EMFAC HK Emissions Inventory Model

Training Materials

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What is EMFAC-HK

- Computer model written in FORTRAN which is based on CARB's EMFAC model
- Calculates emission factors (g/km) for a "Fleet Average Vehicle" and total emissions
- Uses for petrol, diesel, LPG, on-road vehicles
- Calculates Emissions for All HK Vehicle Types
- Exhaust and Evaporative Hydrocarbon Emissions (HC)
- Exhaust Carbon Monoxide (CO)
- Exhaust Nitrogen Oxides (NOx)
- PM

Index	Vehicle Class Description	Fuel*	GVW (tonnes)	in executables	in csv output file	in rtl & bcd output files (VEH_Label4)	Symbolic Names (Params.for)
1	Private Cars (PC)	ALL	ALL	Private Cars (PC)	PC	PC	PCP$
2	Placeholder (P1)	--	--	Placeholder (P1)	P1	P1	HKP1$
3	Taxi	ALL	ALL	taxi	taxi	taxi	TAXI$
4	Light Goods Vehicles	ALL	<=2.5t	Light Goods Vehicles<=2.5t	LGV<=2.5t	LGV3	LGV3$
5	Light Goods Vehicles	ALL	>2.5-3.5t	Lt Goods Vehicles2.5-3.5t	LGV2.5-3.5t	LGV4	LGV4$
6	Light Goods Vehicles	ALL	>3.5-5.5t	Light Goods Vehicles>3.5t	LGV>3.5t	LGV6	LGV6$
7	Medium & Heavy Goods Vehicles	ALL	>5.5-15t	Heavy Goods Vehicles<=15t	HGV<=15t	HGV7	HGV7$
8	Medium & Heavy Goods Vehicles	ALL	>15t	Heavy Goods Vehicles >15t	HGV>15t	HGV8	HGV8$
9	Placeholder (P2)	--	--	Placeholder (P2)	P2	P2	HKP2$
10	Placeholder (P3)	--	--	Placeholder (P3)	P3	P3	HKP3$
11	Public Light Buses	ALL	ALL	Public Light Buses	PLB	PLB	PLB$
12	Private Light Buses	ALL	<=3.5t	Private Light Bus<=3.5t	PrLB<=3.5t	PV4	PV4$
13	Private Light Buses	ALL	>3.5t	Private Light Bus>3.5t	PrLB>3.5t	PV5	PV5$
14	Non-franchised Buses	ALL	<=6.36t	Non-franchised Bus<=6.4t	NFB<=6.4t	NFB6	NFB6$
15	Non-franchised Buses	ALL	>6.36-15t	Non-franchised Bus 6.4-15t	NFB6.4-15t	NFB7	NFB7$
16	Non-franchised Buses	ALL	>15t	Non-franchised Bus>15t	NFB>15t	NFB8	NFB8$
17	Single Deck Franchised Buses	ALL	ALL	Franchised Bus(SD)	FBSD	FBSD	FBSD$
18	Double Deck Franchised Buses	ALL	ALL	Franchised Bus(DD)	FBDD	FBDD	FBDD$
19	Motor Cycles	ALL	ALL	Motorcycle (MC)	MC	MC	HKMC$
20	Placeholder (P4)	--	--	Placeholder (P4)	P4	P4	HKP4$
21	Placeholder (P5)	--	--	Placeholder (P5)	P5	P5	HKP5$

What Can the Model Do?

- Analytical Tool that can be applied for Air Quality Planning
- Can be used to estimate emission impacts from:
  - Future Vehicle Fleets
  - Diesel/Alternate Fuel Use
  - Vehicle Speeds
  - Ambient Temperature
  - Fuel RVP/Sulfur content
  - Air Conditions
  - Cold Starts
  - Inspection/Maintenance Programs
  - New Vehicle Standards
  - Other Strategies
    - Evaporative Controls

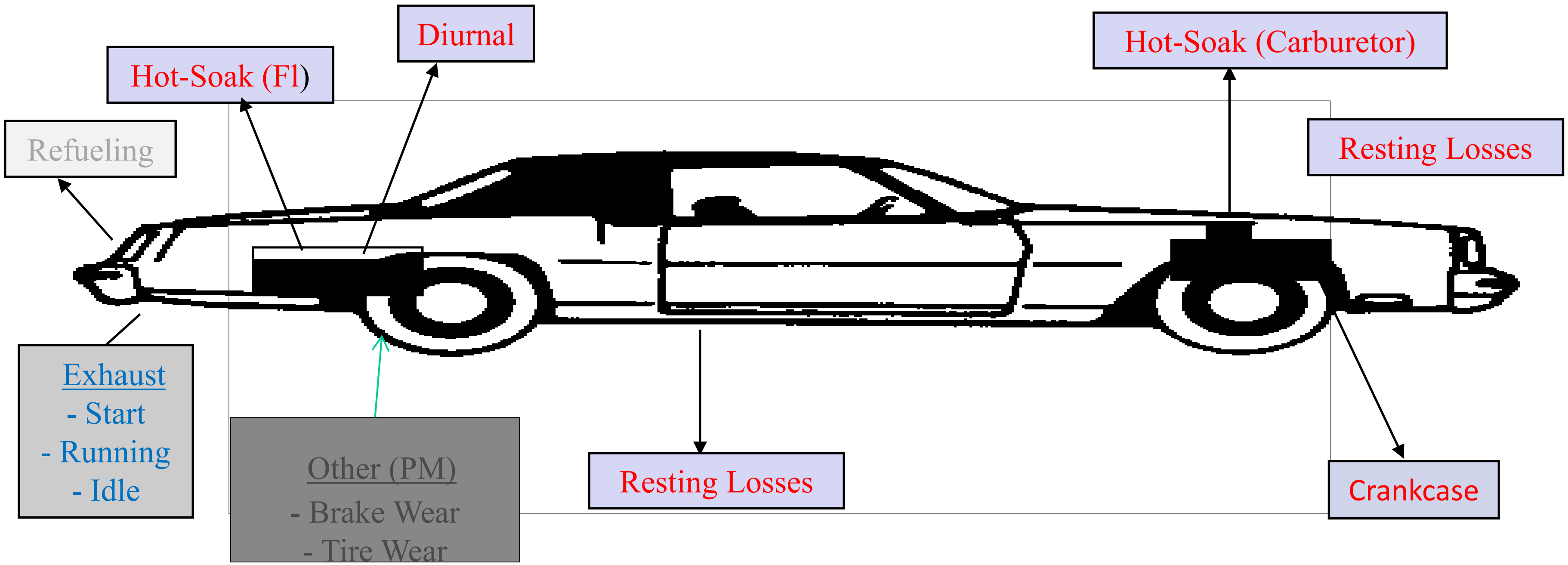
Regulatory Uses of Model

- National Implementation Plan Inventories and Control Strategy Analysis
- Conformity Demonstrations
- Rate of Progress Requirements
- National Inventories
- Rule Development
- Local/fleet-specific analyses
- Setting up of Roadway Network Speed Limits

Vehicle Emissions Data Used for Development of Model

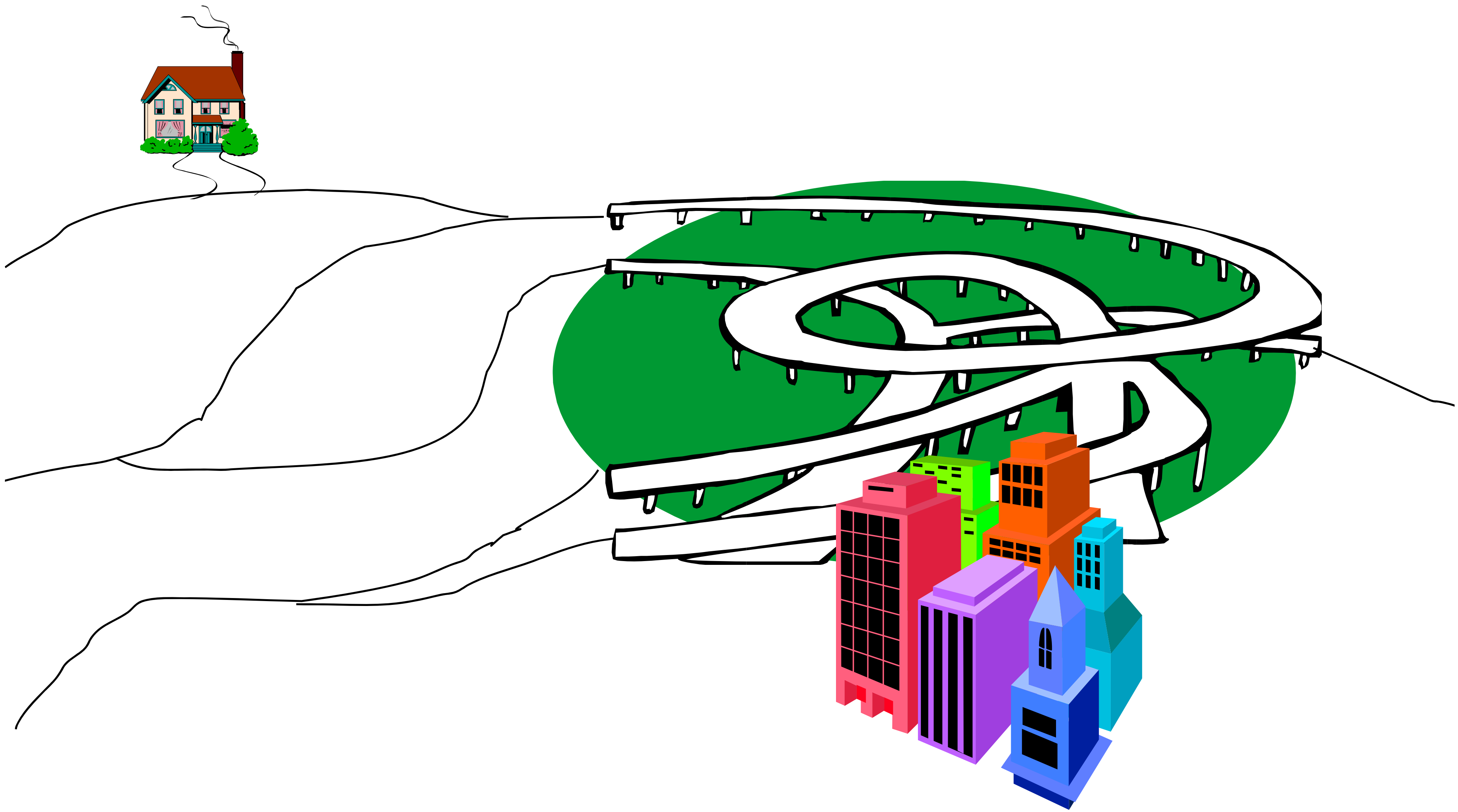
- In-use vehicle emission testing (Dynamometer based) from early 70's to date for EMFAC data
- Vehicles tested primarily on FTP, UC cycle (we'll have a whole session on cycles)
- Other tests conducted using different cycles, temperatures, fuel labs, cold start conditions, mileage, etc.
- Vehicles of various technologies tested in good condition, malfunctioning state, and tampered state
- Developed emission relationships
- Recent use of PEMS data for developing relationships
- I/M and Remote Sensing data can be used to characterize (eg. Emission Regime fractions)

Emissions Processes

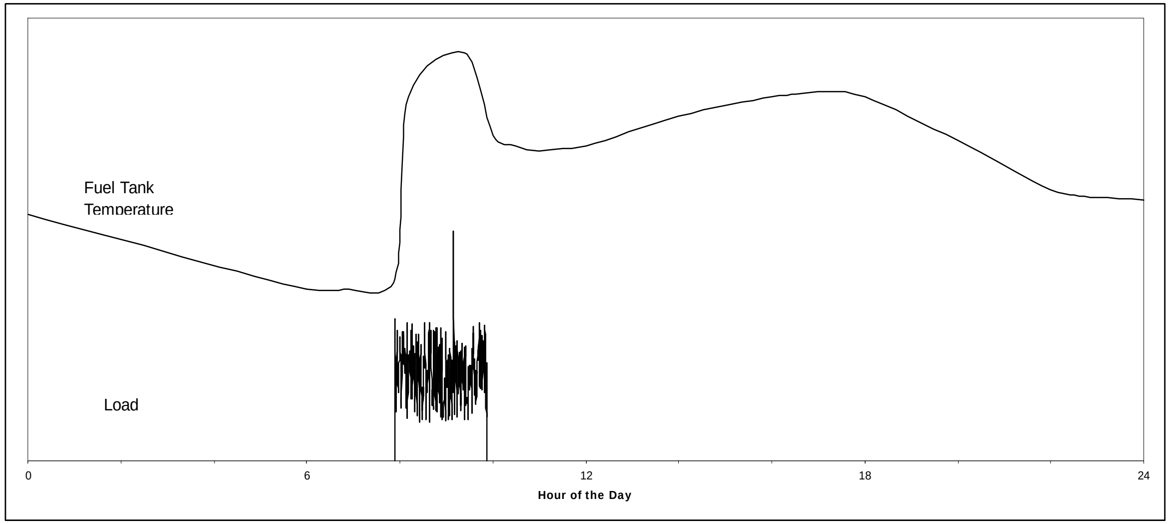


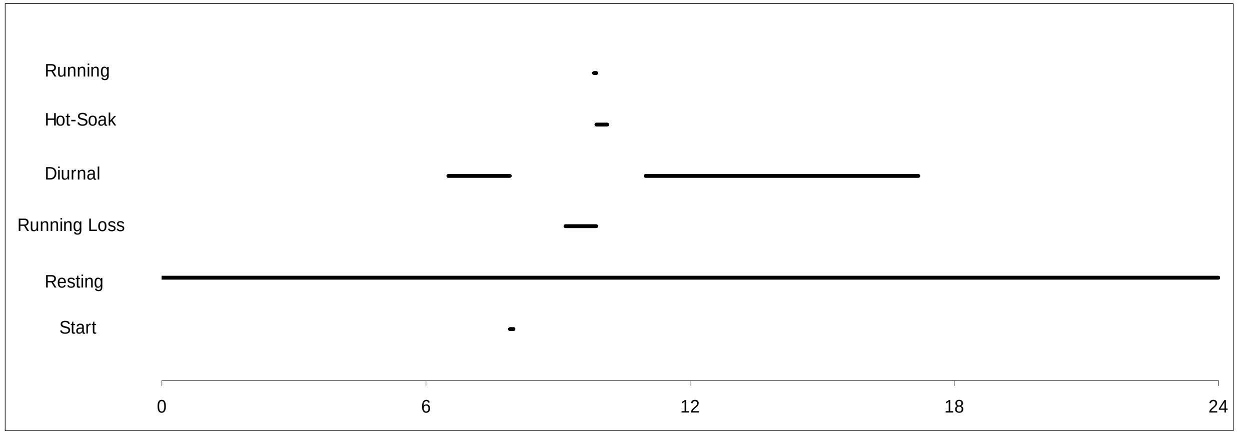
Evap Exhaust

Are you aware of your driving/emissions?



When Do Emissions Occur?





Calculation Methodology

Main Exhaust Calculations

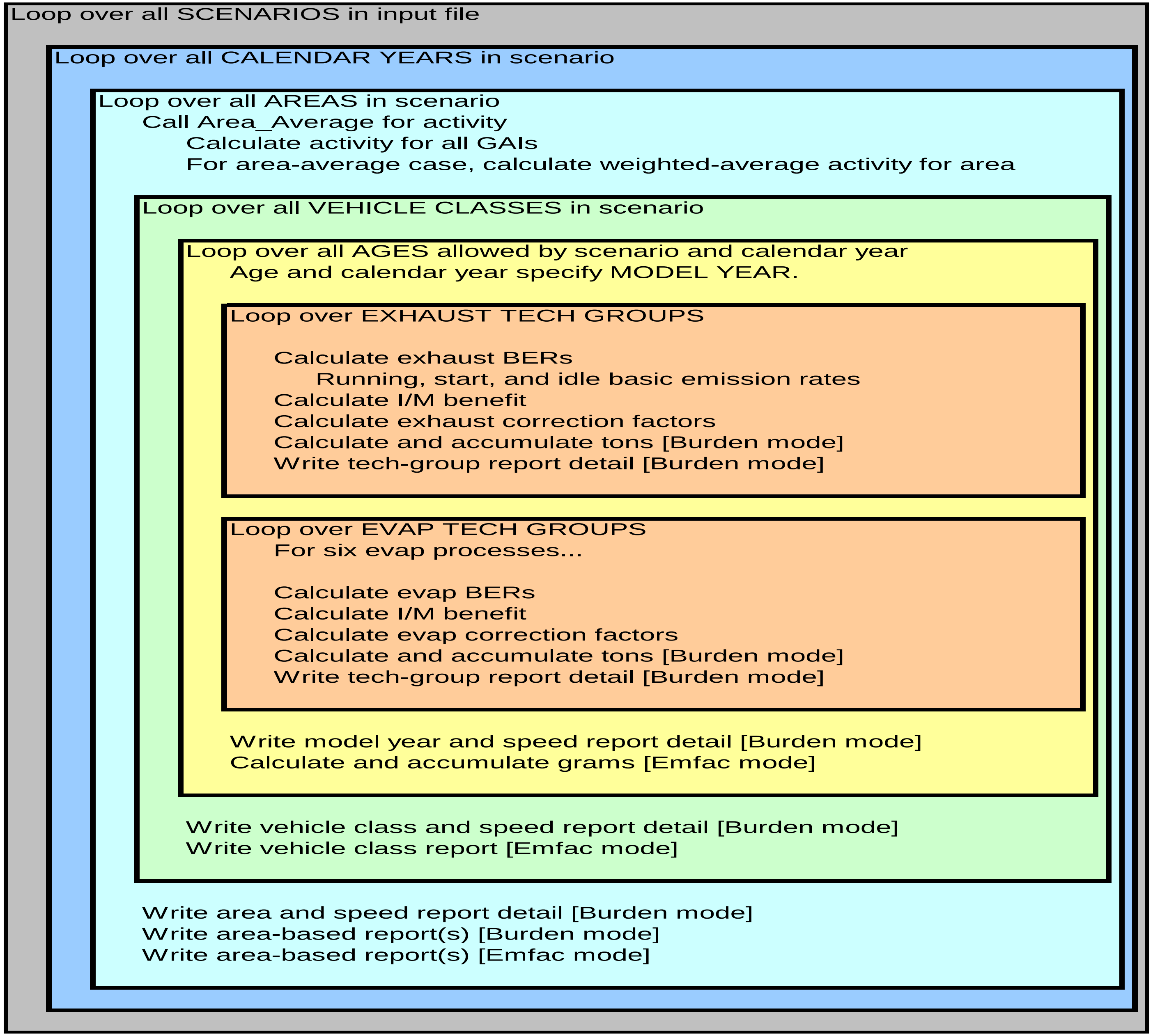
Primary Groups

Technology/Emission Status	Many groups
Emissions Status	Super/ High/Normal
Emissions Type	Start/Running/idle/Evap

2-Step Process

Emissions Calculations; and

Activity Matrices


Loop over all SCENARIOS in input file
Loop over all CALENDAR YEARS in scenario
Loop over all AREAS in scenario
Call Area_Average for activity
Calculate activity for all GAIs
For area-average case, calculate weighted-average activity for area
Loop over all VEHICLE CLASSES in scenario
Loop over all AGES allowed by scenario and calendar year
Age and calendar year specify MODEL YEAR.
Loop over EXHAUST TECH GROUPS
Calculate exhaust BERs
Running, start, and idle basic emission rates
Calculate I/M benefit
Calculate exhaust correction factors
Calculate and accumulate tons [Burden mode]
Write tech-group report detail [Burden mode]
Loop over EVAP TECH GROUPS
For six evap processes...
Calculate evap BERs
Calculate I/M benefit
Calculate evap correction factors
Calculate and accumulate tons [Burden mode]
Write tech-group report detail [Burden mode]
Write model year and speed report detail [Burden mode]
Calculate and accumulate grams [Emfac mode]
Write vehicle class and speed report detail [Burden mode]
Write vehicle class report [Emfac mode]
Write area and speed report detail [Burden mode]
Write area-based report(s) [Burden mode]
Write area-based report(s) [Emfac mode]

Exhaust Calculations

- For Each Calendar Year and Vehicle Type
  - Calculate emissions (each Pollutant) for each Age
    - Call Exhaust
    - *Call I and M- Handled in a special way for HK*
    - Call Correction Factors
  - Combine emissions for all Ages

Exhaust Calculations

Exhaust subroutine

- Each Age is associated with a particular Model year
- In each model year there are few technology groups assigned (TF_EX_Assign)
- For each technology groups
  - Estimate emitter category Regime Fraction
  - Estimate emitter category Regime Emissions

Technology Group Assignment

- Vehicle TYPE- PC
  - Model Year =1995
    - FRAC (tech group-1 Non Cat) =0.1%
    - FRAC (tech group-8 Three way Catalyst Carb) =37.4%
    - FRAC (tech group-31 Three way Catalyst FI) =62.1%

Emitter Category-

Regime Fractions

- For each Age and Vehicle type the odometer is assigned
- Regime Size Calculated for Super, High, and Normal Emitters
- Regime Size is calculated as (data in Reg_Size):

$$RegSize = A + B * Odo + C * Odo^{2} + D * \sqrt{(Odo)}$$

Exhaust Calculations
Emitter Category Emissions

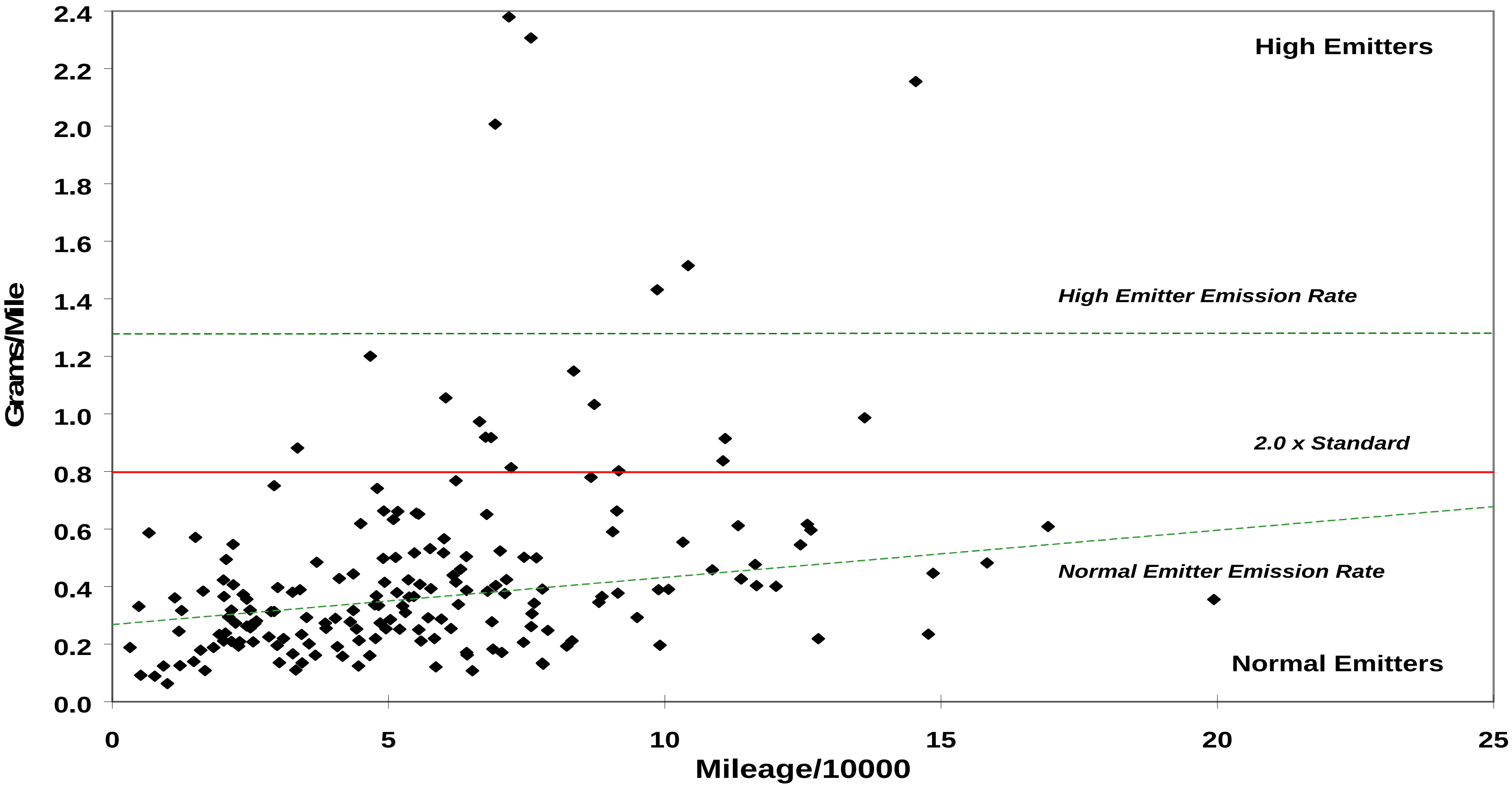
- For Each Myr, Age, Tech group :

$$E_{emit\_cat} = E_{zero} + Det\_rate * Odo$$

$$E_{emit\_cat} = f\ (poll, mode, tech\ group)$$

Data included in BER_Data

NO_x: Tier 1 LDVs



Exhaust Emissions

Tech Group/ Model Year Emissions
For Each Pollutant – Before I/M

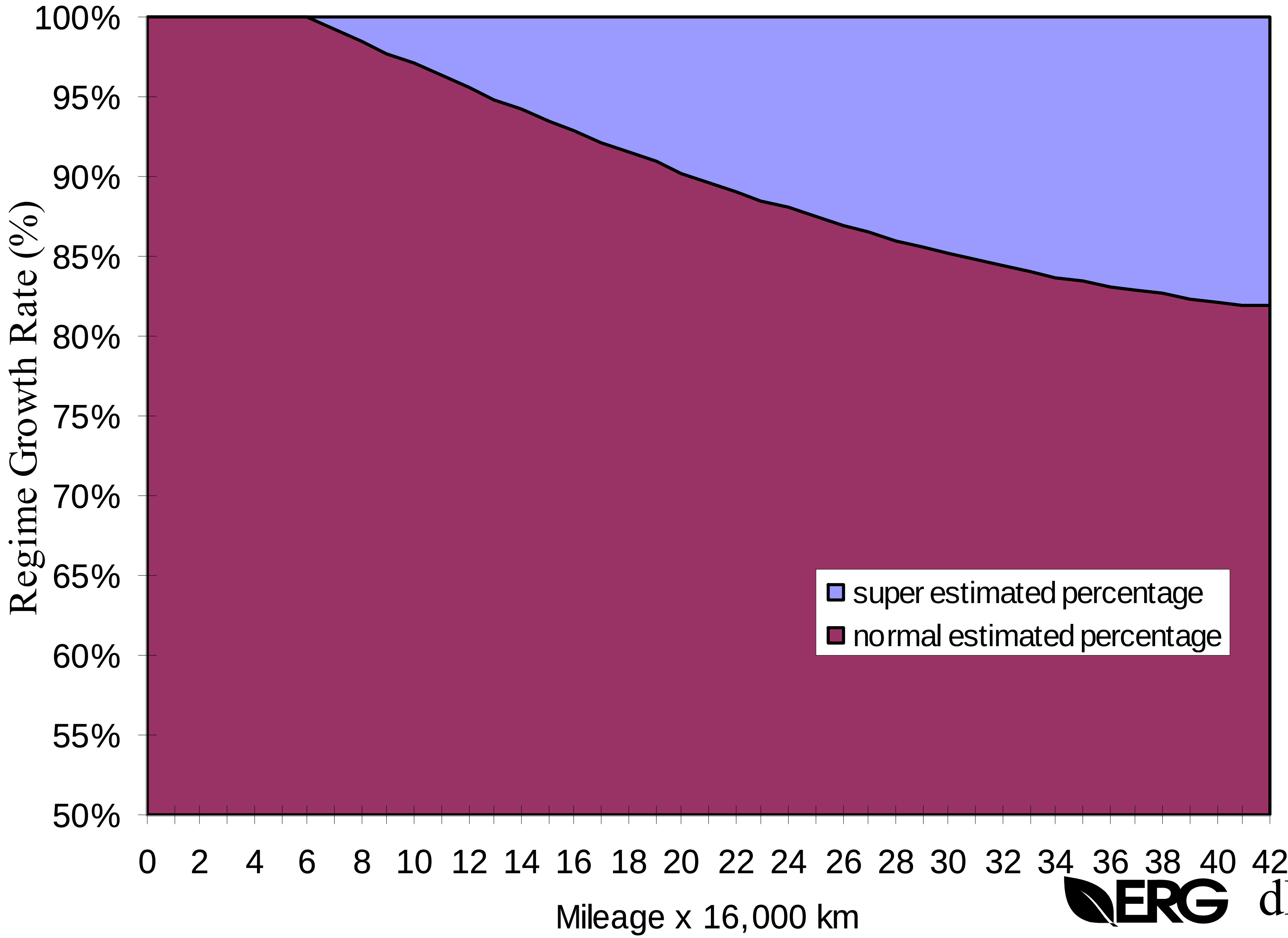
$$E_{tech\_group} = E_{super} * RegSize_{super} + E_{high} * RegSize_{high} + E_{normal} * RegSize_{normal}$$

$$E_{model\_year} = \sum E_{tech\_group}(my, tg) * Tech\_Frac\ (my)$$

Gross Emitter Model for Diesel Vehicles in Hong Kong

- Diesel vehicles were subdivided into 2 regimes:
  - normal & super
- The percentages of super emitters are estimated from annual smoky vehicle number

Regime Growth Rates for Heavy Goods Vehicles in 2001



ERG dKC

Exhaust Emissions
Calculation of Calendar Emission Rates

$$E_{cal\_year} = \sum E_{model\_year}(my) * \text{travel fraction (age)}$$

Where,

$$\text{Travel fraction} = \text{reg fraction (age)} * \text{annual miles (age)} / \sum \text{reg fraction} * \text{annual miles}$$

LDGV Model Year Specific Emission Rates for Calendar Year 2005							
						Model Year Emission Rates (g/mi)	
Model Year	Age	REG_dist	Annual MILES	REG*MILES	Travel Fraction	VOC	NOx
2005	0	0.053	40.853	2.169	0.0803	0.156	0.105
2004	1	0.071	39.341	2.781	0.1030	0.177	0.207
2003	2	0.071	37.400	2.644	0.0979	0.215	0.327
2002	3	0.071	35.555	2.510	0.0929	0.276	0.475
2001	4	0.070	33.801	2.380	0.0881	0.333	0.618
2000	5	0.070	32.133	2.246	0.0831	0.575	0.833
1999	6	0.069	30.548	2.108	0.0780	0.677	0.934
1998	7	0.068	29.041	1.966	0.0728	0.859	1.031
1997	8	0.066	27.608	1.811	0.0670	1.198	1.118
1996	9	0.063	26.246	1.648	0.0610	1.504	1.205
1995	10	0.059	24.950	1.470	0.0544	2.213	1.374
1994	11	0.054	23.720	1.281	0.0474	2.650	1.638
1993	12	0.046	22.549	1.035	0.0383	3.126	1.925
1992	13	0.036	21.436	0.778	0.0288	3.595	2.007
1991	14	0.029	20.378	0.587	0.0217	4.062	2.109
1990	15	0.023	19.373	0.442	0.0164	4.604	2.191
1989	16	0.018	18.418	0.333	0.0123	5.153	2.263
1988	17	0.014	17.509	0.252	0.0093	5.588	2.366
1987	18	0.011	16.645	0.190	0.0070	6.675	2.690
1986	19	0.009	15.824	0.142	0.0053	7.172	2.739
1985	20	0.007	15.043	0.107	0.0040	8.373	3.001
1984	21	0.006	14.300	0.080	0.0030	8.873	3.080
1983	22	0.004	13.595	0.060	0.0022	9.396	3.147
1982	23	0.003	12.923	0.044	0.0016	10.219	3.242
1981	24	0.010	12.287	0.118	0.0044	10.606	3.293
				Calendar Emission Rate:		**1.419**	**1.022**

Vehicle Mileage Surveys

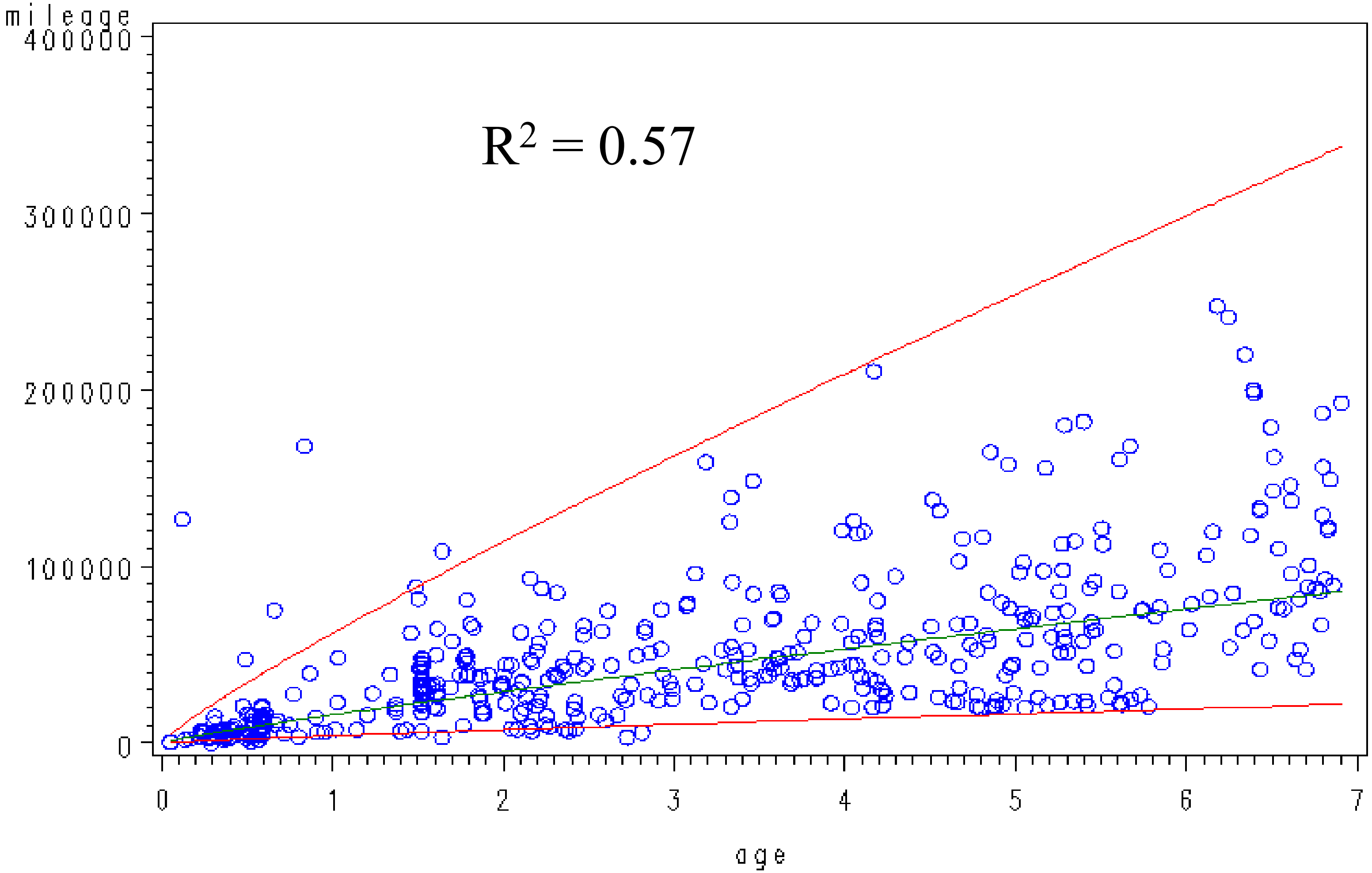
The sources included:

- Surveys conducted at petrol filling stations, car parks, and vehicle examination centres.
- Data provided by franchised bus companies.

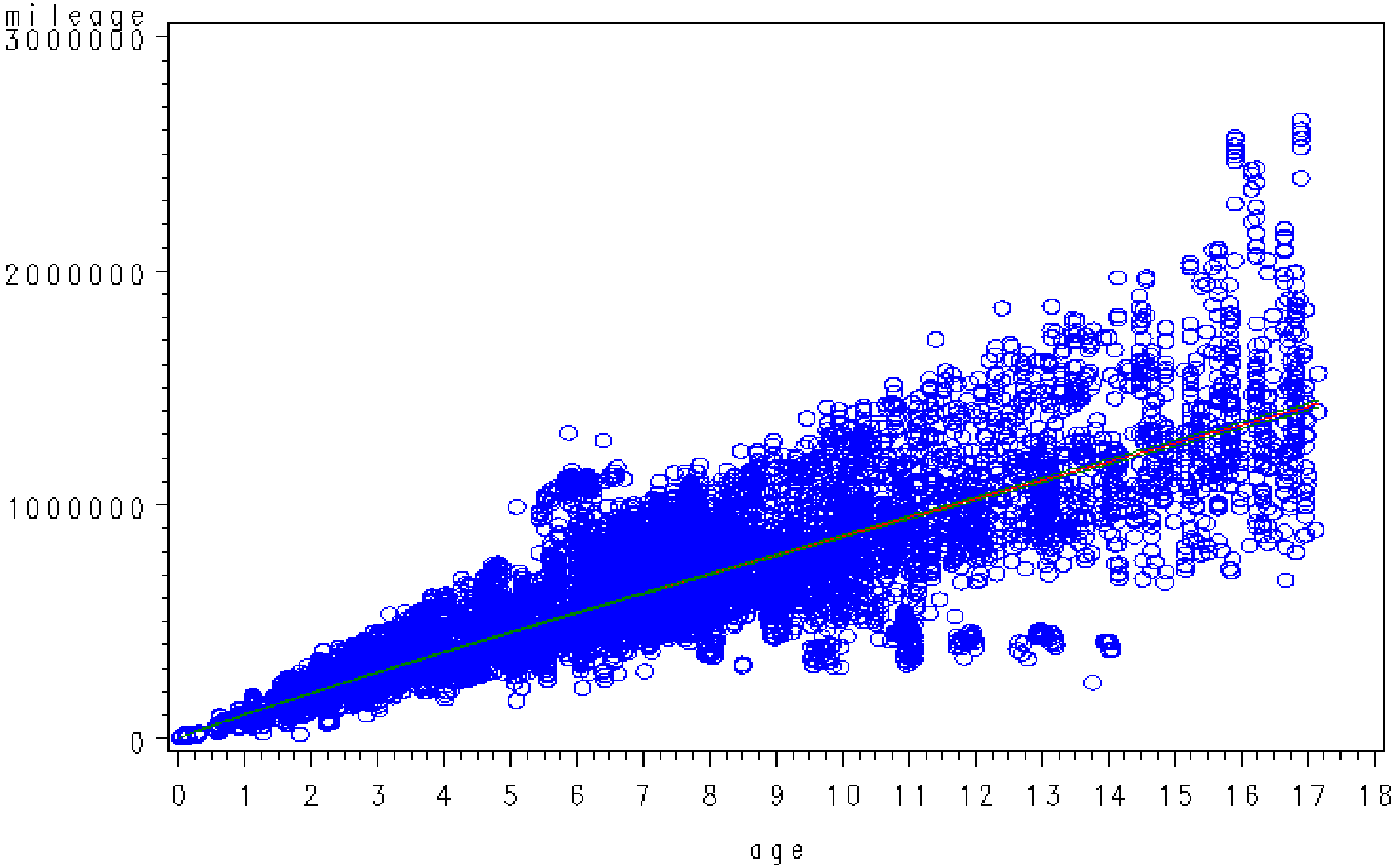
Analysis:

- Screen out those with too low mileage for certain age for commercial vehicles.
- Estimates the relationship between accrual rates and age using PROC REG or PROC NLIN in SAS for the variation of vehicle mileage and age.

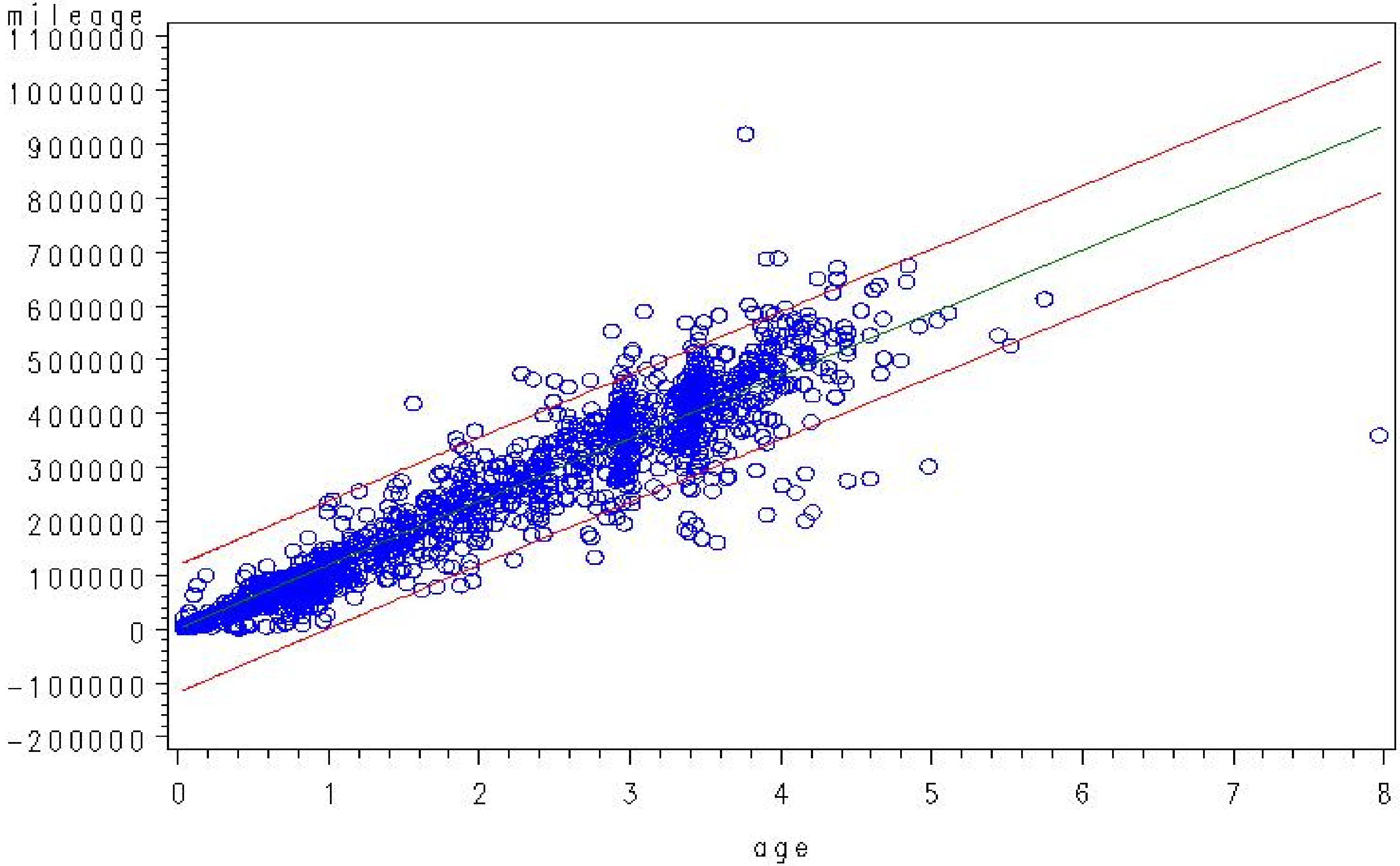
Distribution of Odometer Reading vs. Age for Private Petrol Cars



Distribution of Odometer Reading vs. Age for Large Buses



Distribution of Odometer Reading vs. Age for Taxis

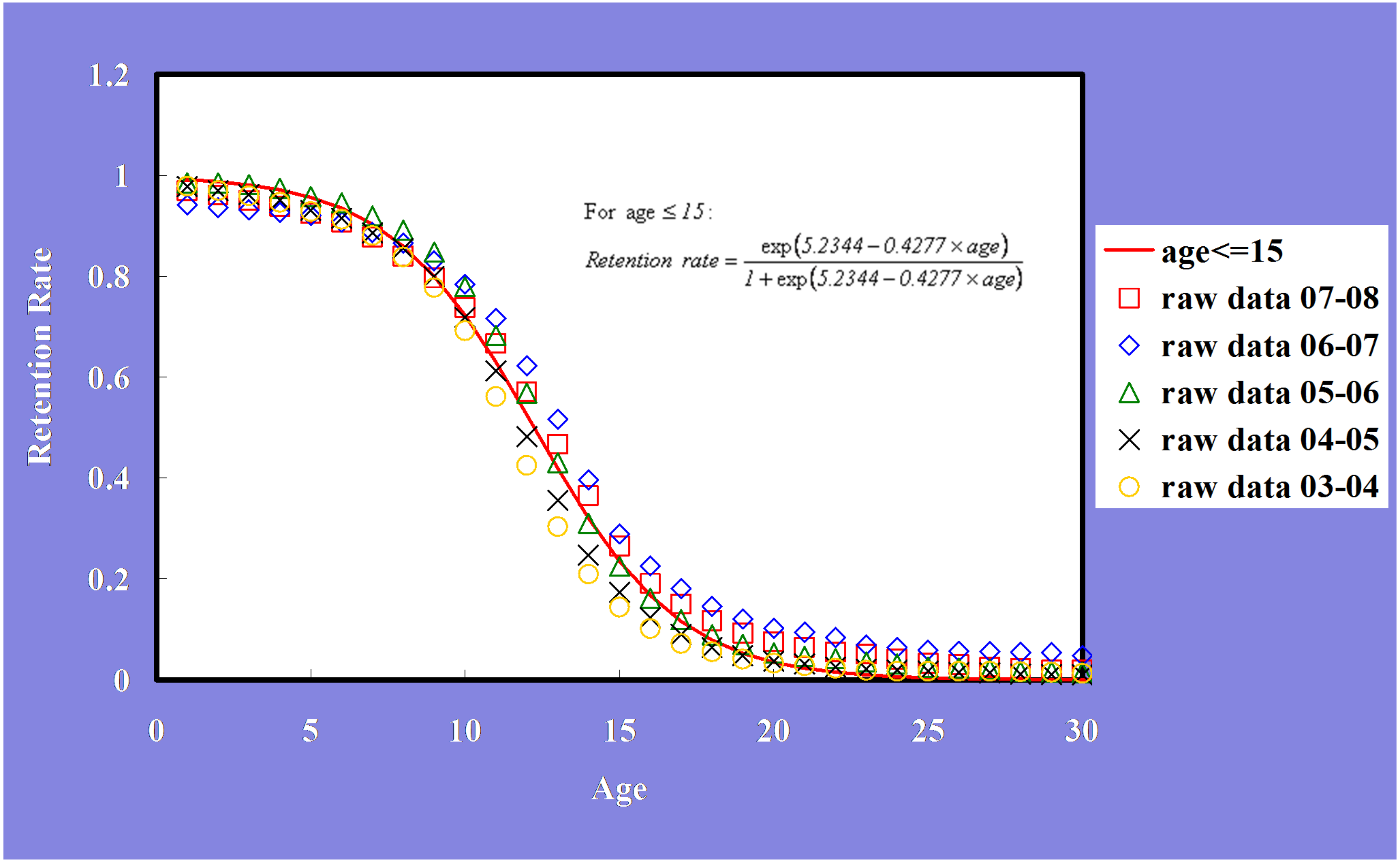


Forecast of Vehicle Population

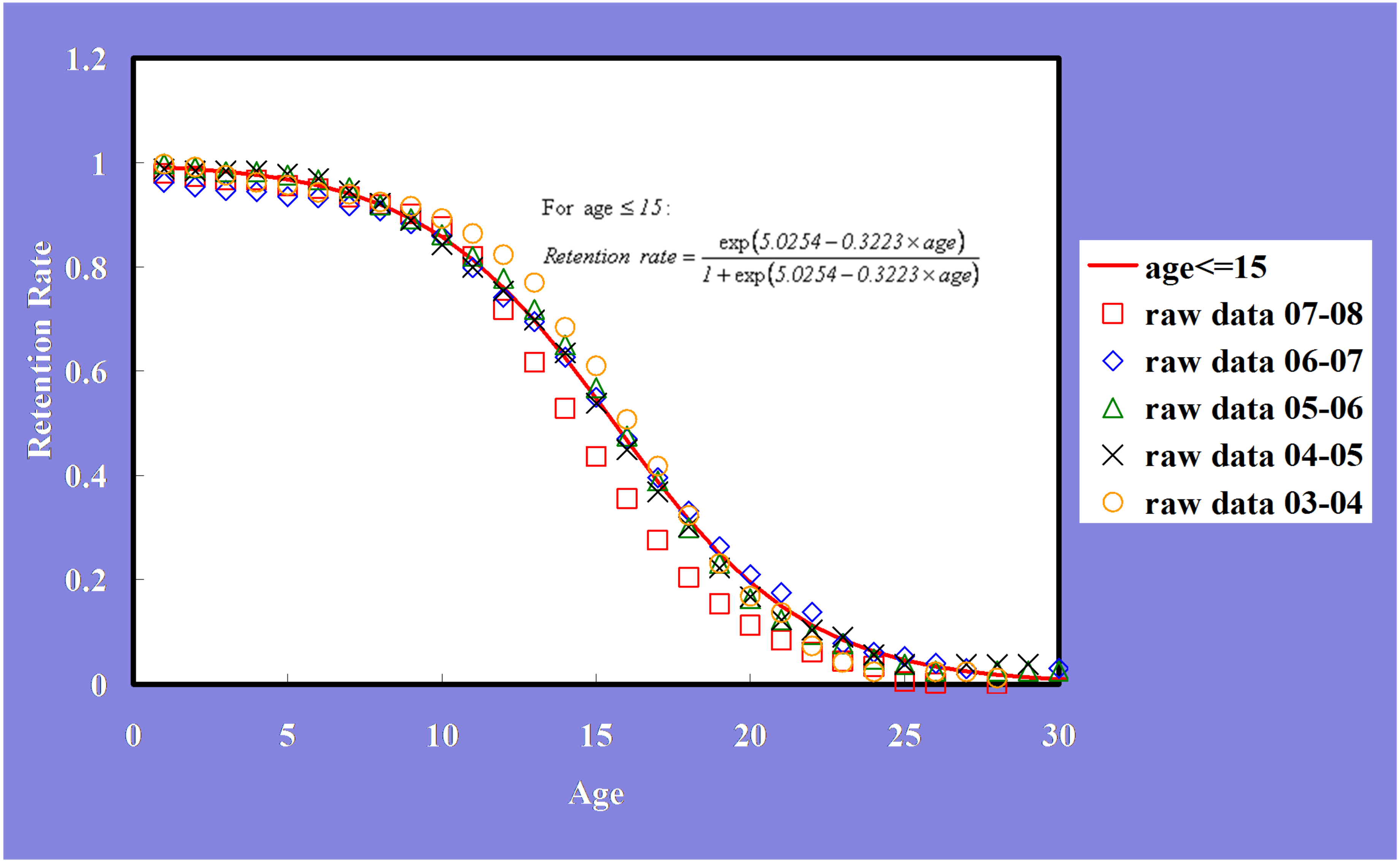
- EMFAC uses the population of a specific model of vehicles for consecutive calendar years to derive a variation curve of the percentage of vehicles sold still remain in the fleet after a specified amount of time has elapsed – retention rate. The curve is then used to forecast vehicle population.
- Retention rates is used in EMFAC for both forecasting to future calendar years and back-casting for those years where vehicle registration information is unavailable.

Distribution of Goods Vehicles > 15 t Population vs. 1st Reg. Year

Retention Rates for Private Cars



Retention Rates for Heavy-duty Goods Vehicles



Exhaust I/M calculations for EPD EMFAC HK-IM Version

- I/M only causes the regime size fractions to change
- Emissions changes are caused as vehicles deteriorate at a lower level
- The emissions levels of emissions regimes doesn’t change- only regime size changes
- After I/M the fraction of high emitters is lower

Exhaust Calculations
After IM
Emitter Category Emissions

- For Each Myr, Age, Tech group :

$$E_{emit\_cat\text{-}HK\text{-}POST\text{-}IM} = E_{zero\ (HK\text{-}POST\text{-}IM)} + Det\_rate_{\ (HK\text{-}POST\_IM)} * Odo$$

$$E_{emit\_cat\text{-}HK\text{-}POST\text{-}IM} = f\ (\text{poll, mode, tech group})$$

Data developed by HK EPD

Exhaust Emissions

Tech Group/ Model Year Emissions For Each Pollutant – After I/M

$$E_{tech\_group\_post\_IM} = E_{super} * RegSize_{super\_post\_IM} + E_{high} * RegSize_{high\_post\_IM} + E_{normal} * RegSize_{normal\_post\_IM}$$

$$E_{model\_year\ \_post\_IM} = \sum E_{tech\_group\_post\_IM}(my, tg) * Tech\_Frac(my)$$

Exhaust Emissions
Calculation of Calendar Emission Rates
After I/M

$$E_{cal\_year\_post\_IM} = \sum E_{model\_year\_post\_IM}(my) * \text{travel fraction (age)}$$

Where,

$$\text{Travel fraction} = \frac{\text{reg fraction (age)} * \text{annual miles (age)}}{\sum \text{reg fraction} * \text{annual miles}}$$

Exhaust Correction Factors

- Calculate each of the correction factors
- Call ExhCF_Cycle()
- Call ExhCF_Altitude()
- Call ExhCF_Load()
- Call ExhCF_Speed()
- Call ExhCF_Temperature()
- Call ExhCF_NOx()
- Call ExhCF_AC()
- Call ExhCF_Fuel()
- Call ExhCF_HighIdle()
- ! Combine them into AllCF

- Call ExhCF_Finalize()

Cycle Correction Factors

- Applied only to FTP Bag 2
- Develop corrections for Running Exhaust Emissions
- Only for HC CO Nox

Speed Correction Factor

Speed correction Factors are calculated on the emission by speed bin

For each speed bin by area (time spent in each spped bin 2.5-87.5 by

SCFactor = 0.0

+ SCF%Coefs(1) * (Speed - SAdj)

+ SCF%Coefs(2) * (Speed - SAdj)**2

+ SCF%Coefs(3) * (Speed - SAdj)**3

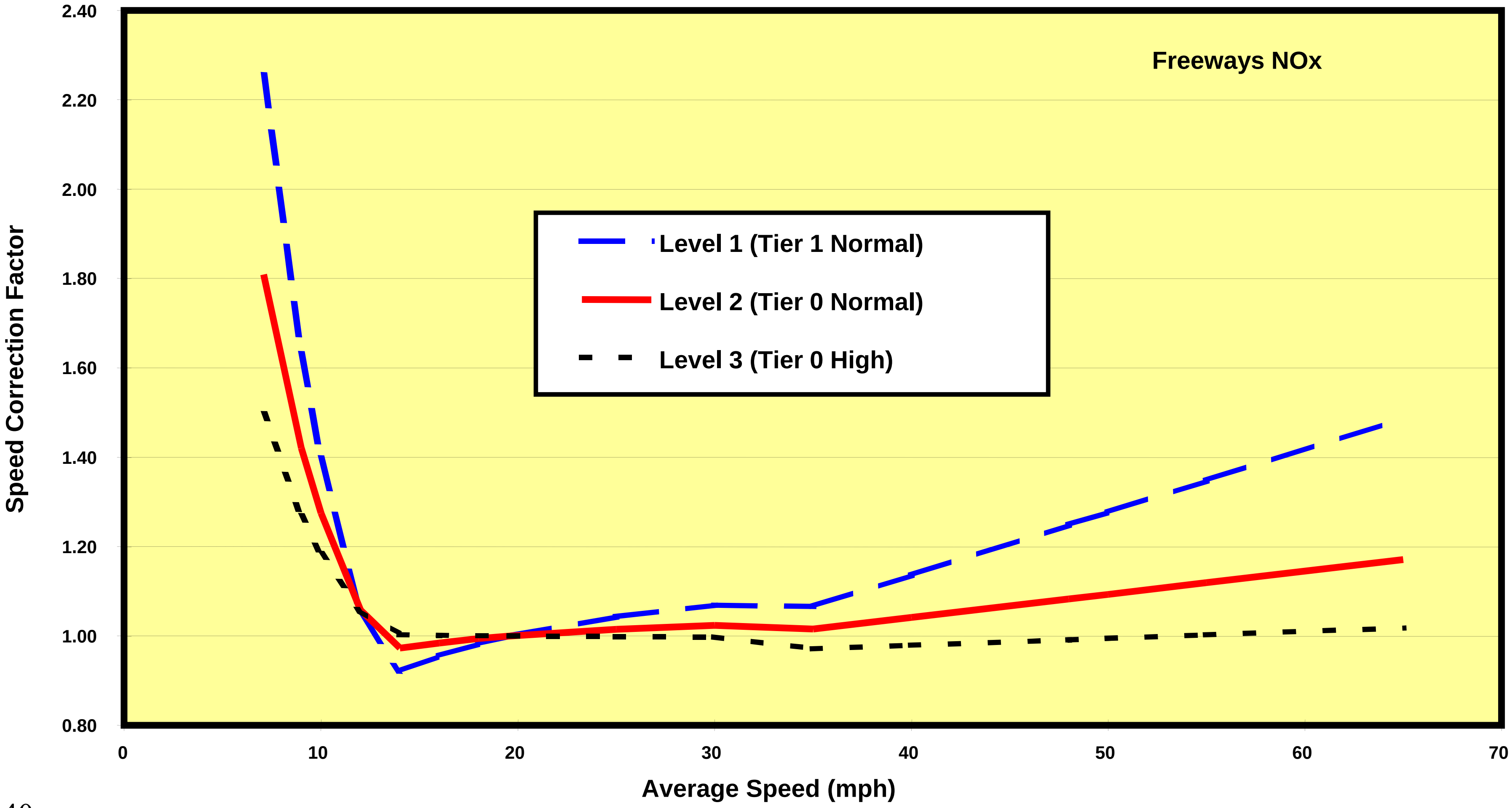
+ SCF%Coefs(4) * (Speed - SAdj)**4

AvgSCF = Time spent in each bin by area* SCFactors

Calculation of Speed Correction Factors

$$SCF_{speed} = \frac{Emissions_{speed}}{Emission_{ref\ mph}}$$

Example Speed Correction Factors

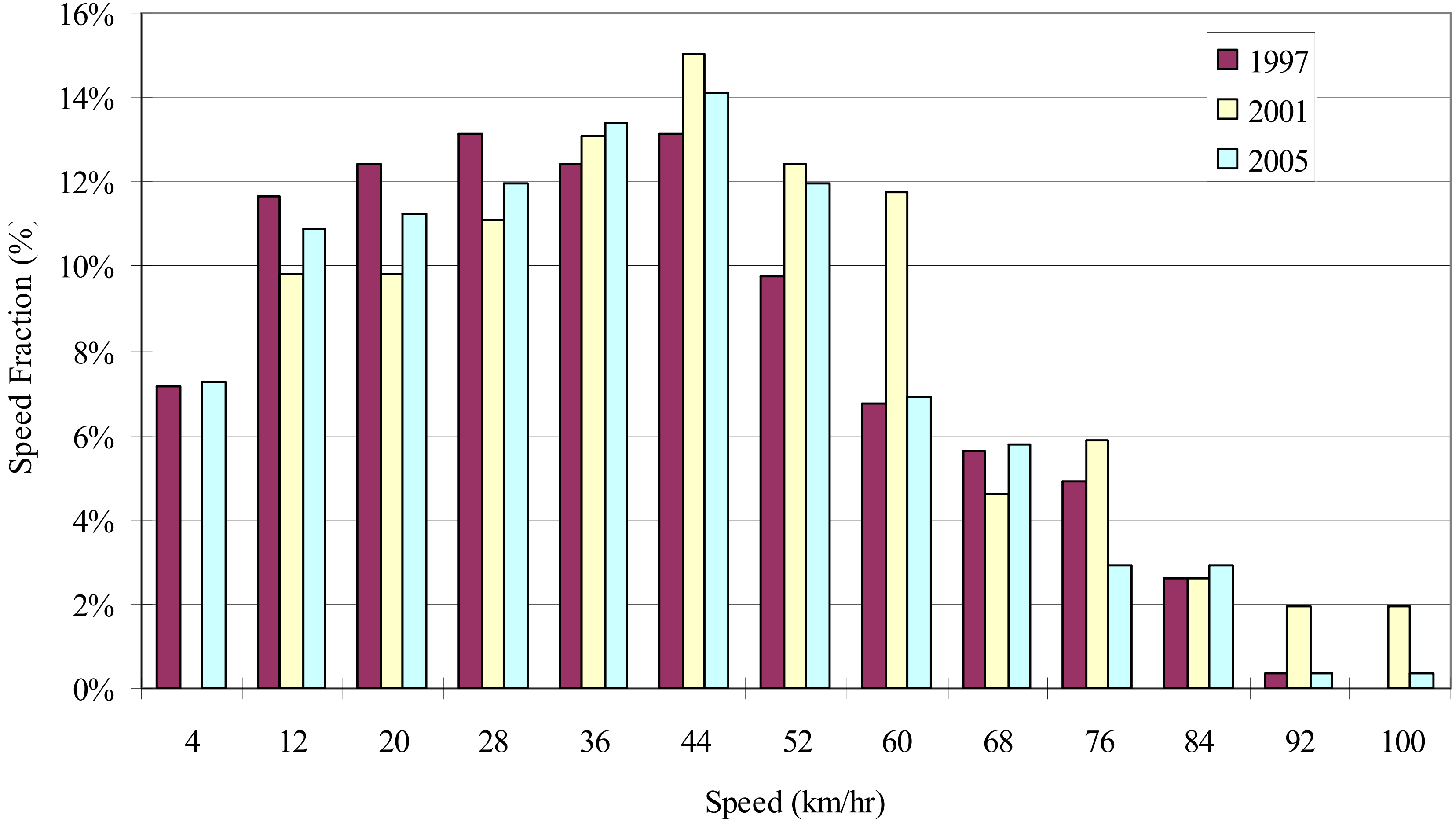


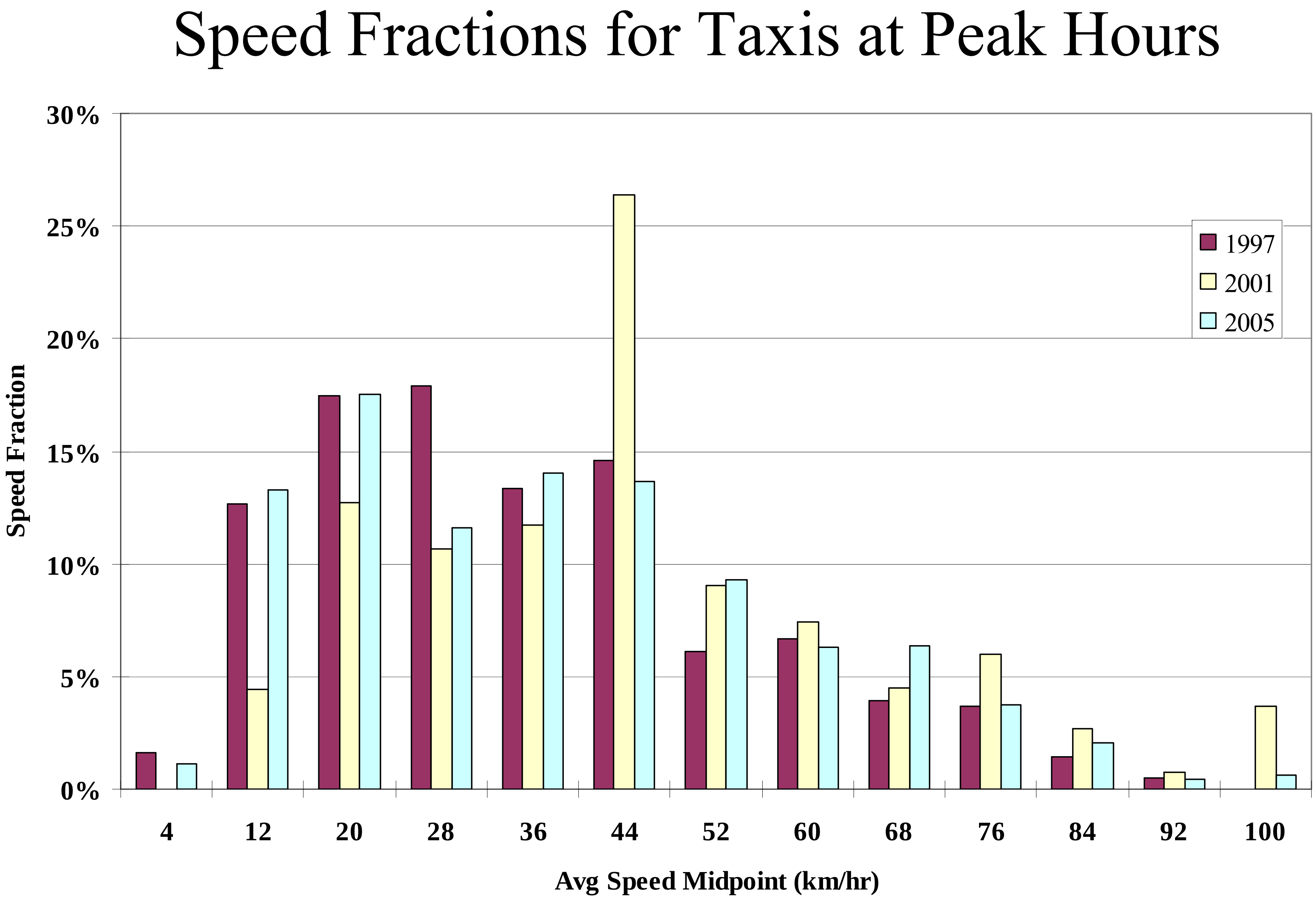
Speed Fractions

Data Sources:

- Congested speeds at 0800-0930 (TD)
- Speed limits (Highway Department)
- Speed vs. volume / capacity ratio from Travel Demand Model Study in Hong Kong (TD)

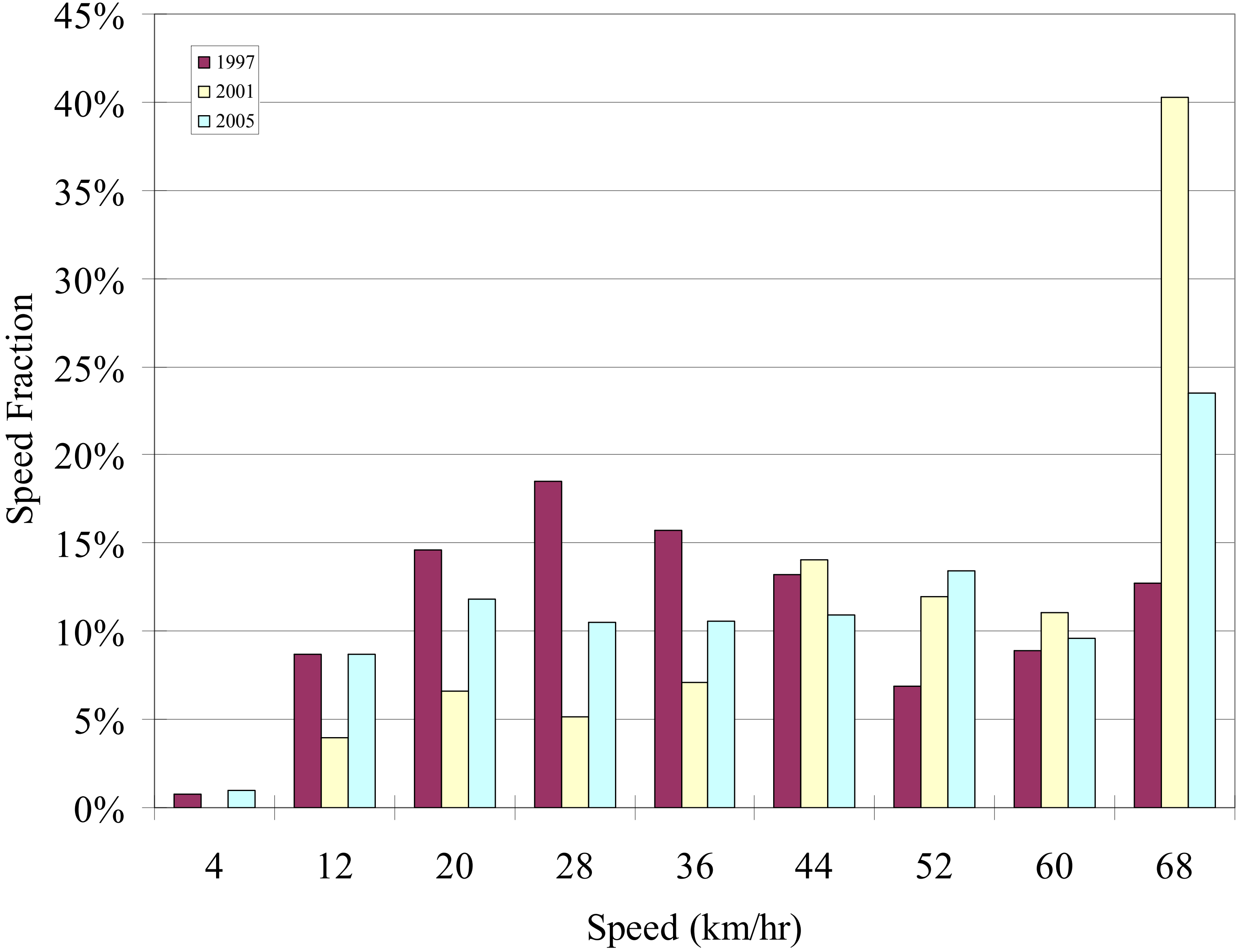
Speed Fractions for Private Cars at Peak Hours



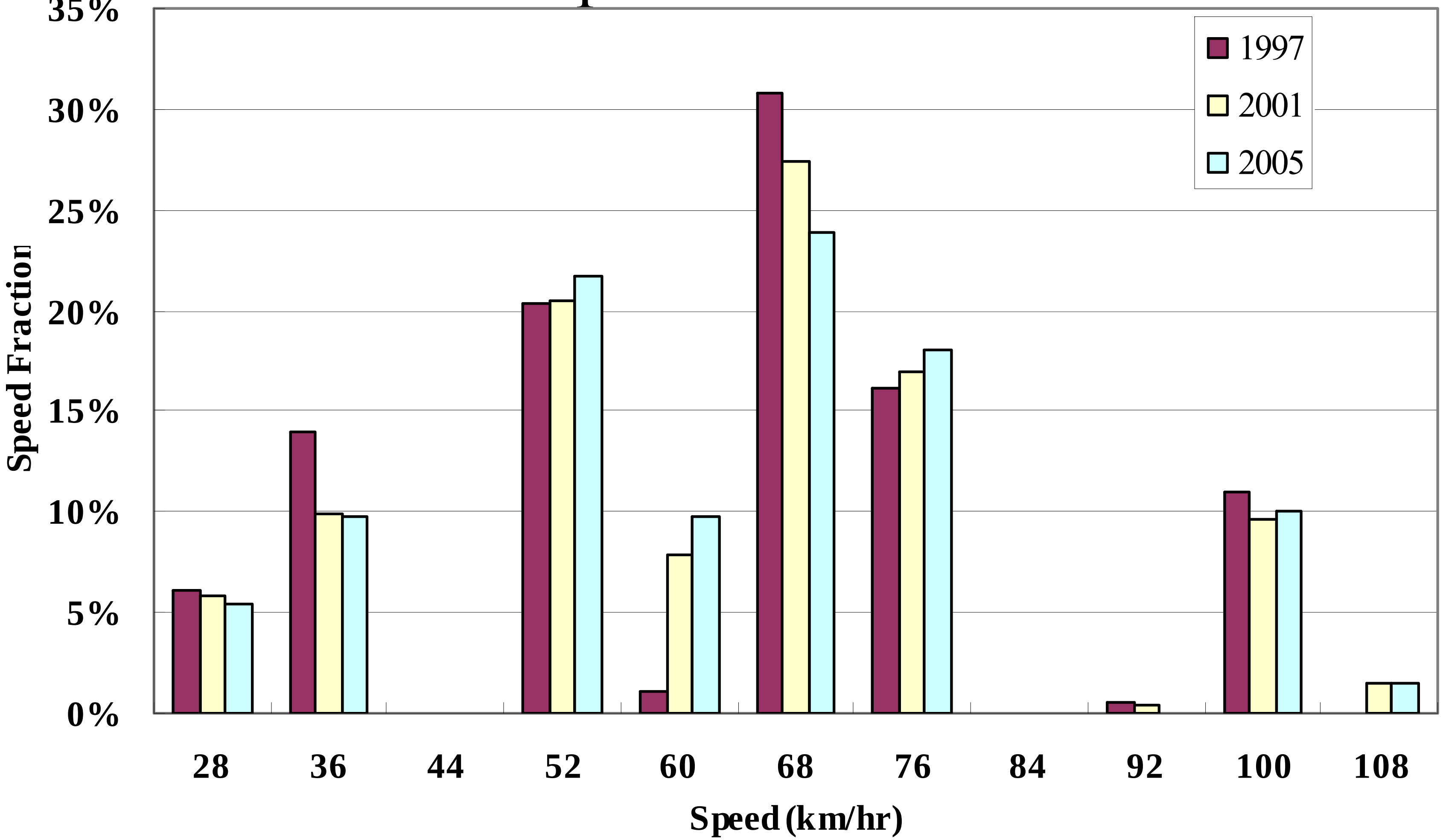


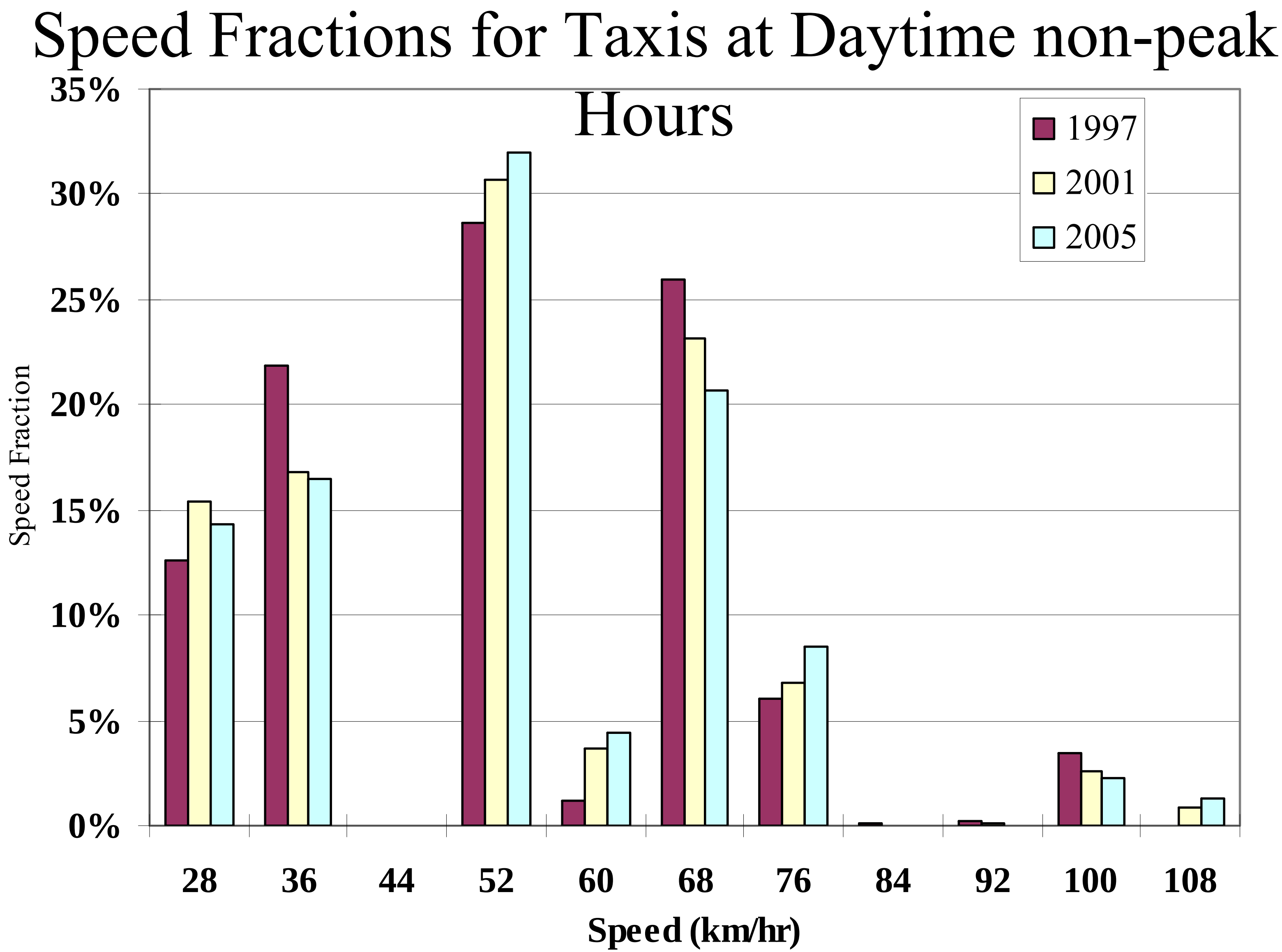
Speed Fractions for Taxis at Peak Hours
30%
25%
20%
15%
10%
5%
0%
Speed Fraction
1997
2001
2005
4
12
20
28
36
44
52
60
68
76
84
92
100
Avg Speed Midpoint (km/hr)

Speed Fractions for Large Buses at Peak Hours

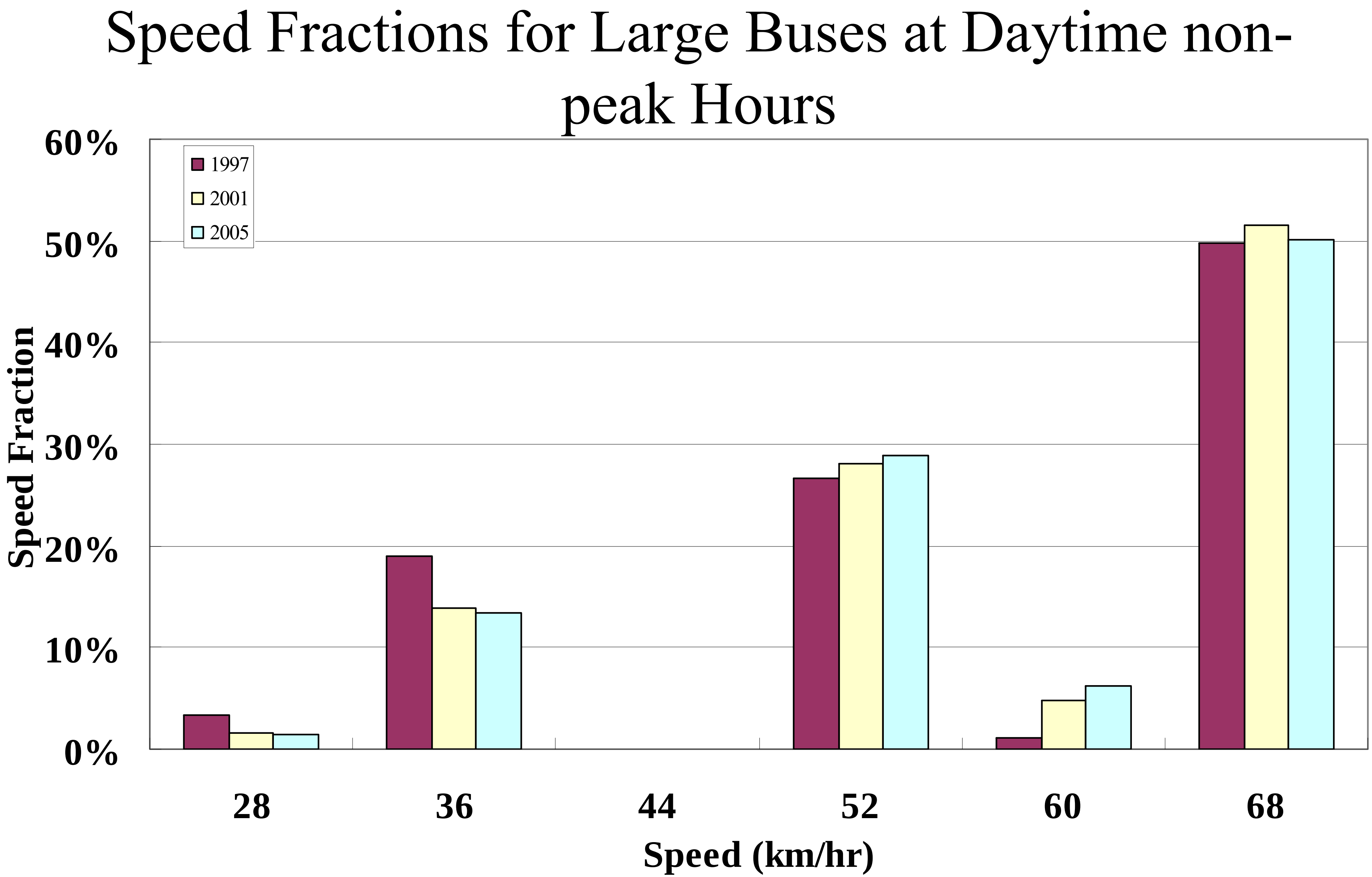


Speed Fractions for Petrol Cars at Daytime non-peak Hours

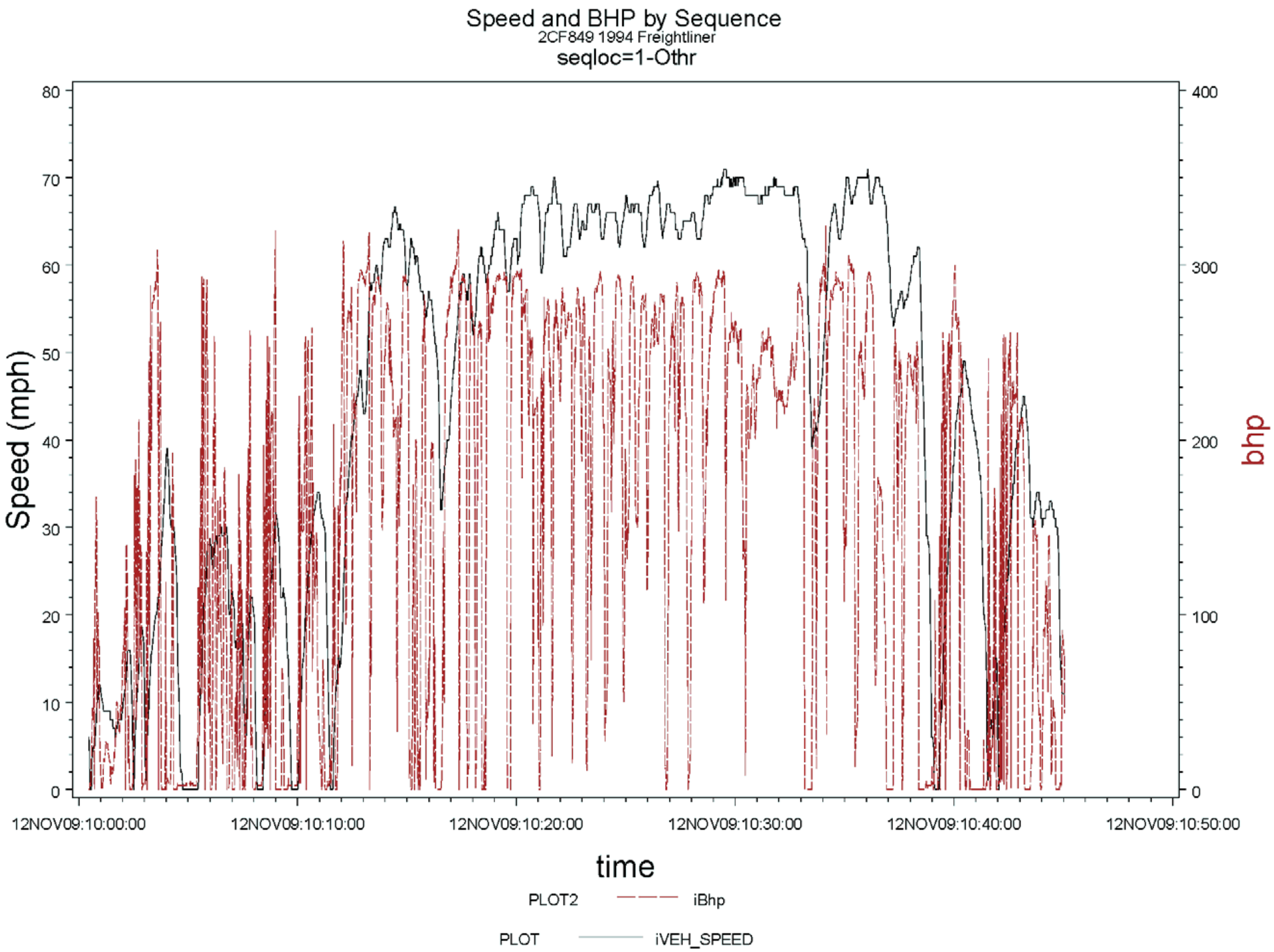




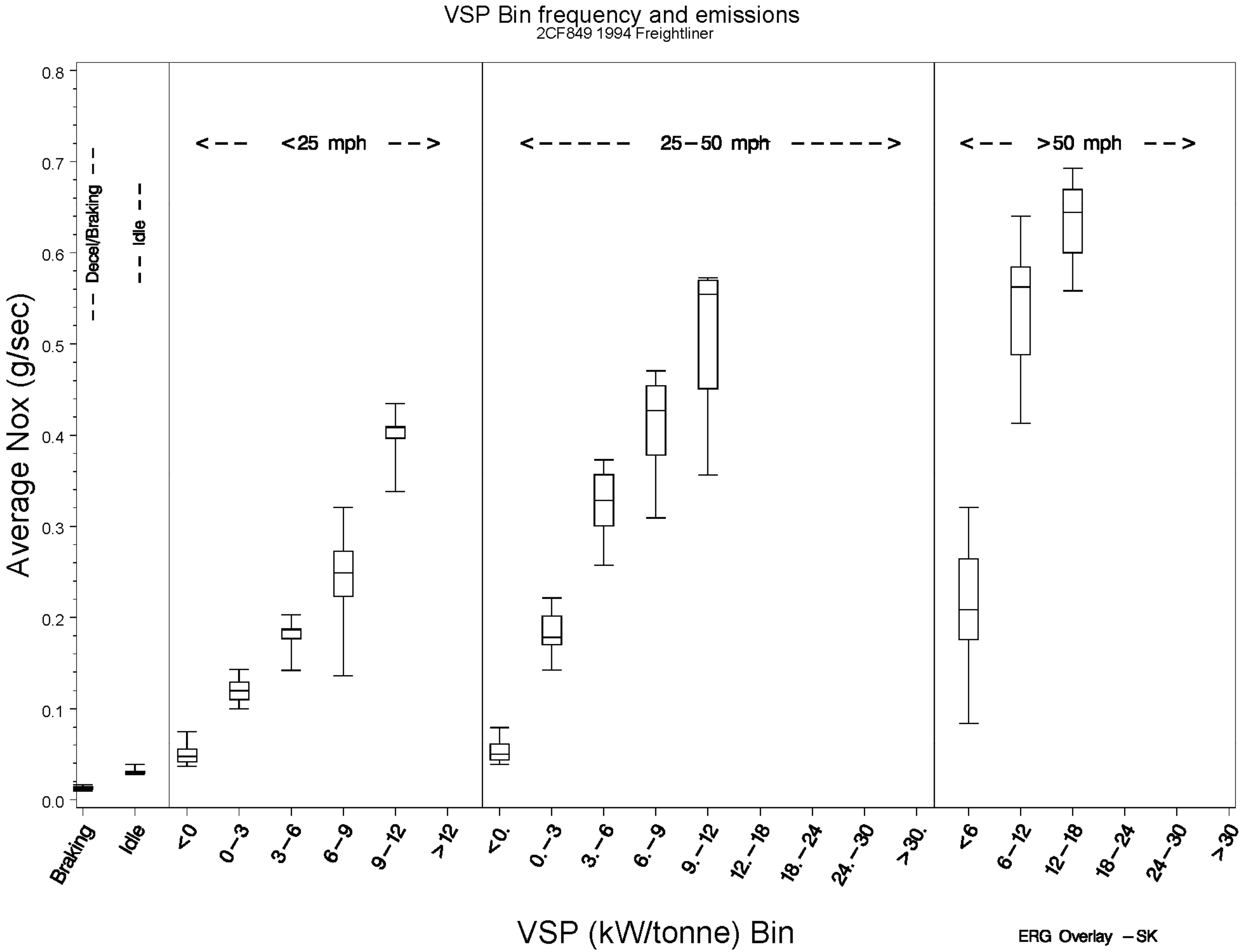
Speed Fractions for Taxis at Daytime non-peak Hours
35%
30%
25%
20%
15%
10%
5%
0%
Speed Fraction
1997
2001
2005
28
36
44
52
60
68
76
84
92
100
108
Speed (km/hr)

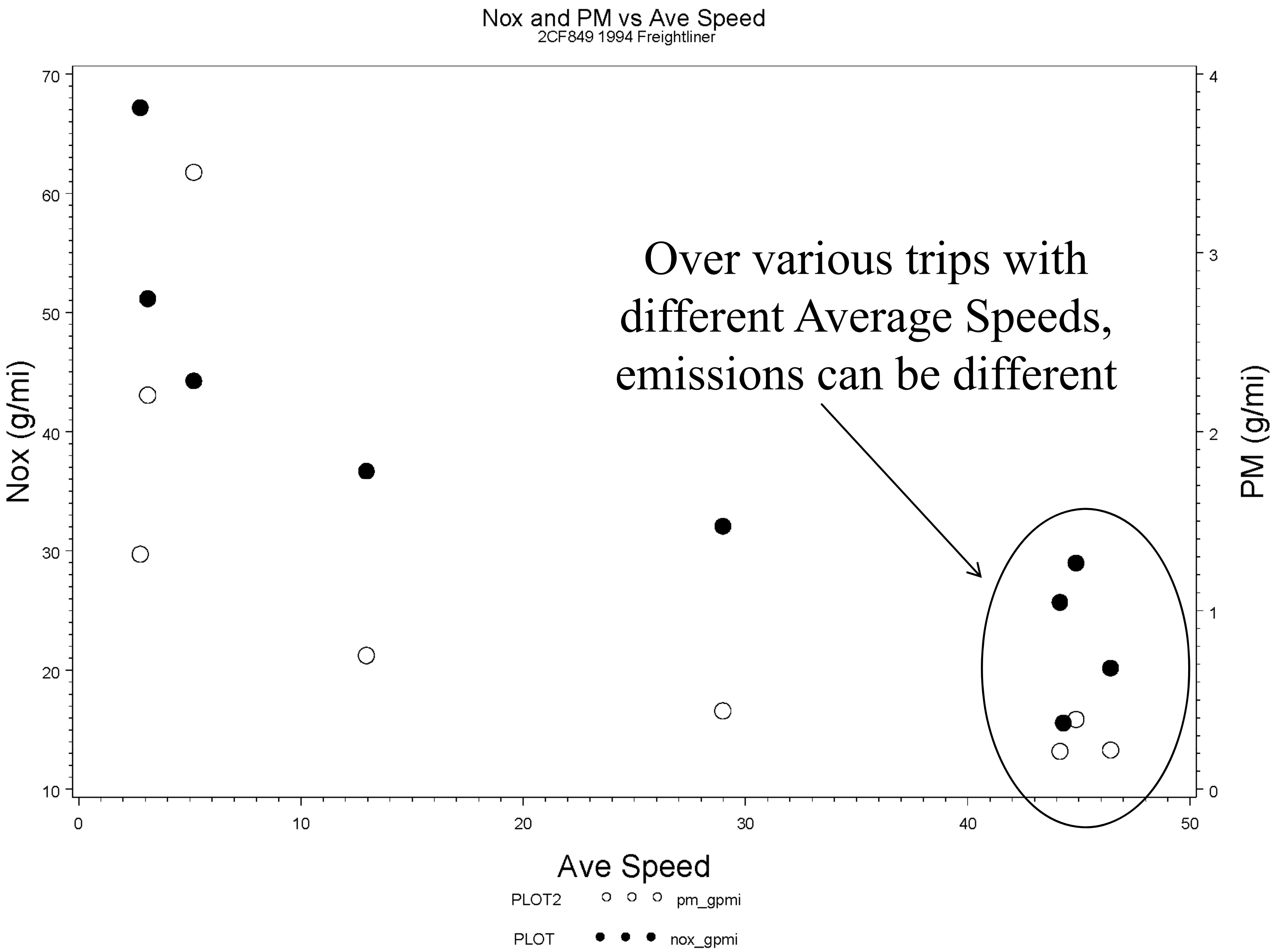

Speed Fractions for Large Buses at Daytime non-peak Hours
60%
50%
40%
30%
20%
10%
0%
Speed Fraction
1997
2001
2005
28
36
44
52
60
68
Speed (km/hr)

```
                                    !
! The speed activity data coded in modules SPDA and SPDB is set up
! as a number of logical records, one for each unique region and time period.
! The format is as follows:
!
! Record #: N
!
! area, yr, hr, idle,      0-5 MPH,  5-10 MPH, 10-15 MPH, 15-20 MPH,
!            20-25 MPH, 25-30 MPH, 30-35 MPH, 35-40 MPH, 40-45 MPH,
!            45-50 MPH, 50-55 MPH, 55-60 MPH, 60-65 MPH, 65-70 MPH,
!            70-75 MPH, 75-80 MPH, 80-85 MPH, 85-90 MPH
!
! area =    the county index as defined in the user manual
!
! yr   =   the last year for which the speed data is applicable, i.e.,
!          if  there is only one record for an area, it will have a
!          year of 2040, and the data is applicable for 1960-2040.
!
! hr   =   The last hour for which the speed data is applicable, i.e.,
!          if the hr=5 on the first record for a given area & Year -
!          then the speed data is good from midnight through 5 AM.
!
! MPH  =    The fraction of travel in the given speed bin.  There are
!          seven speed distributions for each record:
!            P = PC, LDT1, LDT2, MDV, MCY
!            L = LHDV1, LHDV2
!            M = MHDV
!            H = HHDV
!            S = LHV
!            B = UB
!            B = SBUS
                                    !
```



Speed and BHP by Sequence
2CF849 1994 Freightliner
seqloc=1-Othr
Speed (mph)
0
10
20
30
40
50
60
70
80
bhp
0
100
200
300
400
12NOV09:10:00:00
12NOV09:10:10:00
12NOV09:10:20:00
12NOV09:10:30:00
12NOV09:10:40:00
12NOV09:10:50:00
time
PLOT2 iBhp
PLOT iVEH_SPEED

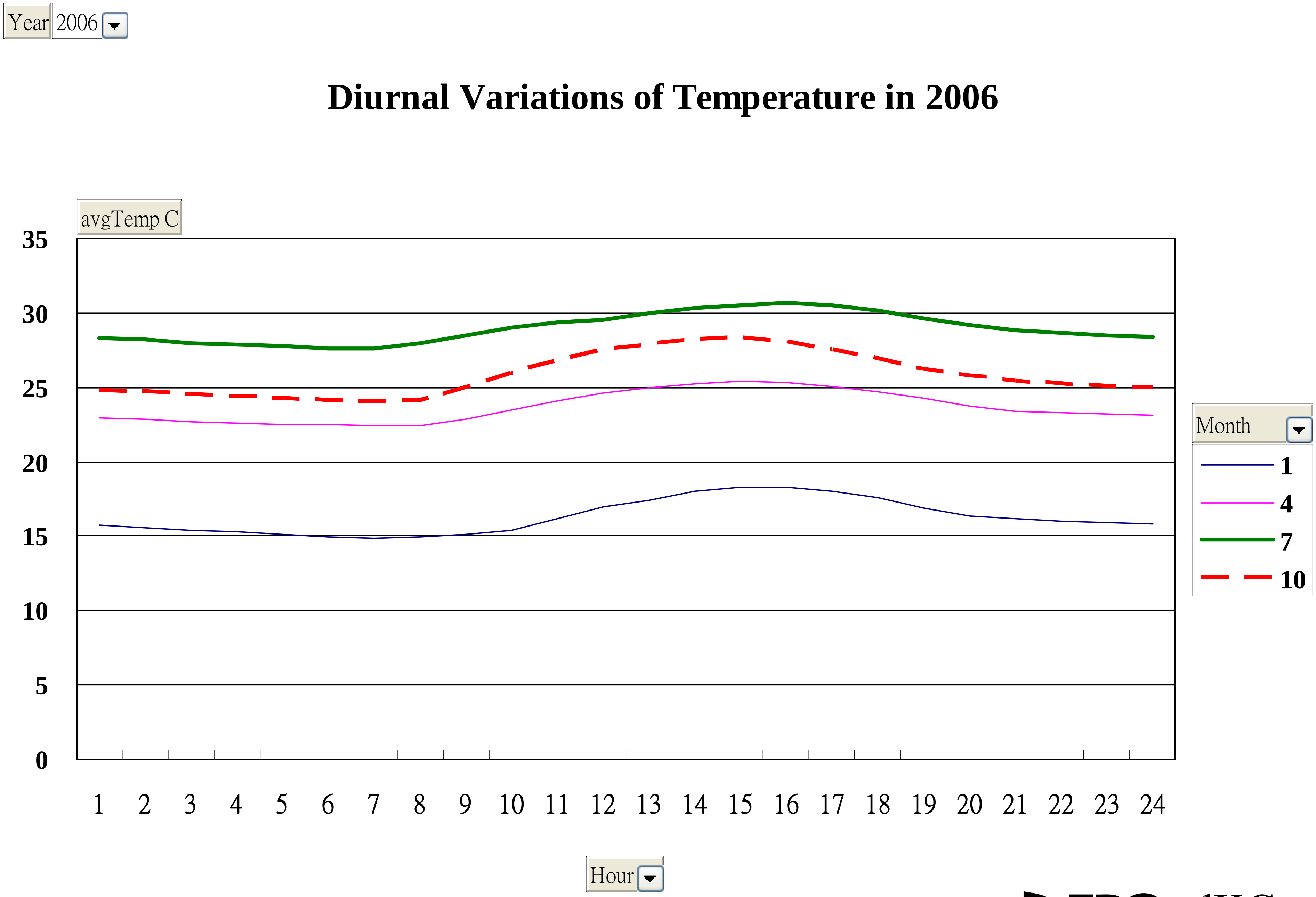

VSP Bin frequency and emissions
2CF849 1994 Freightliner
Average Nox (g/sec)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Decel/Braking
Idle
<--- <25 mph --->
<------ 25-50 mph ------>
<--- >50 mph --->
Braking
Idle
<0
0-3
3-6
6-9
9-12
>12
<0.
0.-3
3.-6
6.-9
9.-12
12.-18
18.-24
24.-30
>30.
<6
6-12
12-18
18-24
24-30
>30
VSP (kW/tonne) Bin
ERG Overlay -SK


Nox and PM vs Ave Speed
2CF849 1994 Freightliner
Nox (g/mi)
PM (g/mi)
Ave Speed
Over various trips with different Average Speeds, emissions can be different
PLOT2 pm_gpmi
PLOT nox_gpmi
70
60
50
40
30
20
10
4
3
2
1
0
0
10
20
30
40
50

Temperature Correction Factor

- Temperature correction based on the temperature for area and hour
- Coefficients A, B ,C are for Pollutant, driving mode, and tech group
- Form for equation cat vehicles is :

TCF = 1 + A * (TEMP-75) + B * (TEMP-75)**2 + C * (TEMP-75)***3



Year 2006
Diurnal Variations of Temperature in 2006
avgTemp C
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Hour
Month
1
4
7
10

ERG dKC

Humidity for Nox

The basic form of the correction factor is as follows:

$$RHUM\_CF = \frac{(1 + (M\_MANOS * (Ht - Hs))) * (1 + (M\_CLASS * (H - Hs)))}{1 + M\_CLASS * (Ht - Hs)}$$

where:

RHUM_CF = humidity correction factor (ratio)

M_MANOS = -0.0047, a constant derived by Manos et al (1972) in "Effect of Laboratory Conditions on Exhaust Emissions“

Ht = tech group specific base humidity (grains/lb) (different for Light and Heavy vehicles, stored in RHCFData.for)

Hs = 75 grains/lb, standard humidity

M_CLASS = tech group specific humidity correction factor constant (different for DSL and Petrol, stored in RHCFData.for)

H = scenario humidity to which correction is to be performed (grains/lb)

Absolute Humidity

H = RH * (A + B * T + C * T**2 + D * T**3)

where:

H = scenario humidity (grains/lb)

T = scenario temperature (deg F)

A = -0.09132

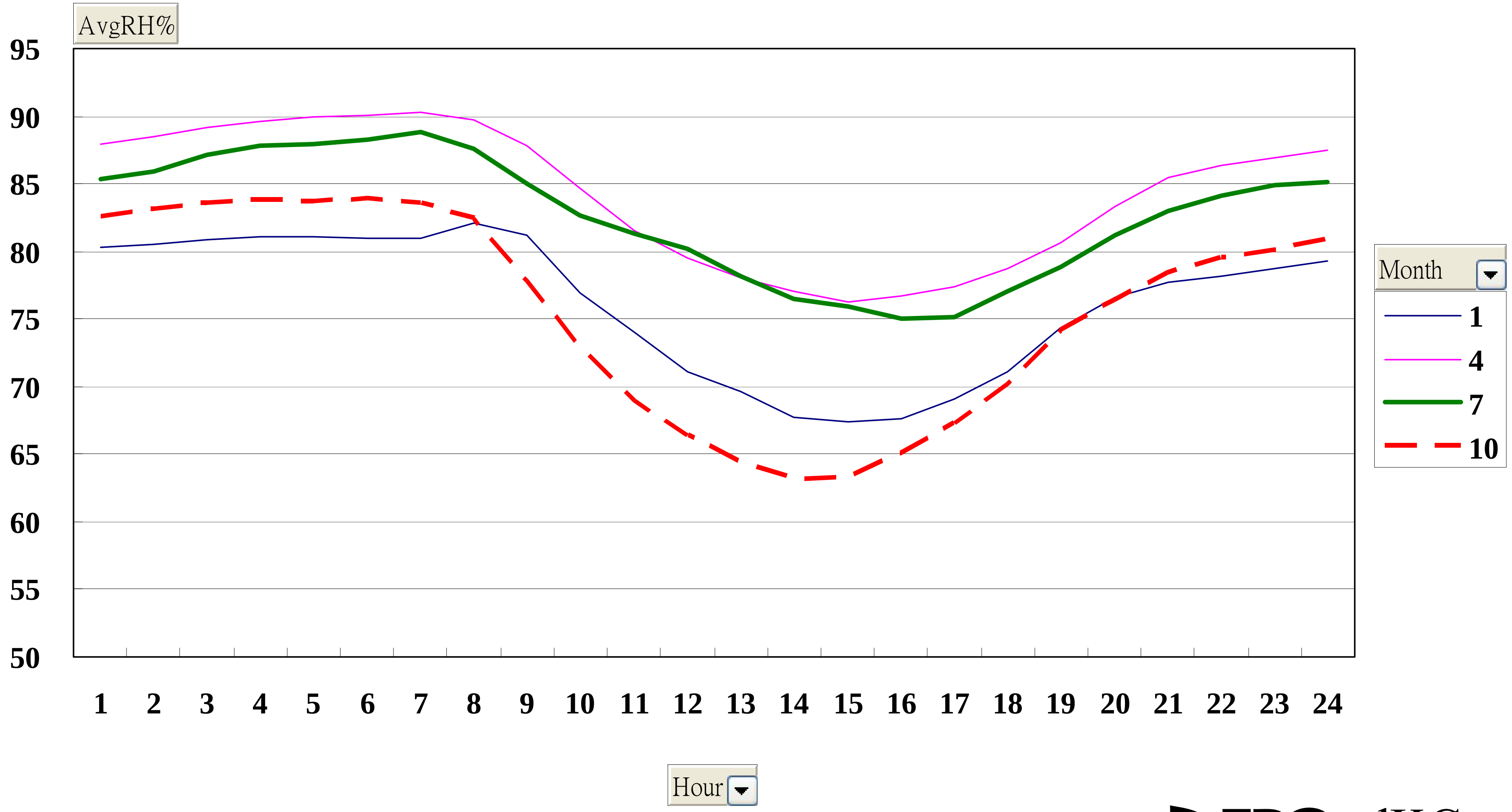
B = 0.01594

C = -0.00029

D = 4.37E-06

Year 2006

Diurnal Varlations of Relative Humidity in 2006



ERG dKC

AC Correction

BERadj = (ACon) * (m * BER + C) + (1 - ACon) * BER

where:

BERadj = base emission rate adjusted for A/C usage

ACon = air conditioning activity factor

m = slope of regression equation

BER = base emission rate

C = constant from regression equation

AC On Fraction

ACon = ACfrac * ACfunc * COMPon

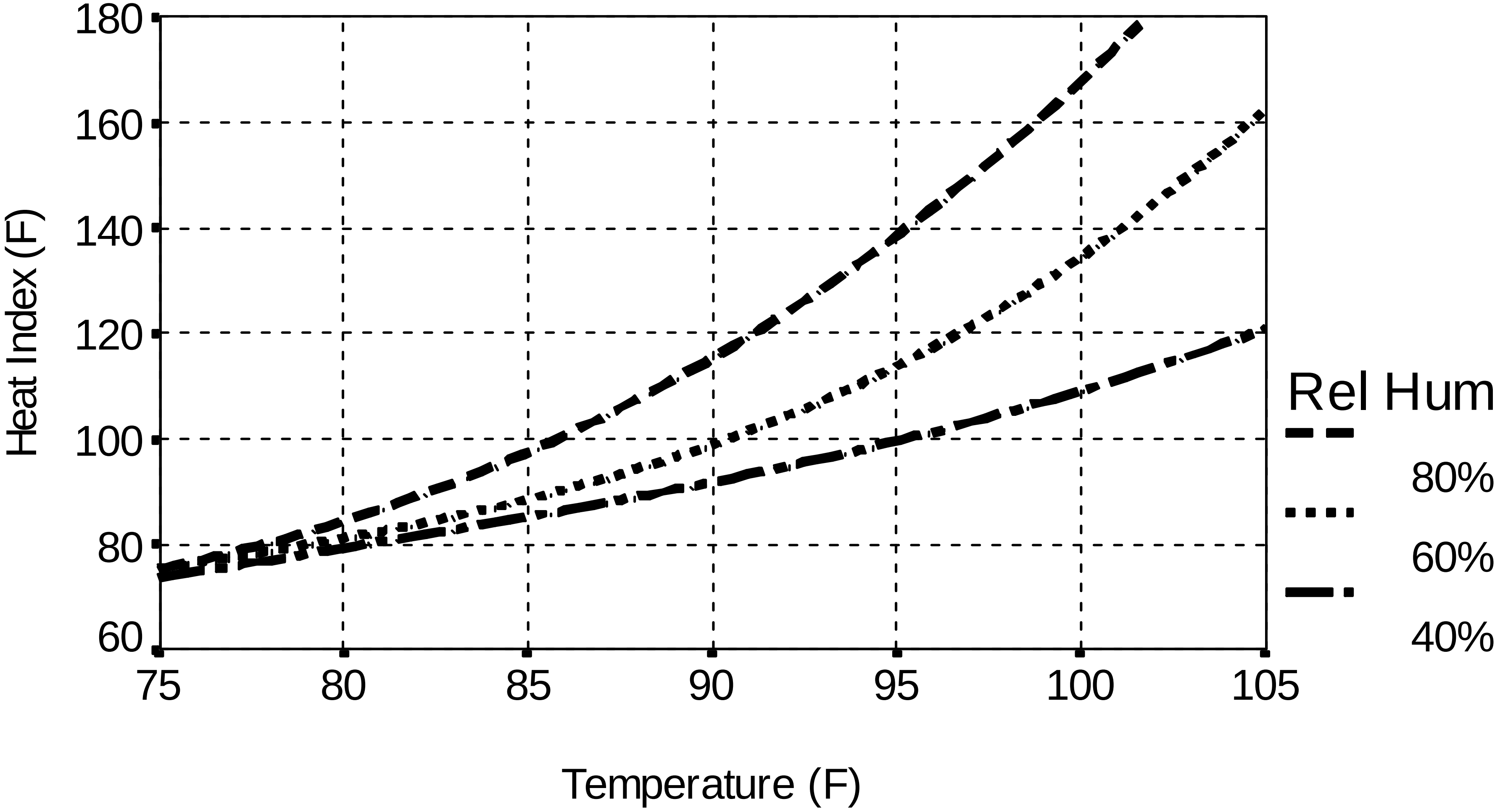
where:

ACfrac = Fraction of vehicles equipped with A/C units

ACfunc = Fraction of A/C units functional

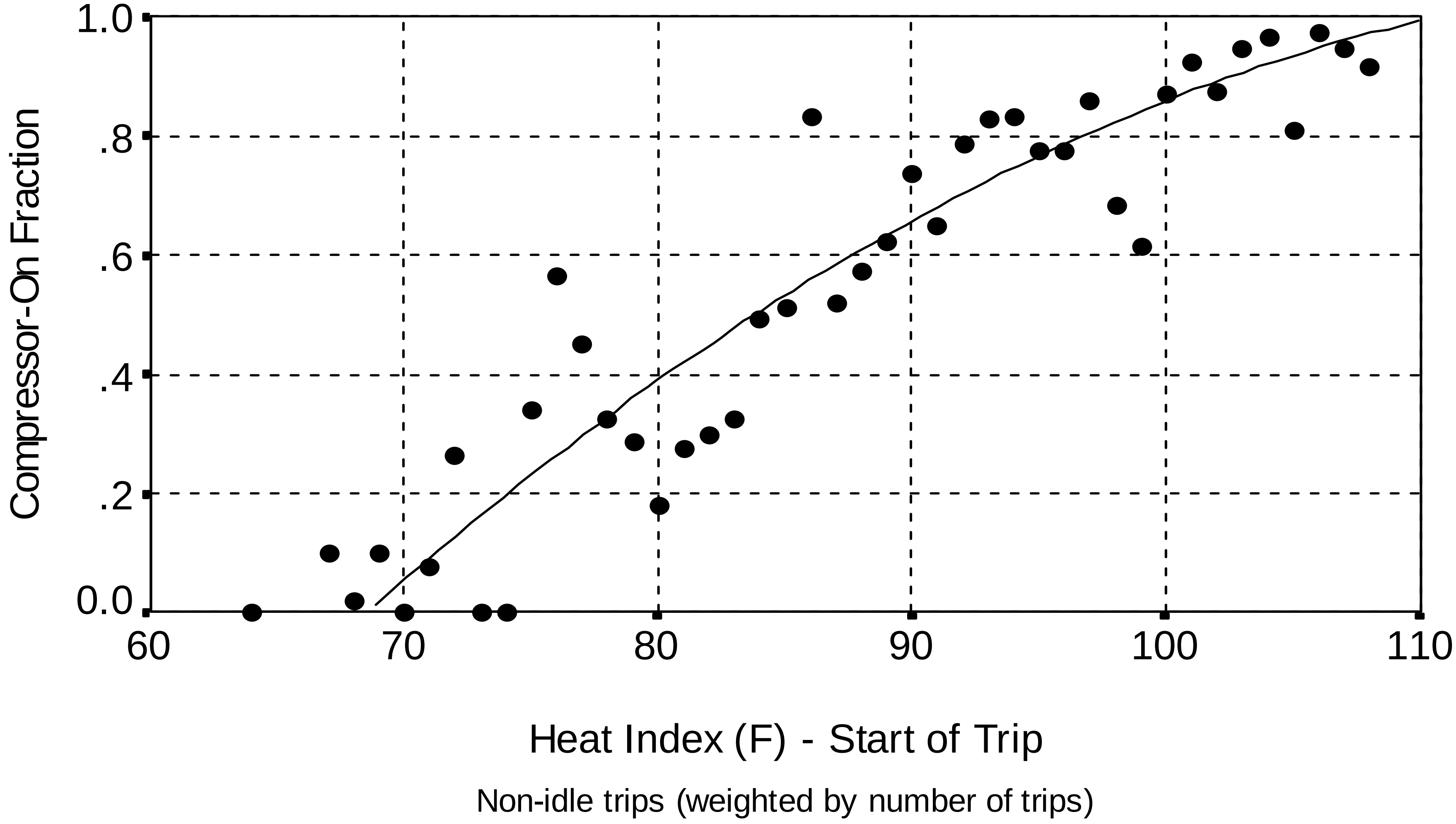
COMPon = Factor representing compressor activity as a function of temperature and humidity.

Temperature, Humidity, and Heat Index



Note: Heat Index values based on shady conditions

Compressor-On vs. Heat Index



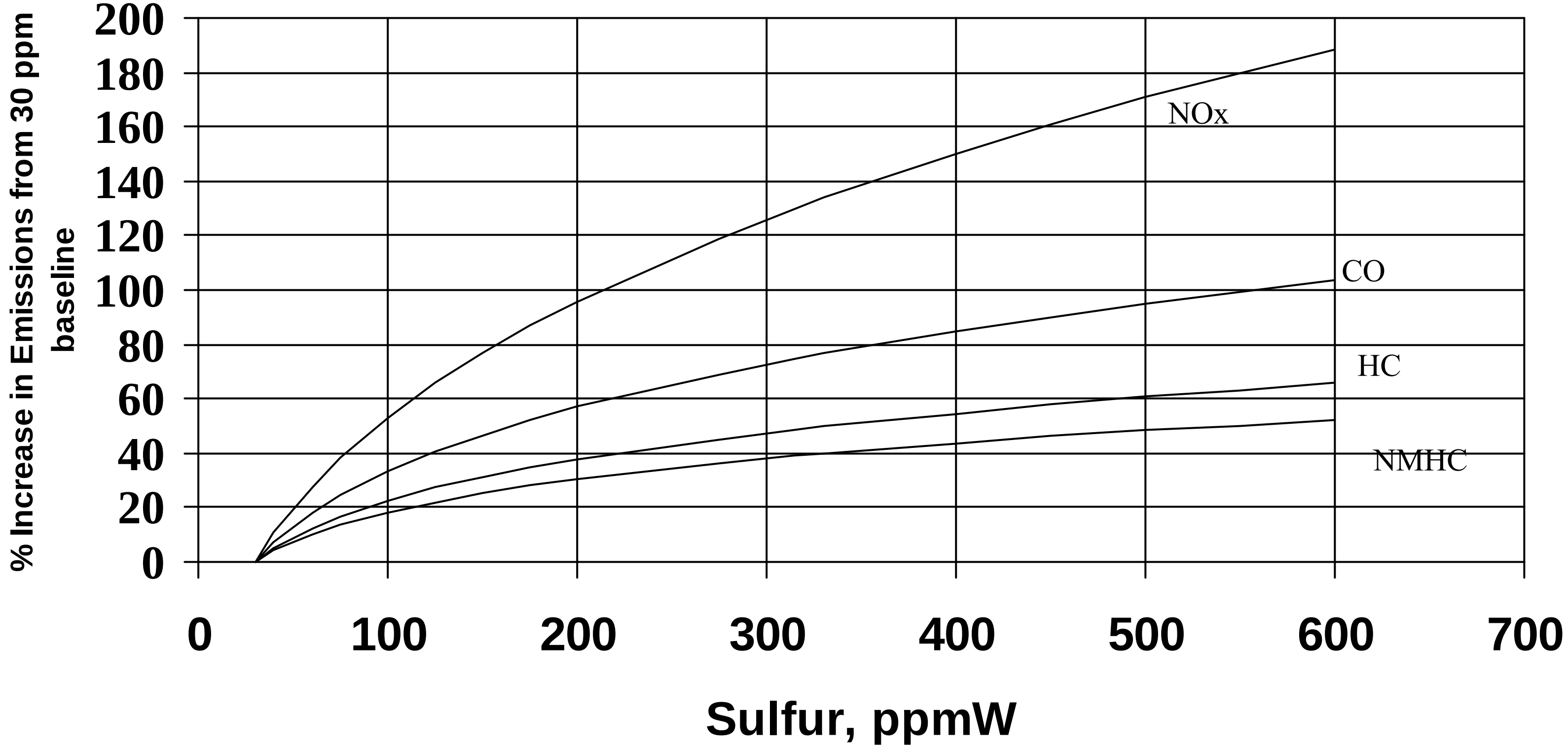
Fuel Correction Factors

- Petrol correction factors are
  - Driving mode, pollutant, season, fuel reg, and tech group
- Diesel correction factors are
  - Driving mode, pollutant, season, fuel reg, and tech group
- Stored in FCF_Data.for

Effects of Fuel Composition

- Updated effects of oxygenated fuels on CO emissions
- Explicit effects of sulfur on exhaust emissions
  - including long-term and irreversibility effects.
- Explicit modeling of LPG vehicles

LEV Normal Emitter Composite Emission Effects Based on Regression Coefficients



Fuel overview

- Most modern petrol-fueled vehicles use catalysts to reduce HC, CO, and NO_x emissions
- Sulfur is a catalyst poison. Increased sulfur levels in fuels thereby increase emissions through catalyst deactivation

Modeling Objectives

- Identify valid data for sulfur's effect on exhaust emissions
- Develop correlations between sulfur and exhaust emissions as a function of:
  - Pollutant
  - Emitter class
  - Vehicle technology
  - Emission mode (composite, running, start)

High Idle Correction

Correction for “hoteling” or long term idle for Heavy Duty trucks only –may be added for all vehicles in the future

Summer, Winter Factors:

1.7, 2.2, ! HC

3.1, 7.3, ! CO

2.1, 1.8, ! NOx

CombinedCorrection Factor

```
CF = CF
    &           + ALTCF
    &           * CCF
    &           * LOADCF
    &           * SCFACTOR(iPer)
    &           * EX_TCF(iMode,iAge,iPer,iMon)
    &           * RH_CF(iPer,iMon)
    &           * AC_CF(iPer,iAge,iMon)
    &           * FCF(iMode,iAge,iMon)
    &           * HI_CF
```

Burden Calculations

- Emission Rate E_{model_year}, for pollutant
- Correction Factors (CCF)
- Activity (Population, VMT, Starts)
- By Area
- Calculate for both No_I/M and Post I/M
- Estimate Tons/year :

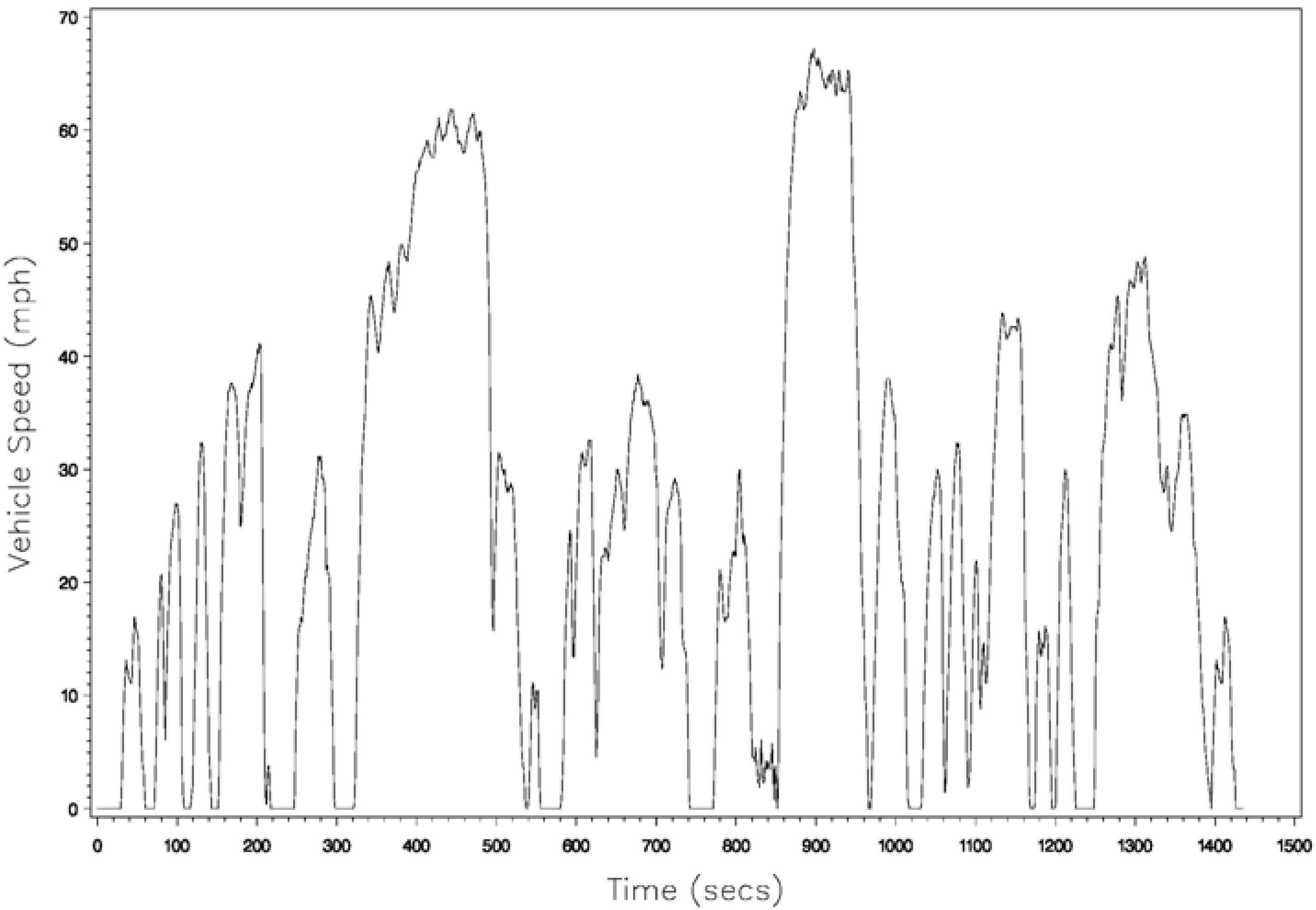
E_{model_year} * ALL_CCF * Activity

Driving Cycles

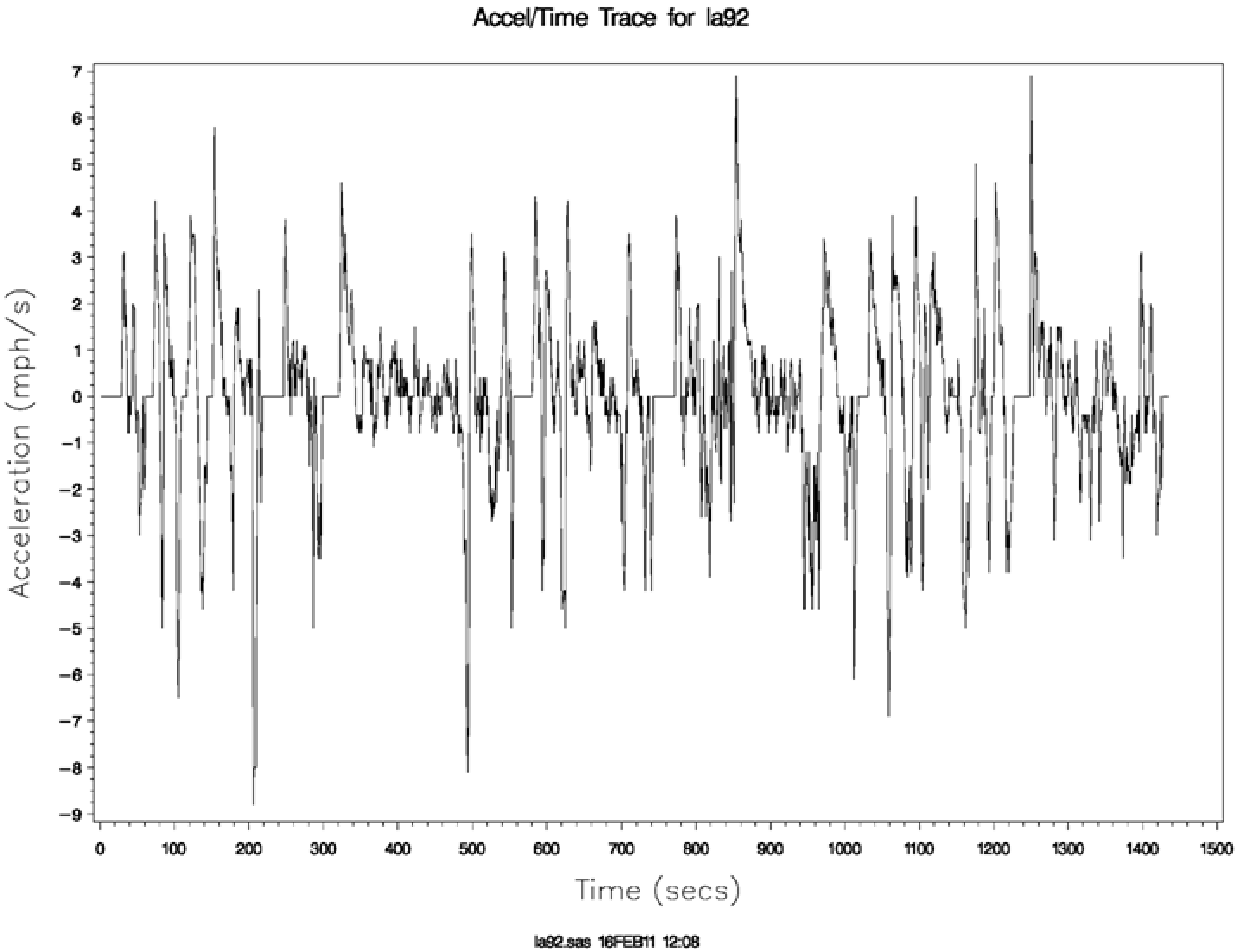
- UDDS-LA4
- Unified Cycle – LA92
- IM240
- NYCC
- HFET
- SC03
- US06
- ECE- Part 1
- ECE- Part2
- EUDC

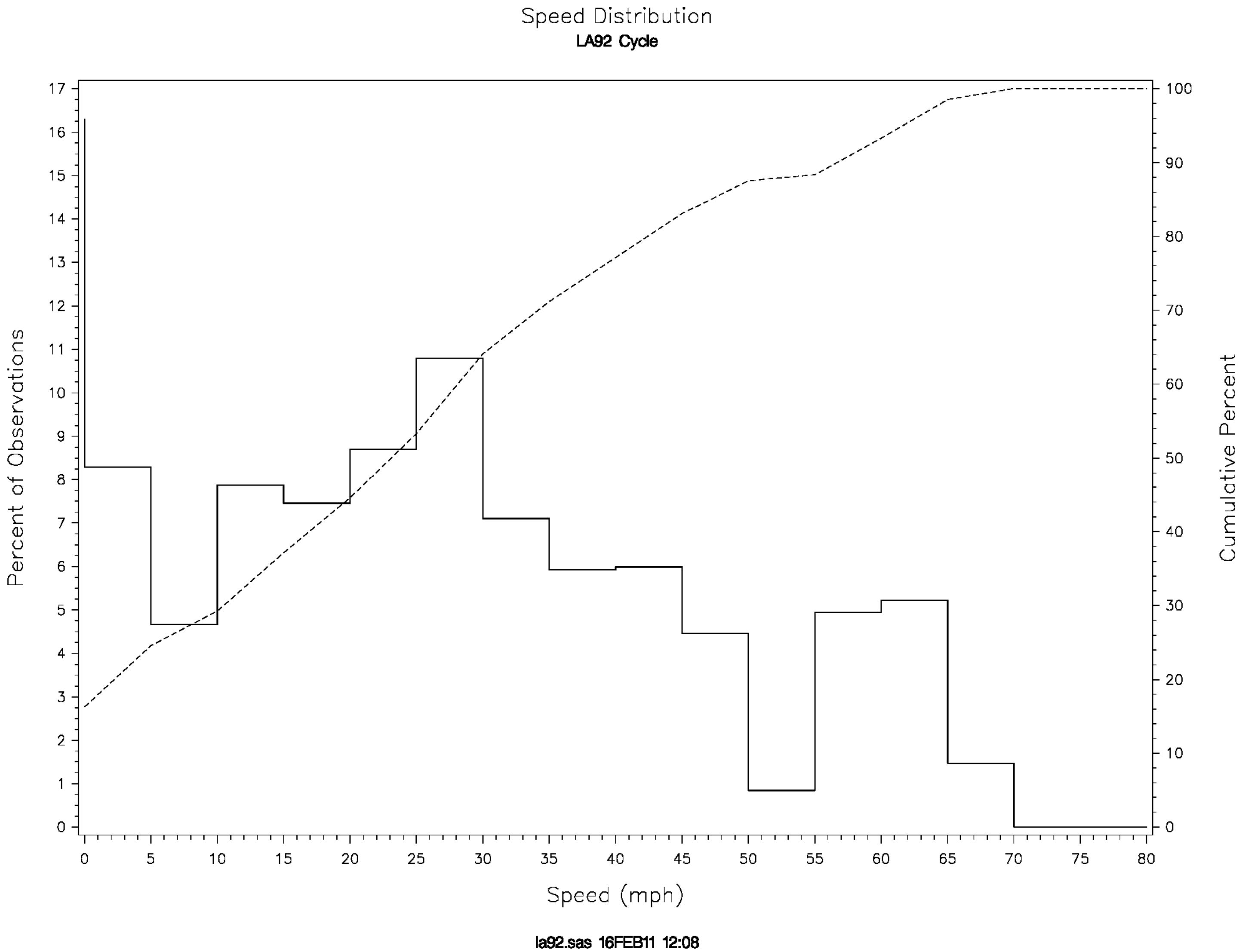
Review Plots and Statistics in Excel File (cycles_sbs.xls)

Speed/Time Trace for la92

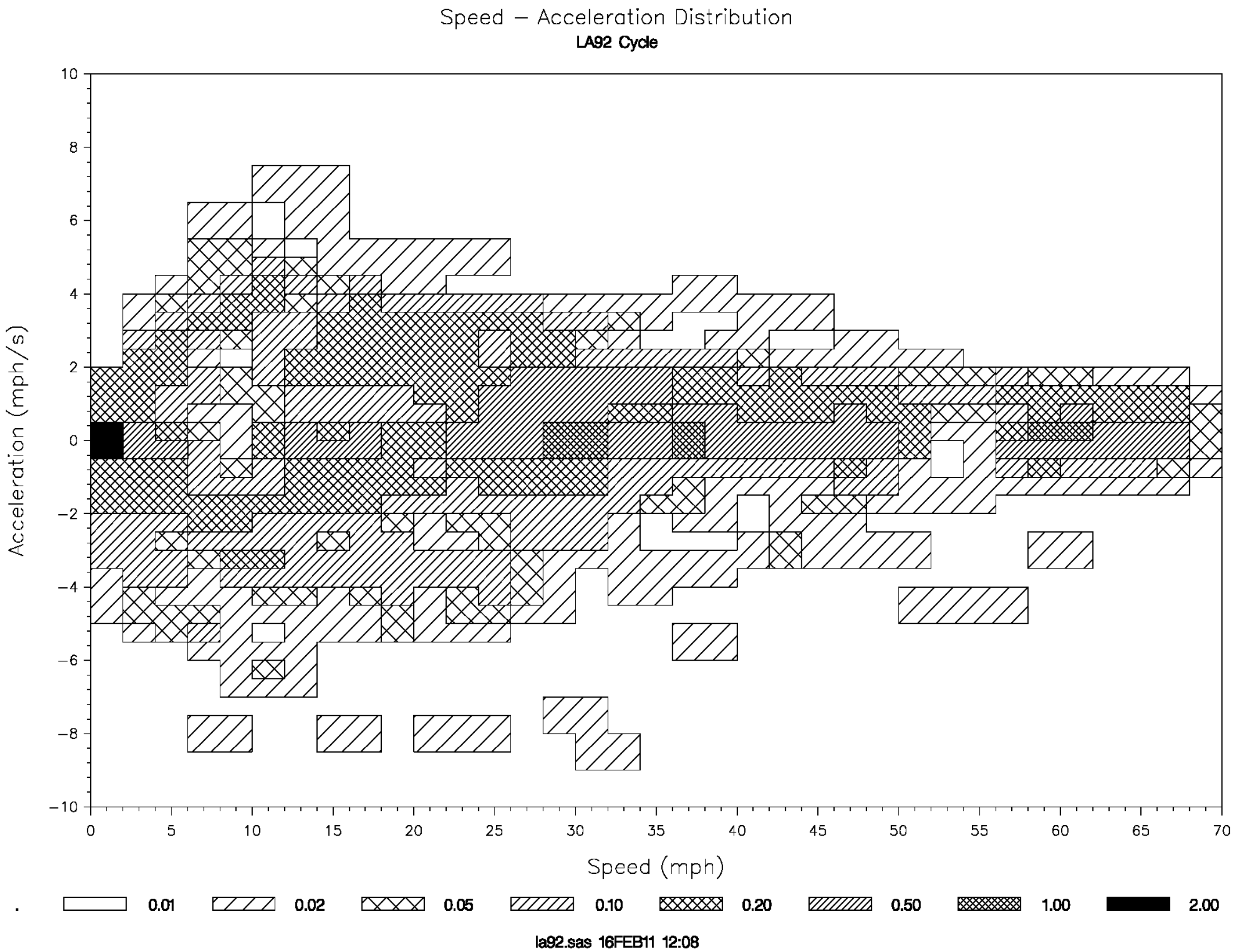


la92.sas 16FEB11 12:08

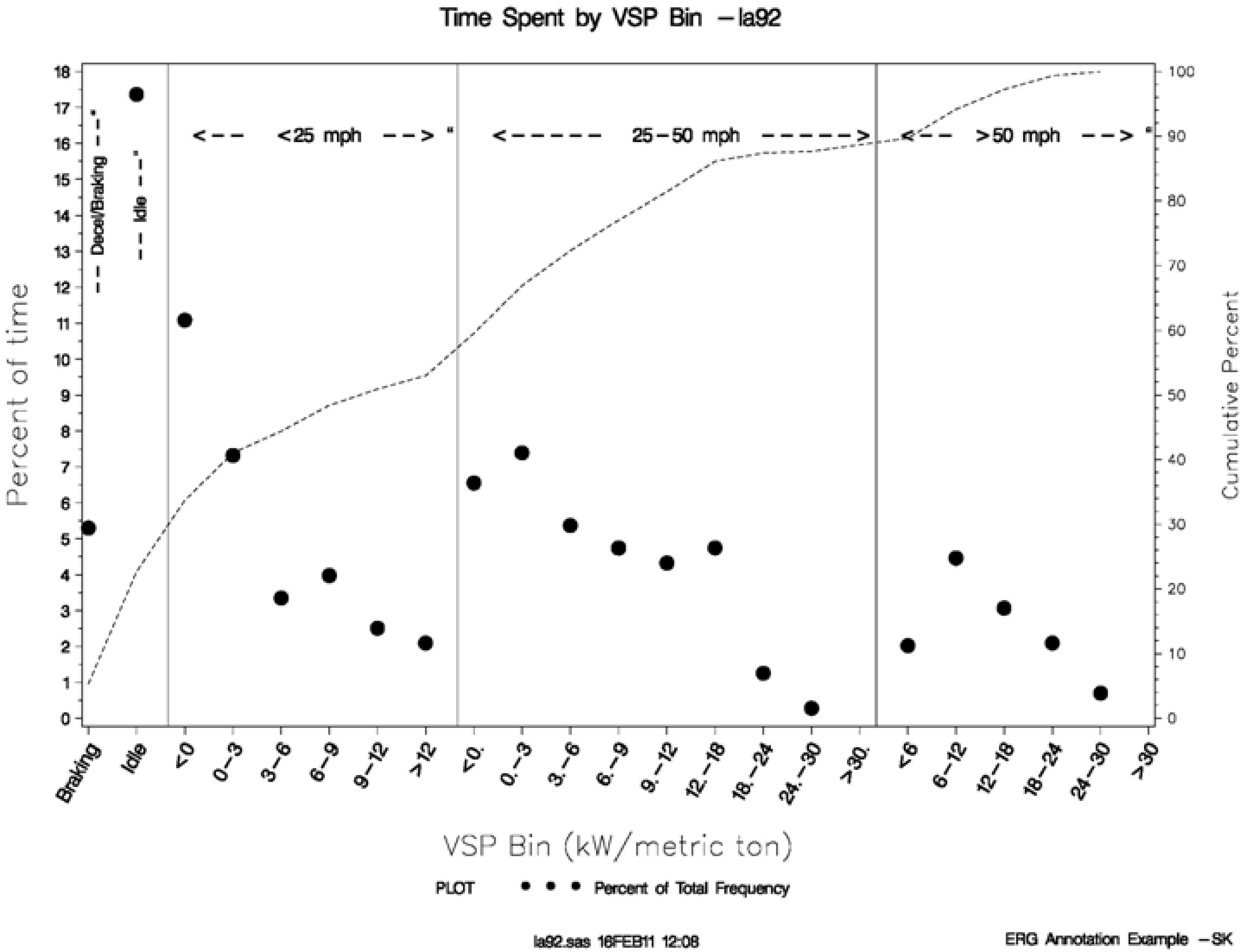

Accel/Time Trace for la92
Acceleration (mph/s)
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Time (secs)
la92.sas 16FEB11 12:08



Speed Distribution
LA92 Cycle
Percent of Observations
Cumulative Percent
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
10
20
30
40
50
60
70
80
90
100
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Speed (mph)
la92.sas 16FEB11 12:08



Speed – Acceleration Distribution
LA92 Cycle
Acceleration (mph/s)
10
8
6
4
2
0
–2
–4
–6
–8
–10
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
Speed (mph)
0.01
0.02
0.05
0.10
0.20
0.50
1.00
2.00
la92.sas 16FEB11 12:08

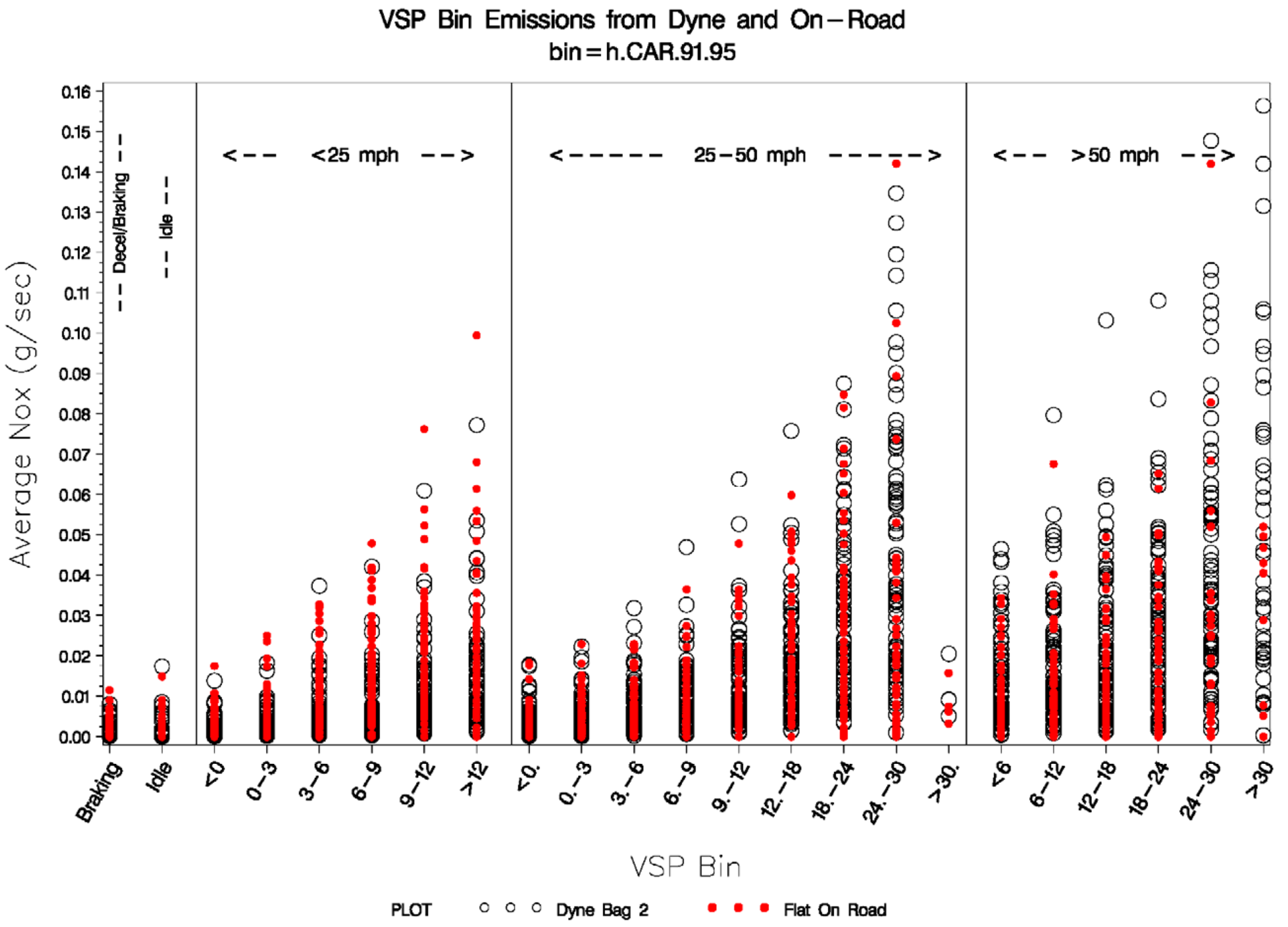


Time Spent by VSP Bin – la92
Decel/Braking
Idle
<– – <25 mph – – >
<– – – – – 25–50 mph – – – – – >
<– – >50 mph – – >
Percent of time
Cumulative Percent
Braking
Idle
<0
0–3
3–6
6–9
9–12
>12
<0.
0.–3
3.–6
6.–9
9.–12
12.–18
18.–24
24.–30
>30.
<6
6–12
12–18
18–24
24–30
>30
VSP Bin (kW/metric ton)
PLOT • • • Percent of Total Frequency
la92.sas 16FEB11 12:08
ERG Annotation Example – SK

Obs	variable	units	aver	stdd	maxx	minn	count
1	MPH	(mph)	24.61	19.72	67.2	0	1436
2	ACCEL	(mph/s)	0	1.78	6.9	-8.8	1435
3	VSP	(KW/M-to	3.39	8.72	32.66	-53.1	1435
4	Dist	(miles)	.	.	9.82	.	.

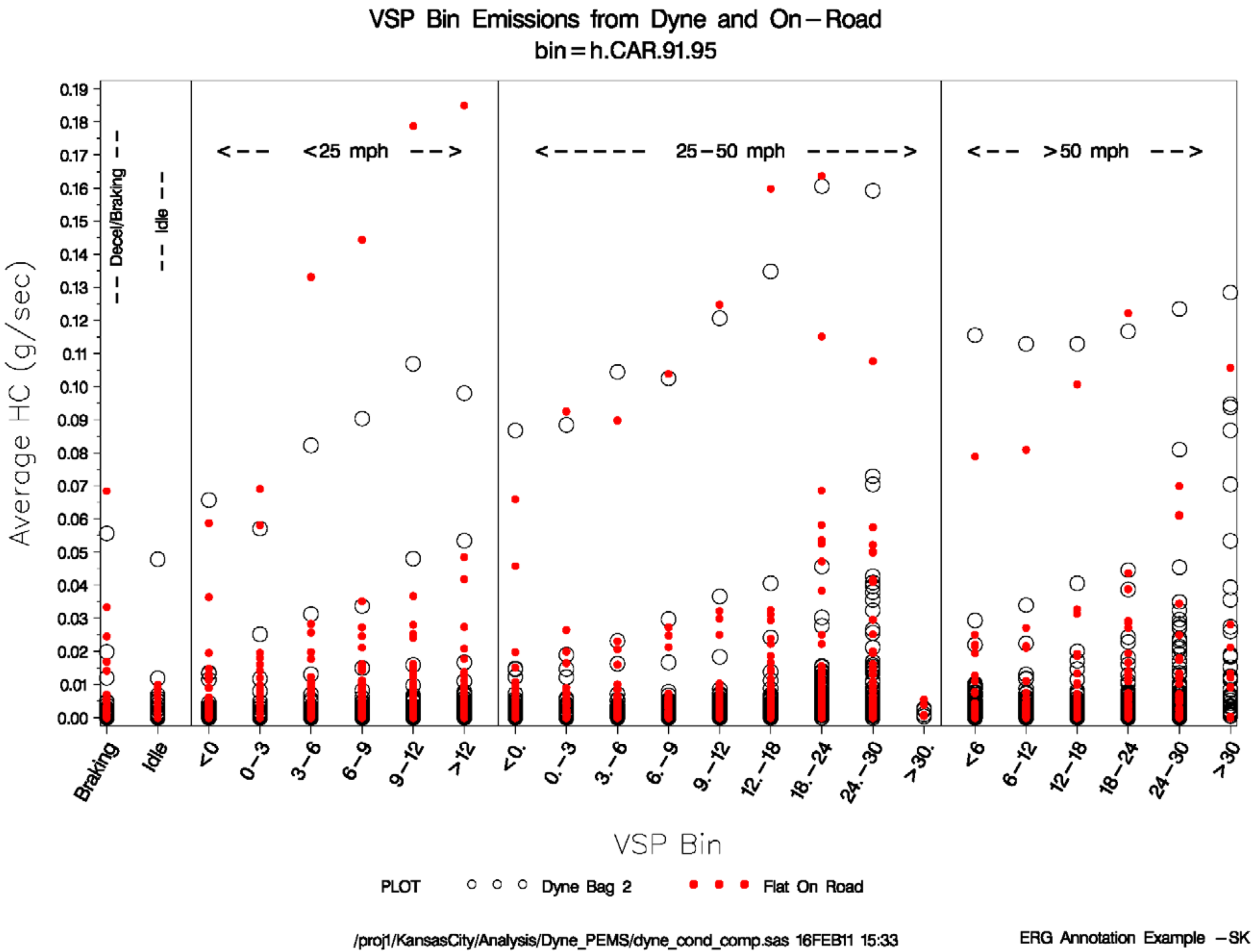
File: C:\Documents and Settings\SKishan\My Documents\Projects\National_PEMS\cycles\la92.lst 2/16/2011, 12:08:58 PM

	Accelearation (mph/s)																	
	>-9 <=-8	>-8 <=-7	>-7 <=-6	>-6 <=-5	>-5 <=-4	>-4 <=-3	>-3 <=-2	>-2 <=-1	>-1 <0	=0	>0 <=1	>1 <=2	>2 <=3	>3 <=4	>4 <=5	>5 <=6	>6 <=7	All
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Speed (mph)																		
=0	.	.	.	.	.	.	0.07	0.56	0.49	15.12	.	.	.	.	.	.	.	16.2
>0 <=5	.	.	.	0.21	0.28	0.70	0.70	1.25	1.11	0.77	1.11	1.32	0.63	0.21	.	.	.	8.2
>5 <=10	0.07	.	0.07	0.21	0.14	0.70	0.84	0.42	0.14	.	0.14	0.35	0.28	0.91	0.28	0.14	.	4.6
>10 <=15	.	.	0.14	0.07	0.21	0.56	0.42	0.91	1.18	1.11	0.49	0.91	0.77	0.56	0.35	0.07	0.14	7.8
>15 <=20	0.07	.	.	0.28	0.35	0.49	0.35	0.91	0.77	0.70	0.42	1.11	1.32	0.56	0.14	.	.	7.4
>20 <=25	0.14	.	.	0.07	0.35	0.63	0.35	0.70	1.11	0.91	1.39	1.53	0.84	0.63	0.07	.	.	8.7
>25 <=30	.	0.07	.	.	0.14	0.14	0.42	0.91	2.02	1.60	2.51	2.09	0.77	0.14	.	.	.	10.8
>30 <=35	0.07	.	.	.	0.07	0.14	0.14	0.63	1.39	0.77	1.53	2.09	0.14	0.14	.	.	.	7.1
>35 <=40	.	.	.	0.07	.	0.14	0.07	0.14	1.60	1.25	1.60	0.91	0.07	0.07	.	.	.	5.9
>40 <=45	.	.	.	.	.	0.21	0.14	0.21	2.02	0.84	1.60	0.84	.	0.14	.	.	.	5.9
>45 <=50	.	.	.	.	.	0.14	.	0.35	0.98	0.91	1.67	0.35	0.07	.	.	.	.	4.4
>50 <=55	.	.	.	.	0.07	.	.	0.14	.	.	0.35	0.28	.	.	.	.	.	0.8
>55 <=60	.	.	.	.	0.07	0.07	.	0.07	1.39	1.60	1.32	0.42	.	.	.	.	.	4.9
>60 <=65	.	.	.	.	.	.	.	0.14	1.53	1.60	1.81	0.14	.	.	.	.	.	5.2
>65 <=70	.	.	.	.	.	.	.	.	0.49	0.42	0.49	0.07	.	.	.	.	.	1.4
All	0.35	0.07	0.21	0.91	1.67	3.90	3.48	7.32	16.24	27.60	16.45	12.40	4.88	3.34	0.84	0.21	0.14	100.

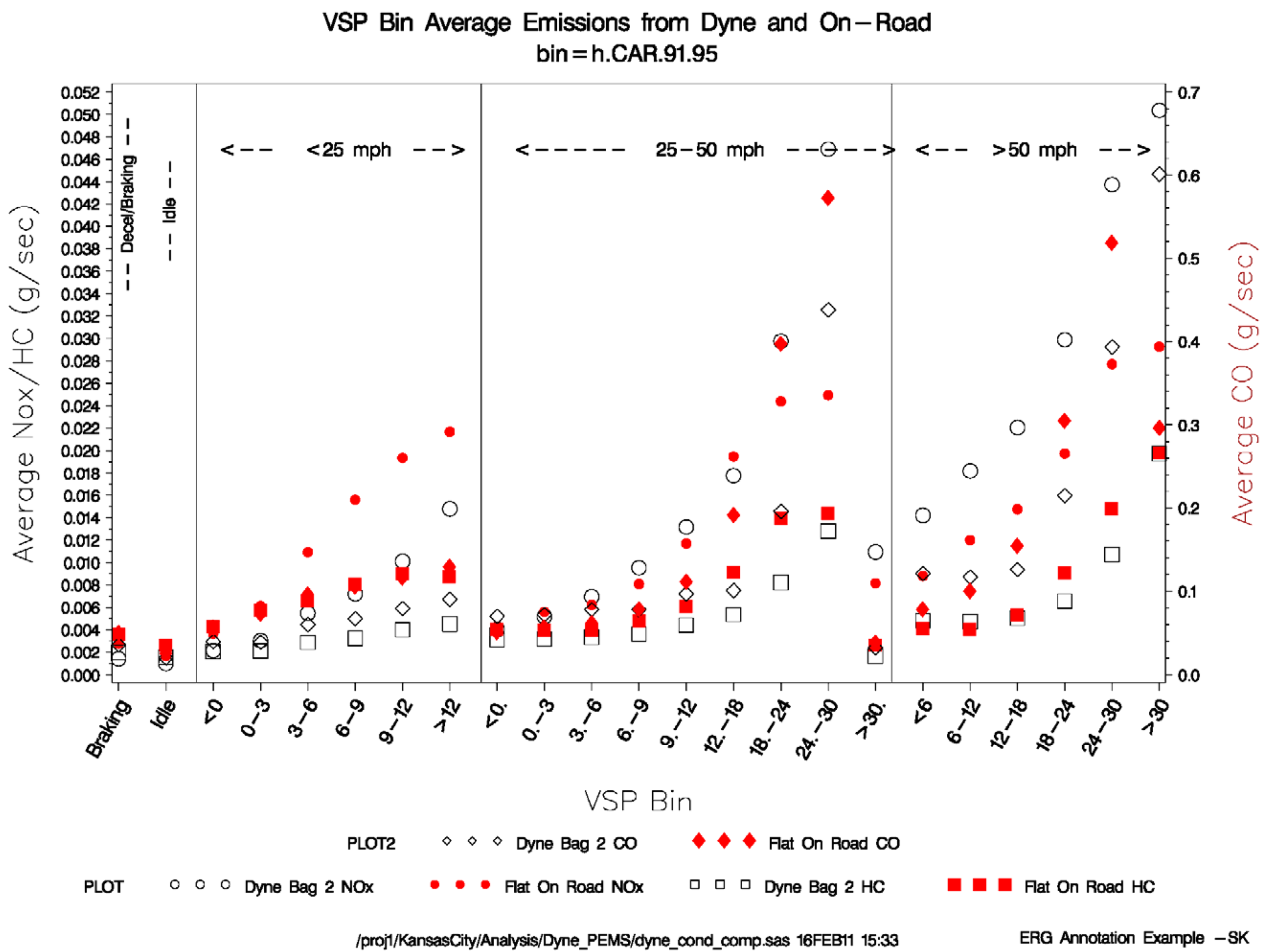


/proj1/KansasCity/Analysis/Dyne_PEMS/dyne_cond_comp.sas 16FEB11 15:33

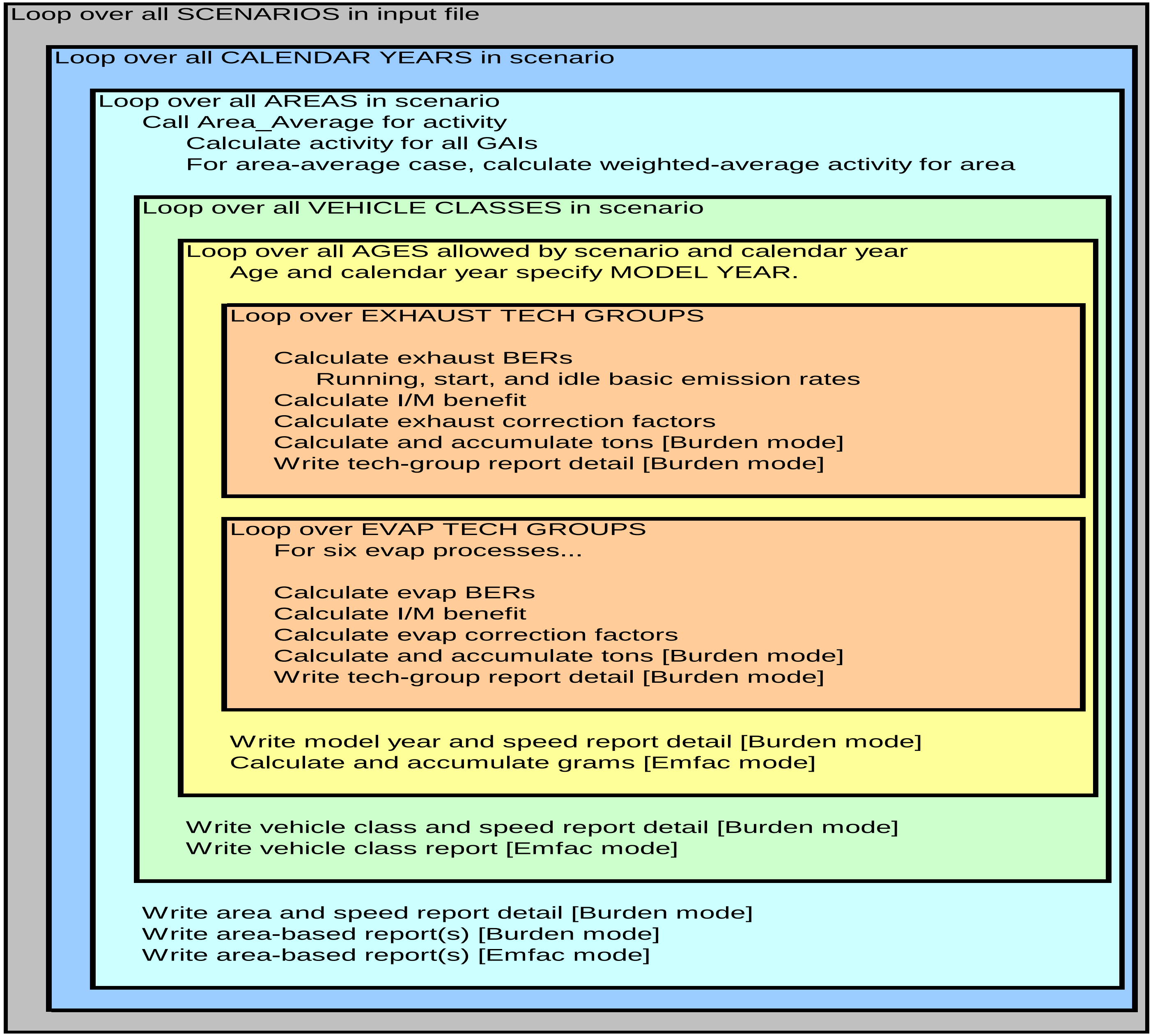
ERG Annotation Example -SK



VSP Bin Emissions from Dyne and On-Road
bin=h.CAR.91.95
Average HC (g/sec)
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-- Decel/Braking --
-- Idle --
<--- <25 mph --->
<------ 25-50 mph ------>
<--- >50 mph --->
Braking
Idle
<0
0-3
3-6
6-9
9-12
>12
<0.
0.-3
3.-6
6.-9
9.-12
12.-18
18.-24
24.-30
>30.
<6
6-12
12-18
18-24
24-30
>30
VSP Bin
PLOT
Dyne Bag 2
Flat On Road
/proj1/KansasCity/Analysis/Dyne_PEMS/dyne_cond_comp.sas 16FEB11 15:33
ERG Annotation Example -SK



VSP Bin Average Emissions from Dyne and On-Road
bin=h.CAR.91.95
Average Nox/HC (g/sec)
Average CO (g/sec)
Decel/Braking
Idle
< -- <25 mph -- >
< ----- 25-50 mph ----- >
< -- >50 mph -- >
VSP Bin
Braking
Idle
<0
0-3
3-6
6-9
9-12
>12
<0.
0.-3
3.-6
6.-9
9.-12
12.-18
18.-24
24.-30
>30.
<6
6-12
12-18
18-24
24-30
>30
PLOT2
Dyne Bag 2 CO
Flat On Road CO
PLOT
Dyne Bag 2 NOx
Flat On Road NOx
Dyne Bag 2 HC
Flat On Road HC
/proj1/KansasCity/Analysis/Dyne_PEMS/dyne_cond_comp.sas 16FEB11 15:33
ERG Annotation Example -SK


Loop over all SCENARIOS in input file
Loop over all CALENDAR YEARS in scenario
Loop over all AREAS in scenario
Call Area_Average for activity
Calculate activity for all GAIs
For area-average case, calculate weighted-average activity for area
Loop over all VEHICLE CLASSES in scenario
Loop over all AGES allowed by scenario and calendar year
Age and calendar year specify MODEL YEAR.
Loop over EXHAUST TECH GROUPS
Calculate exhaust BERs
Running, start, and idle basic emission rates
Calculate I/M benefit
Calculate exhaust correction factors
Calculate and accumulate tons [Burden mode]
Write tech-group report detail [Burden mode]
Loop over EVAP TECH GROUPS
For six evap processes...
Calculate evap BERs
Calculate I/M benefit
Calculate evap correction factors
Calculate and accumulate tons [Burden mode]
Write tech-group report detail [Burden mode]
Write model year and speed report detail [Burden mode]
Calculate and accumulate grams [Emfac mode]
Write vehicle class and speed report detail [Burden mode]
Write vehicle class report [Emfac mode]
Write area and speed report detail [Burden mode]
Write area-based report(s) [Burden mode]
Write area-based report(s) [Emfac mode]

Evaporative Emissions

- Evap calculations are done for a specific combination of:
  - Calendar year,
  - Area,
  - Vehicle class,
  - Vehicle age, and
  - Evap technology group.
- Evap emissions are calculated for six distinct emissions processes:
  - Hot soak
  - Running losses
  - Partial-day resting losses
  - Multi-day resting losses
  - Partial-day diurnal losses
  - Multi-day diurnal losses
- There are three emitter class regimes defined in the model:
  - Normal
  - Moderate
  - High

Hot Soak Emissions

Basic Emission Rates are calculated for each emitter regime as:

Type of Equation Based on Tech Group		Age	Odometer
	Linear	1	2
	Exponential	3	4

Emissions Calculations:

$$EF_{N,M,H} = EF_O + Det * \begin{bmatrix} Age \\ or \\ Odo \end{bmatrix}$$

or

$$= \exp\left(EF_O + Det \begin{bmatrix} Age \\ or \\ Odo \end{bmatrix} \right)$$

Running Loss Emissions

Emission rates for running loss emissions are calculated by the use of the following equation:

$$EF_{(N,M,H)} = Zm$$
$$+ DR * Odo$$
$$+ RL\_Age * Age$$

A correction factor is calculated for use later which accounts for increased running loss due to longer trips. This factor is calculated as:

RL_TOF = RL_TIME * TIME_ON[a1]
Evap_EF = EF $_{(N,M,H)}$ + RL_TOF

Partial Day Resting Losses

Stored in :

Partial day results:	Rest_BER(1,:,:,:)
Single day results:	Rest_BER(2,:,:,:)
Multiple day results:	Rest_BER(3,:,:,:)

Next, the BER is calculated as a function of temperature T. For normal and moderate emitters, between 55F and 65F the emissions relationship is linear:

$\text{Rest\_BER\_All} = (T-55) * EF_4 * \text{RVP\_CF}$

Beyond 65°F, the equation form used is a polynomial in temperature:

$\text{Rest\_BER\_All} = [EF_{0} + EF_1 * T + EF_2 * T^2 + EF_3 * T^3] * \text{RVP\_CF}$

Where:

Numerator = A + B * (T+15) + C * RVP + D * (T+15) * RVP

Denominator = A + B * (T+15) + C * 9.0 + D * (T+15) * 9.0

RVP_CF = Numerator/Denominator

The Coefficients A,B, C, and D are stored in Array EVAP_TCF, which is the file TCF_Data.for

Multiple Day Resting Losses

Multiple day resting losses are calculated by scaling the partial day BERs with a multi-day factor selected based on the tech group:

$$Rest\_BER\_All_2 = Rest\_BER\_All_1 * MD\_Factor_2$$
$$Rest\_BER\_All_3 = Rest\_BER\_All_1 * MD\_Factor_3$$

Partial Day Diurnal Emissions

Stored in :

Partial day results:	Drnl_BER(1,:,:,:)
Single day results:	Drnl_BER(2,:,:,:)
Multiple day results:	Drnl_BER(3,:,:,:)

Diurnal emission factors are a function of primary temperature and RVP. In the EVAP subroutine an additive emission factor is estimated as follows and another multiplicative emission factor is applied in Burden.

Drnl_BER = F (T)
= Additive in Evap Subroutine
= Multiplicative in Burden

$$\text{Drnl\_CF} = CF_0 + CF_1 * (T + 15) + CF_2 * RVP + CF_3 * (Temp + 15) * RVP$$

$$\text{Drnl\_BER(1)} = A + B * Temp + C * Temp^2 + D * Temp^3 + \text{Dirnl\_CF}$$

Diurnal losses only occur when temperature is rising.
Diurnal emission factors are stored for each vehicle age, emitter category, and tech group.

Multiple Day Diurnal Emissions

Multiple day diurnal losses are calculated by scaling the partial day BERs with a multi-day factor selected based on the tech group:

$$Drnl\_BER\_All_2 = Drnl\_BER\_All_1 * MD\_Factor_2$$
$$Drnl\_BER\_All_3 = Drnl\_BER\_All_1 * MD\_Factor_3$$

Evap I/M

- Not in current version of EMFAC HK – may be added later
- I/M only causes the regime size fractions to change- Similar to Exhaust Calculations
- Emissions changes are caused as vehicles “MOVE” from higher emitting regimes to lower emitting regimes
- The emissions levels of emissions regimes doesn’t change
- After I/M the fraction of high emitters is lower

For evap emissions, the overall purpose of subroutine I_and_M is to load arrays EVAP_PRE_REGFRAC and EVAP_POST_REGFRAC with regime fractions that represent the I/M-corrected fleet

EVAP_REGFRAC - Regime fractions for "no I/M" fleet
EVAP_PRE_REGFRAC - Regime fractions for fleet prior to I/M inspection
EVAP_POST_REGFRAC - Regime fractions for fleet immediately after I/M inspection

Evap IM Cycle

Loop from age 1 to scenario age

- IMSetUpTest
- IMEvIDRates - Set up ID rates (How many high emitters are identified)
- IMEvMove - Set repair effectiveness in "move" matrix
- IMInspect - Perform "inspection" by calculating ID rates for scheduled and unscheduled (change of ownership) inspections
- IMRepair - Apply ID rates & repair MOVE matrices to regime fractions
- IMAfterRepair
- IMNextYear – Prepare for next loop: Copy current year into “previous year.”

End loop

Evap IM Cycle

The evap ID rates are based almost entirely on the gas cap fail rate. The gas cap fail rate calculation uses an odometer-based equation:

GasCapFailRate = $K_0/(1 + B_0 * \exp(R_0 * \text{Odometer}[a1]))$

K_0, B_0, R_0 in Function GasCapFailRate in I_and_M.for

Evap ID Rate[a2] = $\frac{GasCapFailRate}{FailRateforModerates}$ .. Are estimated in IMEvpIDRates

Evap_MOVE Normals = All vehicles that fail are assumed to be repaired to

Post_Evap_RegFrac =

= [PreI/M RegFrac – IDRate]
+ [MOVE matrix * IDRate]

$$= \left[\begin{bmatrix}\text{PRE}-\text{IM}\\ \text{Regsize}\end{bmatrix} - [\text{IDRate}]\right] + \left[\begin{bmatrix}\text{MOVE}\\ \text{Matrix}\end{bmatrix} * [\text{IDRate}]\right]$$

$$= \left[\begin{bmatrix}S & \%\\ \vdots & \\ N & \%\end{bmatrix} - \begin{bmatrix}S & \%\\ \vdots & \\ N & \%\end{bmatrix}\right] + \left[\left[\begin{bmatrix}S\cdots N\\ \vdots\\ N\end{bmatrix} * \begin{bmatrix}S & \%\\ \vdots & \\ N & \end{bmatrix}\right]\right]$$

$$= \text{POST I/M}\begin{bmatrix}S & \%\\ \vdots & \\ N & \%\end{bmatrix}$$

Evap Correction Factors

Hot Soak Correction

Temperature and RVP correction: The hot soak corrections for temperature and RVP are based on “correcting” temperature from 75F to actual and “correcting” RVP from 9.0psi to actual, using the following equation form:

$$\text{HS\_RVP\_TEMP\_CF} = \frac{\exp\left(A + B * (T - 75) + C * (Rvp - 9)\right)}{\exp\left(A + B * (75 - 75) + C * (9 - 9)\right)}$$

Estimate the number of soak events in time periods that are below 40 minutes (5 periods, periods are 0-5, 6-10, 11-20, 21-30, 31-40 (with mean of 35), 41-50, 51-60, 61-120 etc.)

Run_Frac allows us to discount the hot soak emissions which follow very short trips (4 minutes or less).

$$\text{Run Frac} = \left[\frac{\text{Sum of Trips which are greather than 5 minutes}}{\text{Sum of all trips}}\right]$$

$P = [C_1 * [C_2 t + C_3 t^2 + C_4 t^3 + C_5 t^4]/C_6/100]$
F = frequency of trips with this time-off period at this hour

Where t is the length of the time-off period from TIME_OFF, C_1 to C_6 are constants specific to the emitter regime, and F is evaluated from array TIME_OFF_FREQ.

Partial _Soak factor = Sum(P*F) / Sum(F)

The function result is the combination of the two corrections:

HS_BER_TO_GM_PER_HR = Run_Frac * **Partial_Soak**

The final hot soak correction factor is the combination of temperature and RVP correction and basis conversion:

CF = HS_RVP_TEMP_CF * HS_BER_TO_GM_PER_HR

Running Loss Correction

$$RL_{CF} = \frac{A + Time\_On * (B * RVP * Temp + C + RVP + D * Temp)}{E + F * TIME\_ON}$$

RL_{CF} are only valid for Time_On values < 60 minutes

Evap EF ( ) =

$$\sum_{TIMEON} RL\_TOF * RL_{cf} * TIME\_ON\_FREQ$$

Time ON Matrix

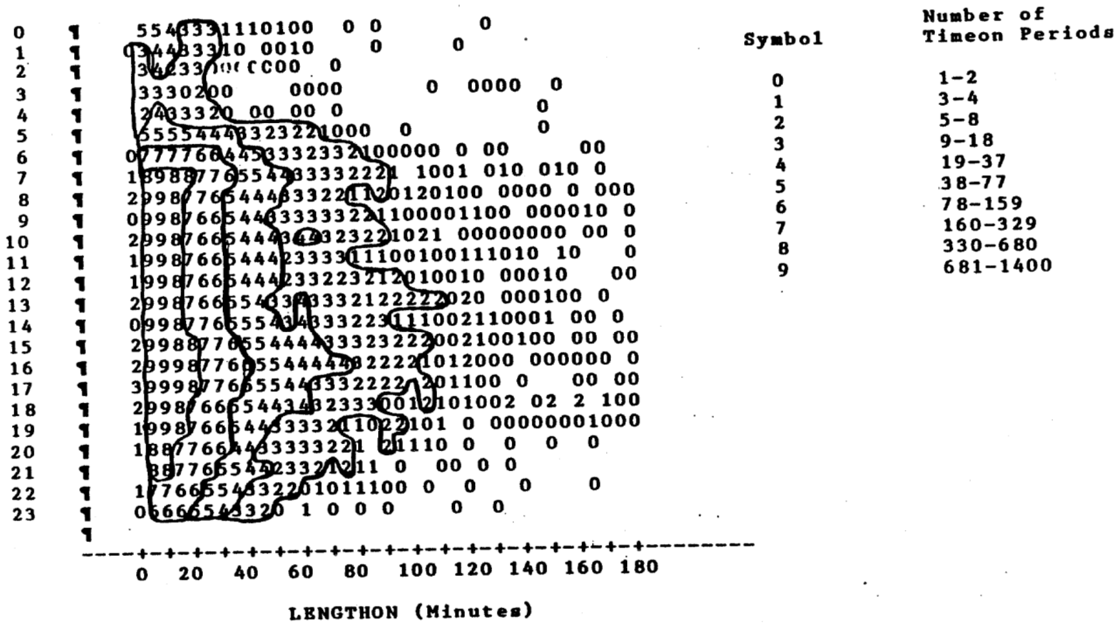


Figure 6-11. Frequency Distributions of Timeon Periods (Monday-Friday)

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Diurnal and Resting Loss Corrections

The four resting and diurnal loss processes are not corrected any further for RVP and Temperature, the corrections are include in the raw BER:

Partial day resting loss CF	=	1.0
Multi-Day Resting Loss CF	=	1.0
Partial Day Diurnal CF	=	1.0
Multi-Day Diurnal CF	=	1.0

Evap EF = Rest_BER (1,2,3) * Activity (AT_Rest(1,2,3)

Evap EF = Diurnal_BER (1,2,3) * Activity (AT_Rest(1,2,3)

Partial – Index 1
Multiple – Sum of 2 and 3

Time OFF (AT_Rest) Matrix

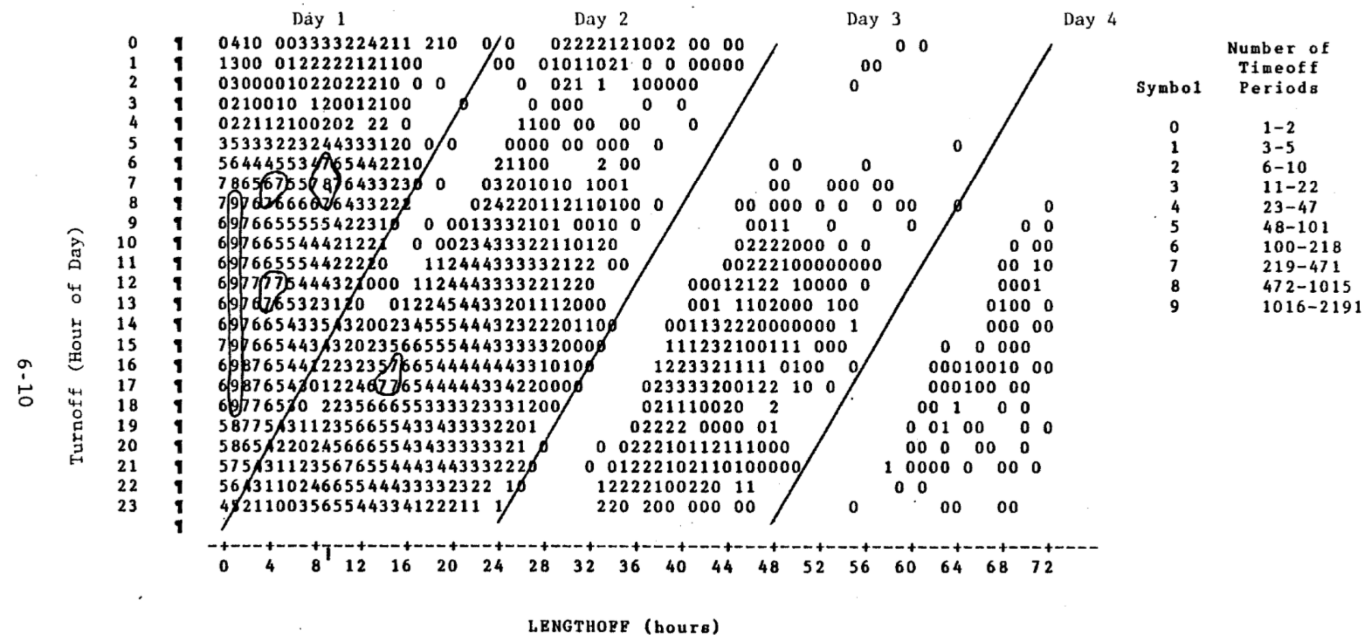


Figure 6-3. Frequency Distribution of Timeoff Periods (Monday-Friday)

Evaporative Emissions –

Fuel Cap Survey

- Sampled at random a certain proportion of vehicles of different vehicle ages from the relevant vehicle classes for a fuel cap pressure test.
- Conducted a survey on the general maintenance condition of the vehicle and a visual assessment.

Distributions of Private Cars over make and First Reg. Year

Year of first registration	Toyota	Honda	Nissan	Mazda	Benz	BMW	Mitsubishi	Others	Survey conducted
2005	32	27	8	2	8	5	2	24	108
2004	37	12	6	5	11	5	1	18	95
2003	27	13	6	5	13	10	7	14	95
2002	30	23	16	5	5	2	3	15	99
2001	22	24	8	5	8	3	7	20	97
2000	27	10	12	11	15	2	7	11	95
1999	25	6	9	17	8	2	9	20	96
1998	26	20	9	8	9	4	8	10	94
1997	28	20	15	8	4	6	9	4	94
1996	6	13	6	5	10	3	6	7	56
1995	15	9	9	6	9	5	5	2	60
1994	14	13	5	5	6	2	5	5	55
1993	24	5	7	4	6	2	3	6	57
1992	14	4	1	2	5	1	2	4	33
1988-1991	10	2	4	1	7	1	1	7	33
before 1988	3	0	0	0	0	1	0	7	11
								Total	1178

* These brands made up about 80% of the whole fleet

Sampling Locations

Motor cycle repair shop

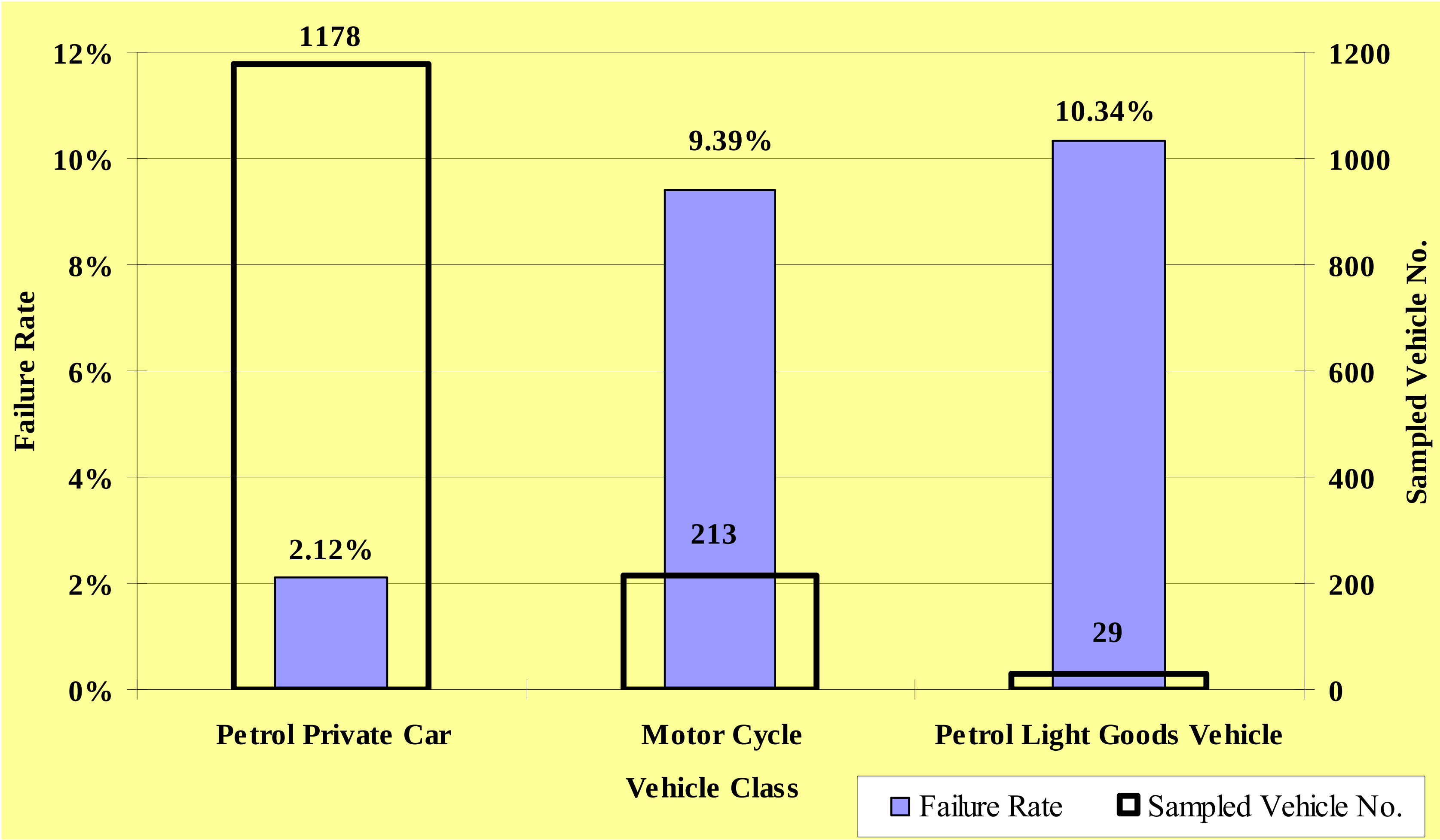
Petrol filling station

Wash & Wax Shop

Private car repair shop

To ensure randomness, surveys were mainly conducted at dKC petrol filling stations over strategic locations.

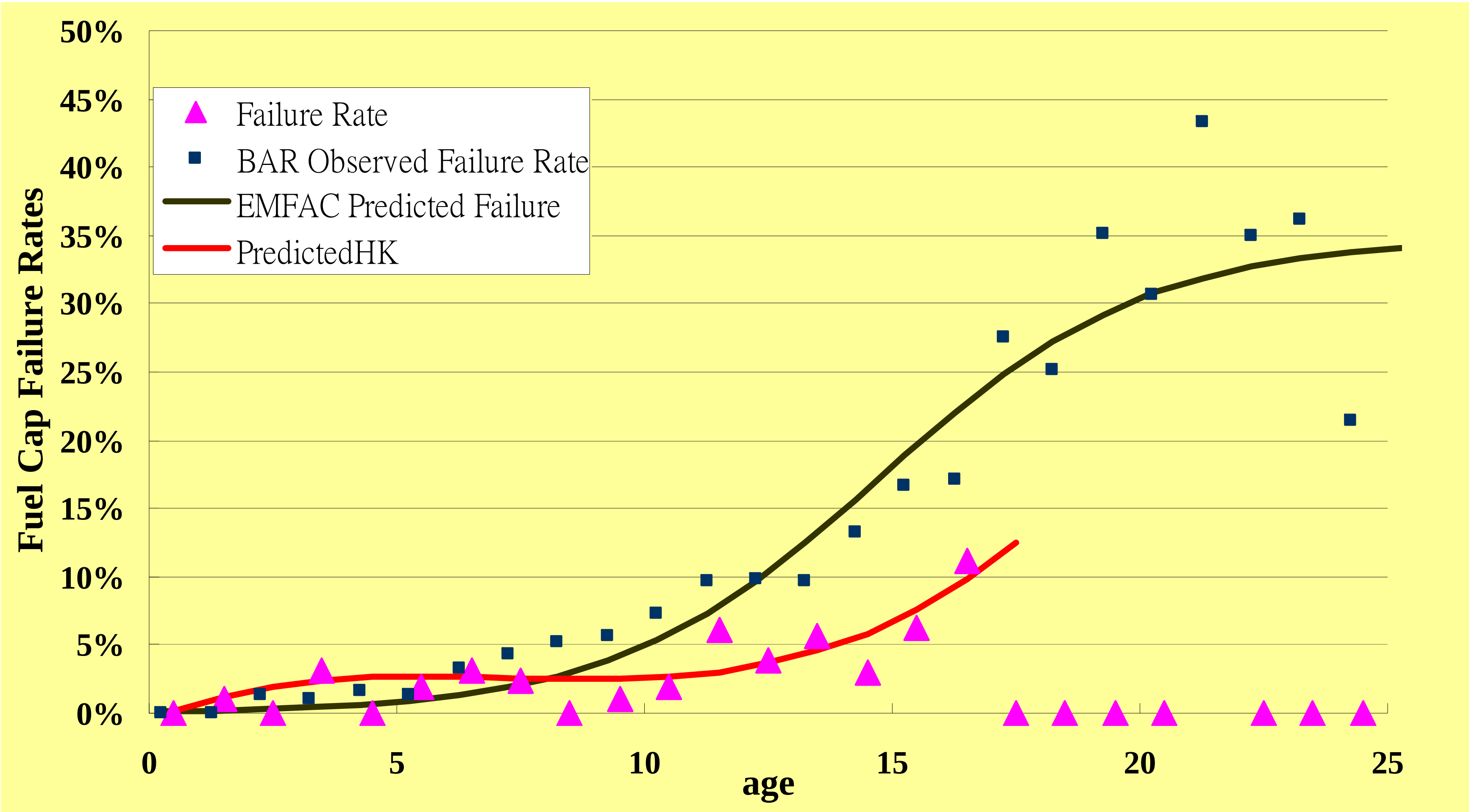
Fuel Cap Failure Rates of Petrol Vehicles in Evaporative Survey in 2006



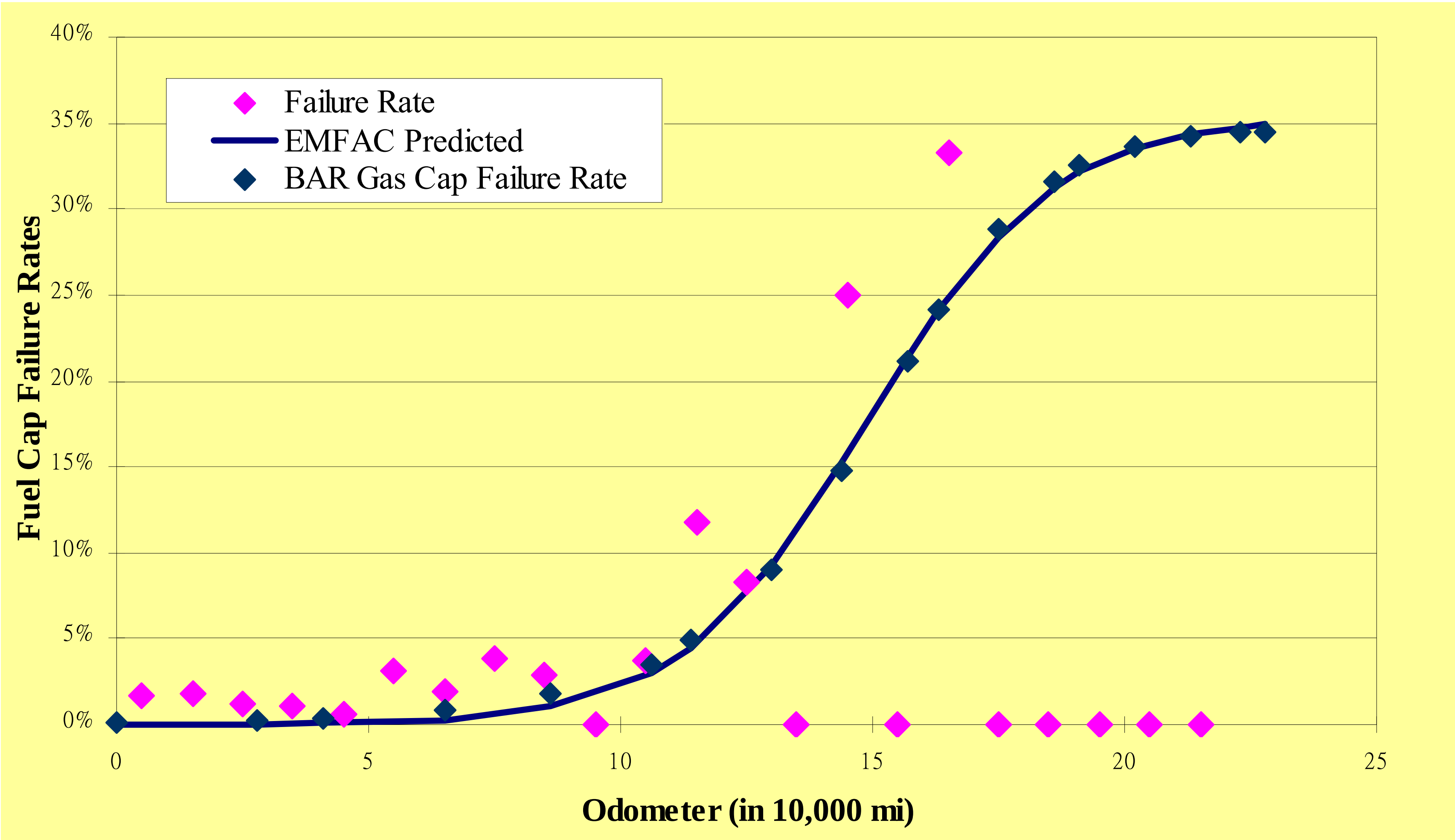
Key Observations

- The overall evaporative emissions for private cars in Hong Kong is relatively minor. Out of the 1178 cars sampled, 2% failed the test.
- The emission problems for motorcycles are much higher. Out of 213 motorcycles sampled, 9% failed the test.
- The emission problems for light goods vehicles is inconclusive due to small sample size (3 out of 29 vehicles failed the test.)

Comparison of Fuel Cap Failure Rates with BAR for Petrol Private Cars



Comparison of Fuel Cap Failure Rates with BAR for Petrol Private Cars



Key Observations – Private Cars

- As compared with the observation of BAR and EMFAC's predicted failure rate, the private cars in Hong Kong have a lower failure rates on a vehicle age basis probably because of their lower mileage (being typically less than 7,500 mi a year).
- But it showed a higher values when young and when compared on a mileage basis, the failure rate has become somewhat higher in the case of Hong Kong vehicles probably due to general lack of concern on evaporative emissions.
- For older age (>10) , due to small sample size (over 90% of cars are of age $\leq$12), the result is inconclusive.