WLTC* Construction

Proposed by Japan

GRPE/WLTP-IG/ DHC subgroup

14 October 2010

Rev1. 17 October 2010

*) WLTC : Worldwide harmonized Light-duty driving Test Cycle

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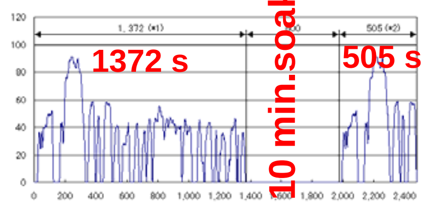
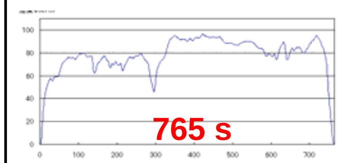
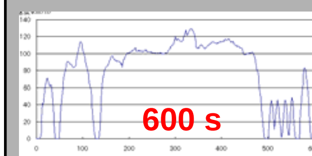
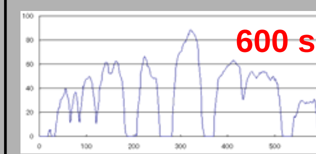
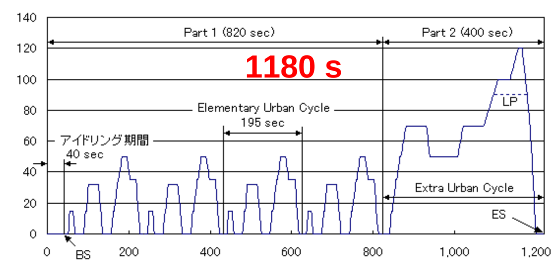
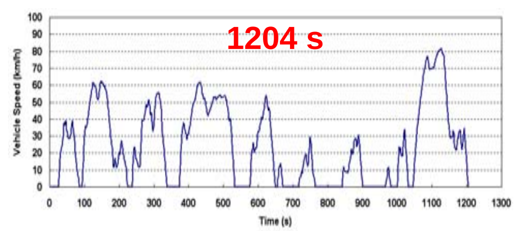
1. Cycle Construction

1.1. Current Test Cycle in EU, US and Japan

1.2. Requirement on Test Cycle

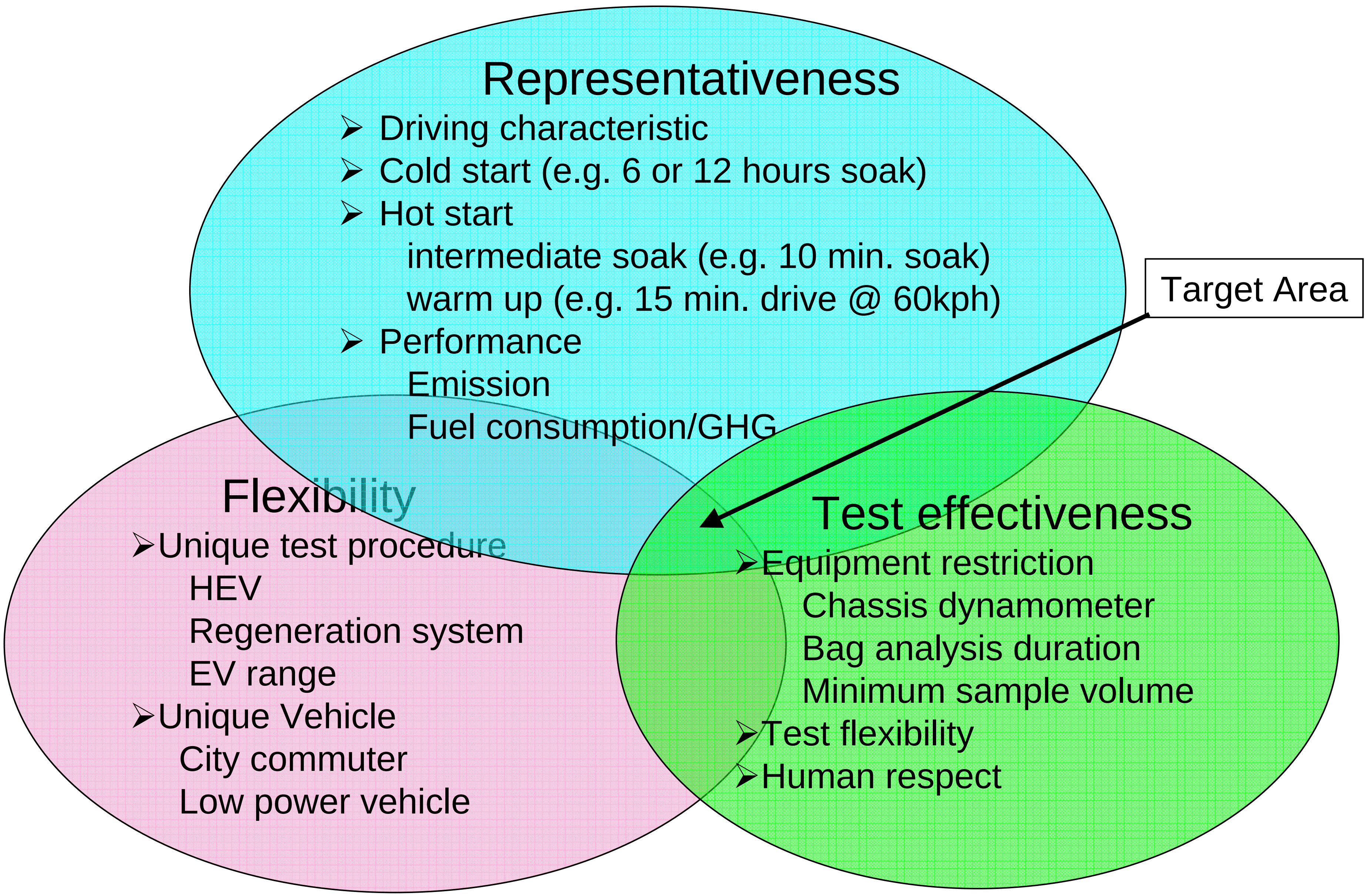
1.3. Case Study of Cycle Construction

1.1. Current Cycle Construction

	Urban / Rural	Motorway	Aggressive mode	AC test
US	Cold start Hot 	Hot start 	Hot start 	Hot start 
EU	Cold start 		NA	NA
JAPAN	Cold start and Hot start (independent test with preconditioning) 		NA	NA

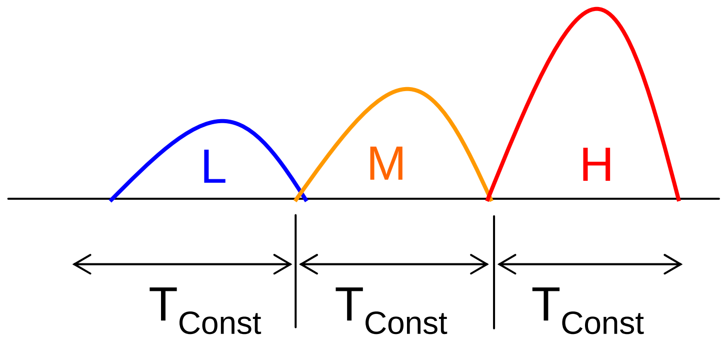
According to WLTP-DHC-05-04, Urban/Rural/Motorway phase will be converted to Low/Middle/High phase respectively.

1.2. Requirement on Test Cycle



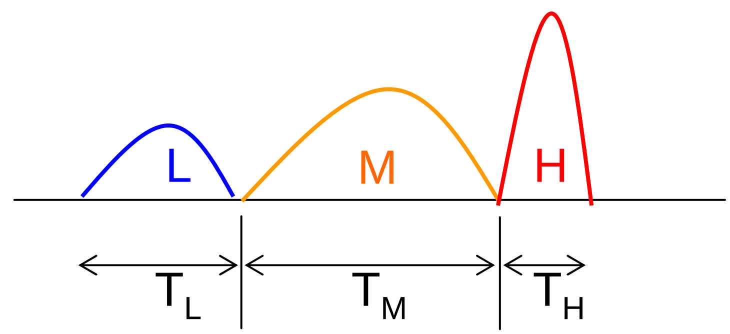
1.3.1. Case Study of Cycle Construction

A. 1:1:1 (≒WMTC)



(= 1:1:1)

B. Based on statistical data (≒WHDC)



$$\mathrm{TimeRatio}_k = \frac{T_k}{T_L + T_M + T_H} = W_k$$

k = L,M,H

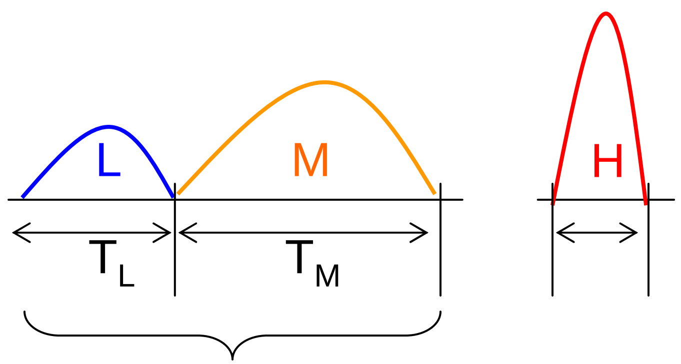
$$W_L = \frac{\sum_i (W_{L,i} \times T_{L,i})}{\sum_i (W_{L,i} \times T_{L,i}) + \sum_i (W_{M,i} \times T_{M,i}) + \sum_i (W_{H,i} \times T_{H,i})}$$

$$W_M = \frac{\sum_i (W_{M,i} \times T_{M,i})}{\sum_i (W_{L,i} \times T_{L,i}) + \sum_i (W_{M,i} \times T_{M,i}) + \sum_i (W_{H,i} \times T_{H,i})}$$

$$W_H = \frac{\sum_i (W_{H,i} \times T_{H,i})}{\sum_i (W_{L,i} \times T_{L,i}) + \sum_i (W_{M,i} \times T_{M,i}) + \sum_i (W_{H,i} \times T_{H,i})}$$

Ref. WLTP-DHC-03-02

C. Compromised way (≒LA4+HW)



T_L+T_M=1200~1372

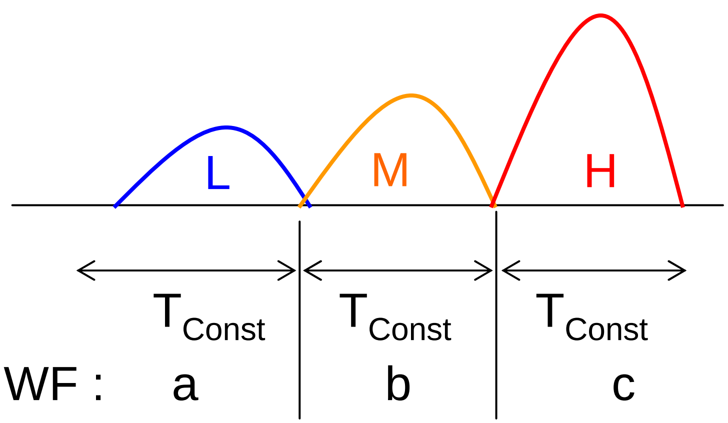
$T_L:T_M=W_L:W_M$

T_H=600~765

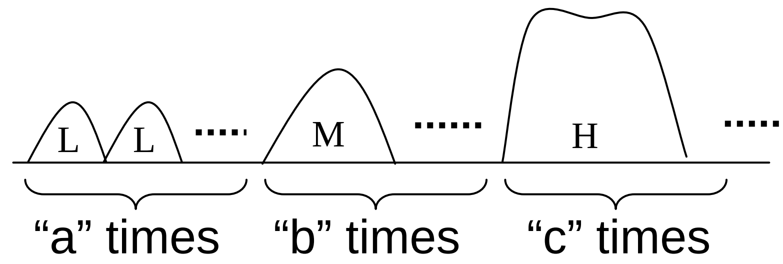
1.3.2. Repeat Drive Cycle – A -

When take into account of Ki determination of regeneration system and/or EV range measurement, repeated cycle procedure is one of key elements of cycle construction.

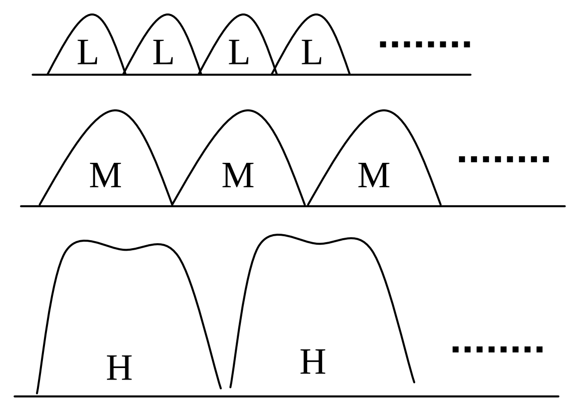
A. 1:1:1 (≒WMTC)



A1. Repeat “x” times of each mode

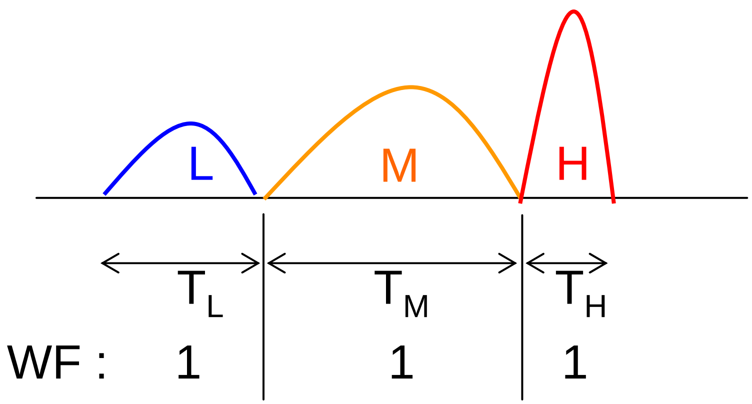


A2. Repeat each mode independently, then combine.



1.3.3. Repeat Drive Cycle – B -

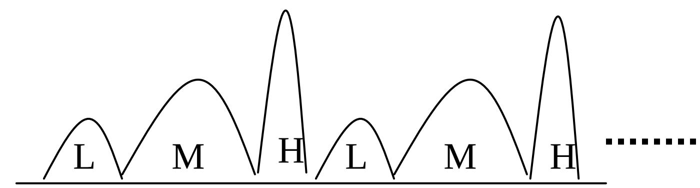
B. Based on statistical data (≒WHDC)



$$\text{TimeRatio}_k = \frac{T_k}{T_L + T_M + T_H} = W_k$$

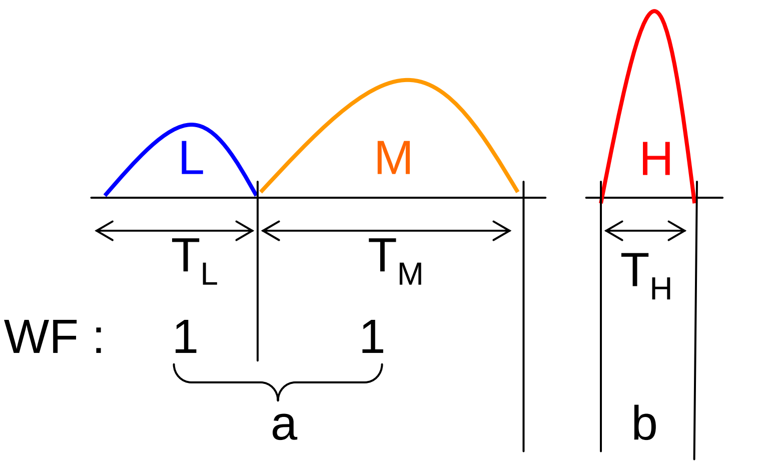
k = L,M,H

B1. Repeat complete cycle



1.3.3. Repeat Drive Cycle – C -

C. Compromised way (≒LA4+HW)

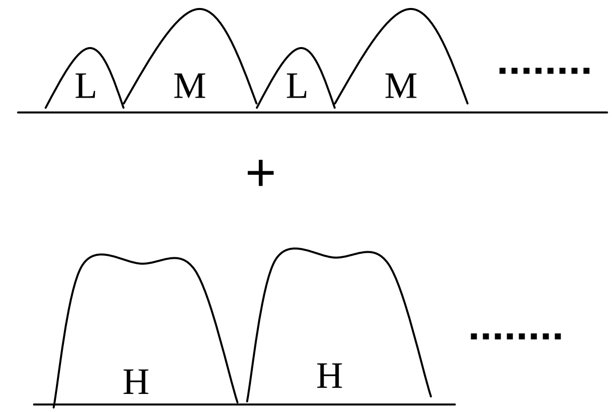


T_L+T_M=XXX~1372

$T_L:T_M=W_L:W_M$

T_H=XXX~765

C. Repeat combined L/M mode and H mode independently



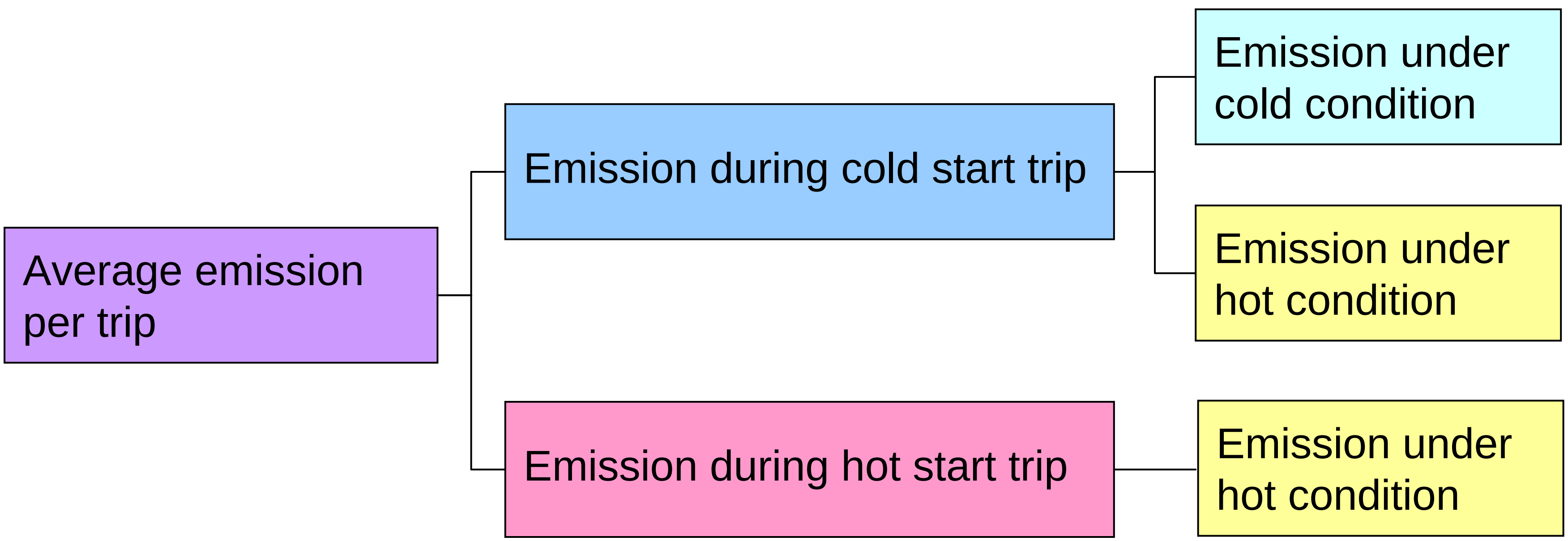
2. Cold/Hot Start Weighting

2.1. How to obtain real-world emissions ?

◆Requirements

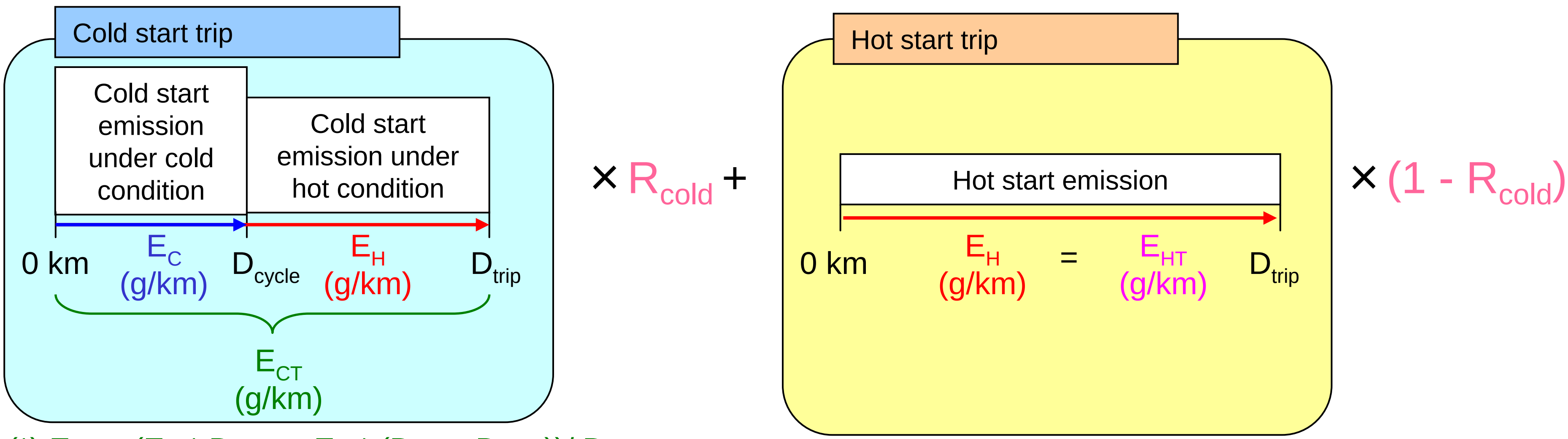
Emission that should be evaluated = Average emission per trip

◆Detail of average emission per trip



2.2. Average Emission per Trip and Cold Weighting Factor

Total Emission E_{total} (g/km) formula is as following.



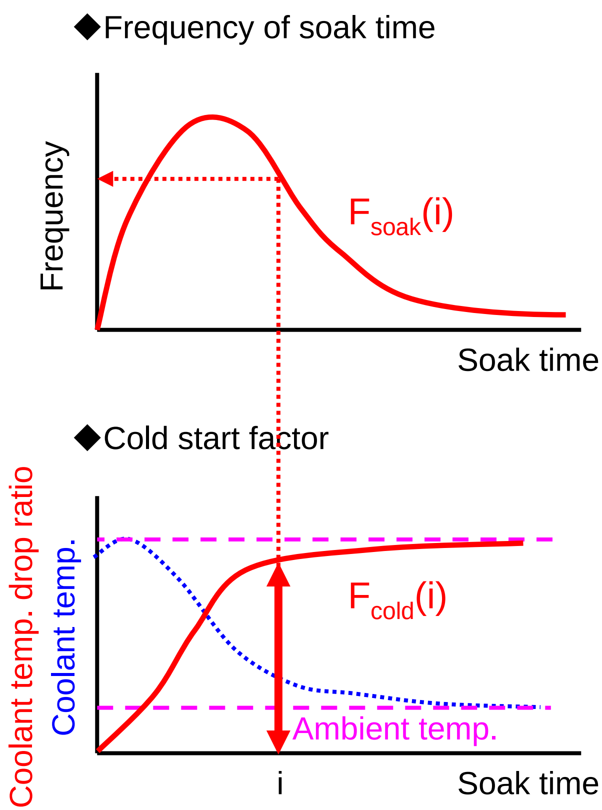
(*) $E_{CT} = (E_C * D_{cycle} + E_H * (D_{trip} - D_{cycle}))/ D_{trip}$

$$E_{total} = E_{CT} * R_{cold} + E_{HT} * (1 - R_{cold})$$
$$= (D_{cycle} * R_{cold} / D_{trip}) * E_C + (1 - D_{cycle} * R_{cold} / D_{trip}) * E_H$$
$$= WF_C * E_C + (1 - WF_C) * E_H$$
$$WF_C = D_{cycle} * R_{cold} / D_{trip}$$

WF_c: Cold start weighting
R_{cold}: Cold start trip ratio
D_{trip}: Average one trip distance (km)
D_{cycle}: Cycle distance (km)
E_{CT}: Cold start trip emission (g/km)
E_{HT}: Hot start trip emission (g/km)
E_C: Cold start emission (g/km)
E_H: Hot start emission (g/km)

2.3. Cold Start Trip Ratio

Generate the cold start trip ratio by multiplying the soak time distribution and the coolant temperature drop ratio as the emission increase ratio



Cold start trip ratio R_{cold} :

$$R_{cold} = \sum \left[F_{soak}(i) \cdot F_{cold}(i) \right]$$

Where,

R_{cold}: Cold start trip ratio (= Average cold start emission increment ratio)

F_{soak}: Frequency of soak time

F_{cold}: Cold start factor (Coolant temp. drop ratio)

2.4.1. Calculation Sample

★Low/Mid. cold + Low/Mid hot + High hot

Cold Start Trip

	Low/Mid. Cold	Low/Mid. Hot	High Hot
WF	W_{LM}		W_H
Distance (km)	D_{trip}		
	$D_{trip} * W_{LM}$		$D_{trip} * W_H$
	$D_{c,LM}$	$D_{trip} * W_{LM} – D_{c,LM}$	
Emission (g/km)	E_{CT}		
	$E_{C,LM}$	$E_{H,LM}$	$E_{H,H}$
Mass (g)	M_{CT}		
	$D_{c,LM} * E_{C,LM}$	$(D_T * W_{LM} – D_{c,LM}) * E_{H,LM}$	$(D_{trip} * W_H) * E_{H,H}$

◆Emission during cold start trip E_{CT} (g/km)

$$E_{CT} = M_{C,T} / D_{trip}$$

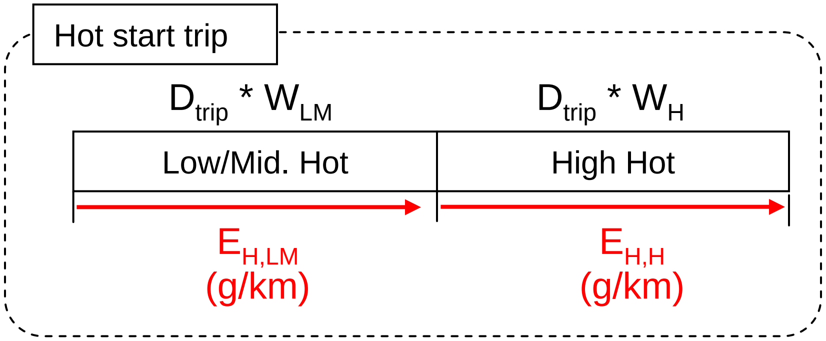
$$= (D_{c,LM} * E_{C,LM} + (D_{trip} * W_{LM} – D_{c,LM}) * E_{H,LM} + (D_{trip} * W_H) * E_{H,H}) / D_{trip}$$

2.4.2 Calculation Sample

★Low/Mid. cold + Low/Mid hot + High hot (conti.)

◆Emission during hot start trip E_{HT} (g/km)

$$E_{HT} = W_{LM} * E_{H,LM} + W_H * E_{H,H}$$



◆Total emission E_{total} (g/km)

$$E_{total} = E_{CT} * R_{cold} + E_{HT} * (1 – R_{cold})$$

$$= (D_{C,LM} * R_{cold} / D_{trip}) * E_{C,L} + (W_{LM} – D_{C,LM} * R_{cold} / D_{trip}) * E_{H,L} + W_H * E_{H,H}$$

$$= WF_{LM,C} * E_{C,LM} + WF_{LM,H} * E_{H,LM} + WF_{H,H} * E_{H,H}$$

◆Cold/Hot weighting factor

$$WF_{LM,C} = D_{c,LM} * R_{cold} / D_{trip}$$

$$WF_{LM,H} = W_{LM} – D_{c,LM} * R_{cold} / D_{trip}$$

$$WF_{H,H} = W_H$$

2.5. Summary

◆Calculation process

- ✓ Calculate cold start trip ratio
  Generate the cold start ratio by multiplying the soak time distribution and the coolant temperature drop ratio
- ✓ Calculate cold start WF
  Generate the cold start WF based on average one trip distance cold start trip ratio and test cycle distance

◆Required information/data

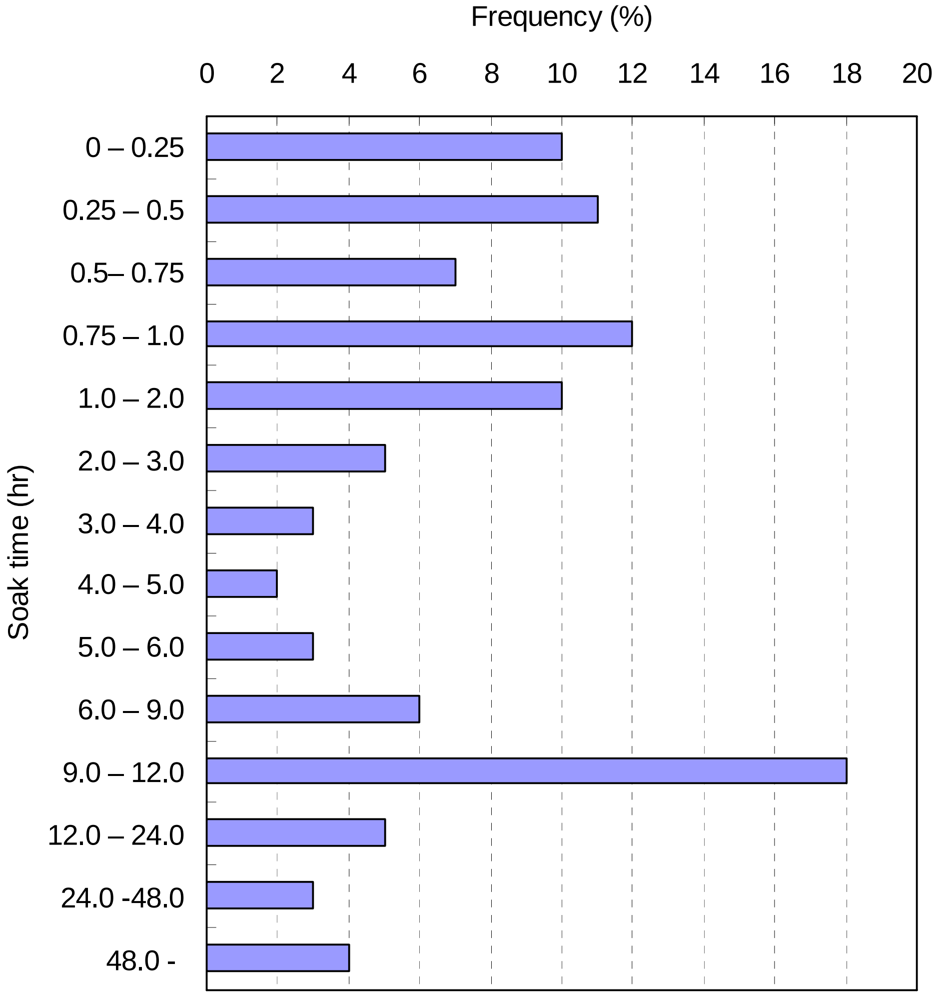
- ✓ Investigate the following two items based on actual vehicle usage
  - ✓ Distribution of soak time
  - ✓ Driving distance per trip
- ✓ Investigate the following based on engine bench test
  - ✓ Coolant temperature drop ratio
- ✓ Other factors
  - ✓ Test cycle distance
  - ✓ The ratio of traffic volume in each phase (L/M/H)

In Japan, these figures are obtained based on survey and traffic senses.

2.6. Required Data -1

◆Distribution of soak time

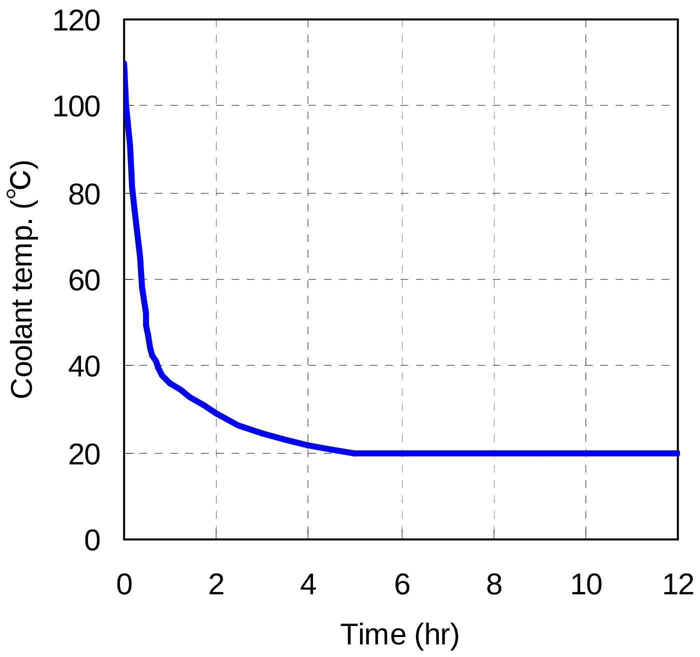
Soak time	Frequency	
	Passenger Car	Light duty commercial vehicle
(hour)	(%)	(%)
0 – 0.25	10.0	10.0
0.25 – 0.5	11.0	11.0
0.5– 0.75	7.0	7.0
0.75 – 1.0	12.0	12.0
1.0 – 2.0	10.0	10.0
2.0 – 3.0	5.0	5.0
3.0 – 4.0	3.0	3.0
4.0 – 5.0	2.0	2.0
5.0 – 6.0	3.0	3.0
6.0 – 9.0	6.0	6.0
9.0 – 12.0	18.0	18.0
12.0 – 24.0	5.0	5.0
24.0 -48.0	3.0	3.0
48.0 -	4.0	4.0
Total	100.0	100.0



2.6. Required Data -2

◆Cold start factor

Soak time	Passenger car		Light duty commercial vehicle	
	Coolant temp.	Cold start factor	Coolant temp.	Cold start factor
(hour)	(℃)	(-)	(℃)	(-)
0	110	0		
0 – 0.25	73	0.41		
0.25 – 0.5	47	0.70		
0.5– 0.75	40	0.78		
0.75 – 1.0	36	0.82		
1.0 – 2.0	29	0.90		
2.0 – 3.0	25	0.95		
3.0 – 4.0	22	0.98		
4.0 – 5.0	20	1.0		
5.0 – 6.0	20	1.0		
6.0 – 9.0	20	1.0		
9.0 – 12.0	20	1.0		
12.0 – 24.0	20	1.0		
24.0 -48.0	20	1.0		
48.0 -	20	1.0		



3. Gear Shift Points

3.1. Analysis Method

3.2. How to define the gear position ?

3.3. Definition of Shift Change

3.4. Factor Analysis / Frequency Distribution

3.5. Regression Analysis

3.6. Analysis Sample (JC08)

3.1. Analysis Method

➢ Developed gear shift points based on in-use survey to represent the real driving behavior.

In-use data collection

↓

Factor analysis
Frequency distribution

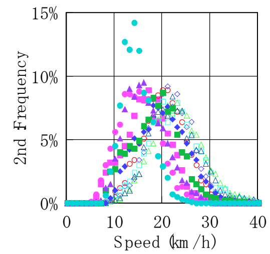
↓

Regression Analysis
Develop Shift point equation

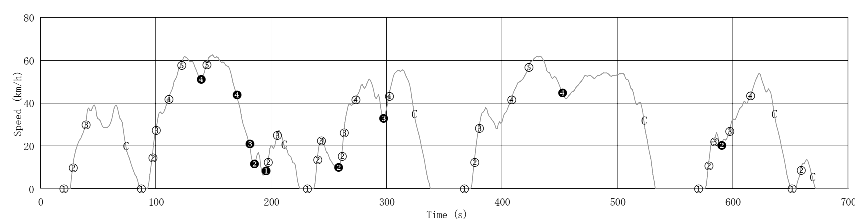
↓

Validation

ex. 2nd Gear Analysis



G(x)=a*V+b*A+・・・・



3.2. How to define the gear position ?

- In case of manual gear shift, the formula for calculating vehicle speed would be the following if the clutch was engaged.

$$V = \frac{2\pi r \cdot Ne}{i_t \cdot i_f}$$

where,

V: Vehicle speed (km/h)

Ne: Engine speed (1/min)

r: radius of tire

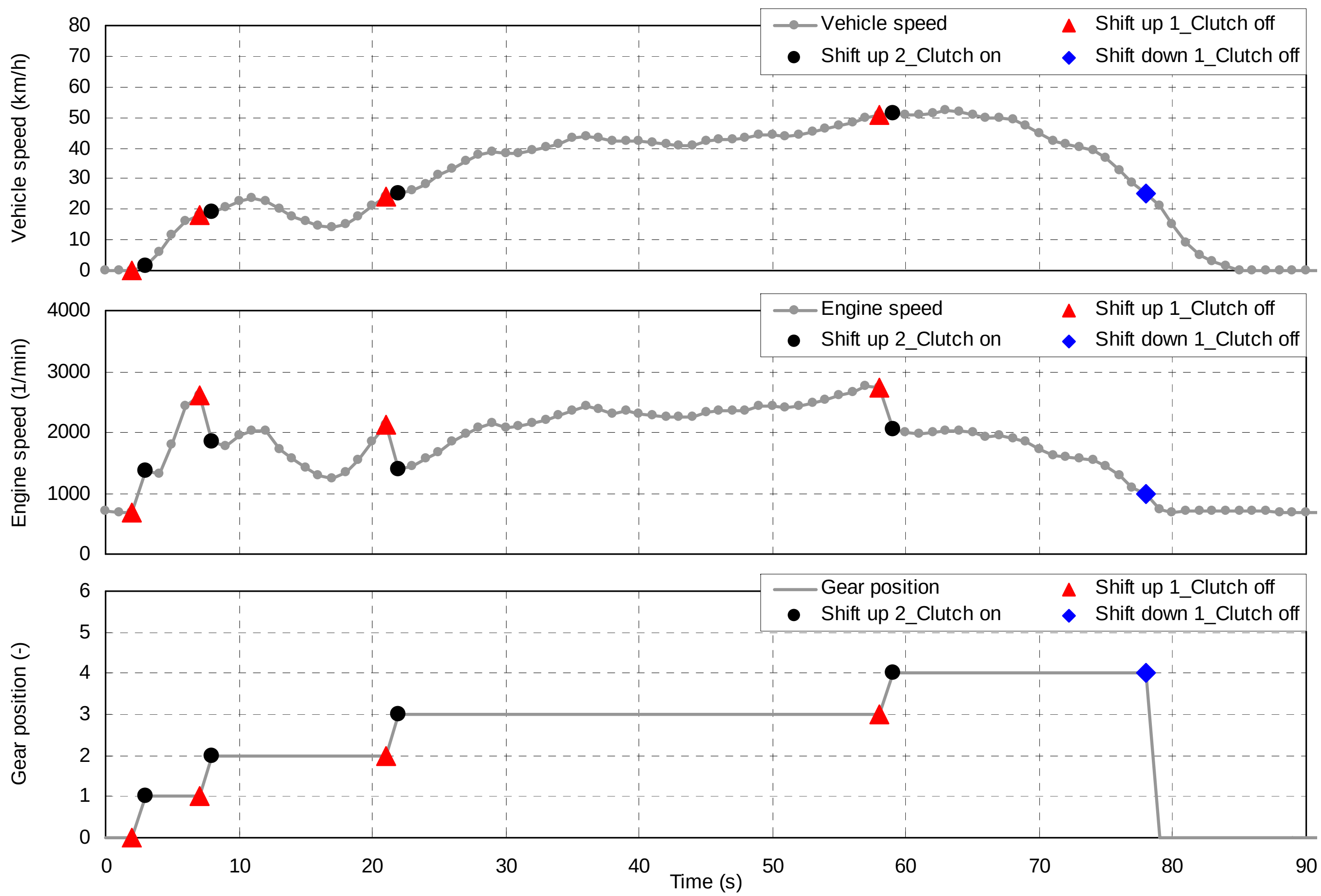
i_t: Gear ratio

i_f: final reduction ratio

- Consequently, gear position can be defined by calculating gear ratio during driving

3.3. Definition of Shift Change

- Shift up_1: Clutch release point for up-shifting
- Shift up_2: Clutch engage point after putting in higher gear
- Shift down_1: Clutch release point for down-shifting or neutral



3.4. Factor Analysis / Frequency Distribution

- Calculate the vehicle speed in each gear position (both up-shift and down-shift), then generate various frequency distribution by each vehicle category and analyze the factors that effect shift operation.

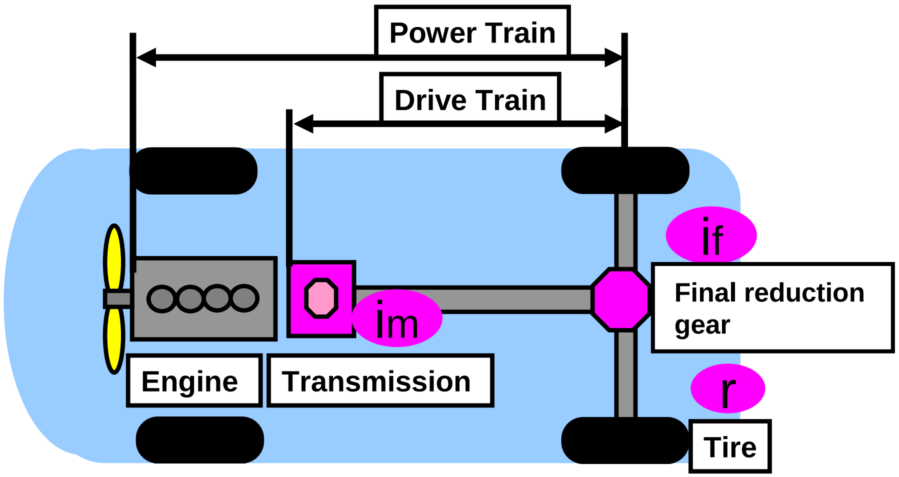
  - Vehicle speed frequency distribution
    （0 ≤ V ≤ 100 km/h，1km/h step）
  - Vehicle acceleration frequency distribution
    （-10 ≤ a ≤ 10 km/h/s, 1km/h/s step）
  - Engine speed frequency distribution
    （600 ≤ r ≤ 6000 rpm, 100rpm step）
  - Standardized engine speed frequency distribution
    （0 ≤ r ≤ 100 %, 10 % step）

3.5.1. Regression Analysis

➢ Develop the shift point equation by Stepwise selection method

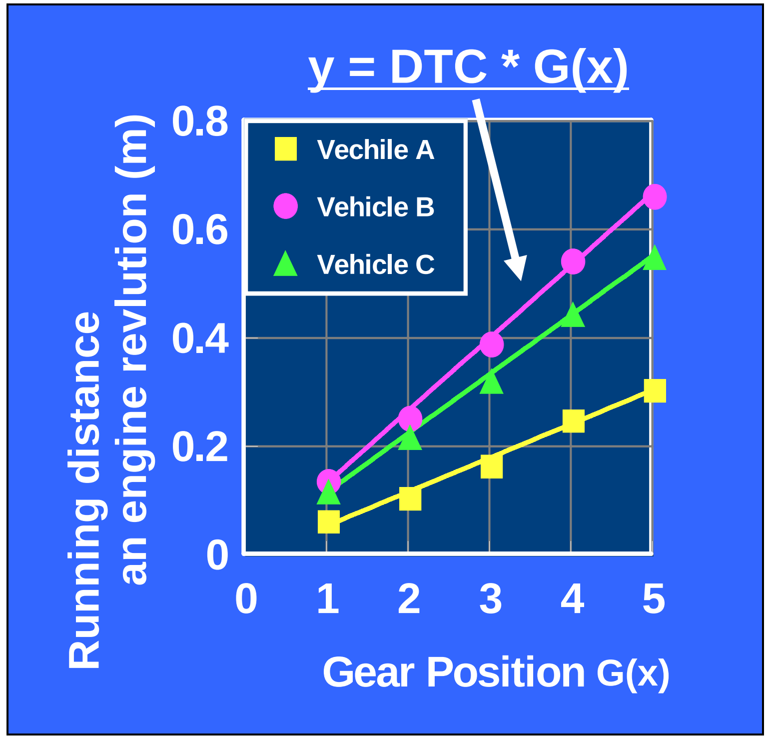
Dependent variable	Explanatory variable	Remark
Gear position	Vehicle speed (km/h)	
	Engine speed (1/min)	
	Normalized engine speed (%)	
	Acceleration (km/h/s)	
	Vehicle category	1: M1, 2: N1, 3: N2,,,
	Fuel type	1: Petrol, 2: Diesel, 3: LPG,,,
	No. of gear	
	Curb weight (kg)	
	Maximum pay load (kg)	
	Gross vehicle weight (kg)	
	Displacement (cc)	
	Maximum power (kW)	
	Maximum torque (Nm)	
	Power to mass ratio (kW/t)	
	Torque to mass ratio (Nm/t)	
	Normalized vehicle weight	Wn = Curb weight / GVW
	Drive train coefficient (DTC)	Refer slide 3.5.2

3.5.2. Drive Train Coefficient（DTC）



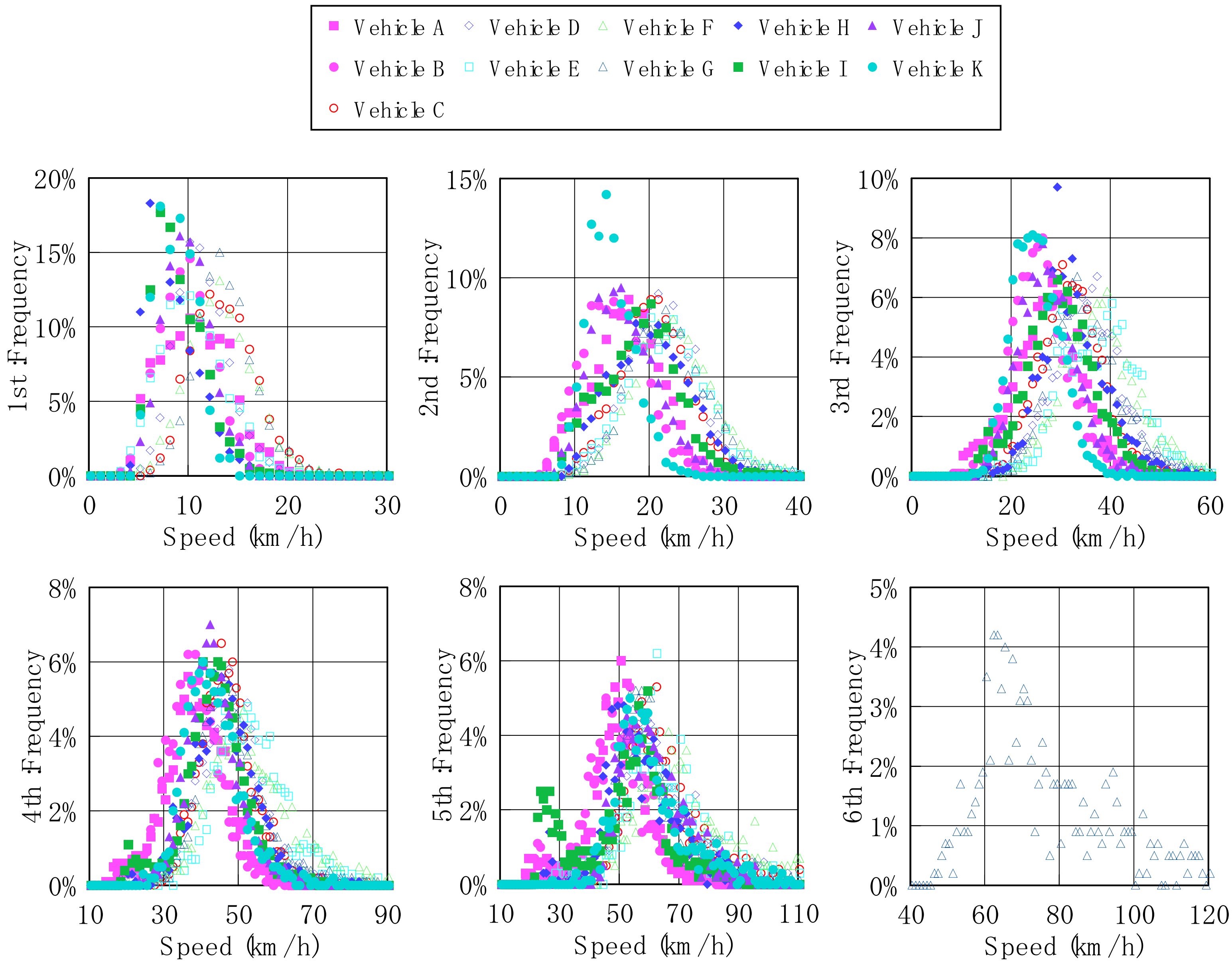
$$\frac{2\pi r}{im \times if} = \frac{V}{Ne} \times \frac{1000}{60}$$

2 π r / (im * if)	:	running distance per engine speed	(m)
r	:	tire radius	(m)
im	:	gear ratio	
if	:	final reduction gear ratio	
V	:	vehicle speed	(km/h)
Ne	:	engine speed	(rpm)

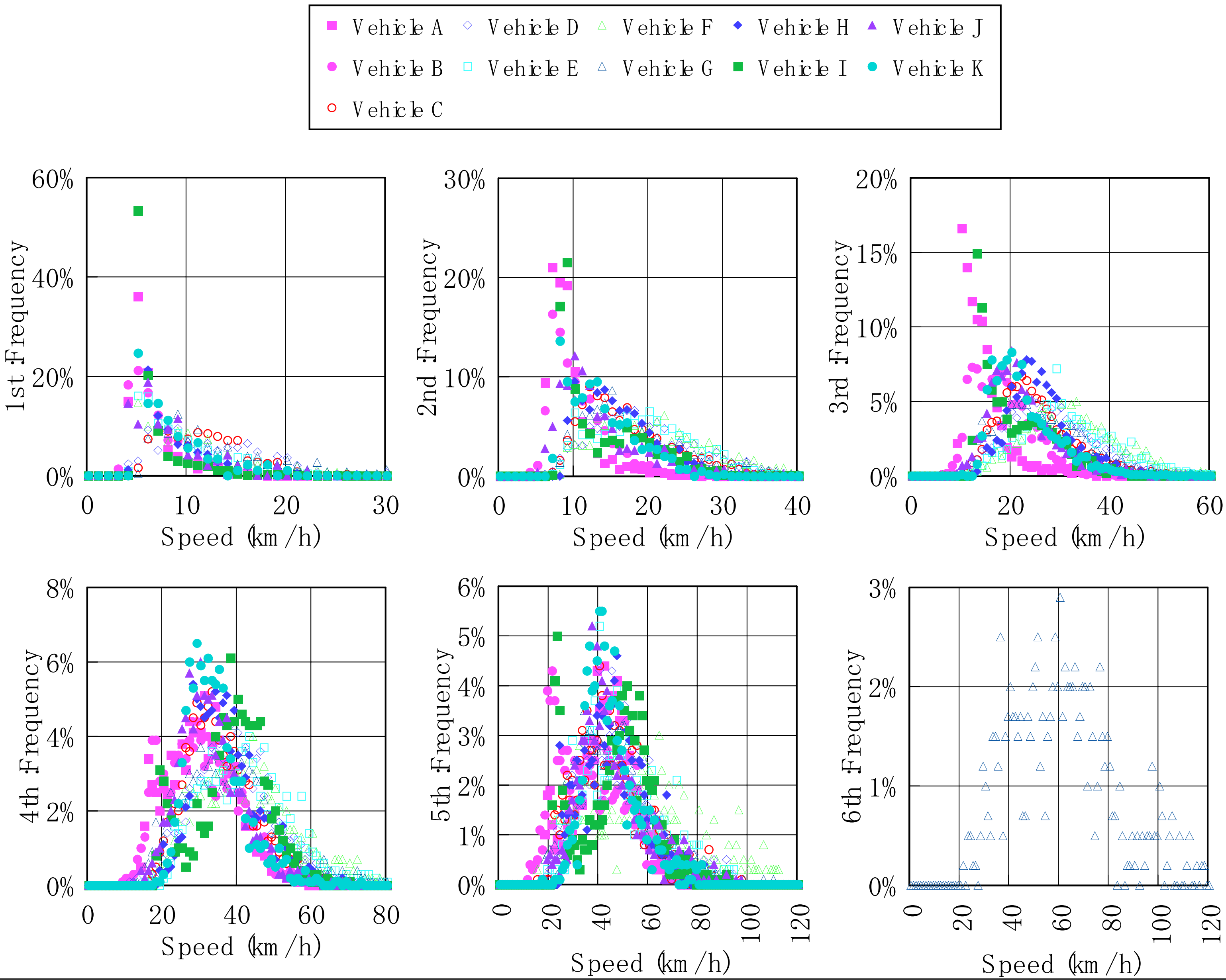


DTC : Drive Train Coefficient

3.6.1. Analysis Sample (JC08) - shift up speed



3.6.2. Analysis Sample (JC08) - downshift speed



3.6.3. Analysis Sample (JC08) - Explanatory variable of shift up

R^2	Explanatory variable						
	1	2	3	4	5	6	7
0.752	Speed						
0.815	Speed	Acceleration					
0.844	Speed	Acceleration	Normalized vehicle weight				
0.847	Speed	Acceleration	Normalized vehicle weight	DTC			
0.851	Speed	Acceleration	Normalized vehicle weight	DTC	Normalized vehicle weight @ running order		
0.851	Speed	Acceleration	Normalized vehicle weight	DTC	Normalized vehicle weight @ running order	Engine Speed @ Max. torque	
0.852	Speed	Acceleration	Normalized vehicle weight	DTC	Normalized vehicle weight @ running order	Engine Speed @ Max. torque	Engine speed @ Max. power

⇒After completion of all data acquisition, the explanatory variable will be determined based on stepwise selection method.

3.6.4. Analysis Sample (JC08) - Explanatory variable of downshift

R^2	Explanatory variable						
	1	2	3	4	5	6	7
0.552	Speed						
0.629	Speed	Engine speed					
0.834	Speed	Engine speed	DTC				
0.841	Speed	Engine speed	DTC	Acceleration			
0.845	Speed	Engine speed	DTC	Acceleration	Maximum torque		
0.846	Speed	Engine speed	DTC	Acceleration	Maximum torque	Normalized vehicle weight	
0.848	Speed	Engine speed	DTC	Acceleration	Maximum torque	Normalized vehicle weight	Engine capacity

⇒After completion of all data acquisition, the explanatory variable will be determined based on stepwise selection method.

3.6.5. Analysis Sample (JC08) - Gearshift equation

- Shift up

$$G(x)_{up} = 2.96 + 0.0576 \cdot V - 0.139 \cdot A - 1.81 \cdot W_n - 3.36 \cdot DTC$$

- Shift down

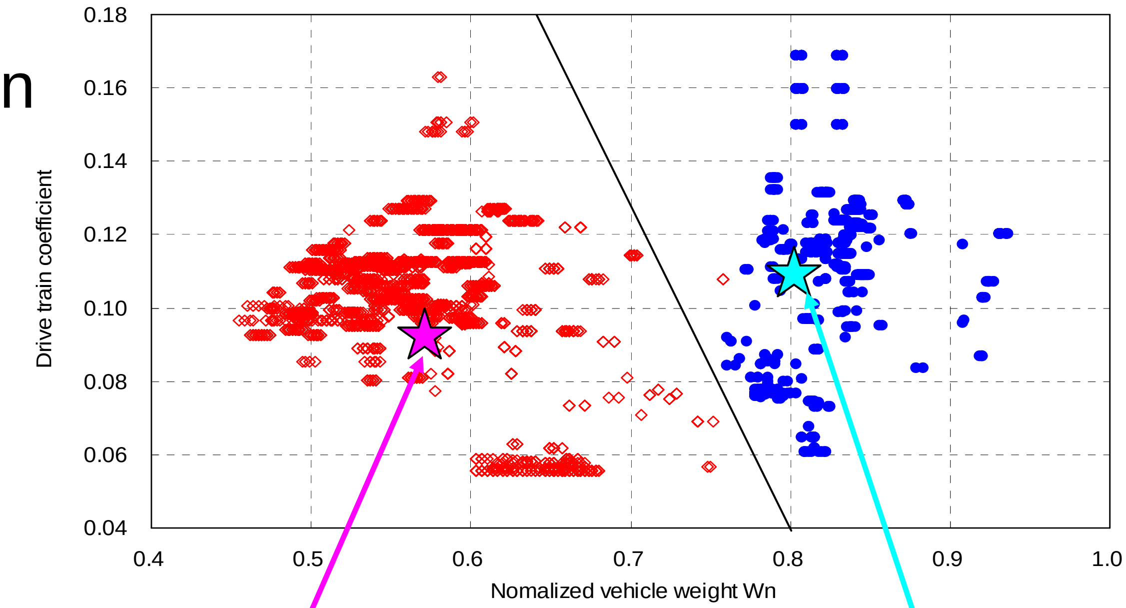
$$G(x)_{down} = 5.12 + 0.0924 \cdot V - 0.043 \cdot A - 0.00129 \cdot E - 25.9 \cdot DTC$$

G(x)	:Gearshift equation
V	:Speed in km/h
A	:Acceleration in km/h/s
Wn	:Normalized vehicle weight (Curb weight / GVW)
E	:Engine speed in rpm
DTC	:Drive train coefficient

⇒After completion of all data acquisition, the gearshift equation for WLTC will be developed.

3.6.6. Analysis Sample (JC08) – Final Shift Points

- Vehicle Categorization
  - ✓ Passenger Car
  - ✓ Light Duty Commercial Vehicle



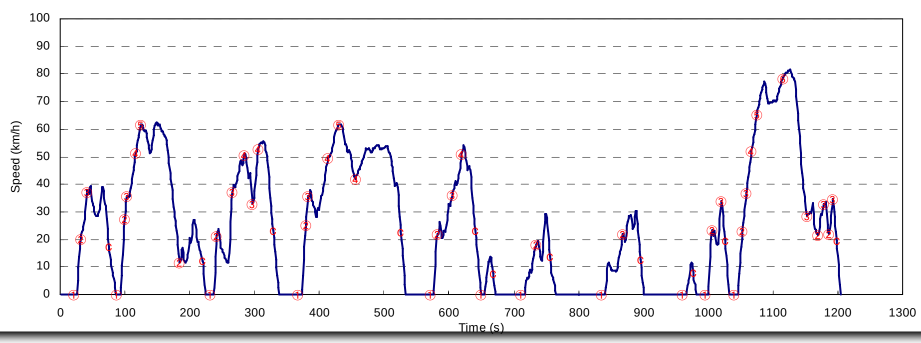
Average of LDCV

Wn=0.58, DTC=0.09

Average of PC

Wn=0.80, DTC=0.11

◆for Passenger cars



◆for Light duty commercial vehicles