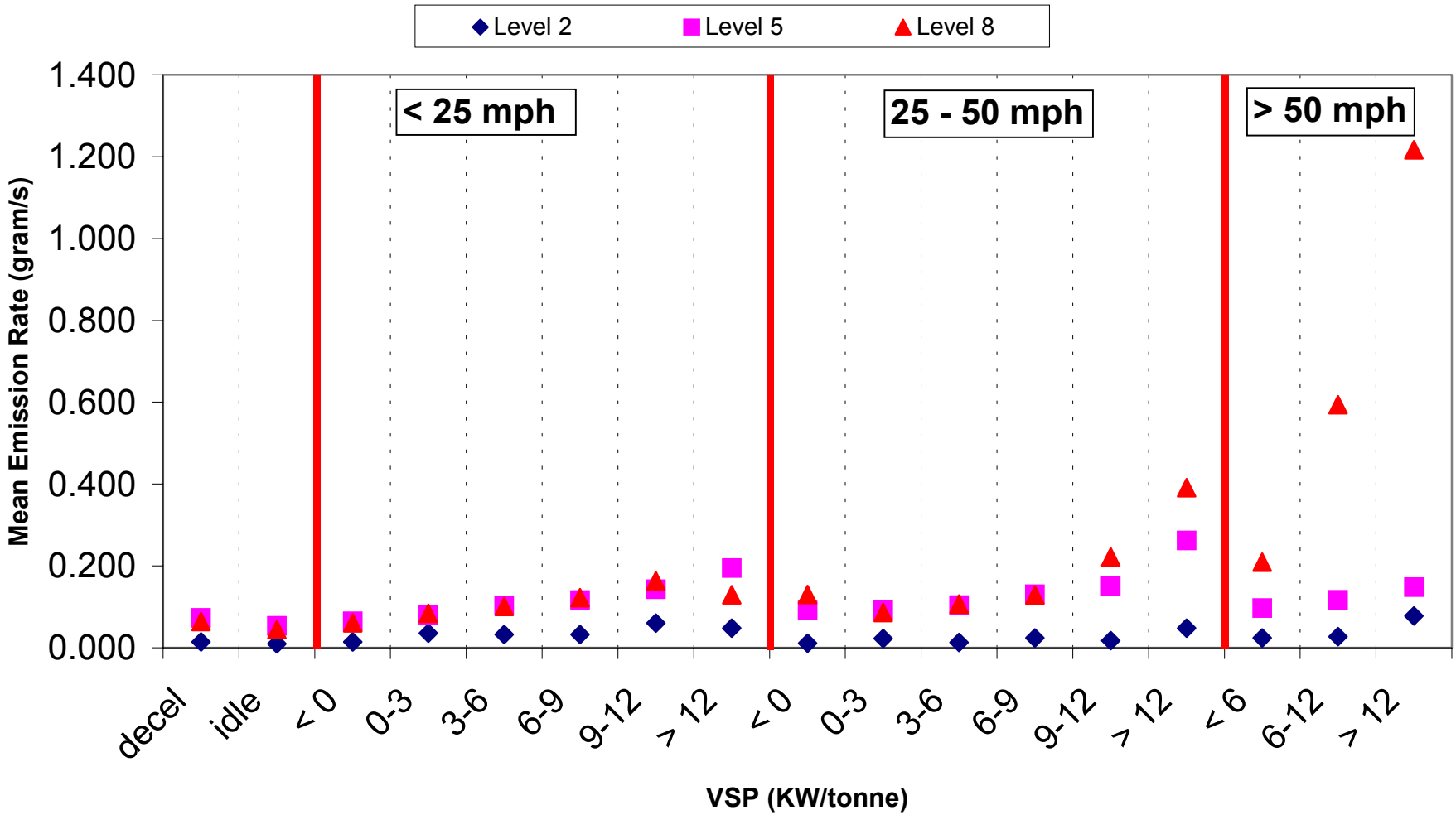
HC Emission Rates By Bin

Source Bin: Light-Duty/86-90 MY



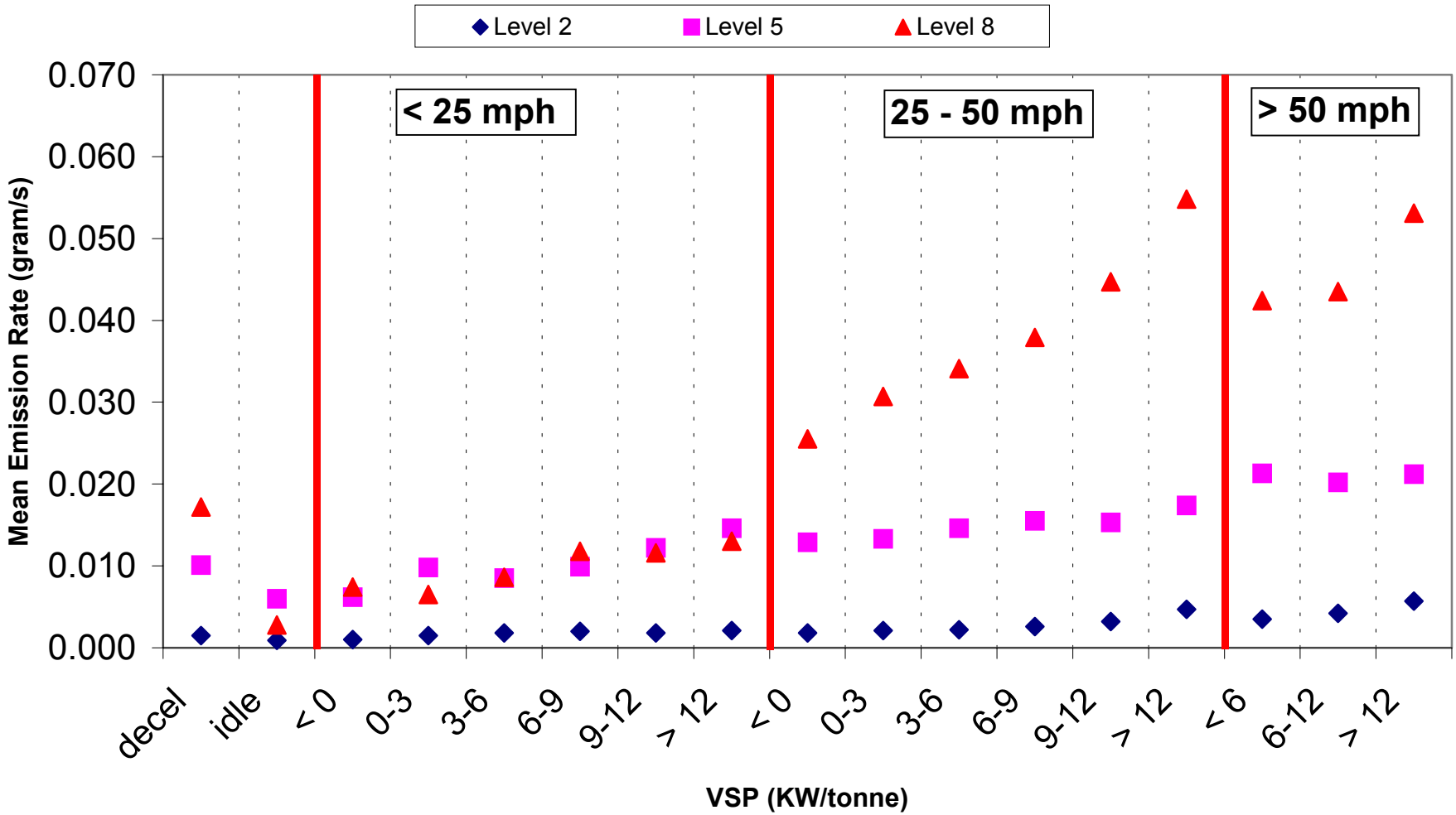
CO Emission Rates By Bin

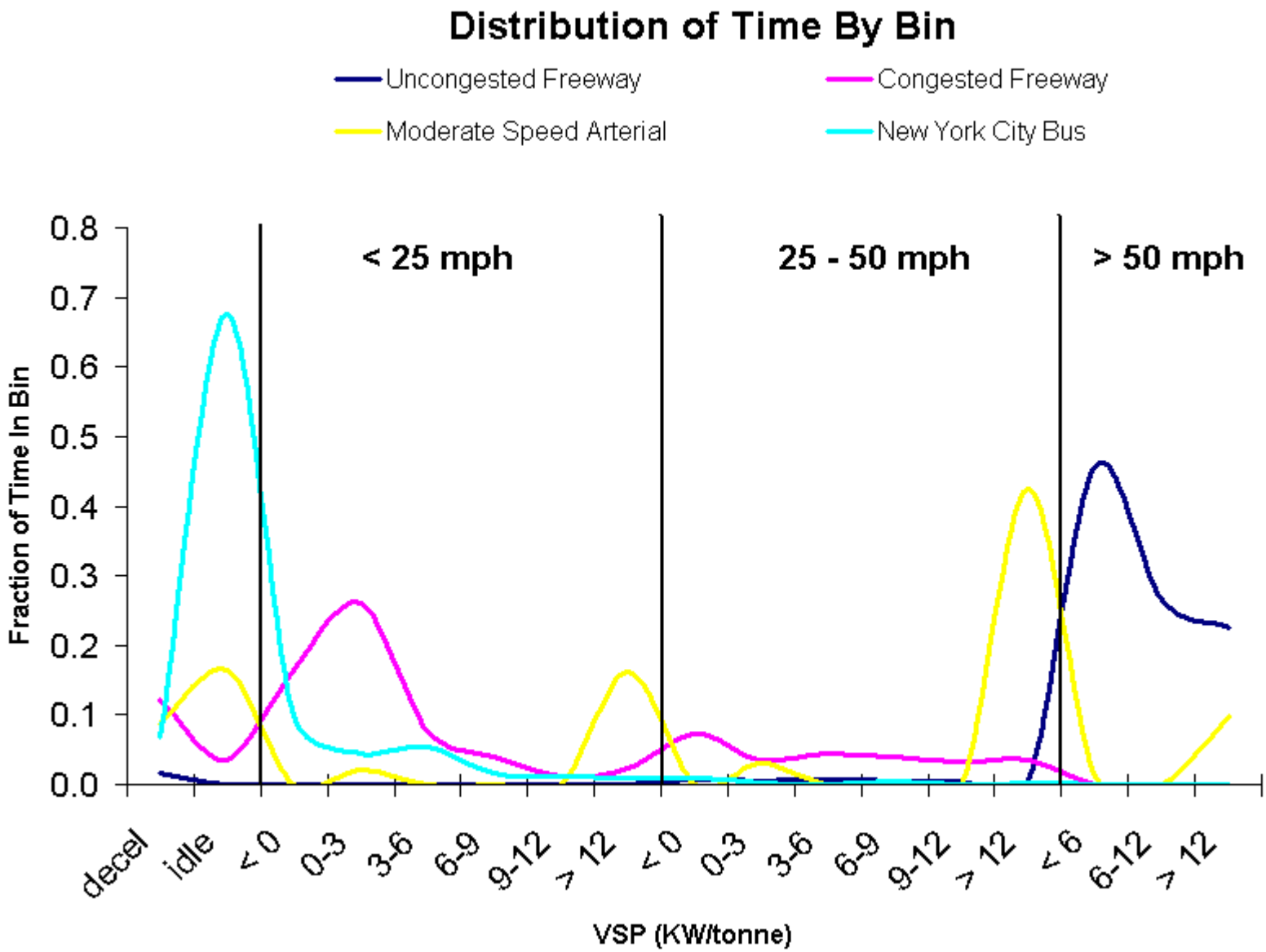
Source Bin: Light-Duty/86-90 MY



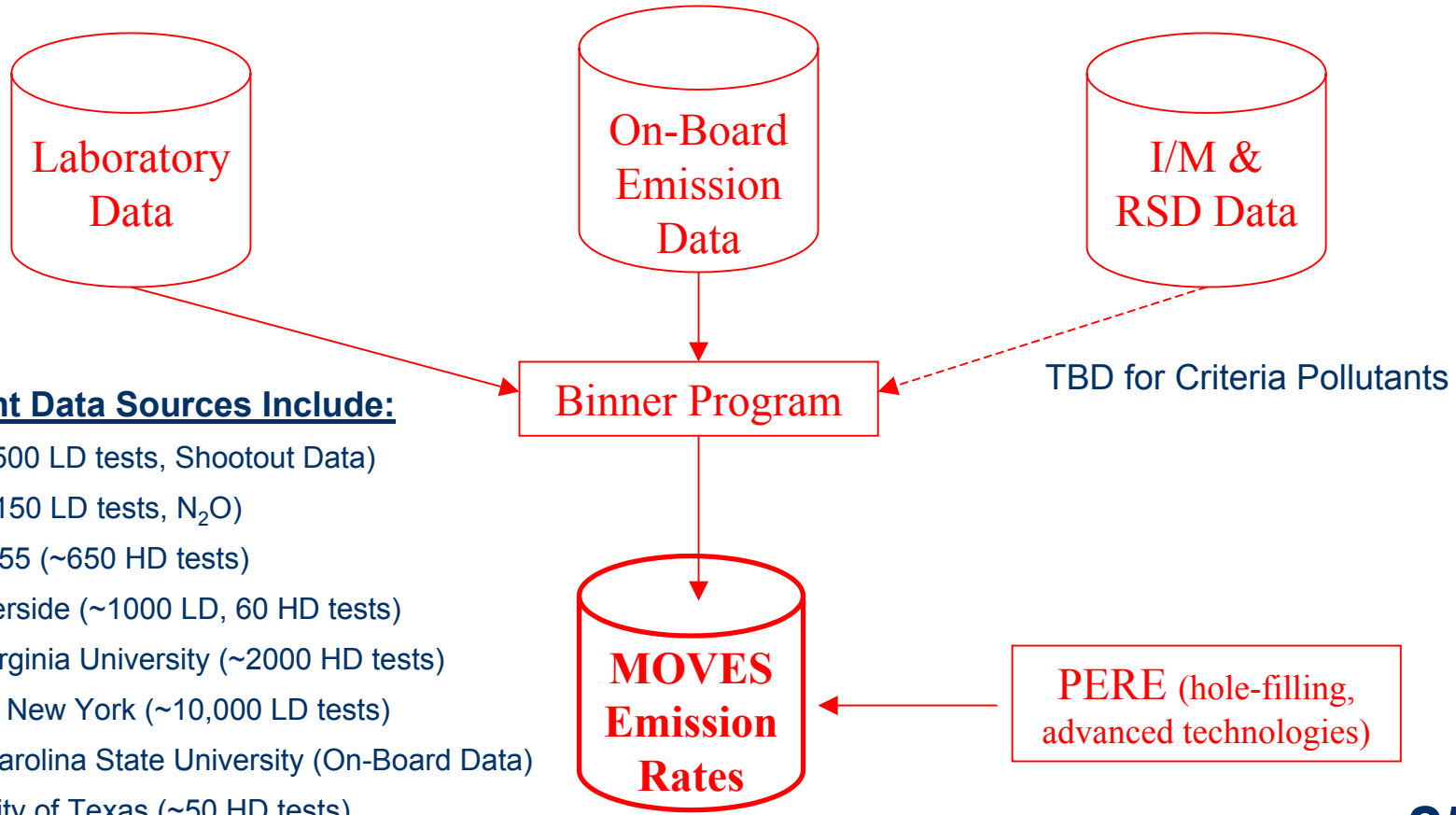
NOx Emission Rates By Bin

Source Bin: Light-Duty/86-90 MY




Distribution of Time By Bin
Uncongested Freeway
Congested Freeway
Moderate Speed Arterial
New York City Bus
< 25 mph
25 - 50 mph
> 50 mph
Fraction of Time In Bin
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
decel
idle
< 0
0-3
3-6
6-9
9-12
> 12
< 0
0-3
3-6
6-9
9-12
> 12
< 6
6-12
> 12
VSP (KW/tonne)

Binning Approach Broadens Data Sources



Current Data Sources Include:

EPA (~500 LD tests, Shootout Data)

ARB (~150 LD tests, N_2O)

CRC E-55 (~650 HD tests)

UC Riverside (~1000 LD, 60 HD tests)

West Virginia University (~2000 HD tests)

State of New York (~10,000 LD tests)

North Carolina State University (On-Board Data)

University of Texas (~50 HD tests)

First-Pass Binner Results

- **Percent of 1999 fleet covered by second-by-second data, by source use type:**

Passenger car: 98%
Passenger truck: 93%
Light commercial truck: 87%
Single Unit Short-haul: 65%
Single Unit Long-haul: 65%
Refuse Truck: 86%

Motorhome: 58%
Combination Short-haul: 36%
Combination Long-haul: 24%
Urban bus: 99%
School bus: 84%
Interstate bus: 100%
Motorcycles: 0%

Filling Holes

- **Energy (and eventually emission) rates needed for:**
  - Current fleet bins not adequately covered by available data
  - Advanced technologies
- **Hole-filling approaches investigated:**
  - Interpolation with surrounding bins
  - Derive binned rates from bag data
  - Use PERE to generate binned data
    - Presentation: “Advanced Technology Vehicle Fuel Consumption Modeling using PERE”
    - Poster: “Medium and Heavy Duty Diesel Vehicle Emissions Modeling Using a Fuel Consumption Methodology”
- **Bins making up very small percentage of a source type (< 1%) will use nearest “filled” bin**

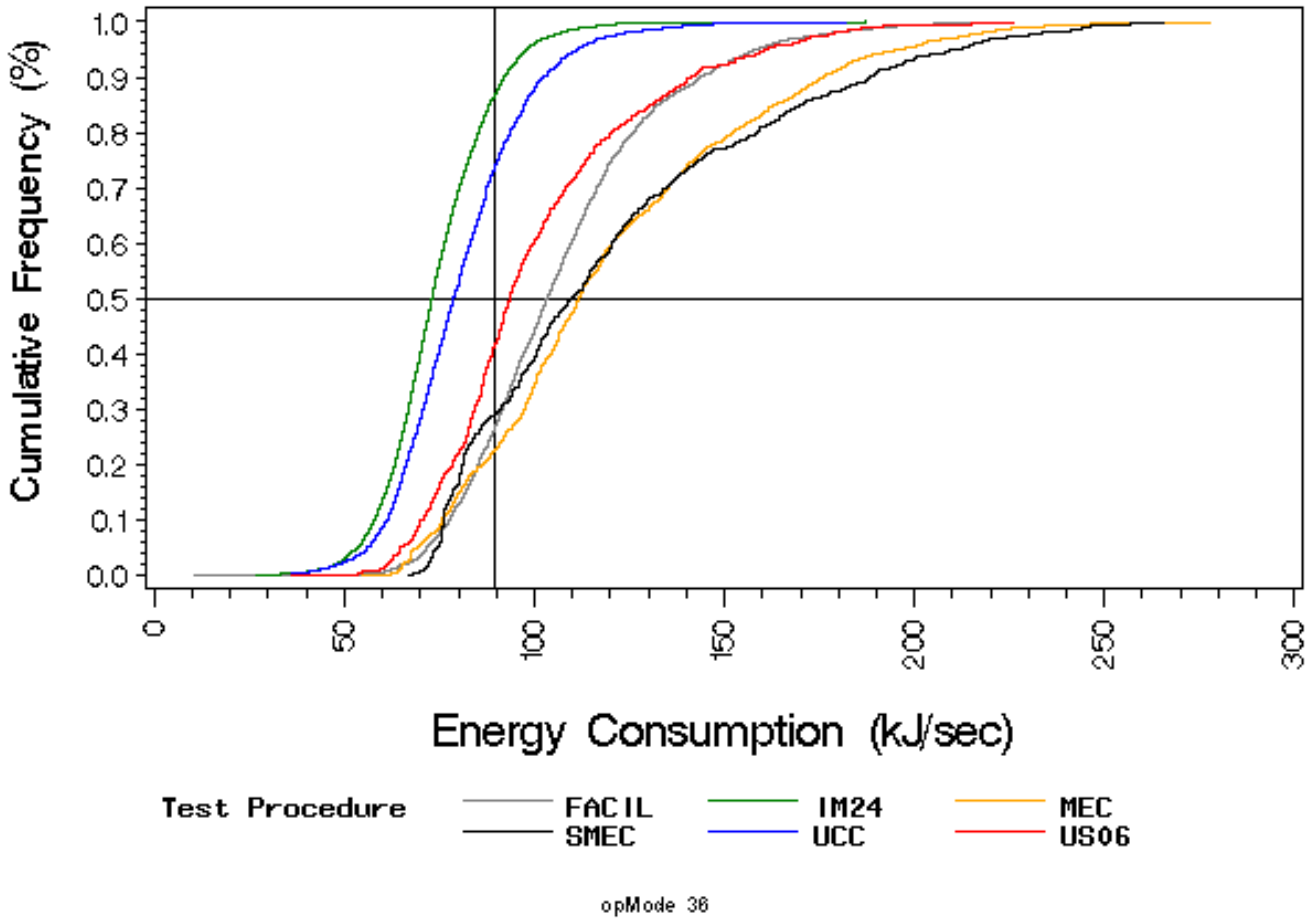
Assessing Data Within A Bin

Source Bin: Gasoline / 86-90 MY / 2.0-2.5 liter / 2500-3000lbs
Operating Mode Bin: VSP > 12 kw/tonne Speed > 50 mph

16,159 seconds of data

Breakdown by cycle:

FTP	*1 %*
UCC	*9 %*
IM240	*51 %*
LA92	*3 %*
Facility	*15 %*
US06	*4 %*
MEC/SMEC	*17 %*



For More Detail See Poster: "Mean Energy Consumption Rates within the MOVES Modal Framework"

Looking Ahead - Criteria Pollutants

- **Are higher VSP bins needed, i.e. for CO?**
- **High emitters**
  - What is a high emitter?
    - A vehicle that has high emissions all the time?
    - A vehicle that has high emissions intermittently?
    - A vehicle that has high emissions only in certain modes?
  - How should a high emitter be defined?
    - Based on aggregate emissions?
    - Within each operating mode?
  - Are we characterizing high **emitters** or high **emissions ?**
  - What data should be used?

Summary

- Emission rates under development for all pollutants/processes in MOVES2004
- Modal binning approach has been developed for running total energy and as prelude for other pollutants; validation looks good
- Binning program “Data Crank” will enable easy updates of emission rates with new data
- Existing data covers large portion of fleet; PERE will be used to fill remaining holes