



Environmental Protection Department

Development of EMFAC-HK using Vehicle Emissions Data Collected by PEMS for the Hong Kong Fleet

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Acknowledgement

- Eastern Research Group, Inc.
- My colleagues,
 - Anson Wong, Casey Lee, Eddie Lo, SW Ng, Eric Kam, Patrick Chung, WH Leung, Michael Ching, Catherine Lau, Ruby Wong

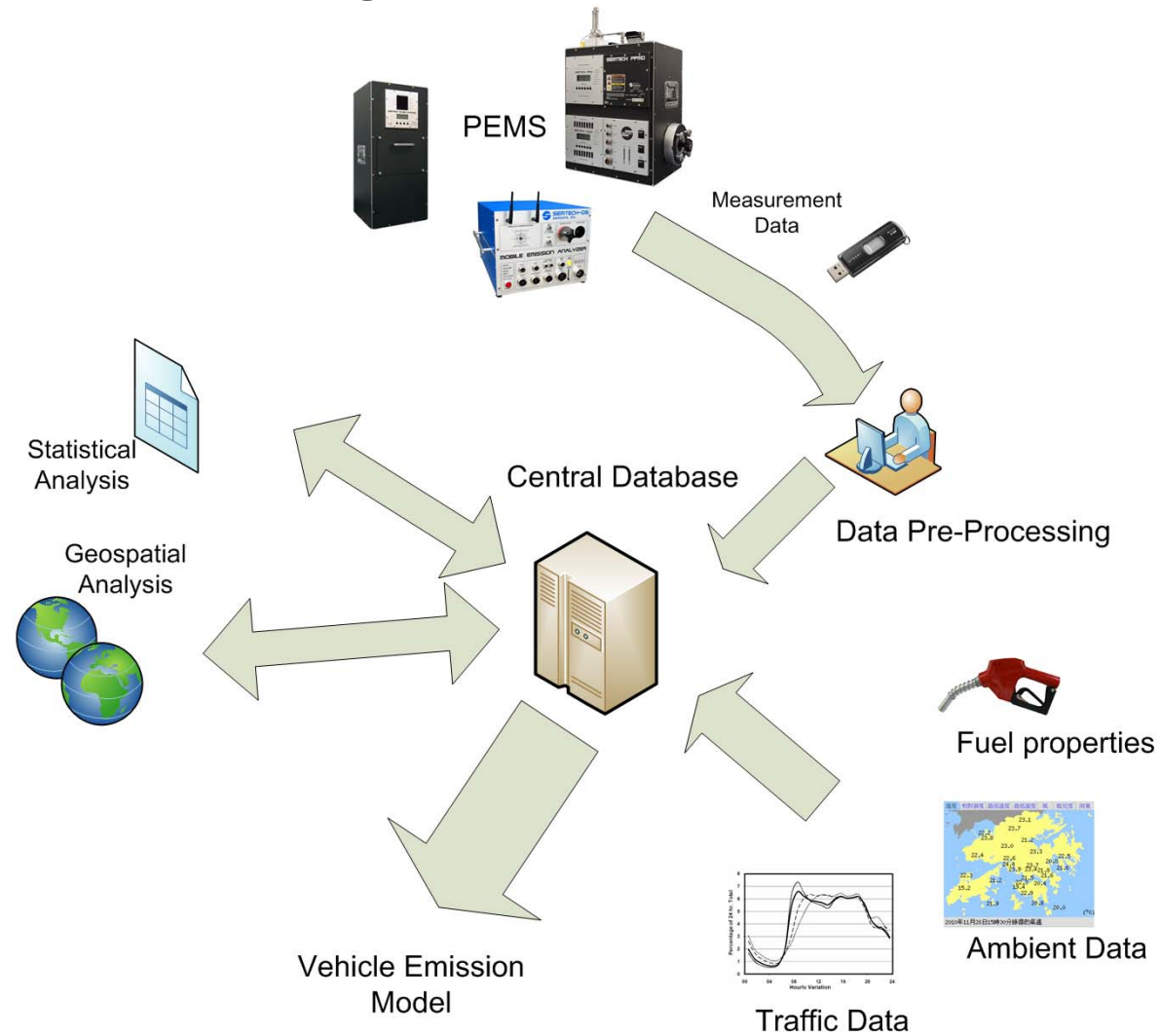
Background

- EMFAC-HK model is currently used for:
 - Compiling local emission inventories
 - Estimating vehicle emissions in support of environmental impact assessments and local projects in Hong Kong

Current Status

- Having been measuring real-world vehicular emissions using PEMS
 - Collected millions of seconds of observations since 2008
- Making reference to the local datasets collected using PEMS since 2008, emission factors in EMFAC-HK were adapted from U.S. datasets.
- Have conducted analysis for vehicle characteristics and fleet activity
- Will conduct more detailed analysis to update the above info.

Vehicle Emission Estimates – Design Flow Outline



Vehicles Explored up to end Mar., 2012

Vehicle Class	Fuel Type	Emission Standard						Total
		Pre-Euro	Euro I	Euro II	Euro III	Euro IV	Euro V	
Cars	Petrol			2	9	13	1	25
Taxis	LPG			12	4	4		20
Public light buses	LPG			1	4	3		8
	Diesel			1		1		2
Goods vehicles <= 5.5 t	Diesel	4	1	3	15	9	3	35
Goods vehicles > 5.5t	Diesel	1		3	13	5	1	23
Single Deck Coaches	Diesel				5	8		13
Double Deck Buses*	Diesel			4	2			6
Total		5	1	26	52	43	5	132

* Double deck buses are retrofitted with diesel particulate filter (DPF).

Example: SCR retrofit program on 3 Double Deck Buses (FBDD) with DPF

Make	Dennis Trident Euro III	Volvo Olympian Euro II	Dennis Trident Euro II
Eng Model	ISMe 335 Euro III/1-08-2003	D10A 245	M11-305E21
Eng Capacity	10.8 litre	9.6 litre	10.8 litre
Emi Standard	Euro III	Euro II	Euro II
First Reg. Date	1 Aug 2003	10 Mar 1998	23 Sept 1998
Engine rated power	246 kW @ 1900 RPM	180 kW @ 2000 RPM	224 kW @ 1900 RPM
Engine rated torque	1410 Nm @ 1200 RPM	1050 Nm @ 1450 RPM	1250 Nm @ 1250 RPM
GVW	23.5 tonnes	22.94 tonnes	23.1 tonnes
Loaded Weight	19.0 tonnes	19.7 tonnes	19.4 tonnes
After treat. device	DPF	DPF	DPF

Installation

Speed meter



Connecting pipes from tailpipe to PEMS



RH & temp sensor

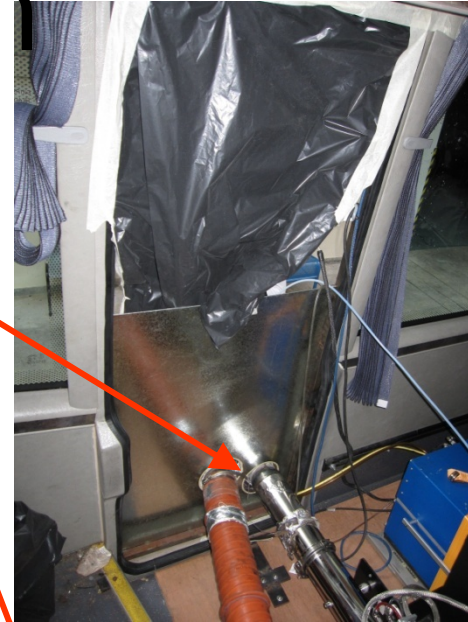
Cable to computer

Installation

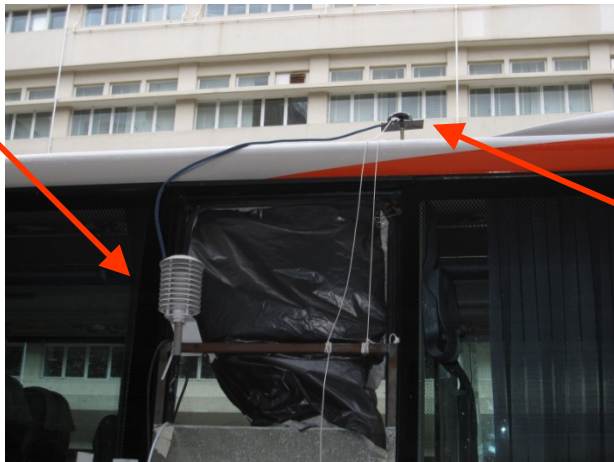


Exhaust flow meter

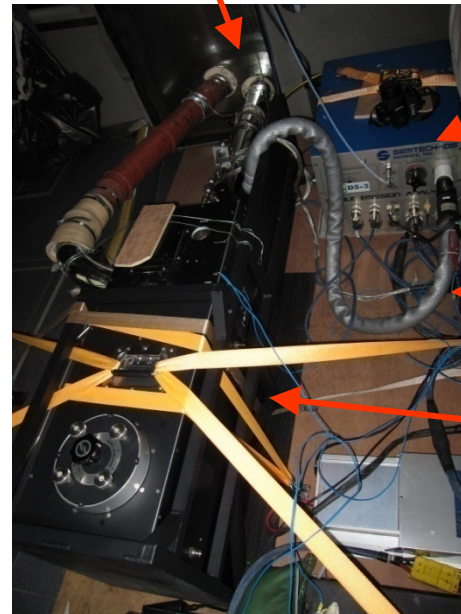
Connecting pipes from tailpipe to PEMS



RH & temp sensor



GPS

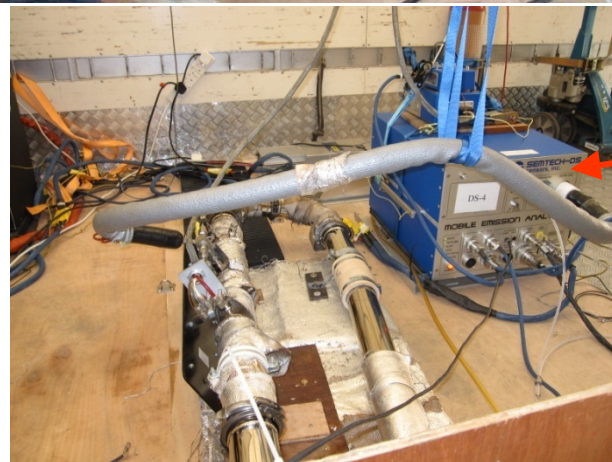
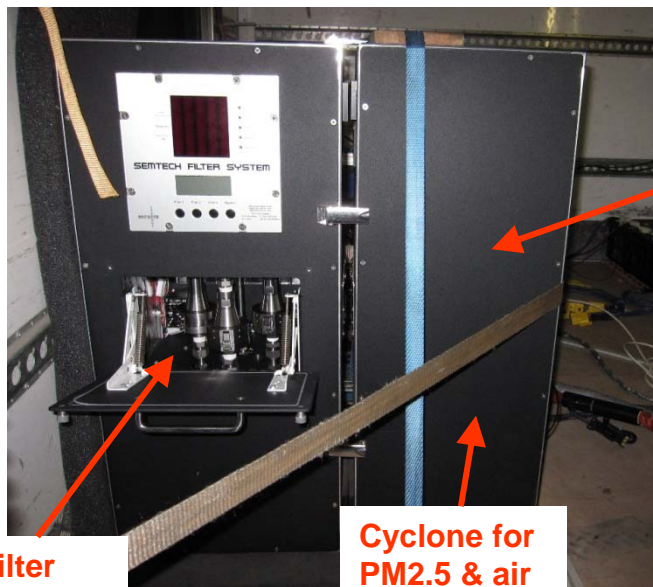
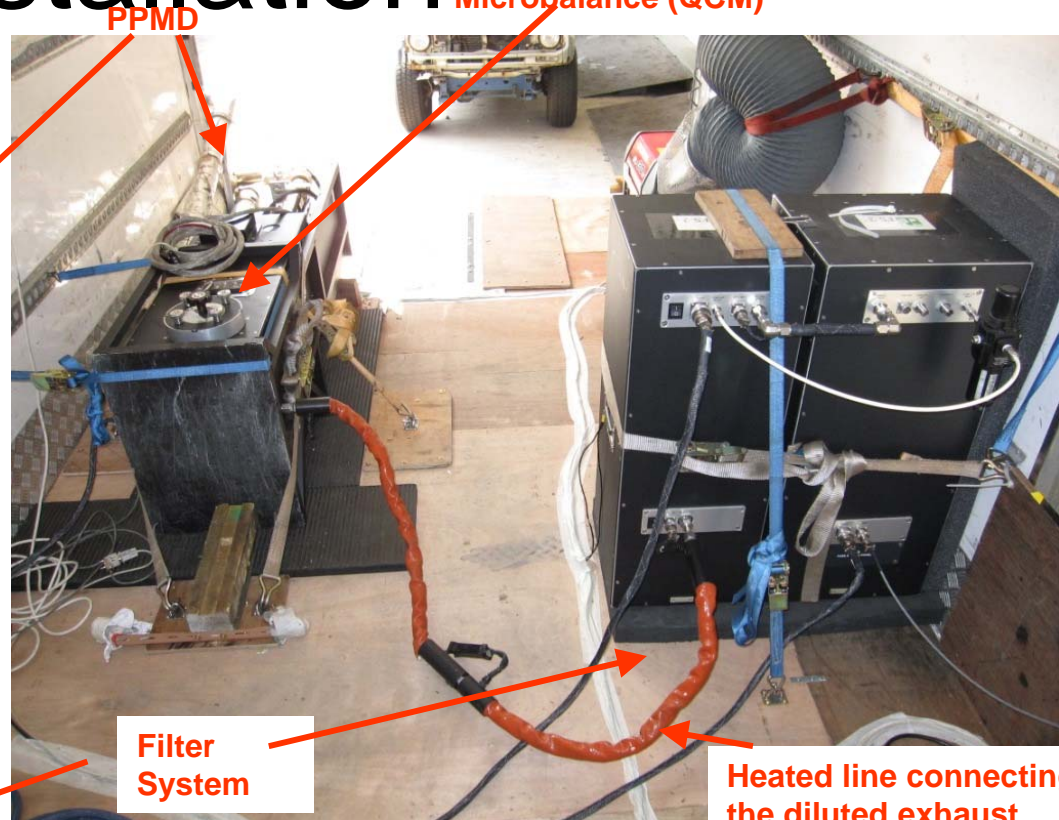
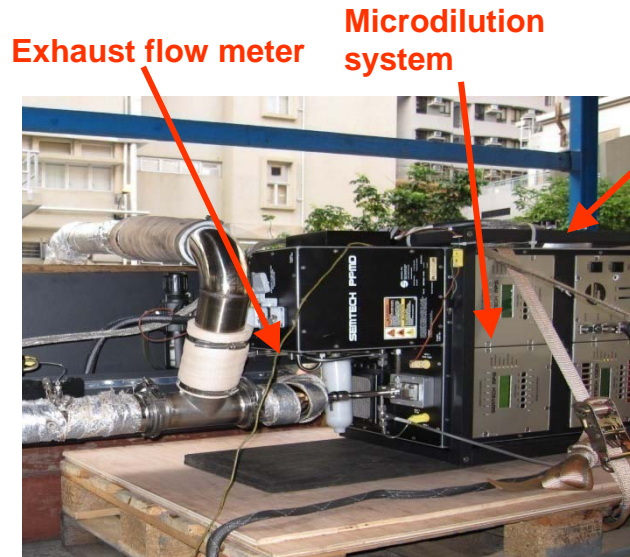


PEMS measuring gaseous pollutants

Heated line

PEMS measuring PM

Installation



Heated line connecting the diluted exhaust from the QCM bypass to the filter system

PEMS for measuring gaseous pollutants

Heated line

PEMS testing – 5 Goods Vehicles

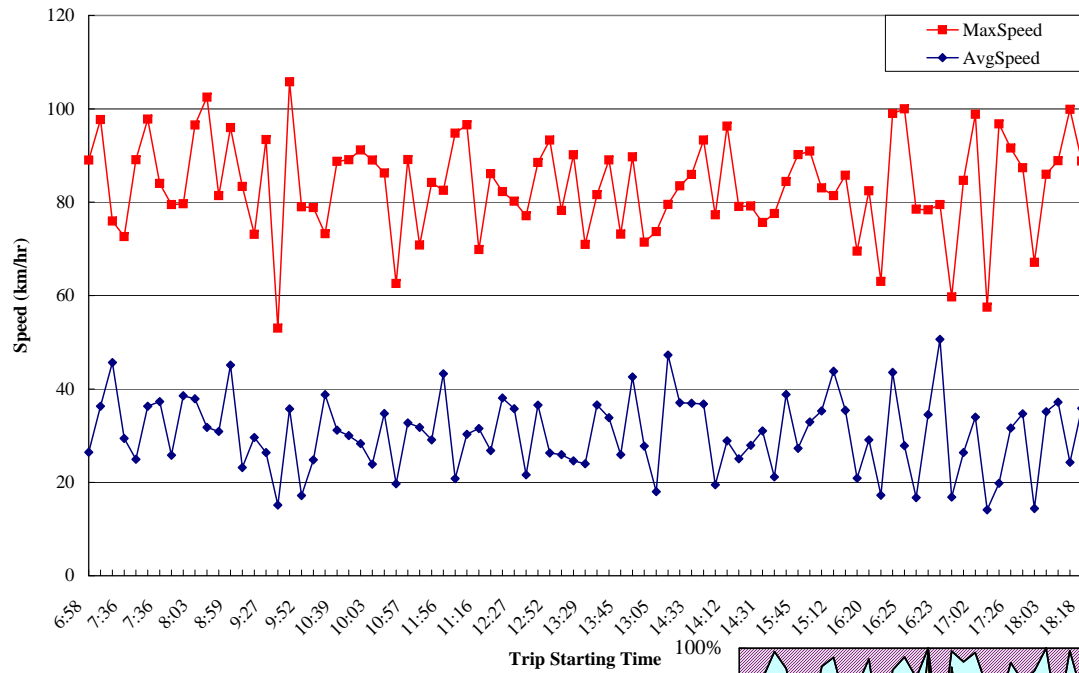
Make	Isuzu	
Fuel Type	Diesel	
Model	4HE1-TC	4HK1E4N
Engine Capacity	4.8 litre	5.2 litre
Emission Standard	Euro III	Euro IV
Manu. year	2004	2007, 2008
Mileage (km)	222319, 276678, 177107	9788, 32261
Engine rated power	107 kW @ 2300 RPM	114 kW @ 2600 RPM
Engine rated torque	471 Nm @ 1600-2000 RPM	419 Nm @ 1600-2600 RPM
Aftertreatment device	Catalytic converter	Diesel Particulate Filter

Test routes for goods vehicles



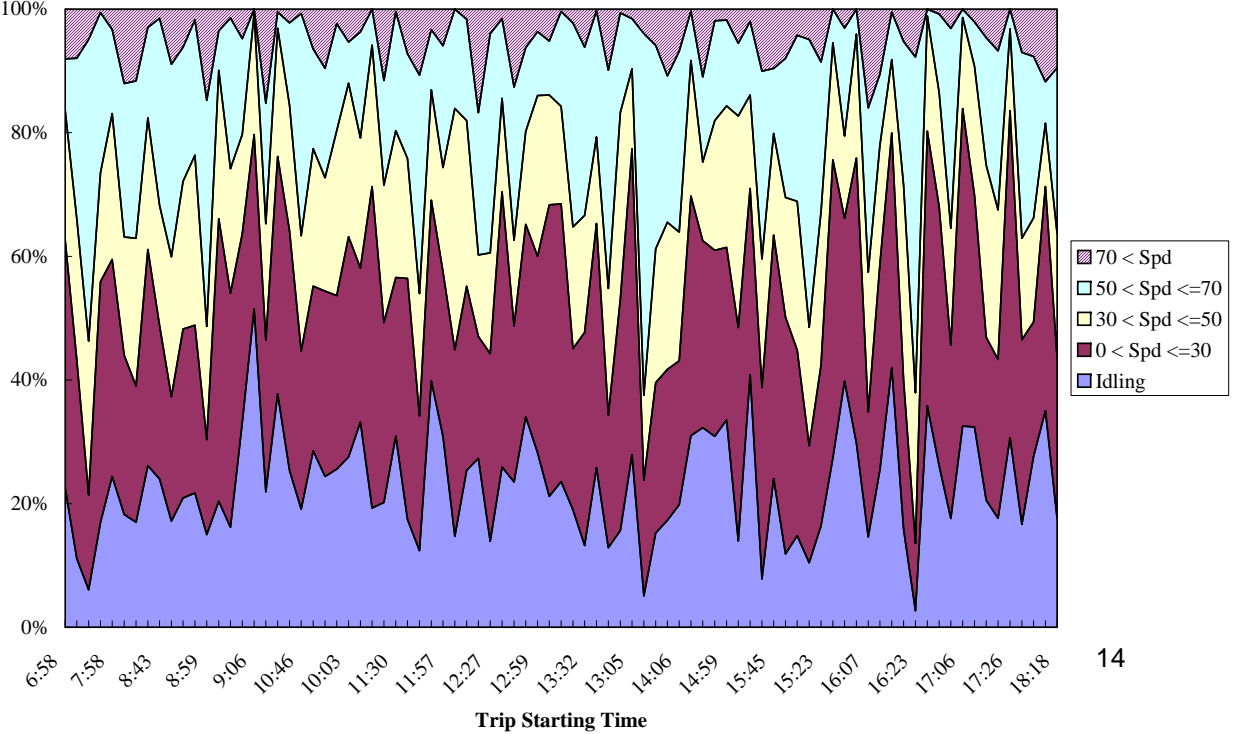
Slide Show on the test route for goods vehicles



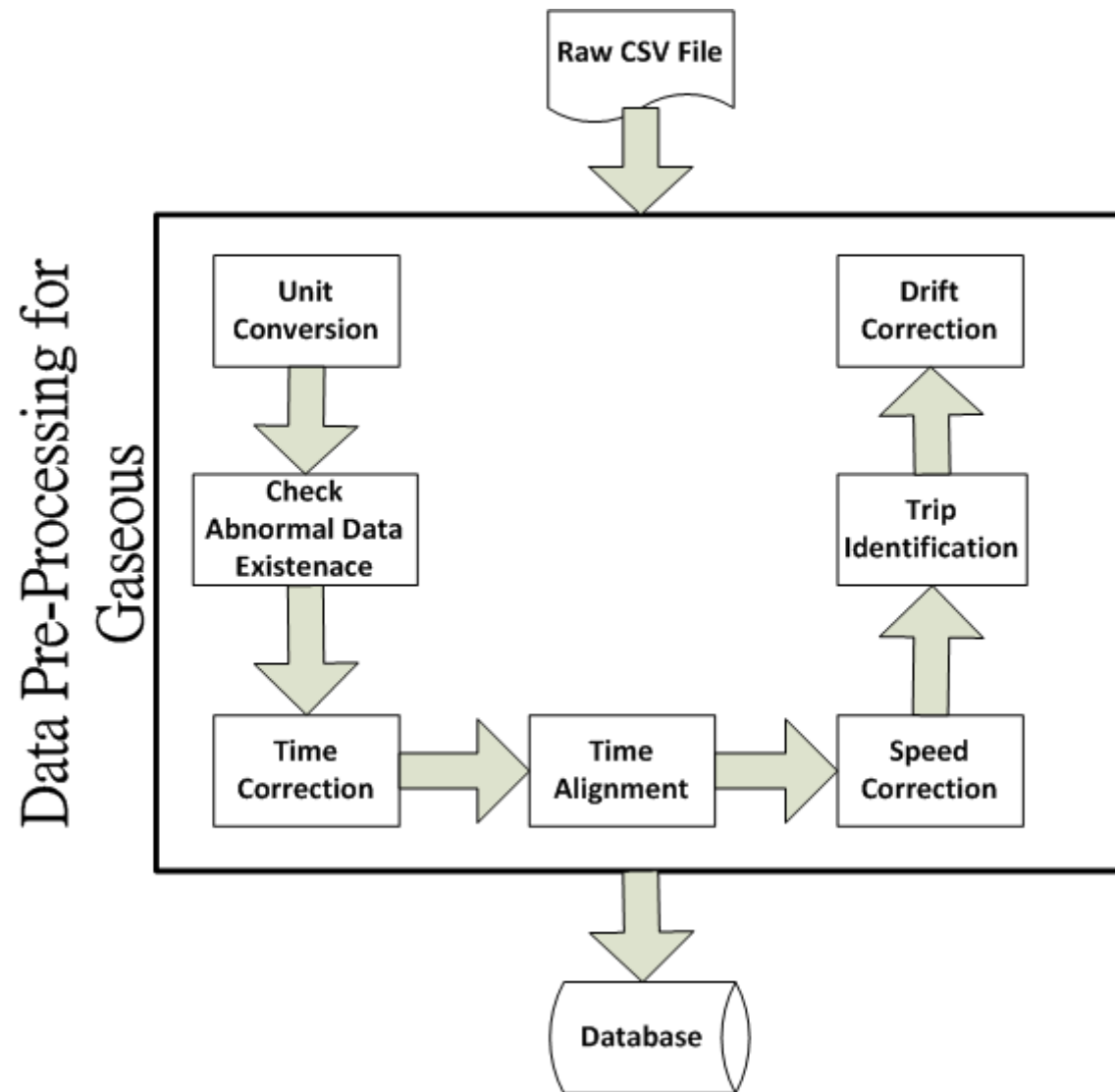


Max and Average Speed

Speed Range



Data Pre-Processing (Gaseous)



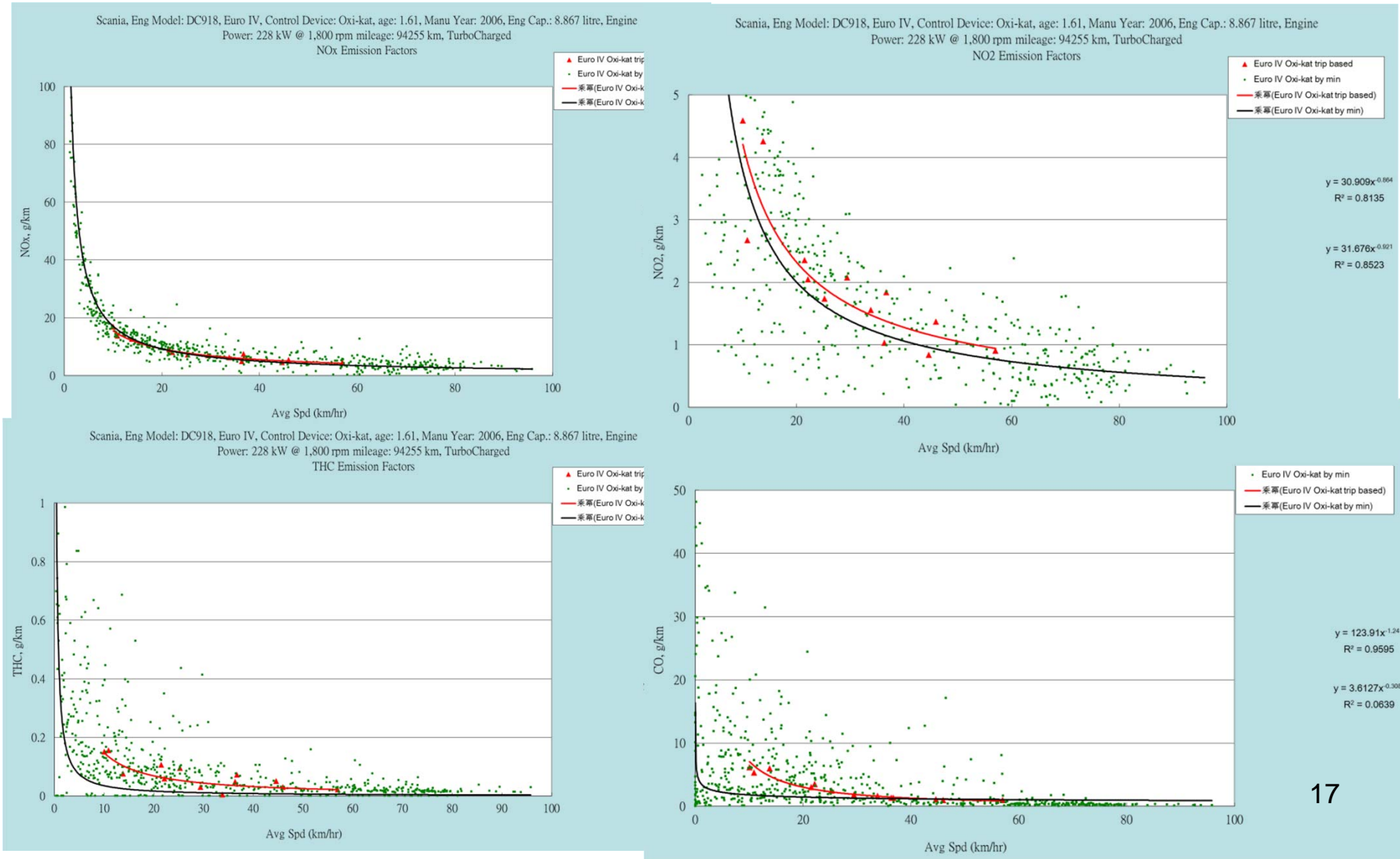
Data QA/QC Checks

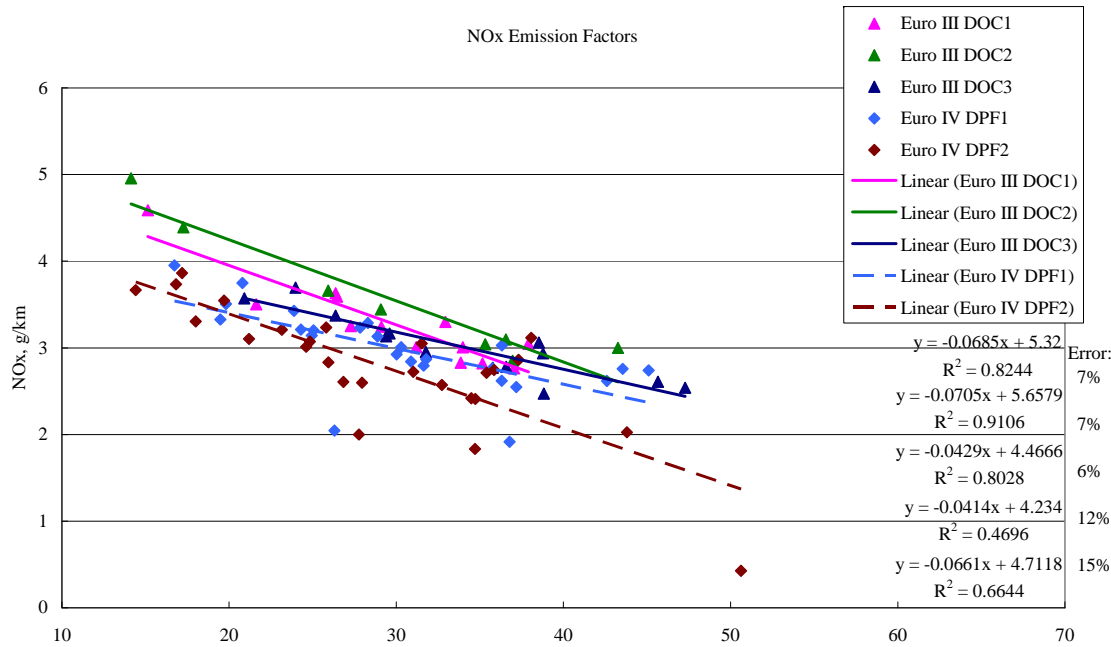
In order to perform the QA/QC task, a variety of plots were created to expose outlying, unusual, or inaccurate data

- Exhaust flowrate distributions by vehicle
- Exhaust concentration distributions by vehicle
- Raw vs corrected exhaust concentrations by vehicle
- Maximum and mean exhaust concentrations by test, displayed together by vehicle
- Exhaust concentrations vs time by test
- VSP bin frequency and VSP binned emission mass rates by vehicle
- data flags in SAS were used to draw attention to values that lie outside of expected ranges

Results after Pre-Processing (Gaseous)

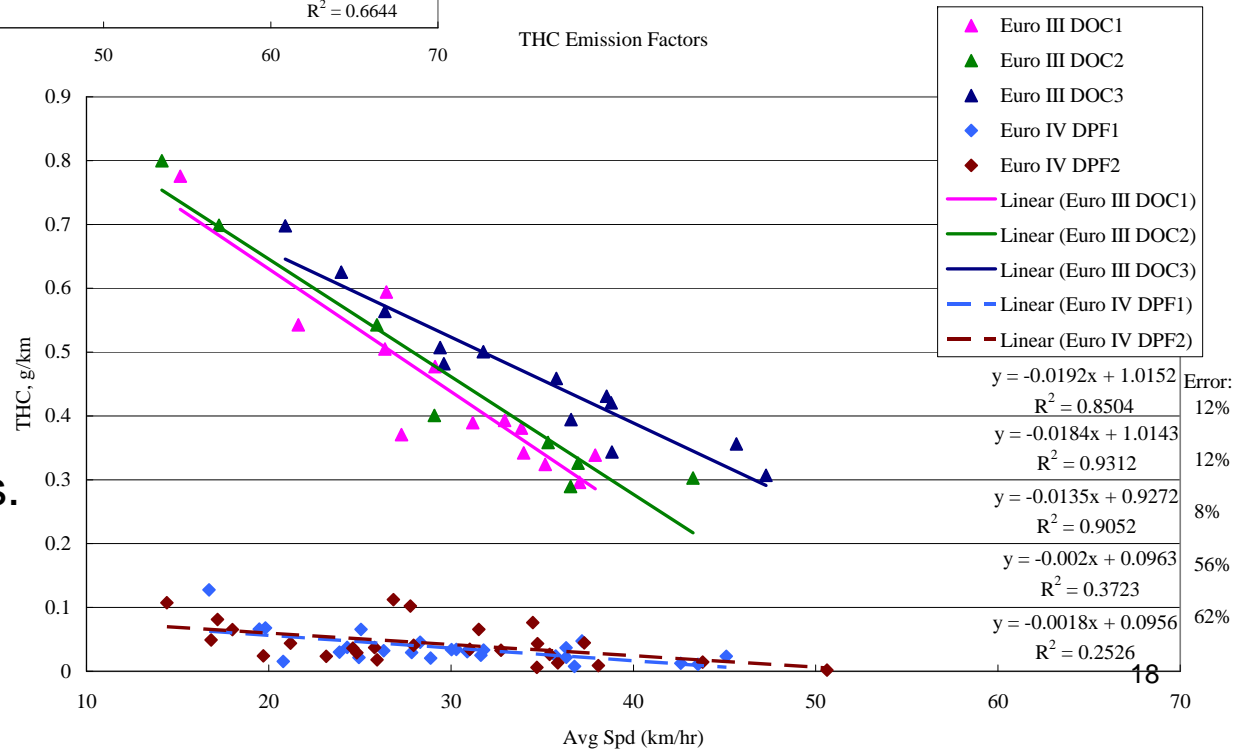
Euro IV coach with EGR & DOC, Eng cap.: 9 litre

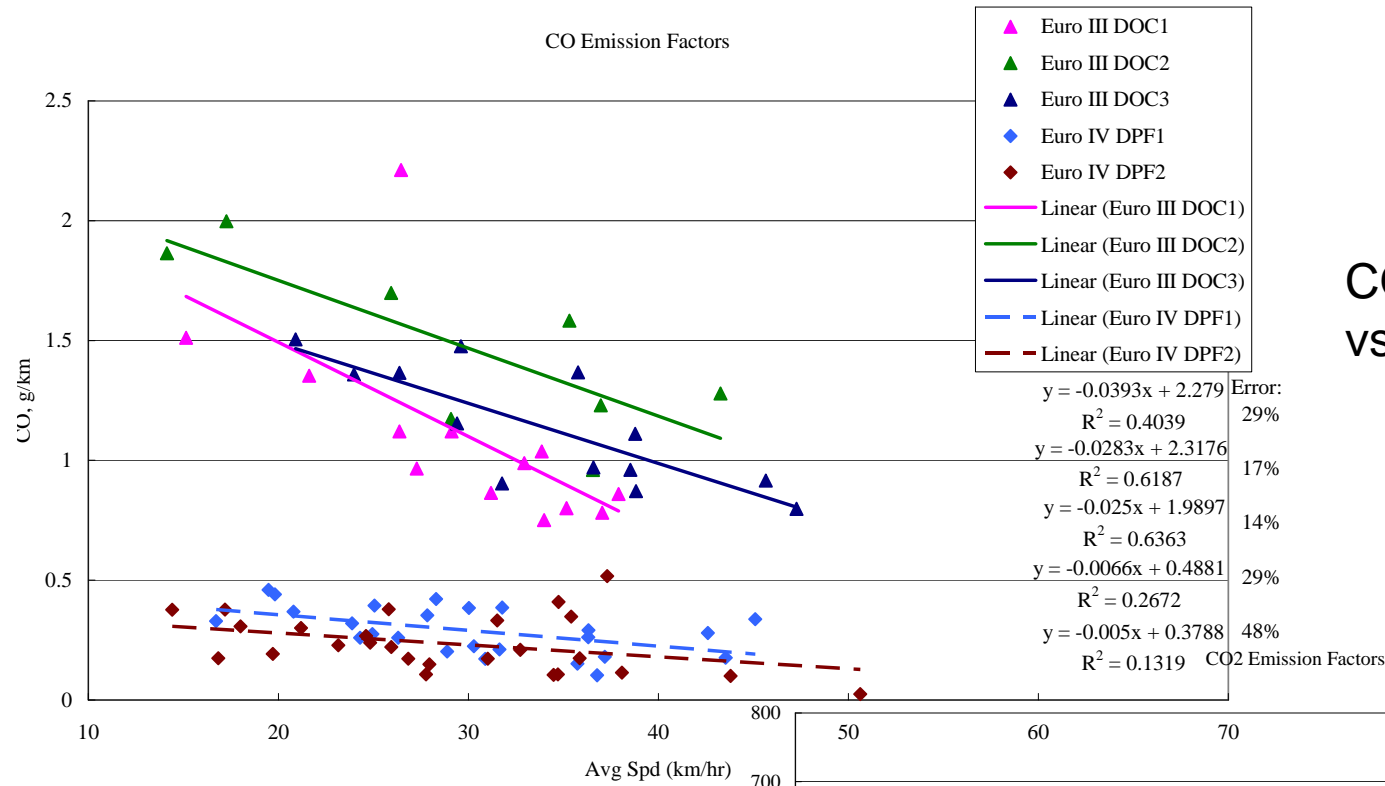




NOx emission factors vs. average speed

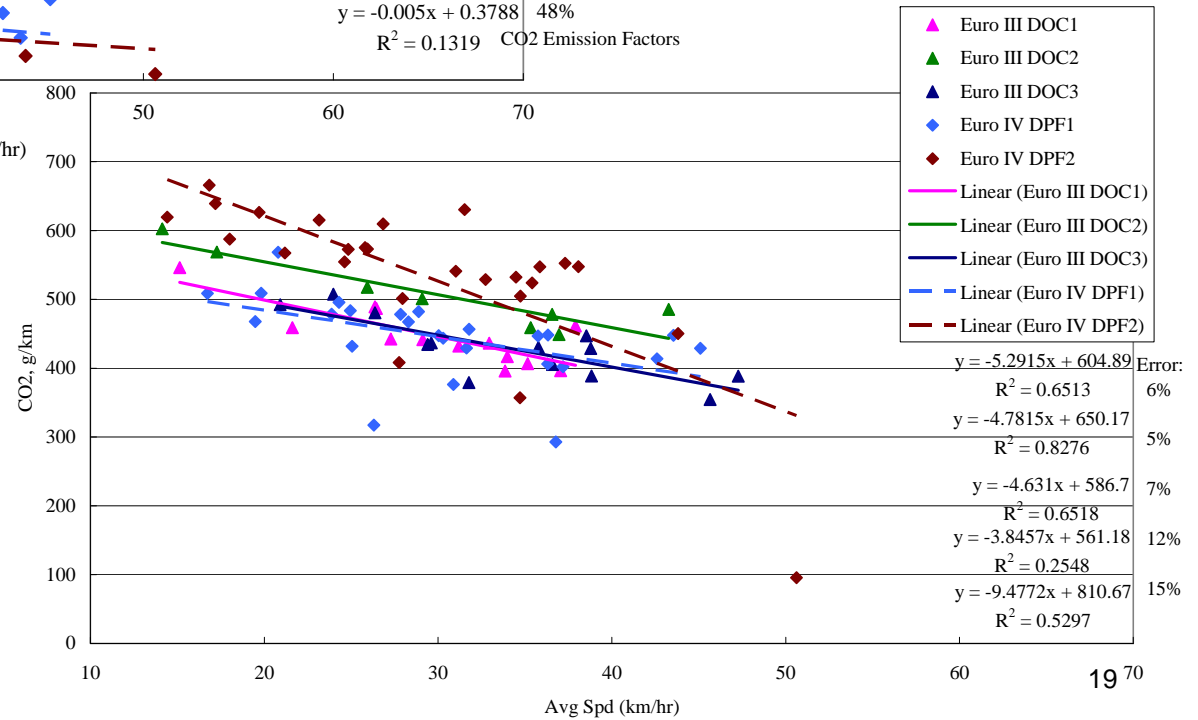
THC emission factors vs. average speed



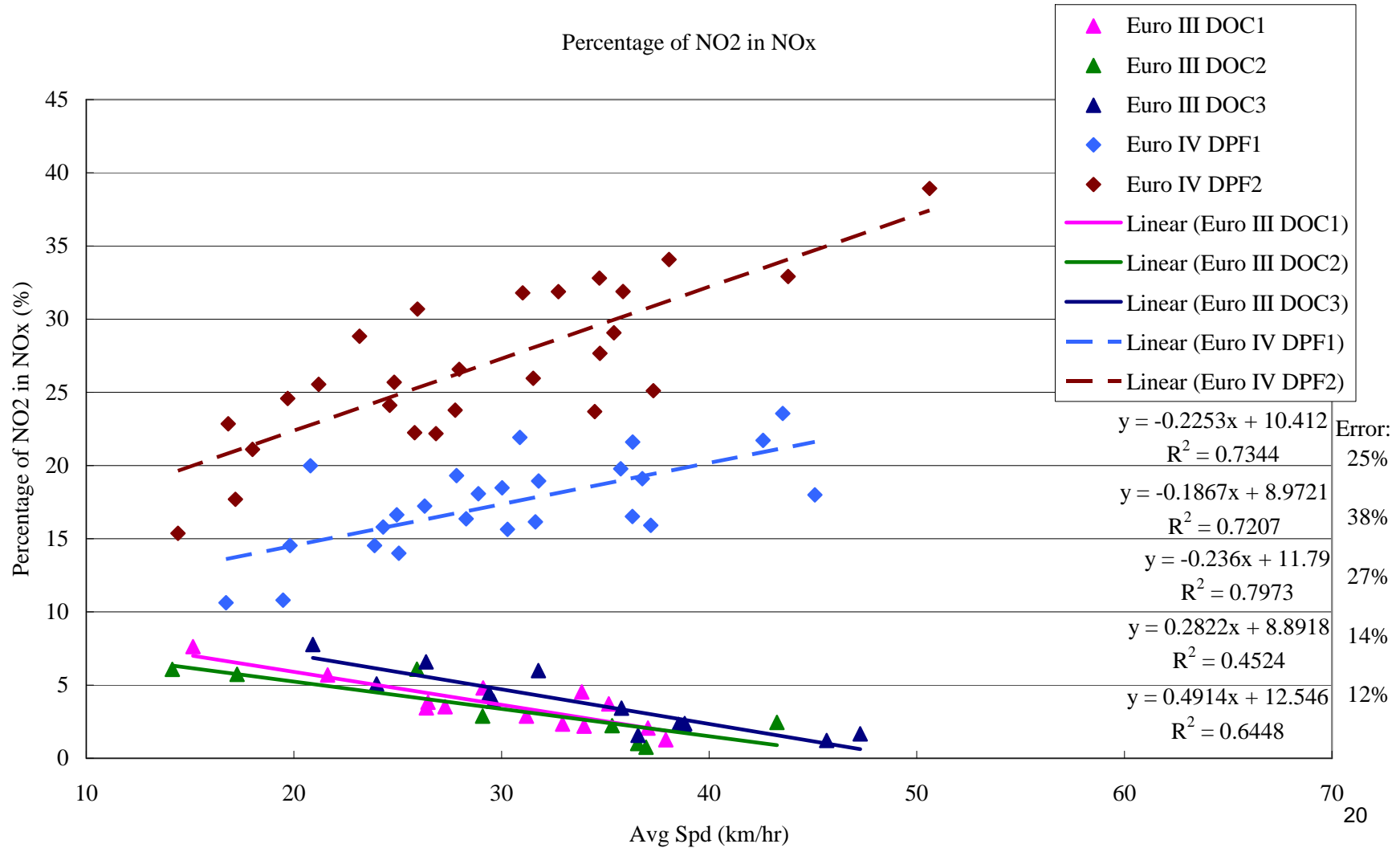


CO emission factors vs. average speed

CO₂ emission factors vs. average speed



Percentage of NO2 in NOx



Data Pre-Processing (PM)

- Buoyancy Correction of filter media
 - Base on ambient temp, pressure and relative humidity
- Calculate
 - the sample time, distance, avg speed,
 - sample volume, exhaust volume, total volume after the dilution, avg dilution ratio, R2 for sample & exhaust flows, percentage error of sample flow
 - PM concentrations, PM emission factors

PEMS testing – Vehicle Description

Vehicle Class	Goods Vehicles		Coach
Make	Isuzu	Mitsubishi	Scania
Fuel Type	Diesel	Diesel	Diesel
Eng Model	4HE1-TC	4M50	DC918
Eng Capacity	4.8 litre	4.9 litre	8.9 litre
Emi Standard	Euro III	Euro IV	Euro IV
Manu year	2004	2007	2006
Mileage	222,319 km	52,753 km	94,255 km
Engine rated power	107 kW @ 2300 RPM	132 kW @ 2700 RPM	228 kW @ 1800 RPM
After treatment device	DOC	POC and DOC	EGR and oxi-kat

The PM Result after Data Pre-Processing - Examples

Vehicle	Dennis Trident FBDD	
Emission std	Euro II	
After-treat. dev.	DPF	DPF+SCR
Overall dil. ratio	19 - 21	15 - 19
R2 for Qex vs. Qsample	0.984 - 0.991	0.990 - 0.991
$\frac{\text{Std dev}^*}{\text{mean}}$	4.06 - 4.70%	3.49 - 4.84%
sampling period (min)	160 - 178	154 - 173
average speed (km/hr)	34 - 38	33 - 36
filter (mg/km)	5.3 - 20	3.3 - 5.9

* for sample flow vs. exhaust flow

The PM Result after Data Pre-Processing - Examples

Vehicle class	Diesel Truck		Diesel Coach
Emission std	Euro III	Euro IV	Euro IV
After-treatment device	DOC	POC & DOC	EGR & oxi-kat
Overall Dilution Ratio	9.0 - 9.7	15.6-17.9	14.8- 18.3
R2 for Qex vs. Qsample	0.98 -0.99	0.98 -0.99	0.96 - 0.99
Std dev mean	4.0% - 5.0%	6.2% - 8.9%	3.8% -6.2%

The PM Result after Data Pre-Processing - example

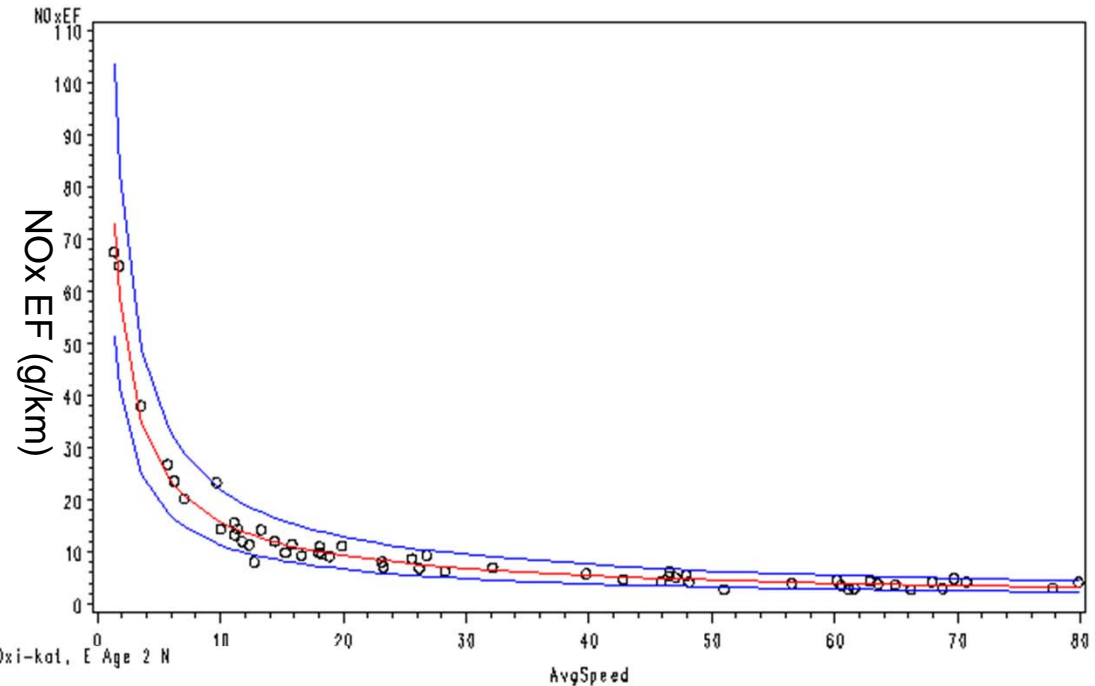
Vehicle class	Diesel Truck		Diesel Coach
Emission std	Euro III	Euro IV	Euro IV
After-treatment device	DOC	POC & DOC	EGR & oxi-kat
sampling period (min)	16 -33	55 - 74	22 - 29
average speed (km/hr)	26 -32	27-40	35 - 45
filter (mg/m ³)	8.3 - 12.8	3.7 - 5.3	15.7 - 18.6
filter (mg/km)	57 - 82	20 - 32	150 - 210

Statistical Analysis

- Calculate emission factors at 1-minute, 8-minute and 1-hour intervals of PEMS data for each vehicle
- Conduct statistical analysis on the emission factors (in g/km) by linear and non-linear models (PROC REG & PROC NLIN in SAS)
- Use the estimated trend lines and 95% confidence intervals to estimate the emissions at average speeds of FTP/UC/UDDS cycles
- The estimate with the smallest confidence interval was selected for each test vehicle

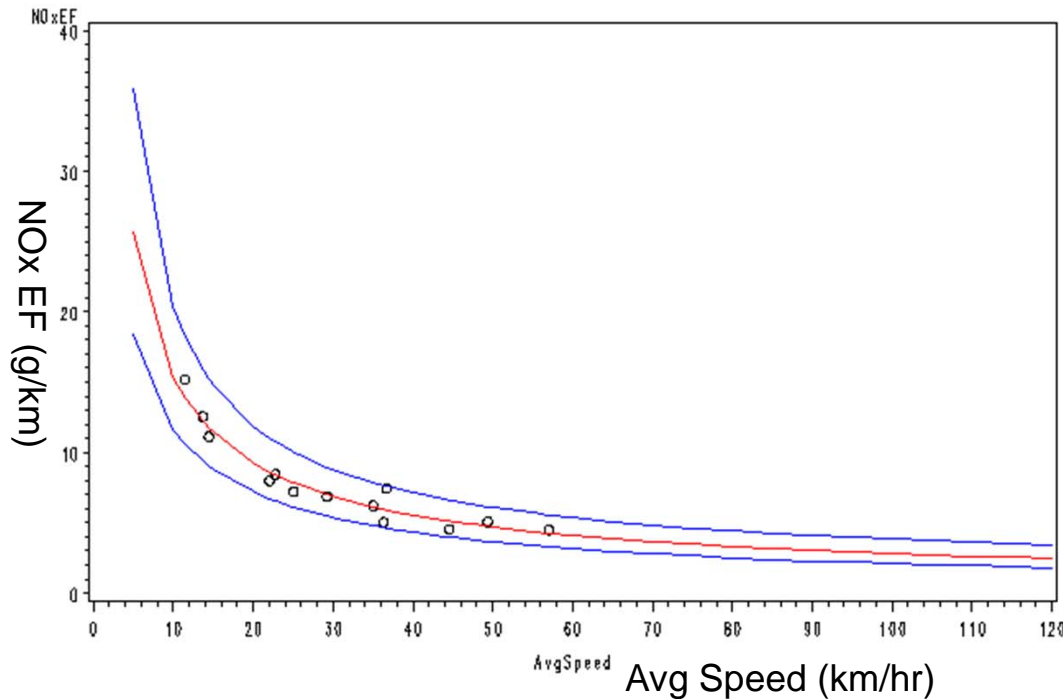
A Euro IV Single deck coach with EGR & DOC, NOx emission factors averaged over 8-minute intervals

E_NO=NG9964 RecType=8M Elcode=NFBB Fuel=Diesel EmiStd=Euro IV dummy=Scania Oxi-kat, E Age 2



Avg Speed (km/hr)

E_NO=NG9964 RecType=T Elcode=NFBB Fuel=Diesel EmiStd=Euro IV dummy=Scania Oxi-kat, E Age 2 H



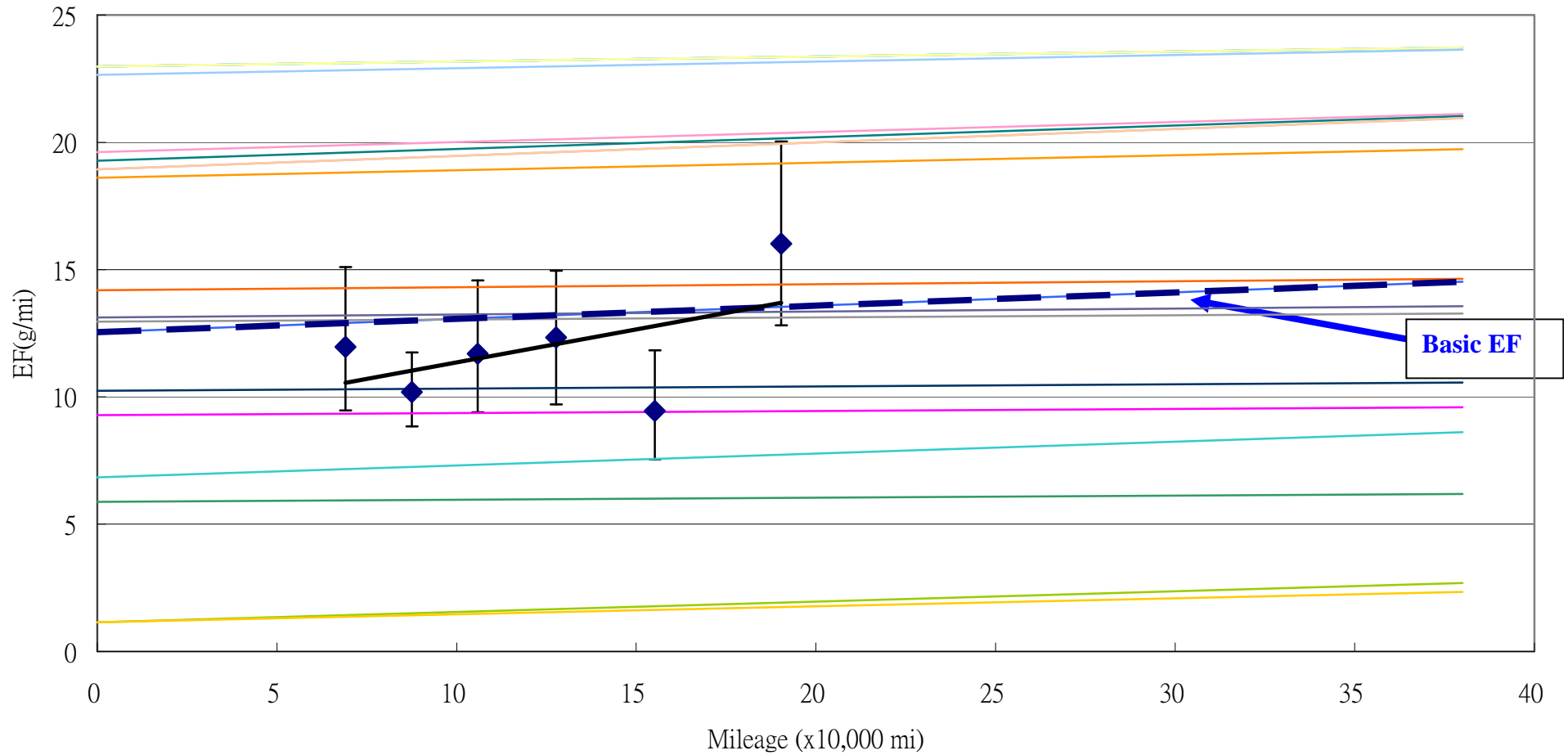
The same Euro IV single deck coach, NOx emission factors averaged over 1-hour intervals

Matching of Technologies

	Euro I	Euro II	Euro III	Euro IV
Petrol cars	1995	1997	2001	2006
Diesel vehicles	1995	1997	2002	2007

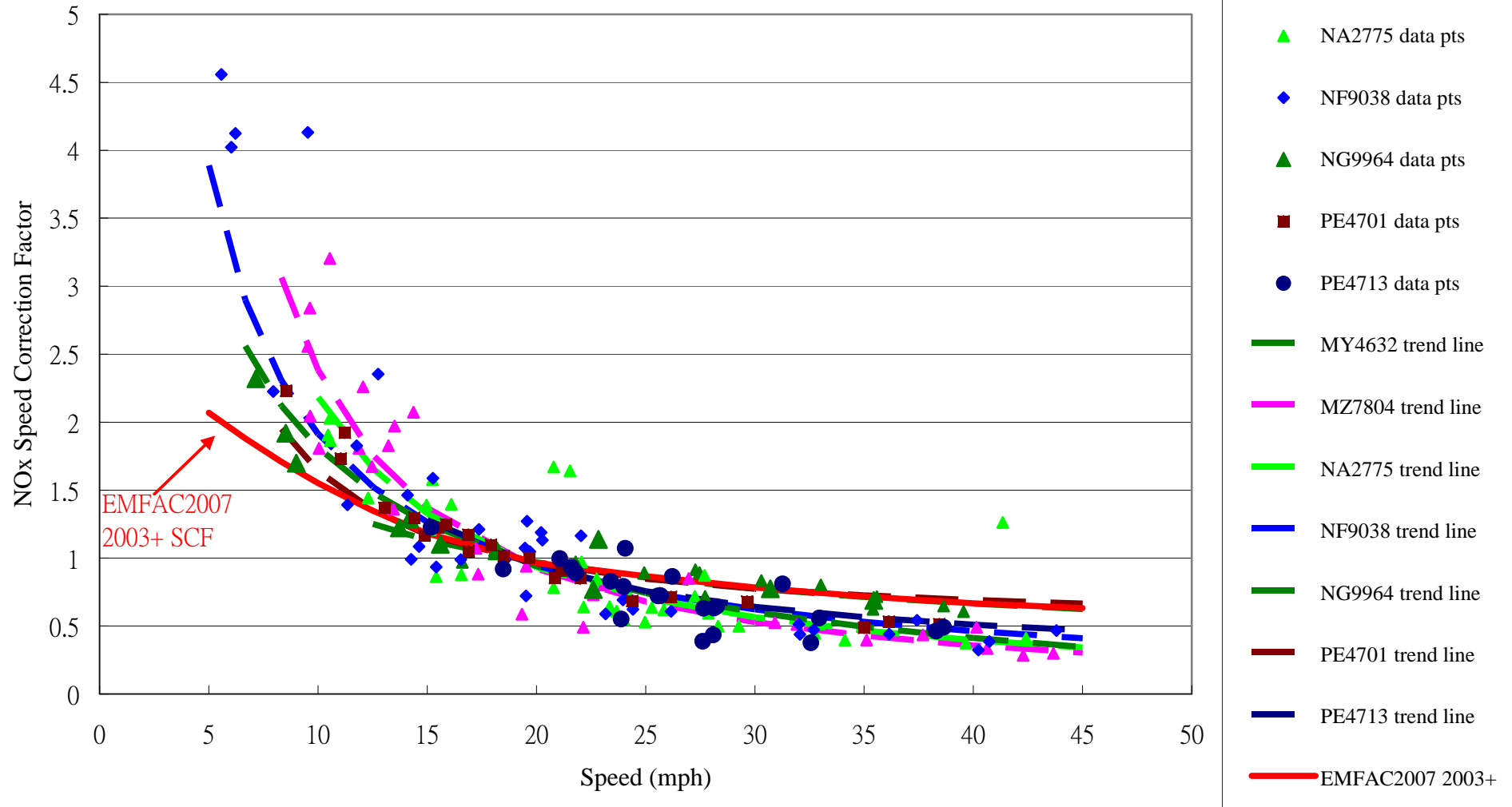
- reference to the emission factors obtained using PEMS data, select zero mile emission factors and deterioration rates in Mobile 5/6, and EMFAC2007
- CO2 emission factors by class is the average of PEMS emission factors over all Euro stds
- If no emission factors for a particular Euro std or vehicle class, estimates are based on the ratio of emission standards and by U.S. conversion factors for different vehicle classes.

NOx emission factors for Euro III Heavy Goods Vehicles of 5.5-15t MOBILE6 Medium-Heavy Duty Trucks 8.85-15t (MHDT) 1998-2003



Comparison of HK dataset with those in EMFAC2007

NOx Speed Correction Factor for Euro IV Single Deck Coaches > 15 tonne

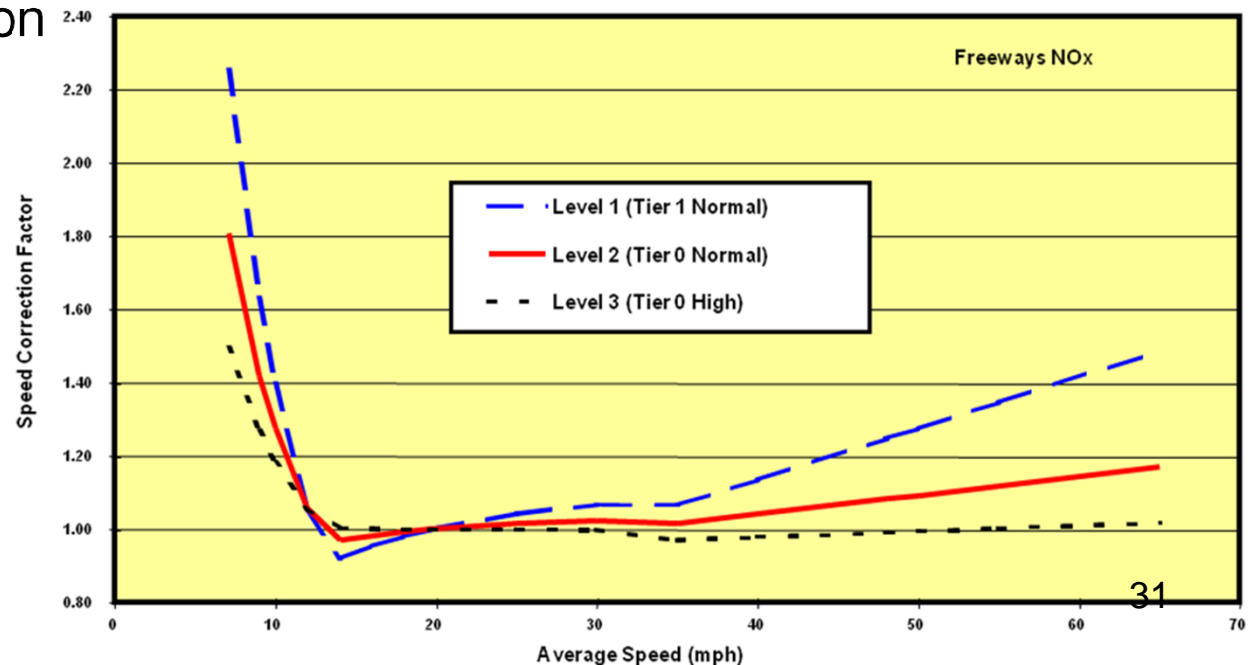


Each data pt is NOx emission factor averaged over 1-hour interval in this case

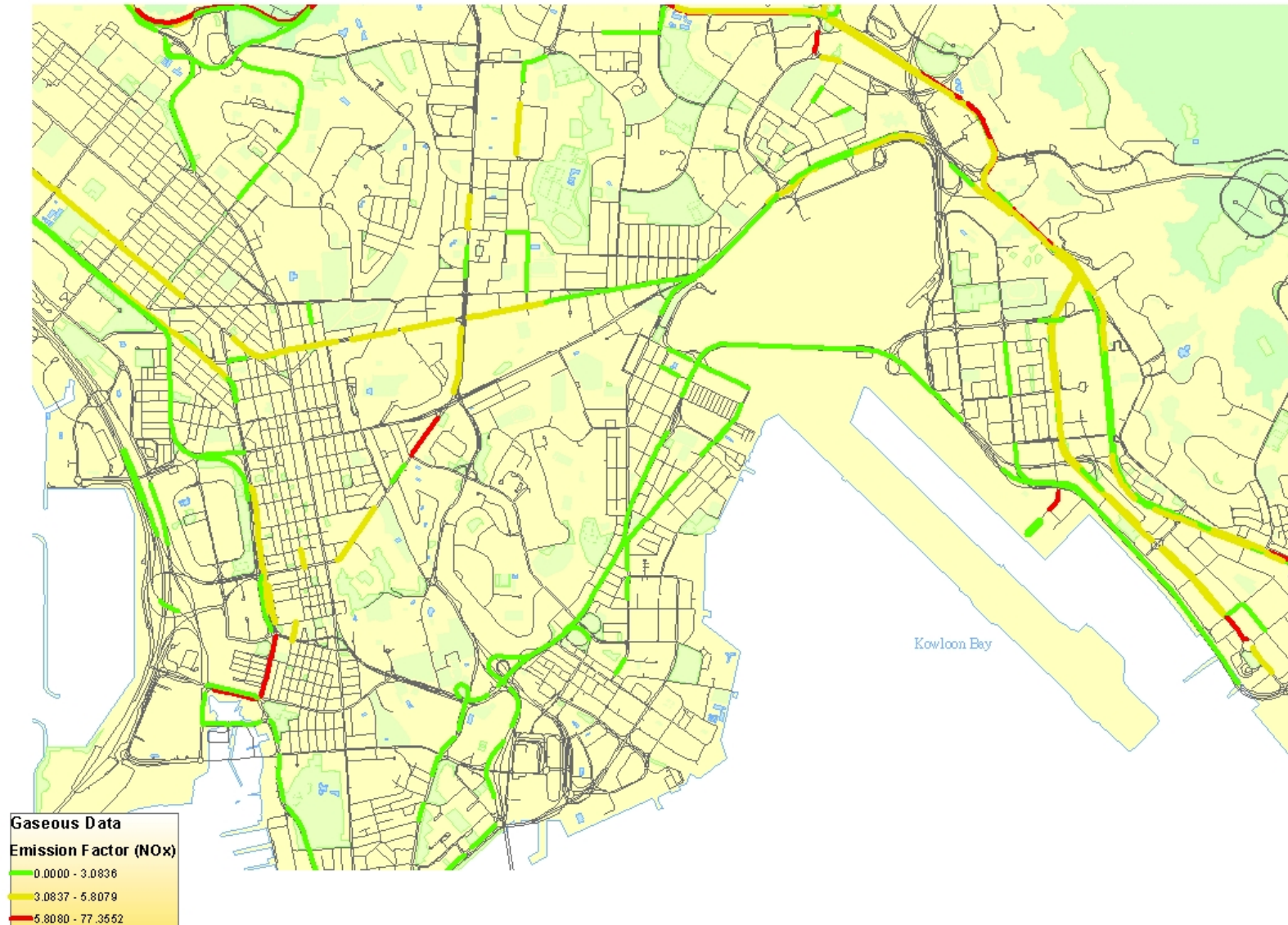
Revise Speed Correction Factors in EMFAC HK Non-VSP Emissions Analysis

- Vehicle speed based analysis
 - Bin trip emissions by vehicle type and average speed over the trip
 - Calculate new speed correction factors based on average emissions over the different trips
 - Compare calculated speed correction factors with previous EMFAC

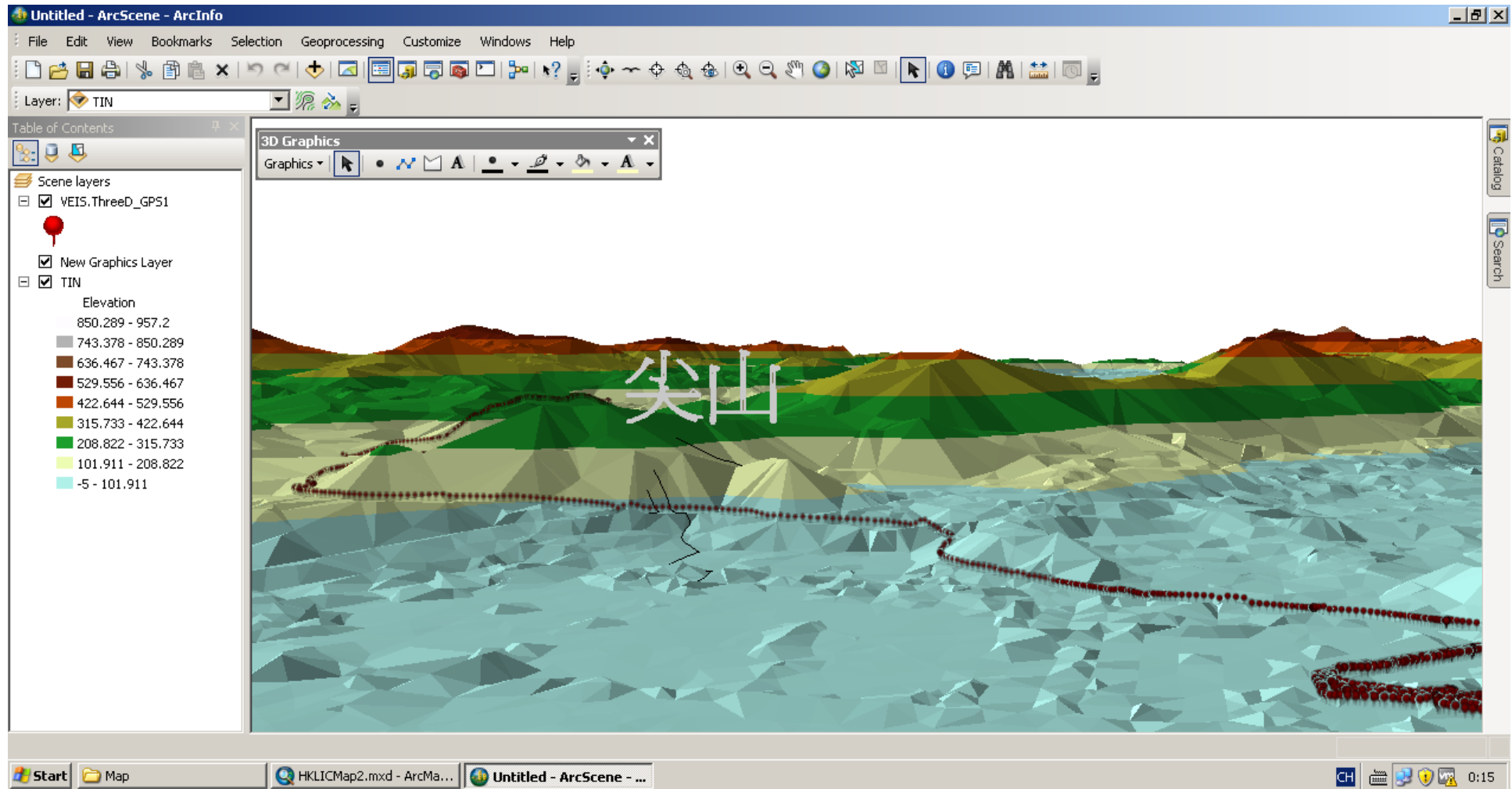
HK speed correction factors for each pollutant



NOx emission factors of the test truck by road type in Kowloon



3D Graphic for Vehicle Trip



Test Vehicle Data

- Information about vehicle mass, rolling resistance, and aerodynamic drag are needed to calculate vehicle specific power (VSP)
- Used vehicle specifications from manufacturers and HK EPD as well as US EPA test data (which include data for setting chassis dynamometers) for similar US-spec vehicles to estimate road loads

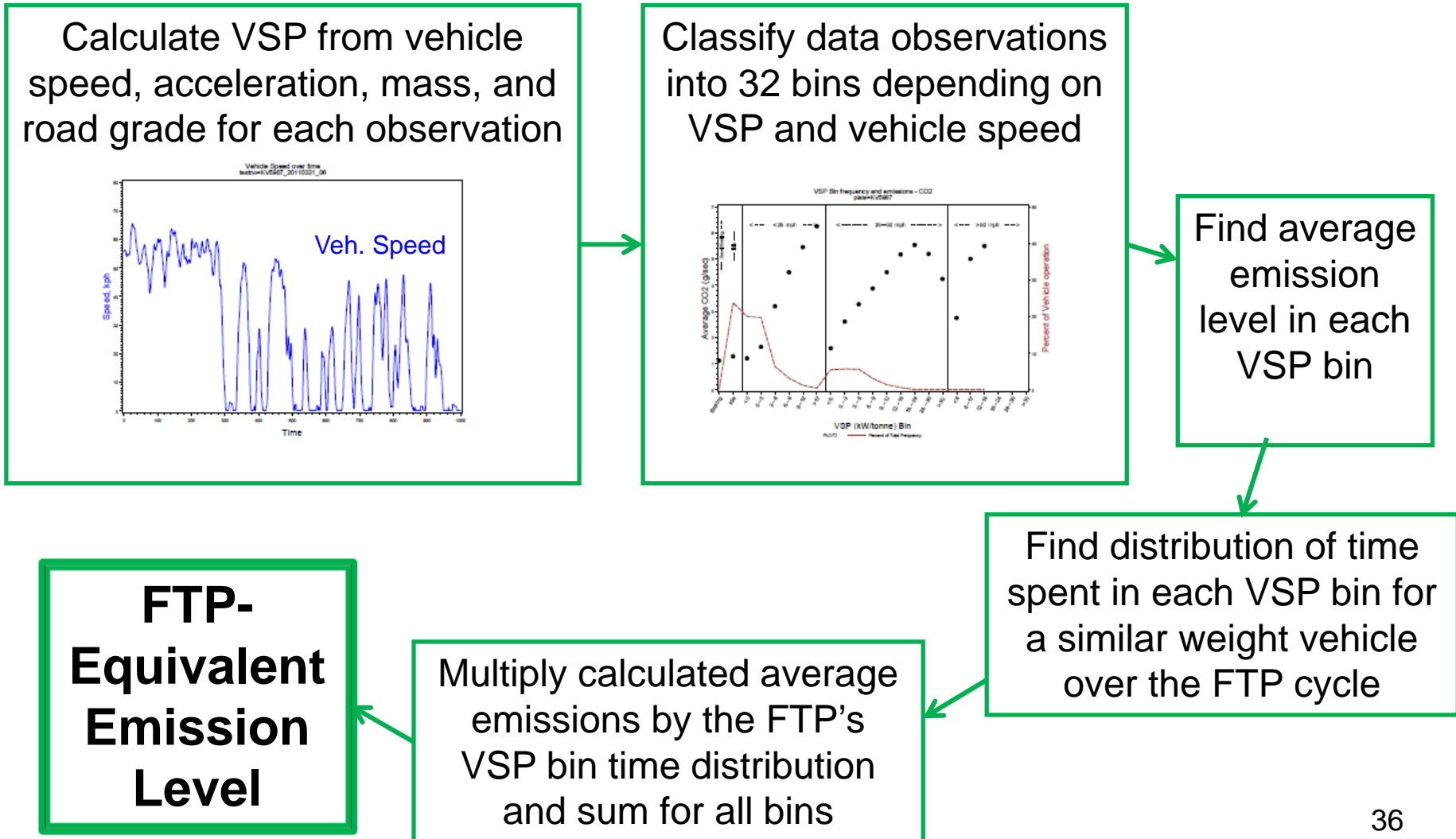
Vehicle Specific Power (kW/ton)

$$VSP_{v,t} = \frac{\overbrace{Av_t + Bv_t^2 + Cv_t^3}^{\text{Road load coefficients}} + \underbrace{mv_t a_t}_{\text{Acceleration term}} + \underbrace{mgv_{\text{vertical}}}_{\text{Grade term}}}{m}$$

- Road load coefficients have units of kiloWatts/(meters/second)^{1,2,or 3}
- Target coefficients for USEPA test vehicles are published by USEPA in lbs/(mph)^{0,1,or 2} for the setting of chassis dynamometers and can be converted for the above equation
- Vehicles older than ~2000 model year typically have only road load horsepower at 50 mph published. For these vehicles, an accepted general road load curve shape can be used in order to get A,B,C coefficients

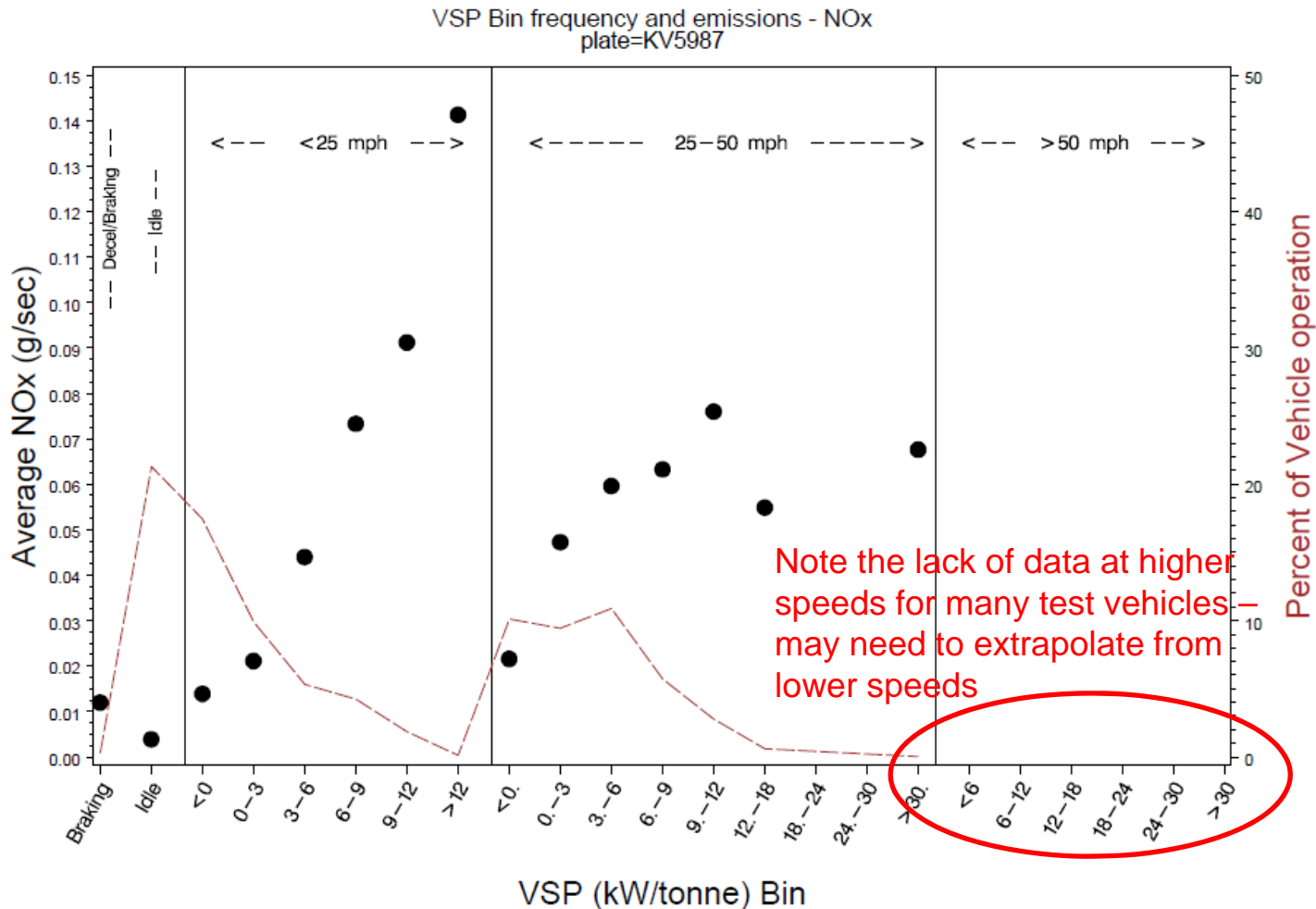
Analysis of Emissions Data by VSP

Method for Estimating FTP-Equivalent Emissions



Using Calculated VSP from Collected Data

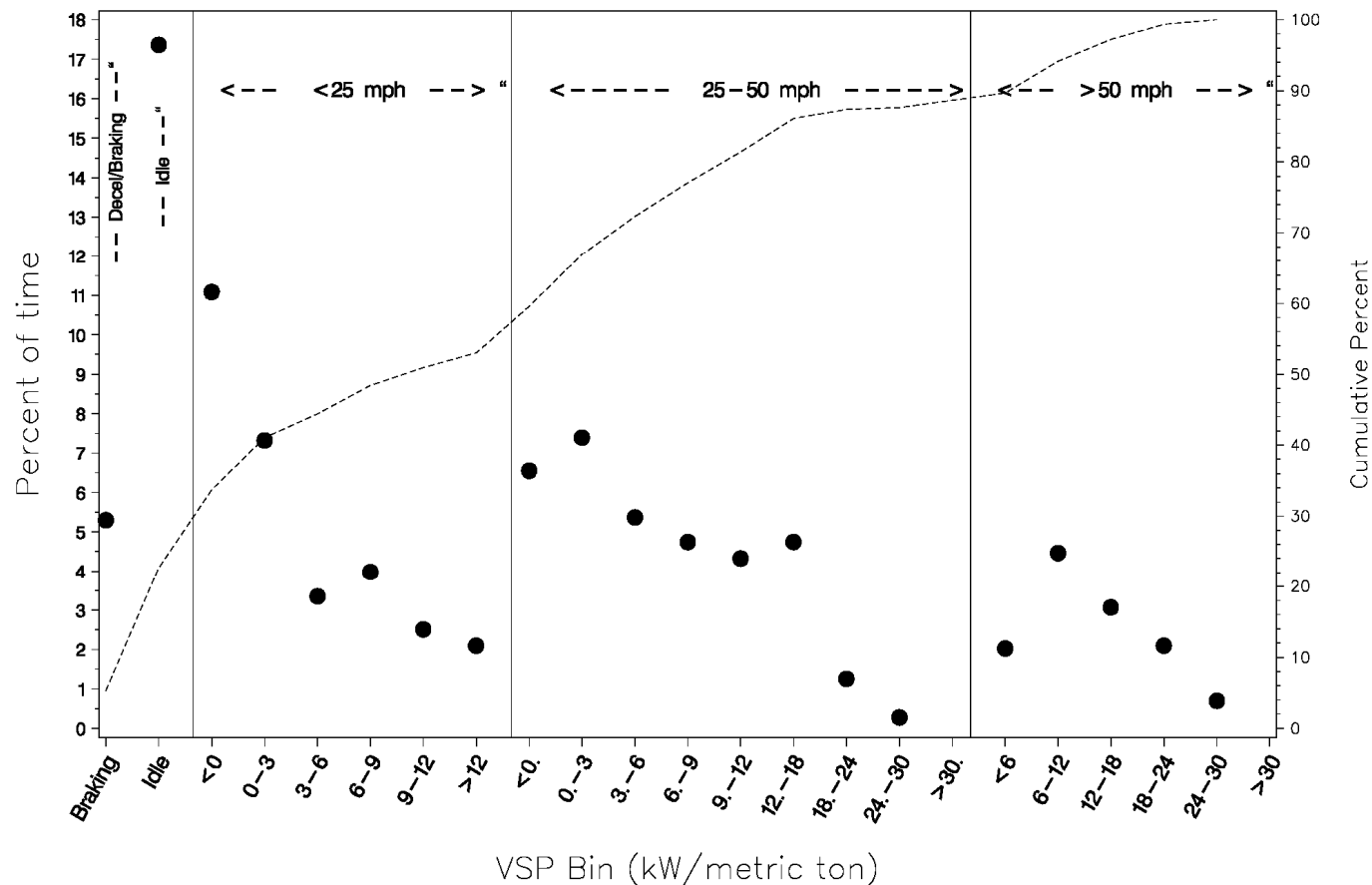
Collected data can be binned by VSP for each second of operation, and emissions can be averaged for each vehicle in each VSP bin



Conversion to FTP-Estimated Emissions

Can calculate VSP bins of operation time for a similar mass vehicle over the FTP cycle

Time Spent by VSP Bin - la92

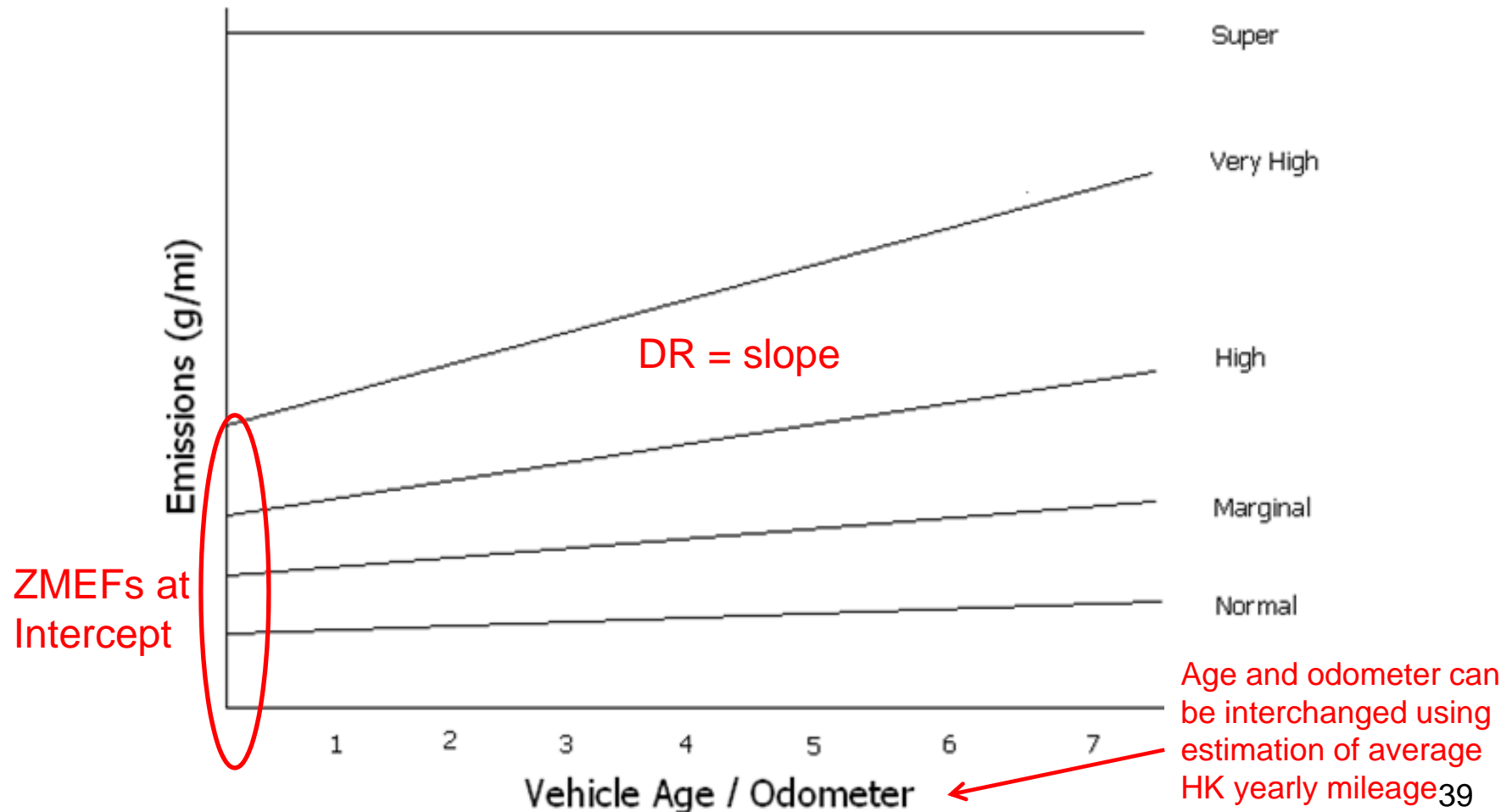


Development of ZMEF and DR

ZMEF – Zero mile emission factor

DR – Deterioration rate

Each line is fitted to FTP equivalent data for a particular emission control system and vehicle type



High Emitter Fractions and Repair Effects

Analysis of Additional, Non-PEMS Data

- analyzed additional data to find high emitter fractions of the HK fleet
 - used data from remote sensing, smoking vehicle, and inspection and maintenance (I/M) programs
- calculated high emitter fractions by age, vehicle type, and technology
 - The goal is to accurately assess and model I/M effectiveness
- Will conduct more detailed analysis

Thank you.

