Proposal for WLTC methodology and guidelines for in-use data collection

proposed by UK and Japan
DHC group
under GRPE/WLTP informal group

version 1 : 24 August 2009

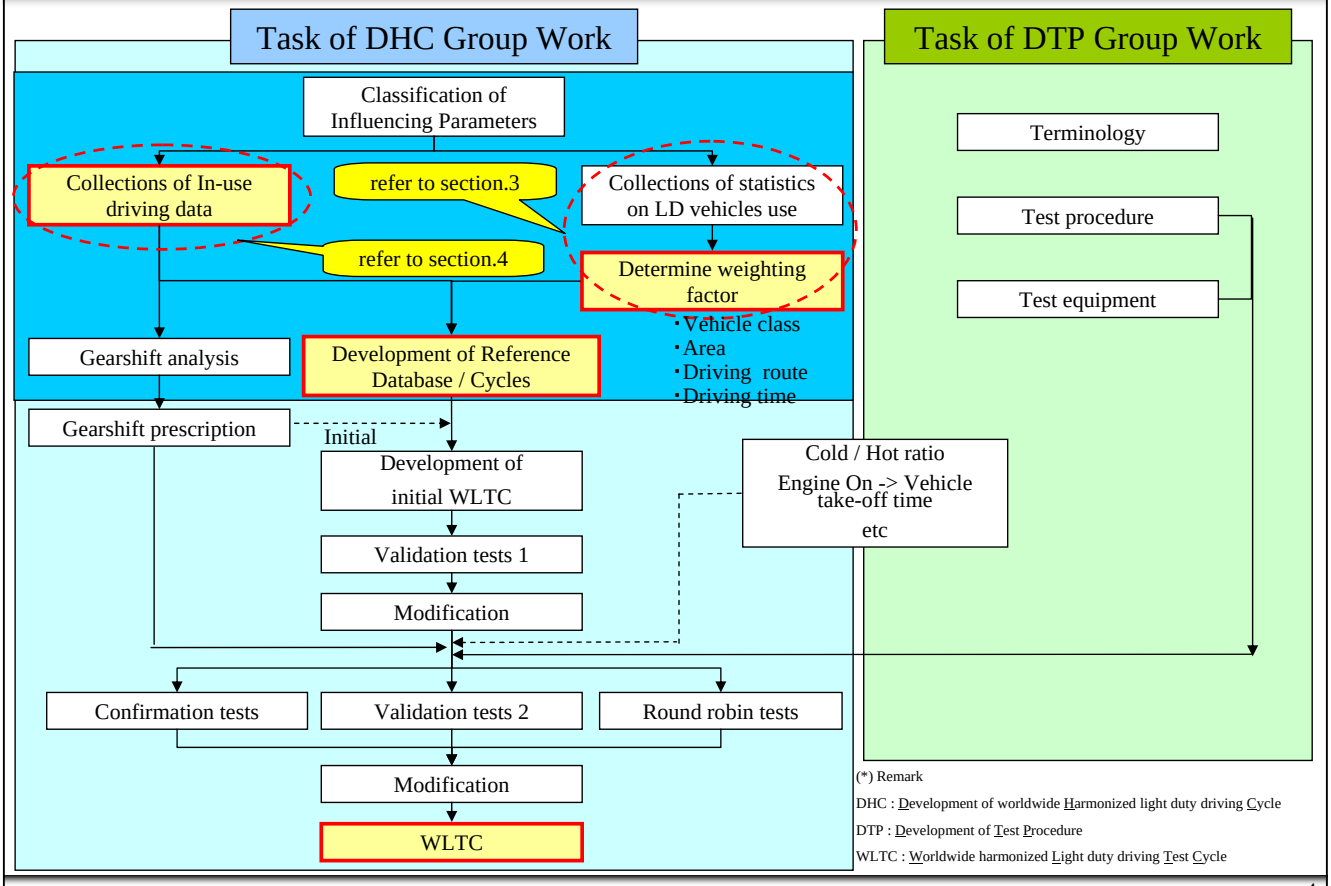
(*) WLTC : Worldwide harmonized Light duty driving Test Cycle

Contents

1. Purpose

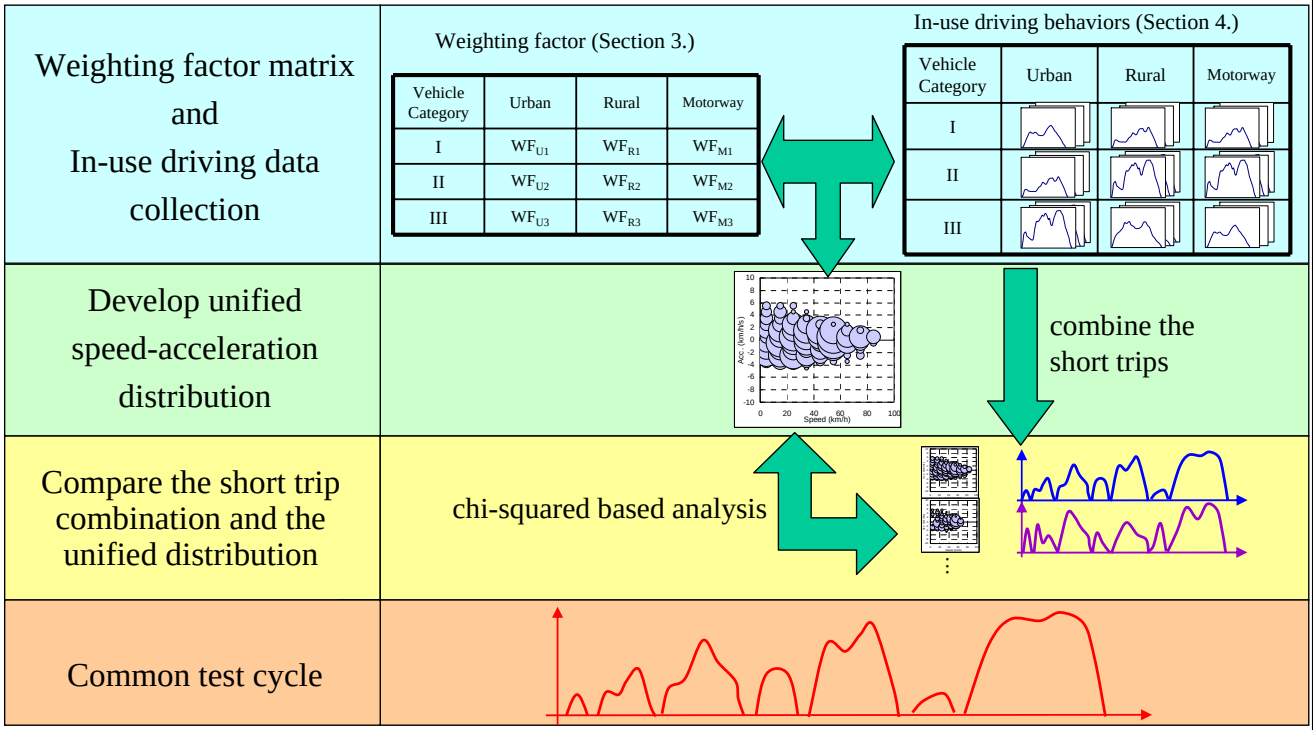
- Develop the world wide harmonized light duty test cycle, which will represent typical driving conditions around the world
  - ✓ Define the methodology to develop the common test cycle and gear shift prescription based on the in-use driving data
  - ✓ Provide guideline for in-use data collection

2.1. Overall Process



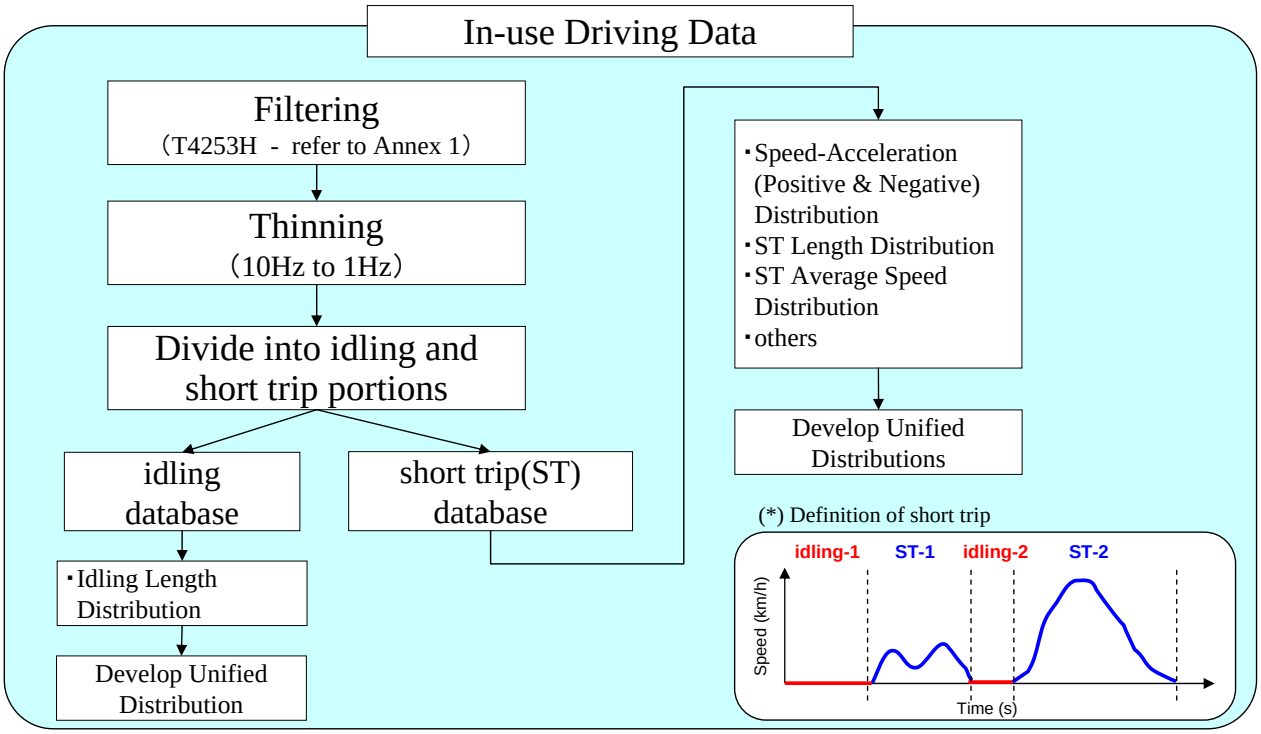
2.2.1. Test Cycle Development - Step1 -

- Common test cycle is developed based on collected in-use data and weighting factor.



2.2.2. Test Cycle Development - Step2 -

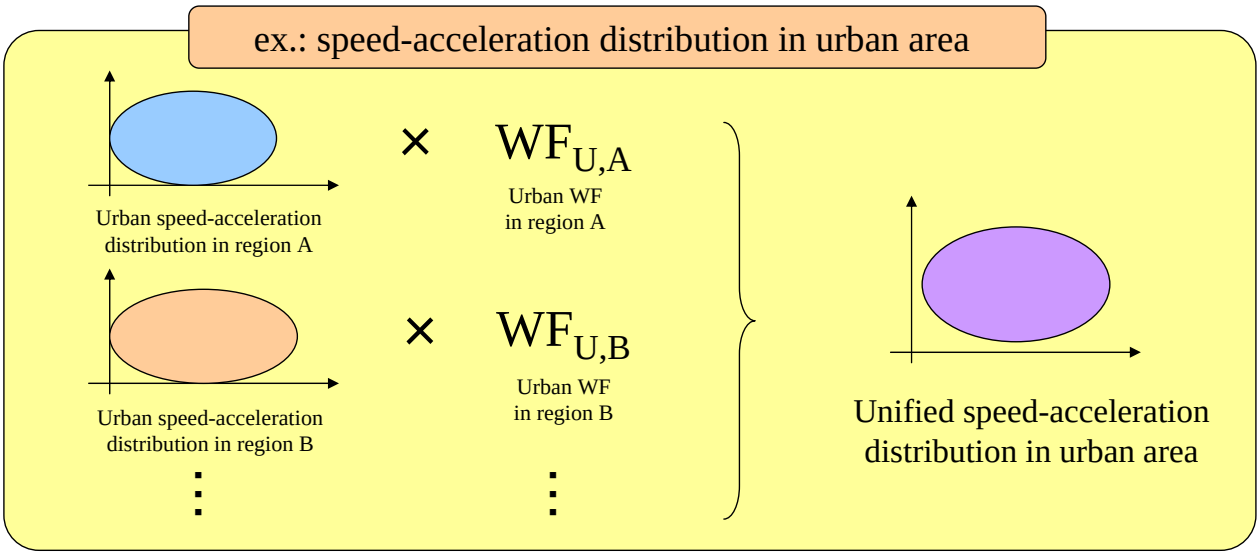
- In-use Driving Data Processing



- ✓ In-use data in each road type and in each regions is processed separately.

2.2.3. Test Cycle Development - Step3 -

➢ Develop the Unified Speed-Acceleration Distribution

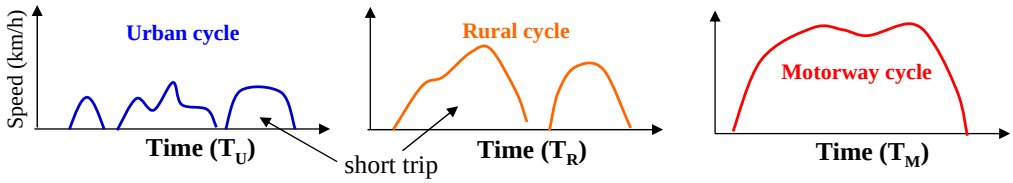


✓ Unified distributions are generated for the following parameters.
Short trip speed - acceleration distribution, Short trip length distribution
Short trip average speed distribution, Idling length distribution

2.2.4. Test Cycle Development - Step4 -

➢ Determine the test cycle duration

< ex. WMTC : 600 x 3parts, WHDC : 1800, LA#4 :1371, NEDC : 1180, JC08 : 1204 (sec) >



➢ Determine the number of idle and short trip in each part

✓ The number of idle = the number of short trip

✓ Calculate the number in each part (Urban, Rural, Motorway)

$$\text{number of idle}(N_U) = \text{number of short trip}(N_U) = \frac{\text{test mode duration in each part } (T_U)}{\text{average short trip duration} + \text{average idling duration}}$$

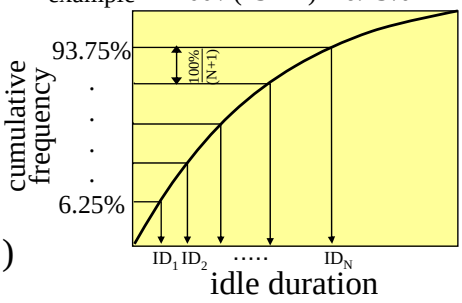
<example> T_U = 600 sec, average urban short trip duration = 25 sec,
average urban idling duration = 15 sec,

number of idle(N_U) = number of short trip(N_U) = 600 / (25 + 15) = 15

2.2.5. Test Cycle Development - Step5 -

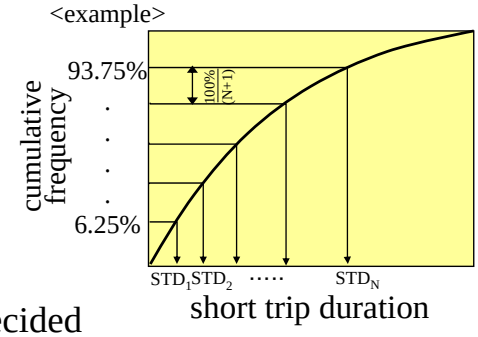
- Determine the N units of idling duration in each part
  - ✓Generate the cumulative frequency graph based on idling data base
  - ✓Divide into (N+1) equally in Y axis
  - ✓N units of idling duration (ID_1, ID_2, ..., ID_N) in each part are decided

<example> 100 / (15 + 1) = 6.25%



- Determine the N units of short trip duration in each part
  - ✓Generate the cumulative frequency graph based on short trip data base
  - ✓Divide into (N+1) equally in Y axis
  - ✓N units of short trip duration (STD_1, STD_2,..... , STD_N) in each part are decided
  - ✓Pick the candidate short trips which duration are STD_1, STD_2, ..., STD_N

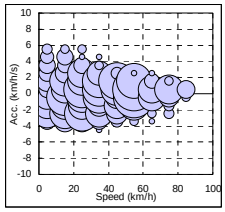
<example>

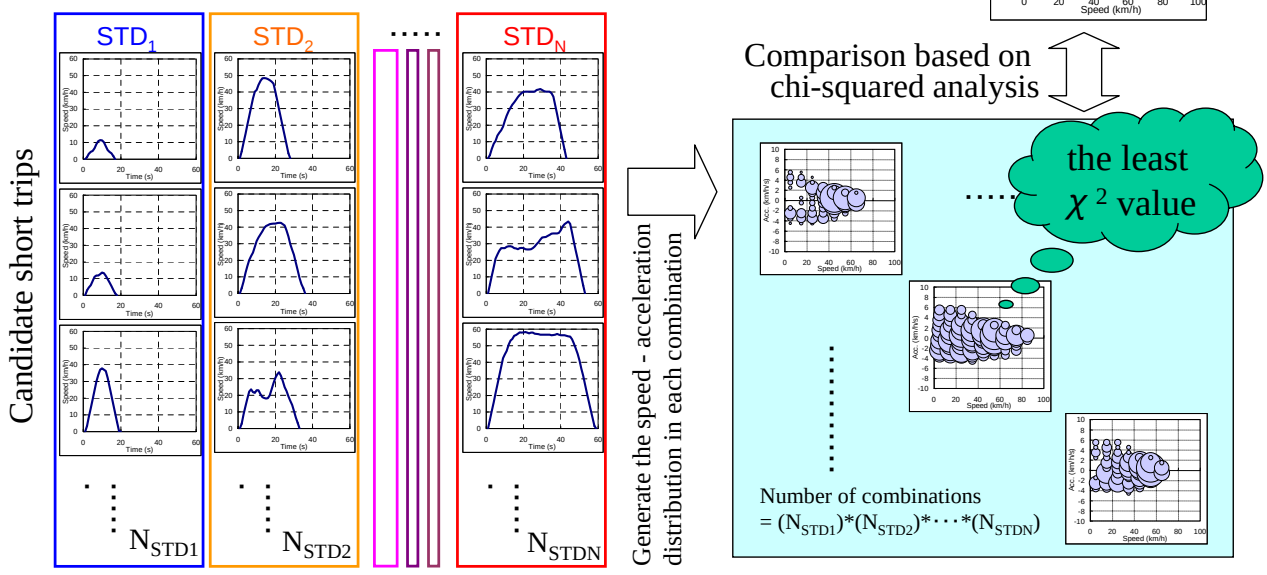


2.2.5. Test Cycle Development - Step6 -

- Determine the short trip combination in each part
  - ✓Generate the speed-acceleration distribution in each combination from candidate short trips
  - ✓Compare with the unified one
  - ✓Select the short trip combination with the least χ^2 value

Unified speed - acceleration distribution





Contents

3.1. Weighting Factor Matrix- Previous Studies

	Weighting factor (Collection of Statistics on vehicle use)					
	Country	Road Type	Vehicle category (Specification)	Power to mass ratio	Matrix	Basic data for weighting factor
WHDC	EU USA JPN	Urban Rural Motorway	rigid trucks trailer trucks buses	3 classes 3 classes 1 class	65	driving duration
WMTC	EU USA JPN China		Engine Displacement 1 : ~ 150 2 : 150 ~ 450 3 : 450 ~		40	driving distance
JC08	JPN	Urban +Rural Motorway				average vehicle speed driving duration

3.2. Basic Concept on Weighting Factor

◆Weighting Factor Matrix

- Statistical data : Traffic volume（driving duration, distance）, vehicle volume
- Countries, Region : Europe, U.S.A. , Asia, etc
- Type of roads : Urban, Rural, Motorway, etc
- Vehicle Categories : Passenger cars, Light goods vehicles Mini Buses, etc
- Days, Time : Weekday/Weekend, On/Off peak, etc
- Method of W.F. : Driving duration or Driving distance
- others

3.3.1. Items for Weighting Factors

- Statistical data
  - ✓ Traffic Volume（driving duration = driving distance / average vehicle speed）
    - same as WHDC methodology
- Countries, Region
  - ✓ China, EU, India, Japan, USA, South America, etc
- Vehicle Categories
  - ✓ Passenger Cars & Vans
    - sub categorized, if necessary
- Type of roads
  - ✓ Urban, Rural, Motorway
    - please refer to Slide 26 for definition
- Days, Hours
  - ✓ Weekday-on peak, Weekday-off peak, Weekend

3.3.2. Development of Weighting Factor - Comparison of 2 Methods

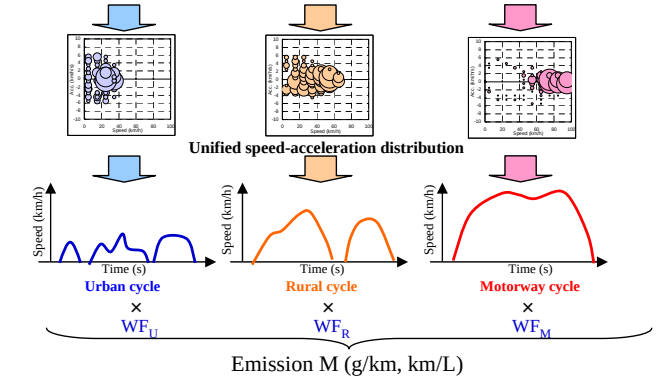
	Weighting Factor using time (duration)	Weighting Factor using distance
Advantage	●Same dimension can be applied to all factors (road type, driving conditions, etc) and to in-use data processing (speed-acceleration distribution, short trip/idle, etc) ●Provides more flexibility to adjust the cycle duration when developing the drive cycle	●Simpler to develop the weighting matrix
Dis-advantage	●Requires more resources to generate weighting factor matrix ●Potential difficulties in obtaining the required statistical data from data collecting CPs	●Inconsistent process to analyze idling periods and short trips ●Difficulty when modifying the test cycle

3.3.3. How to Generate The Weighting Factor Matrix

- WMTC method：Each country by road type accounts for 100%
- WHDC method：Total items account for 100%

○WMTC method（Consisting of 3 parts）

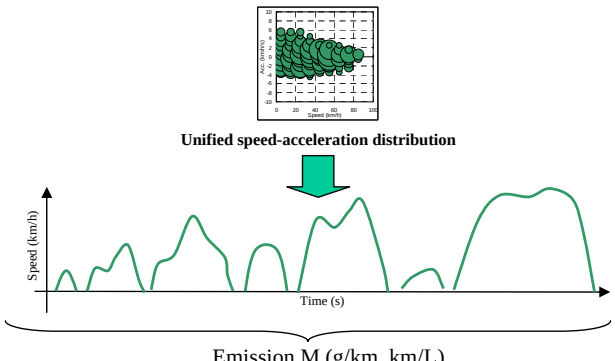
Veh. Cate.	Urban					Rural					Motorway					Total
	C	E	I	・	・	C	E	I	・	・	C	E	I	・	・	
a																
b																
c																
Sub	**(100%)**					**(100%)**					**(100%)**					
Total	** % → WF_U					** % → WF_R					** % → WF_M					100%



○WHDC method

	China			Europe			India			・	・	・	・	・	・	Total
	U	R	M	U	R	M	U	R	M	・	・	・	・	・	・	
a																
b																
c																
																100%

U : Urban, R : Rural, M : Motorway



➢ Proposal ⇒ WMTC Method

[reason]
have more flexibility to adjust and/or modify part duration, candidate short trips and so on.

3.3.4. Development of weighting factor

Calculate total driving duration using statistical vehicle usage and/or traffic census, then find the driving time share ratio of each region

Method 1 : Using traffic census

- Basic data : Traffic census classified by country
- Necessary data : Total road network and traffic volume classified by vehicle categories / road types, Average vehicle speed classified by road types
- Advantages : More precise due to based on actual survey
- Disadvantages : Traffic census information may vary by region due to difference in vehicle categories / road types etc. -> Hard to compare equally

Method 2 : Using vehicle statistical data

- Basic data : Statistical vehicle usage of each country (WHDC method)
- Necessary data : The number of registered vehicles, Annual driving distance, Average vehicle speed on each road type, Vehicle specification information
- Advantages : Easier to obtain same type of information from each country
- Disadvantages : Include assumption, less precise

(*) If lack of data, calculation could be made using data that is in similar condition.

3.3.5. Development of Weighting Factor - Method 1 -

- Using traffic census….

Per vehicle category:

No. of traffic volume in service, divided into per day, period of time and each road type

↓

Total road network on each road type

← Average vehicle speed on each road type

↓

Per vehicle category:

No. of hours in service, divided into per day, period of time and each road type

↓

Per vehicle category:

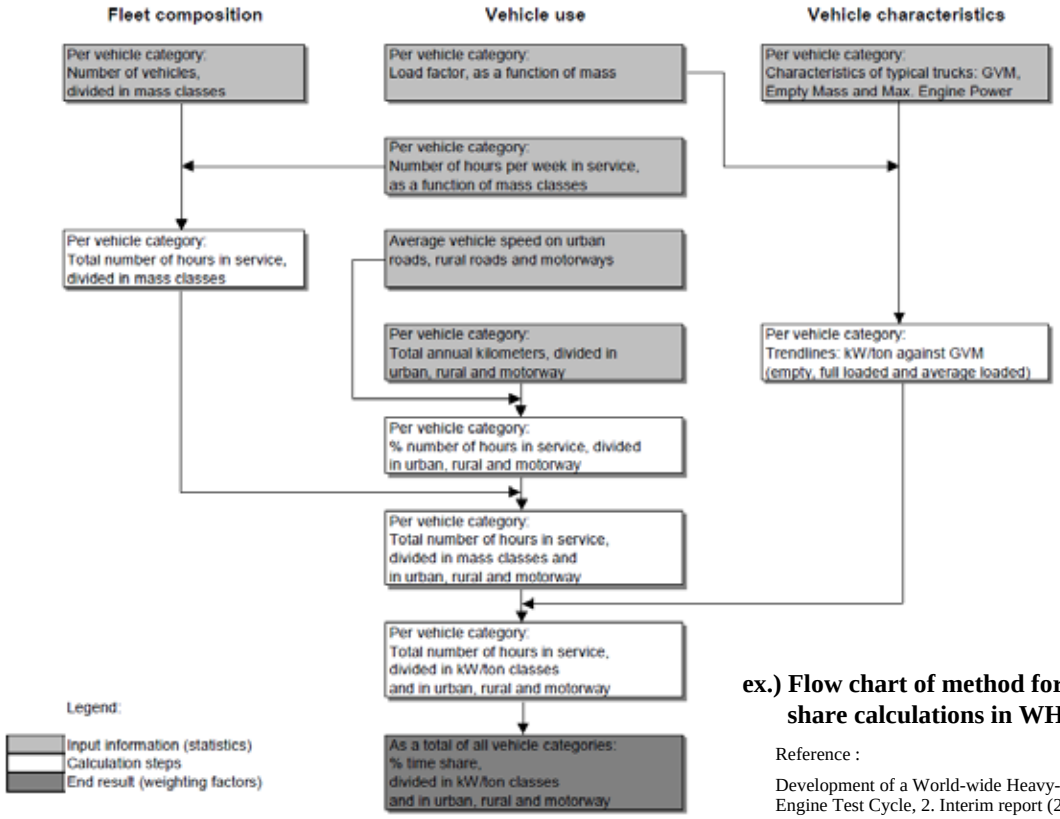
% time share, divided into per day, period of time and each road type

➢ Per vehicle category, Per Road type, Per period of time :

$$\text{No. of hours in service} = \frac{\text{Total road network} \times \text{No. of traffic volume}}{\text{Average vehicle speed}}$$

3.3.6. Development of Weighting Factor - Method 2 -

- Using vehicle statistical data …



ex.) Flow chart of method for time share calculations in WHDC

Reference :

Development of a World-wide Heavy-Duty Engine Test Cycle, 2. Interim report (2000)

3.3.7. Traffic Census in Japan

Road traffic census

✓ Survey season: autumn

- Road condition survey
  - ➢ Length of road
  - ➢ No. of the lane
  - ➢ Width
  - ➢ No. of the traffic signals
  - ➢ Paved / Non-paved
  - ➢ etc
- Traffic volume survey
  - ➢ Per road type
  - ➢ Per vehicle category
  - ➢ weekday and holiday
  - ➢ hourly
  - ➢ etc

- Traveling speed survey
  - ➢ weekday and holiday
  - ➢ On peak

3.4. Weighting Factor Matrix- Final Image

Vehicle Category		Urban										Rural	Motorway
		China			Europe			India	Japan	South America	U.S.A	…	…
A	B	Weekday On peak	Weekday Off peak	Weekend	Weekday On peak	Weekday Off peak	Weekend	…	…	…	…	…	…
Passenger cars	Class I							…	…	…	…	…	…
								…	…	…	…	…	…
								…	…	…	…	…	…
								…	…	…	…	…	…
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								…	…	…	…	…	…
								…	…	…	…	…	…
	Class II (if necessary)							…	…	…	…	…	…
								…	…	…	…	…	…
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								…	…	…	…	…	…
Trucks	…	…	…	…	…	…	…	…	…	…	…	…	…

Total driving duration shall be divided into per vehicle type, road type and driving hours.

B : sub categorized to more specific vehicle category and/or engine displacement and/or GVW, etc

Contents

4.1. In-use Data Collection - Previous Studies

	In-use data collection								
	Country	Cities	# of Vehicles	Vehicle Category (specification)	# of vehicles	driving duration	driving distance (km)	Type of roads	# of drivers
WHDC	EU USA JPN		65	Light trucks GVW < 7.5t Rigid trucks GVW > 7.5t, incl. special purpose trucks and coaches Trailer trucks Public buses	9 21 18 11		2213 13428 56324 2473 Total 74400 Ave 1145	Urban Rural Motorway	
WMTC	EU USA JPN China (India)	Paris Pisa Amsterdam Frankfurt Mandeure Munich Biel Darmstadt Birminggham Tokyo Ji Nan	23 7 9 1	49cc - 1500 cc		518	27224	Urban Rural Motorway	
JC08	JPN	Tokyo Osaka	10	Passenger Cars Light truck 1 Light truck 2	4 1 5	245 64	4937 3450	Urban/Rural Motorway	
JC08 (Shift point)	JPN	Tokyo	11	Passenger Cars (5MT) Passenger Cars (6MT) Light truck 1 (5MT) Light truck 2 (5MT) Light truck 3 (5MT)	4 1 2 1 3			Urban/Rural Motorway	36

4.2. Basic Concept on In-use Data Collection

◆Data Collection

- ➢Regions
  - ✓Countries, Regions : Europe, U.S.A, Japan, China, India, etc
- ➢Vehicle Selection
  - ✓Vehicle Categories : M1/N1, LDV/LDT, Passenger Cars/Trucks
  - ✓Vehicle Performance : Power to mass ratio, Engine swept volume, GVW,etc
- ➢Driving Conditions
  - ✓Driving Condition : Traffic flow, Free, Speed limit, etc
  - ✓Vehicle Condition : Weight (Pay load), Warmed up
  - ✓Driver : gender, age, experience, etc
  - ✓Driving Route : Definition, Altitude, Gradient, etc
  - ✓Days, Hours : Season, Day of the week, Time
  - ✓Amounts of data : distance, time, etc
- ➢others

4.3.1. Test Vehicle Selection

The following criteria should be considered when selecting test vehicles for in-use data collection to ensure representation of the regional market.

< Selection Criteria >

- Vehicle Category : Category 1-1, 1-2, 2 in UN/ECE Special Resolution No.1
- Body type : Saloon, hatchback, station wagon, sports, van, pickup,,,
- Fuel : Gasoline/Diesel/NG/LPG/Ethanol
- Transmission : Automatic（AT･CVT）, Manual
- Drive Train : 2WD（FF, FR）, 4WD, doesn't matter
- Emission standard : Latest regulation, doesn't matter
- Vehicle weight : the lightest ~ the heaviest, the biggest sales volume class
- Engine displacement : the smallest ~ the largest, the biggest sales volume class
- Performance : Power to mass ratio, Top speed, Torque to mass ratio

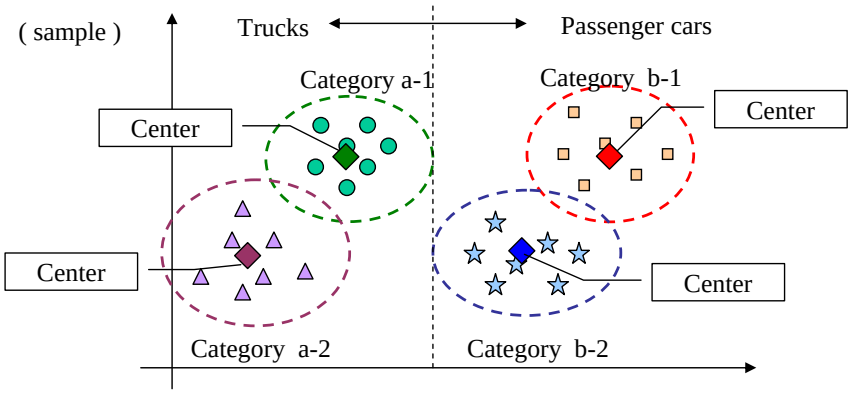
4.3.2. Vehicle Selection Method - 1

- Body Style
  - ✓ Represent the market sales mix
- Fuel
  - ✓ Consider the market sales mix (up to each region decision)
- Transmission
  - ✓ AT(CVT)：1 or more
  - ✓ MT ：1 or more per # of gear (use for gear shift analysis)
- Drive Train
  - ✓ doesn't matter
- Applicable Emission Standard
  - ✓ doesn't matter (preferable latest system for ECU data acquisition)

4.3.3. Vehicle Selection Method - 2

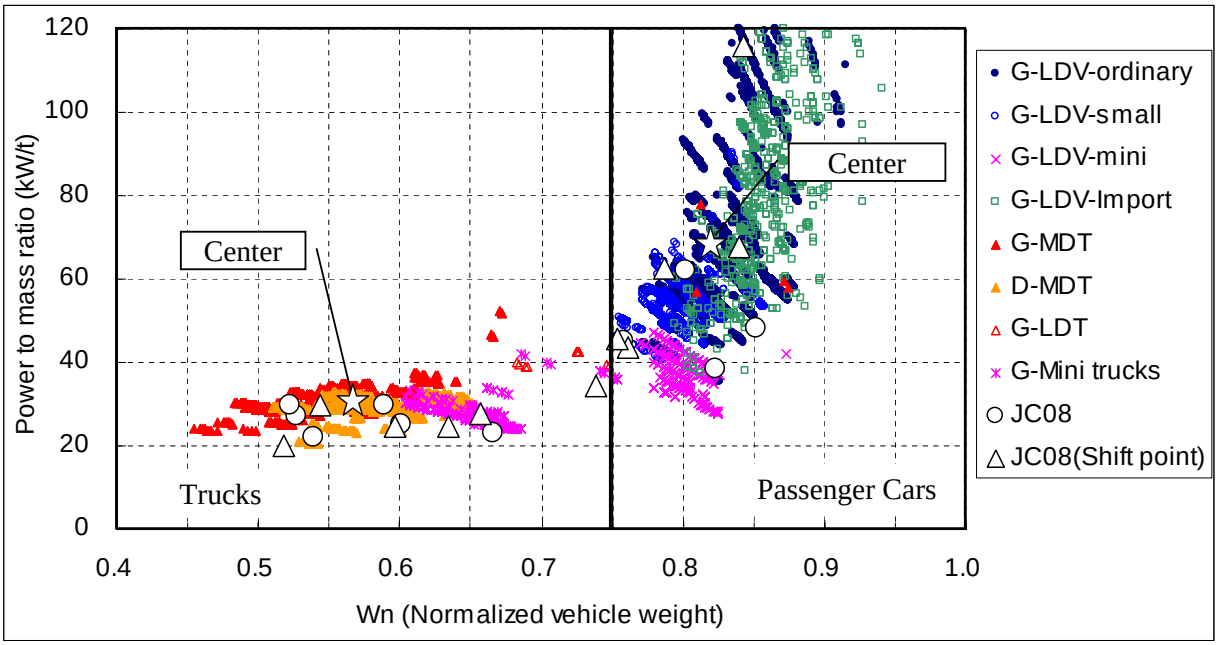
- Divided into two categories : Passenger cars and Vans
- Ramified within each vehicle category, if necessary
  - ✓ LDT => LDT1/2/3/4
  - ✓ N1 => RW : ~ 1305kg / 1305 ~ 1760kg / 1760kg ~
- Select the appropriate factors to represent the each vehicle category

⇒Study the vehicle specification, such as “Power to mass ratio”, “Engine Displacement”, “Maximum Speed”, “Normanized Weight(Wn = Unloaded weight / Gross vehicle weight), etc



4.3.4. Vehicle Selection – JC08 Development

In case of JC08 development, test vehicles were randomly selected in each category.



reference : Vehicle Specification Book (2008) by JSAE

(*) Normalized vehicle weight = Unloaded weight / Gross vehicle weight

4.4.1. Test Conditions

- Driving Behavior
  - ✓ Follow the traffic flow without unique behavior
- Vehicle Conditions
  - ✓ Warm up condition：preferable to test after warming up
  - ✓ Vehicle weight ：unloaded condition
    (driver + measurement equipment + operator)
    (record the actual weight)

4.4.2. Driver Selection

- Gender
  - ✓ Mixture of male/female, - no need to mandate
- Age
  - ✓ preferable at least one driver from three generations,
    (20's, 30's ~40's, 50's ~ 60's)
- Experience
  - ✓ have valid clean driver license

4.4.3. Road Type

➢Definition of road type

	Urban	Rural	Motorway
WHDC (define based on road type)	Roads in urban areas with a speed limit of 50 km/h or lower	Non motorways outside and inside urban areas, with a speed limit between 50 km/h and 80km/h	Roads specially constructed and controlled for fast motor traffic (in most cases with more than 2 lanes)
WMTC (define based on collected data)	Vehicle Speed : ~ 60km/h : 80% or more 90km/h ~ : 0% and Max. speed =< 80km/h and Each Trip distance >= 1m	Vehicle Speed : ~ 60km/h : 70% or less 60 ~ 90km/h : 30% or more 90km/h ~ : 50% or less and Max. speed =< 110km/h	Vehicle Speed : ~ 60km/h : 20% or less 90km/h ~ : 50% or more
Proposed WLTP	Paved roads in urban areas with a speed limit ≤50 km/hour (exclude mountain areas)	Paved non-motorways outside and inside urban areas with a speed limit between 50 and 80 or 100 km/hour (exclude mountain areas)	Paved motorways (multi-lane roads specifically constructed and controlled for fast traffic)

4.4.4. Season / Weather Conditions

➢ Season:

✓ doesn't matter

(if possible, same timing for in-use data collection and statistical data investigation is preferable)

➢ Weather:

✓ Under the conditions where data is collected in a safe manner

The following conditions are NOT preferable

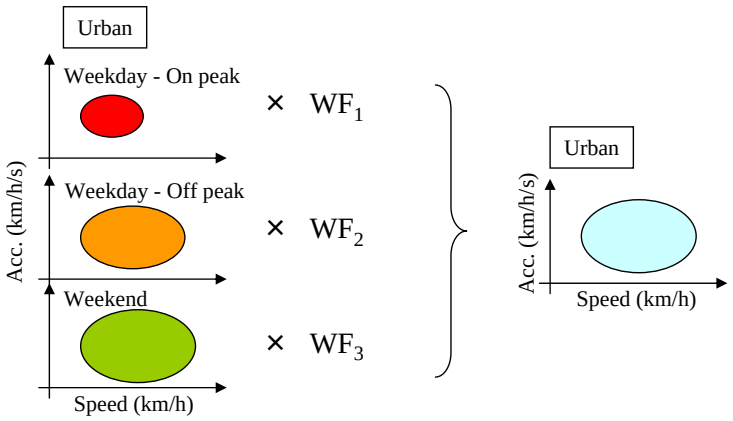
●Low visibility such as rain, fog, snow, storm weather, etc, that might affect the traffic condition.

4.4.5. Time of Data Collection

➢Execute the data collection during the following period of time

- ✓ Weekday - On peak（commuting hours）
- ✓ Weekday - Off peak
- ✓ Weekend（morning, afternoon and evening）

< sample for data handling >



4.4.6. Amount of Data to be Collected

< Criteria >

- Distance : Set upper & lower limit, Set only lower limit, no criteria
- Time Range : Set upper & lower limit, Set only lower limit, no criteria

< Previous Studies >

Mode	Region	# of Vehicles	Vehicle Categories	Road Type	Driving Duration			Driving Distance		
					Total Duration	Average Duration	Average Duration (hrs/vehicle, road type, region)	Total Distance (km)	Average Distance	Average Distance (km/vehicle, road type, region)
WHDC	3	65	4	3	-	-		74400	1145	2067
JC08	1	10	3	Urban/Rural	245	25	82	4937	494	1646
				Motorway	64	6	21	3450	345	1150
JC08 (Shift point)	1	11	4	Urban/Rural	-	Weekdays	-	-	approx. 2500	-
				Motorway	-	20days/vehicle	-	-		-
WMTC	4	40	3	3	518	13	14	27224	681	756

Proposal

➢ Minimum 1000km per each region&category&road type and per each transmission

4.4.7. Measurement Items and Methods

➢ Measurement Items and Methods

	Measurement Items	Necessity	Sampling Time	Measurement Methods
1	Time	MUST	10Hz	-
2	Vehicle Speed (resolution : 0.1km/h)	MUST	↑	①ECU ②GPS Speed Meter ③Calculate from drive shaft speed ・Non-contact vehicle speed meter ・Additional wheel
3	Engine Speed	Recommend （MT：MUST）	↑	①ECU ②Photoelectric Pick Up ③Ignition Pulsation ④Accelerometer
4	Road Grade (altitude)	Recommend	↑	①GPS＋Pressure sensor, Geographic information, etc
5	Clutch Signal	Recommend	↑	①ECU ②Assume from engine speed ③Clutch Depression Switch

✓ Data Format：CSV

✓ Take special care to minimize the noise level (5Hz LPF)

✓ 1Hz data is acceptable, if it was already filtered

4.5.1. Data Collection Matrix

	Country Region	Road Type	Period of time	Driver (Age)	Vehicle Category ①	Vehicle Category ②	Power to mass ratio	TM type	# of test vehicle
# of cells	6	3	3	3	2	2	1	6	1
Total cells	3888 (=> 1944, practically)								
# of test vehicle in each region	-				24 (=> 12, practically)				
Choices	China, Europe, India, Japan, S.A, U.S.A	Urban, Rural, Motorway	Weekday-On peak, Weekday-Off peak, Weekend	20's 30-40's, 50-60's,	Passenger cars Trucks	GVW, Engine swept volume, etc	Class I Class II Class III ・ ・	AT or CVT (3MT) (4MT) 5MT 6MT (7MT)	1~

➢ 24 different kind of test vehicles per region are needed

=> can be reduced to 12 vehicles (Manual transmission 6 => 3)

➢ Total cell number: 3888 (=> 1944)

✓ the number of regions * the number of road types * the number of measurement time range * the number of drivers * the number of vehicles

4.5.2. Image of Data Collection Matrix

Vehicle Category		Transmission type	Power to mass ratio	Driver (Age)	Urban										Rural	Motorway
					China			Europe			India	Japan	South America	U.S.A	…	…
A	B				Weekday On peak	Weekday Off peak	Weekend	Weekday On peak	Weekday Off peak	Weekend	…	…	…	…	…	…
Passenger cars	Class I	AT·CVT	Class 1 (Average)	20's	A1						…	…	…	…	…	…
				30~40's							…	…	…	…	…	…
				50~60's							…	…	…	…	…	…
		5MT	Class 1 (Average)	20's	B1						…	…	…	…	…	…
				30~40's							…	…	…	…	…	…
				50~60's							…	…	…	…	…	…
		6MT	Class 1 (Average)	20's							…	…	…	…	…	…
				30~40's							…	…	…	…	…	…
				50~60's							…	…	…	…	…	…
		…	Class 1 (Average)	20's							…	…	…	…	…	…
				30~40's							…	…	…	…	…	…
				50~60's							…	…	…	…	…	…
	Class II	AT·CVT	Class 1 (Average)	20's	A2						…	…	…	…	…	…
				30~40's							…	…	…	…	…	…
				50~60's							…	…	…	…	…	…
		5MT	Class 1 (Average)	20's	B2						…	…	…	…	…	…
				30~40's							…	…	…	…	…	…
				50~60's							…	…	…	…	…	…
		6MT	Class 1 (Average)	20's							…	…	…	…	…	…
				30~40's							…	…	…	…	…	…
				50~60's							…	…	…	…	…	…
		…	Class 1 (Average)	20's							…	…	…	…	…	…
				30~40's							…	…	…	…	…	…
				50~60's							…	…	…	…	…	…
Trucks	2	3	3	3	…	…	…	…	…	…	…	…	…	…	…	…

A1 + A2 ≧ 1000km

B1 + B2 ≧ 1000km

B : sub categorized to more specific vehicle category and/or engine displacement and/or GVW, etc

Contents

5.1. Process of Gear Shift Point Development（ex. JC08 mode in Japan）

➢ Developed gear shift points based on in-use survey to represent the real driving behavior during JC08 study.

In-Use Survey (data acquisition)

↓

Factor Analysis Frequency Distribution

↓

Regression Analysis Shift Point Formula

↓

Validation

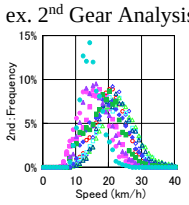
Test Vehicle : Passenger Cars, Trucks

Fuel : Petrol, Diesel

# of test vehicle : 11

# of drivers : 36

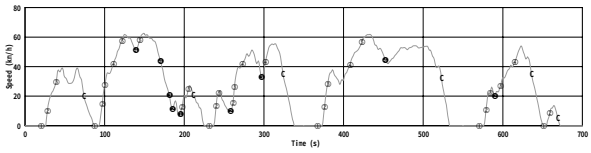
ex. 2nd Gear Analysis



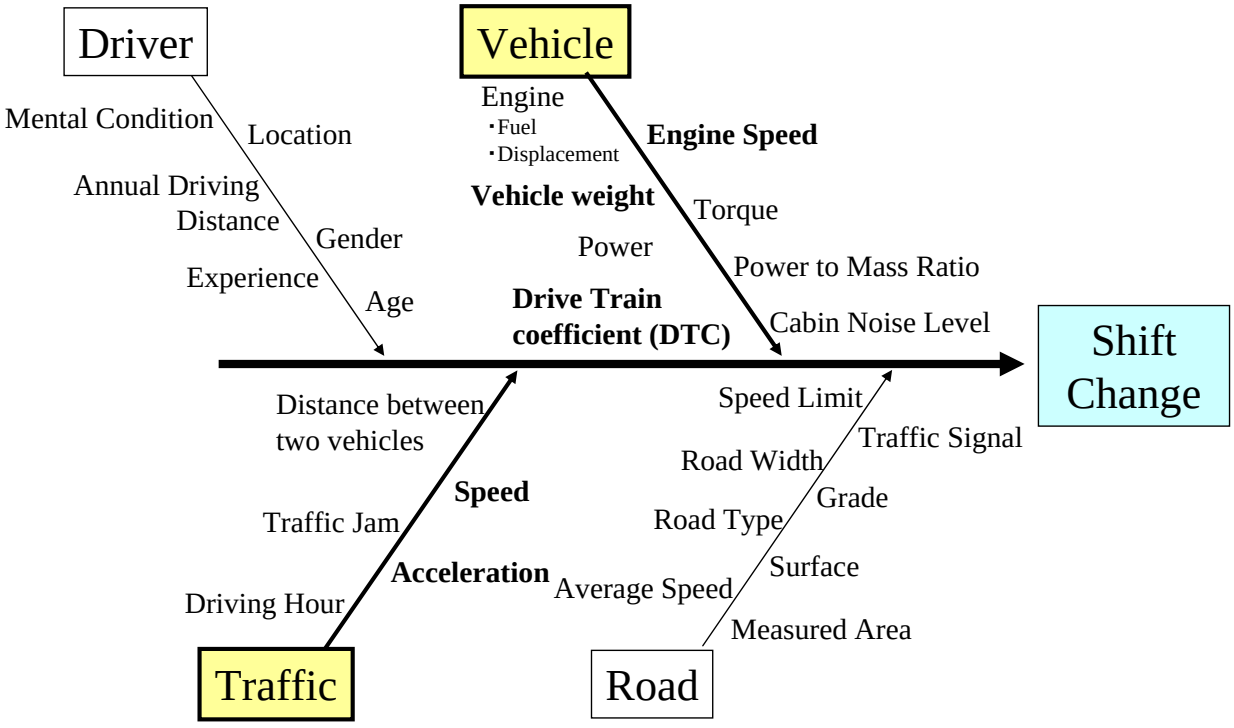
✓Gear shift is influenced mainly by traffic conditions and vehicle specification .

✓Vehicle speed factor, acceleration factor and engine speed factor are normal distribution in each gear shift.

$G(x)=a*V+b*A+\cdots\cdots$



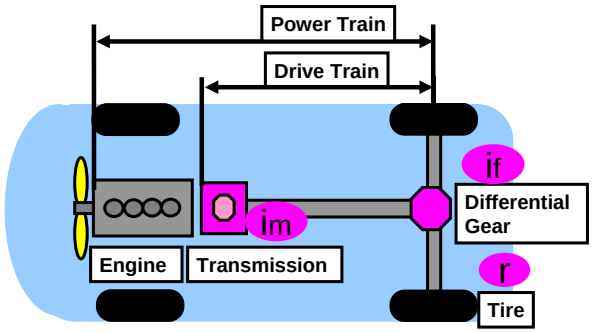
5.2. Factor Analysis (ex. JC08 mode in Japan)



・Shift change is influenced mainly by traffic conditions and vehicle specification.

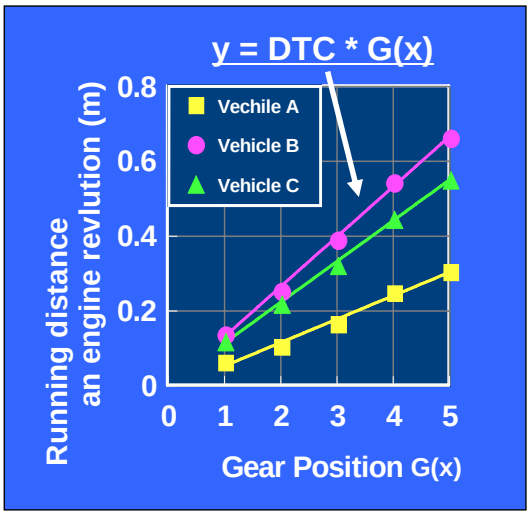
・Few influence by road type and driver is observed in urban area.

5.3. Drive Train Coefficient（DTC）



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

2πr / (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

5.4. Result of regression analysis

The 4 most important explanatory variables were selected by the stepwise regression.

ex.) Up Shift

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 of running order		
0.851	Speed	Acceleration	Normalized vehicle weight	DTC	Normalized vehicle weight of running order	Engine Speed @ Max. torque	
0.852	Speed	Acceleration	Normalized vehicle weight	DTC	Normalized vehicle weight of running order	Engine Speed @ Max. torque	Engine speed @ Max. power

5.5. Gear Shift Formula（ex. JC08 mode in Japan）

- Up shift

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

- Down shift

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

$G(x)$	: Gear shift formula
V	: Vehicle speed km/h
A	: Vehicle Acceleration km/h/s
W_n	: Normalize Weight (=Unloaded Vehicle Weight/Gross Vehicle Weight)
E	: Engine speed rpm
DTC	: Drive Train Coefficient

Annex 1. T4253H smoothing filter

- T4253H smoothing
  (description in the SPSS calculation software)

The smoother starts with a running median of 4, which is centered by a running median of 2. It then resmoothes these values by applying a running median of 5, a running median of 3, and hanning (running weighted averages). Residuals are computed by subtracting the smoothed series from the original series. This whole process is then repeated on the computed residuals. Finally, the smoothed residuals are computed by subtracting the smoothed values obtained the first time through the process. This is sometimes referred to as T4253H smoothing.

For more detail :
ftp://ftp.spss.com/pub/spss/statistics/spss/algorithms/create.pdf