WLTC* methodology

Proposed by Japan
(Reviewed by UK, JRC and Mr. Steven)
DHC group
under GRPE/WLTP informal group

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Palais des Nations, Geneva

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

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(*) U/R/M: Urban/Rural/Motorway, L/M/H: Low/Middle/High

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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 WLTC drive cycle
  - ✓ The WLTC drive cycle will be developed based on combination of collected in-use data and suitable weighting factors.
    - ✓China, EU, India, Japan, South Korea, USA

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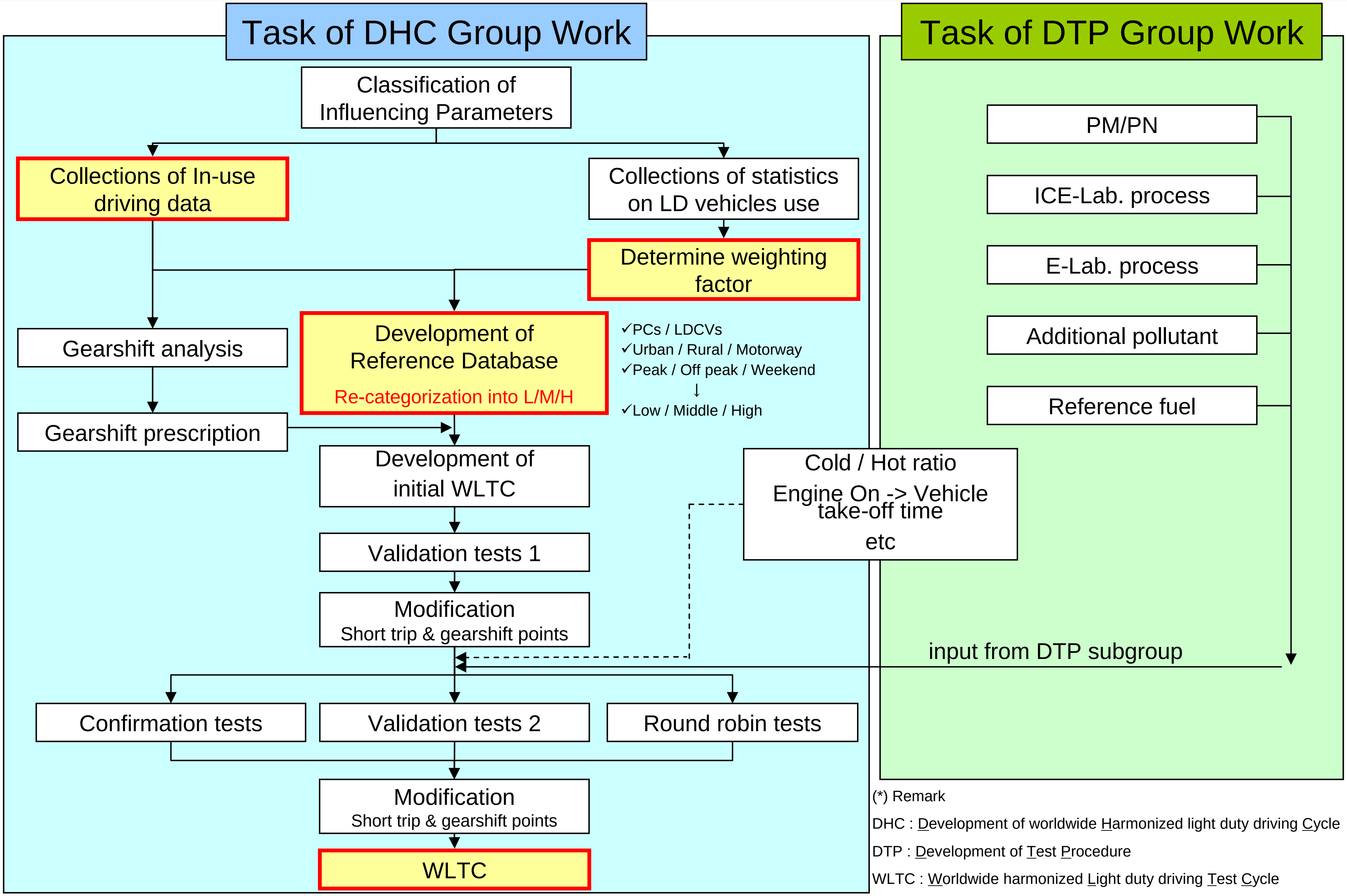
(*) U/R/M: Urban/Rural/Motorway, L/M/H: Low/Middle/High

2.1. Overall process



(*) Remark

DHC : Development of worldwide Harmonized light duty driving Cycle

DTP : Development of Test Procedure

WLTC : Worldwide harmonized Light duty driving Test Cycle

2.2. Basic concept

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

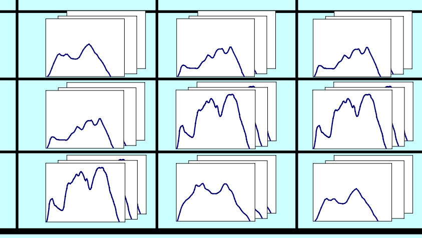
Weighting factor matrix and In-use driving data collection

Weighting factor

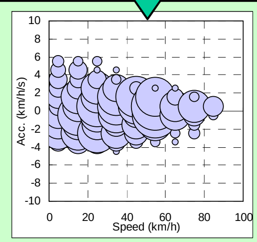
Road Category	Region A	Region B	Region C
I	WF_{A1}	WF_{B1}	WF_{C1}
II	WF_{A2}	WF_{B2}	WF_{C2}
III	WF_{A3}	WF_{B3}	WF_{C3}

In-use driving behaviors

Road Category	Region A	Region B	Region C
I			
II			
III			



Develop unified speed-acceleration distribution

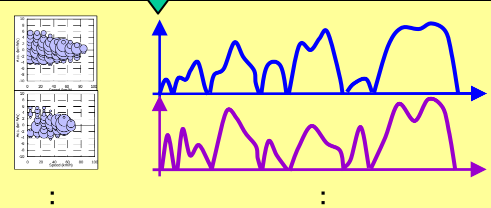


combine the short trips

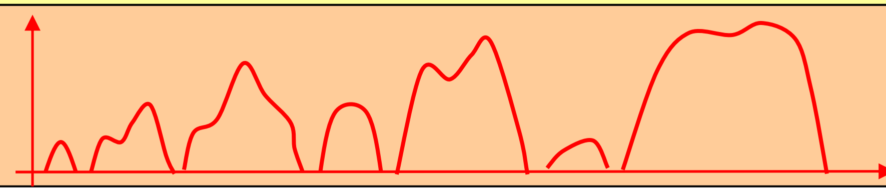
Compare the short trip combination and the unified distribution

➢chi-squared based analysis

➢Other parameter comparison



Common test cycle



2.3. Data collection matrix

- The following matrix is requirement for each in-use data collection CP, with consistency between weighting factors and collected data.
- Sub categorization is acceptable with consistency between weighting factors and collected data.

	Urban			Rural			Motorway		
	Weekday		Week-end	Weekday		Week-end	Weekday		Week-end
	On-peak	Off-peak		On-peak	Off-peak		On-peak	Off-peak	
Passenger Car (PC)									
LD Commercial Vehicle (LDCV)									

(*) In case of luck of statistical information, annual driving distance in red box can be acceptable for data analysis.

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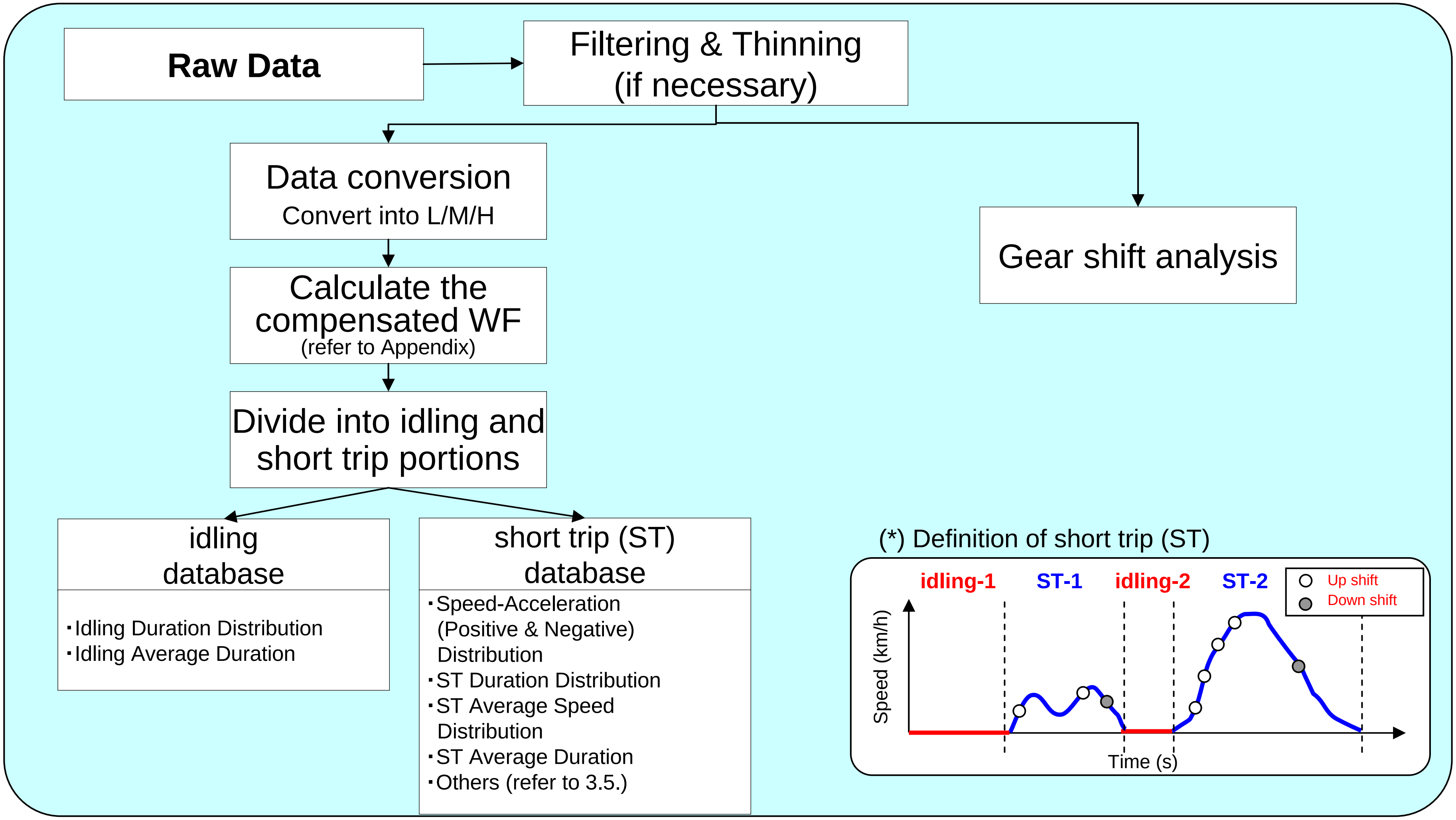
➢ In-use Driving Data Processing



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

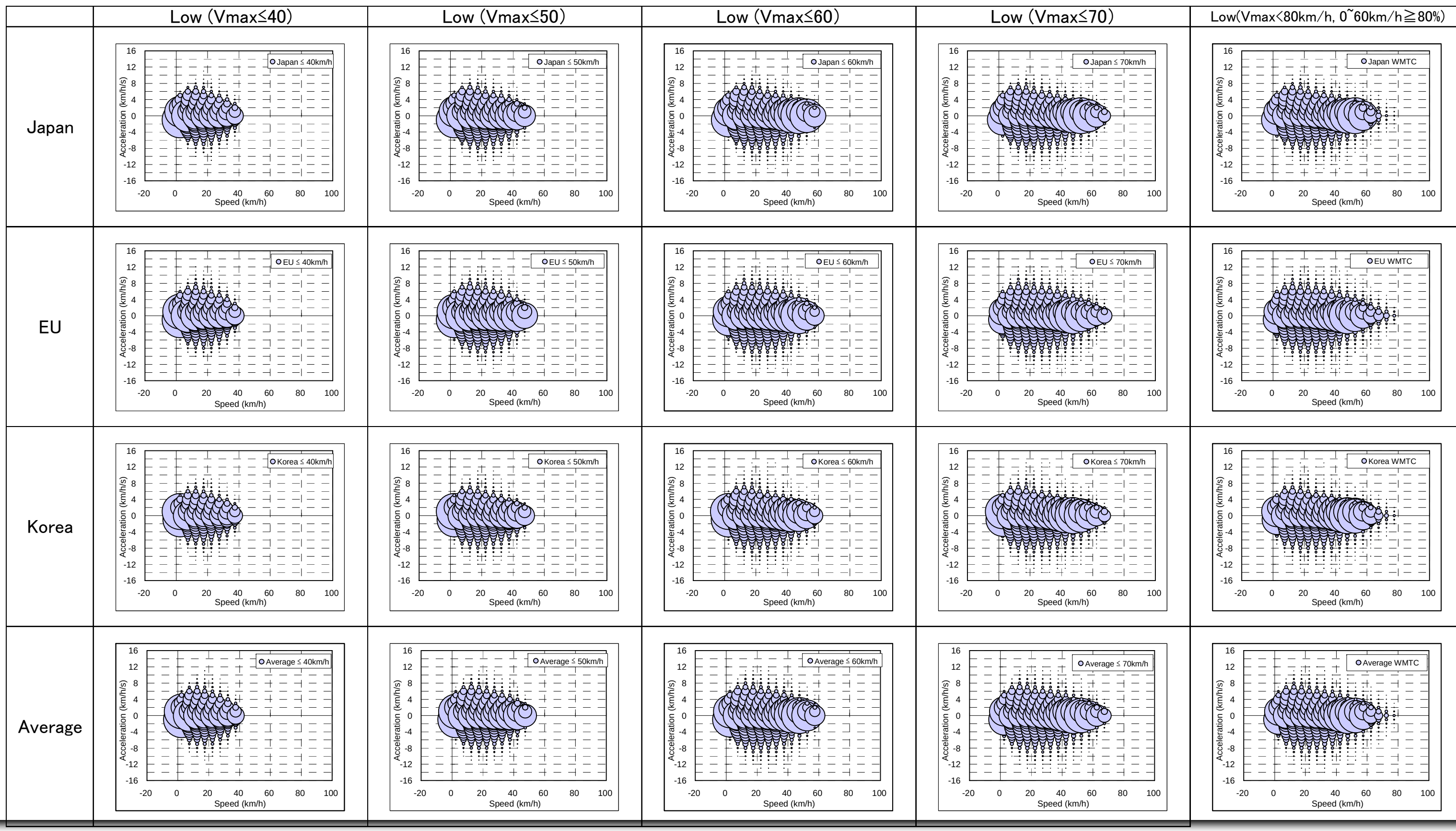
✓Raw data shall be shared within the DHC group.

1. Considering the threshold vehicle speed
   - ✓ Consider threshold based on each countries’ traffic condition and driving characteristic
   - ✓ Find the threshold that shows similar Speed-Acceleration distribution of each countries
2. Calculate the compensated WF
   - ✓ Using Drive condition WF and total driving duration
3. Convert in-use data（U/R/M => L/M/H）
4. Analyze speed-acceleration distribution and driving characteristics（L/M/H）
5. Generate the driving cycle in each phase

3.2.2. Consideration of threshold speed - 1

<Method1> Based on similarity of speed-acceleration distribution

- The threshold of Low/Middle
  - $\text{Vmax}_{L/M}$ = 40 / 50 / 60 / 70? and $\text{Ratio}_{V<60}$ > 80% etc.
- The threshold of Middle/High
  - $\text{Vmax}_{M/H}$ = 80 / 90 / 100/ 110? and $\text{Ratio}_{V<90}$ > 50% etc.



3.2.3. Consideration of threshold speed - 2

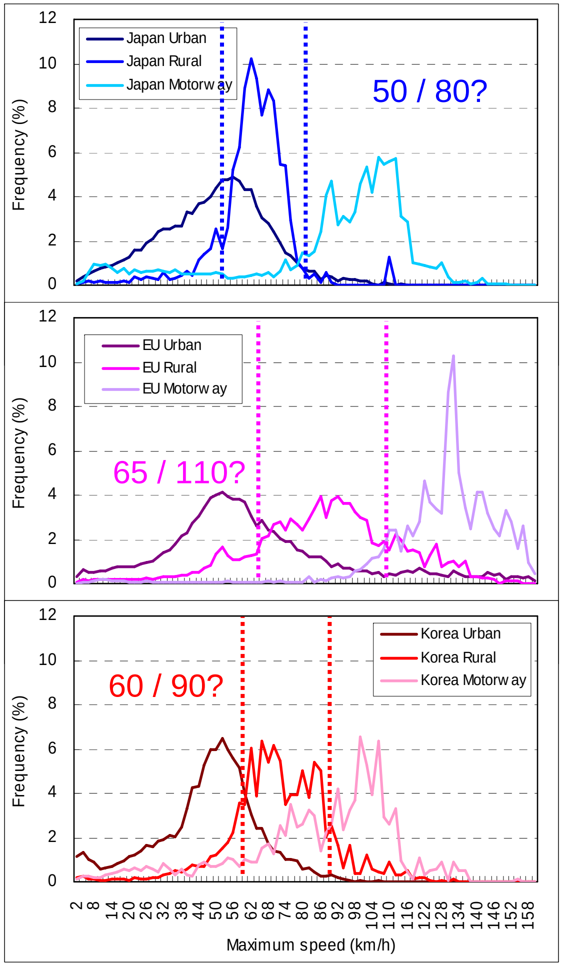
<Method2> Based on parameter value

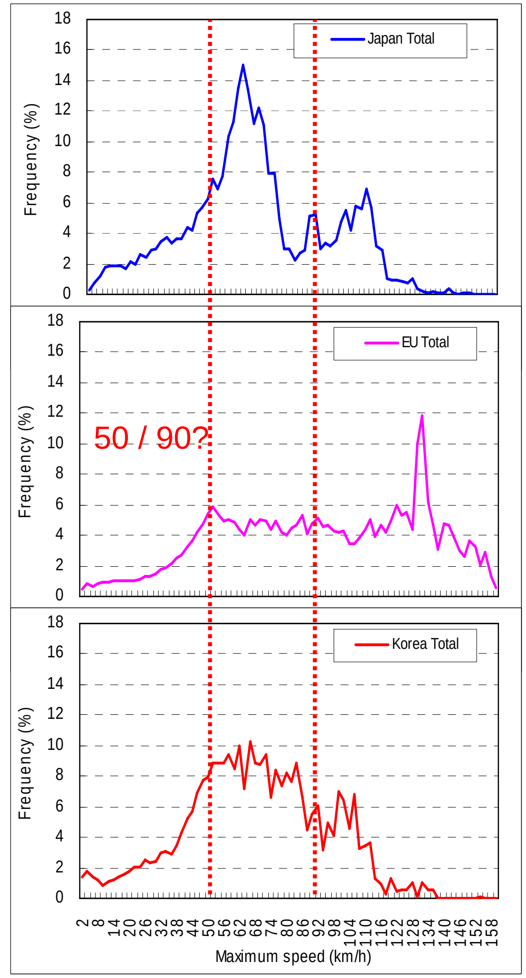
Road type Speed rage		Average speed				Relative positive acceleration				Idling ratio				Average short trip duration				Average idling duration			
		km/h				m/s^2				%				s				s			
		JPN	EU	KOR	Max−Min	JPN	EU	KOR	Max−Min	JPN	EU	KOR	Max−Min	JPN	EU	KOR	Max−Min	JPN	EU	KOR	Max−Min
Urban Low	Urban	22	26	18	8	0.18	0.19	0.19	0.01	32	27	38	11	67	77	55	22	28	24	30	7
	≦40	8	8	7	1	0.21	0.21	0.20	0.01	47	46	50	5	33	30	28	5	25	18	22	7
	≦50	12	14	12	2	0.20	0.21	0.20	0.01	41	36	44	8	43	43	39	4	26	18	25	8
	≦60	17	19	16	3	0.19	0.21	0.19	0.02	36	29	39	10	54	56	50	7	27	18	28	9
	≦70	20	22	18	4	0.18	0.20	0.19	0.02	34	26	36	10	62	67	59	8	28	18	29	10
Rural Middle	Rural	38	53	41	15	0.12	0.14	0.15	0.03	15	7	14	9	132	397	184	264	21	17	29	12
	40 - 80	28	33	26	7	0.18	0.19	0.18	0.02	24	14	26	12	102	149	149	47	31	19	38	19
	40 - 90	29	34	27	7	0.17	0.19	0.18	0.02	25	12	24	12	104	151	127	47	31	19	38	20
	50 - 90	32	38	31	7	0.17	0.19	0.18	0.02	22	10	21	11	120	185	158	65	32	19	41	22
	60 - 90	37	42	37	5	0.16	0.18	0.17	0.02	19	8	16	11	144	238	221	94	31	18	41	23
	70 - 110	45	52	46	6	0.15	0.16	0.15	0.01	15	5	10	10	207	359	351	153	30	18	39	21
Motorway High	Motorway	63	99	49	50	0.09	0.07	0.11	0.04	8	3	8	6	295	828	312	533	19	20	19	1
	80<	59	70	53	17	0.12	0.13	0.15	0.03	6	3	7	4	421	658	518	236	25	19	36	17
	90<	69	76	59	17	0.11	0.12	0.15	0.04	3	3	4	1	696	782	785	89	20	19	31	12
	110<	85	87	64	23	0.09	0.11	0.17	0.08	2	2	2	0	1086	1117	1213	127	18	19	24	6

⇒Select the candidate threshold speed based on least discrepancy in each characteristic.

3.2.4. Consideration of threshold speed - 3

<Method3> Based on maximum speed distribution





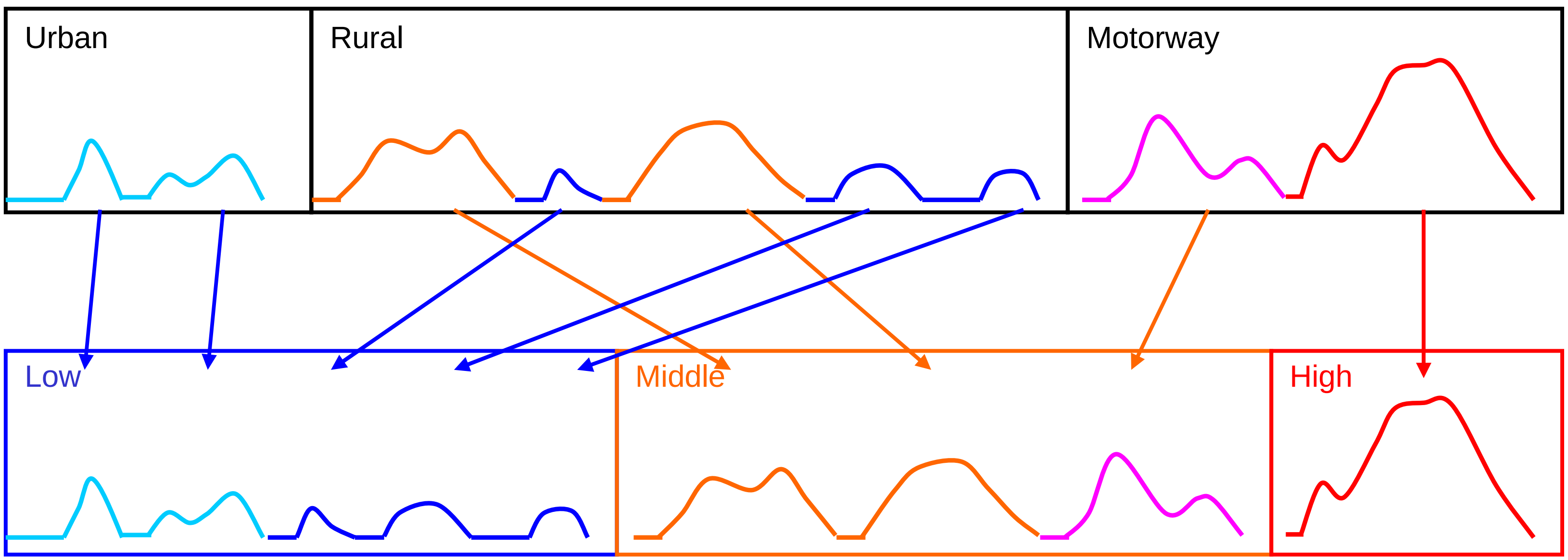
⇒After completion of all data acquisition, final threshold speed will be determined by taking into account of three methods.

3.2.5. Data conversion

Convert the each short trip data including the previous idling portion into new categories (Low/Middle/High) from original (Urban/Rural/Motorway) categories with the compensated WF (w')

- ➢criteria : maximum vehicle speed, speed frequency etc.

◆Image



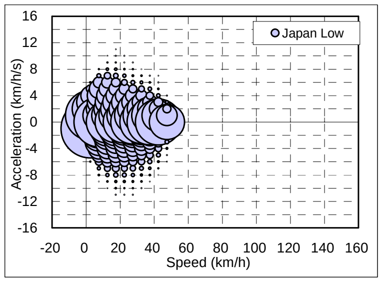
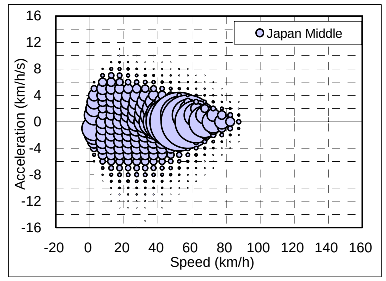
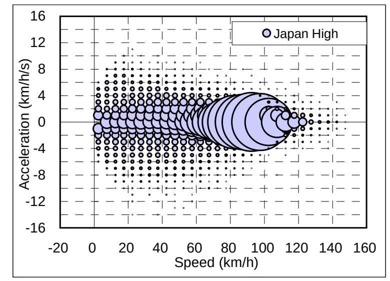
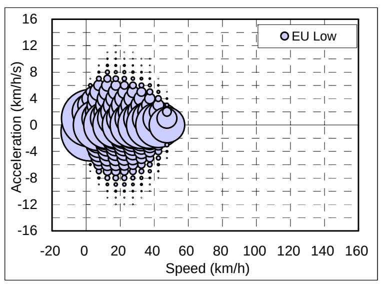
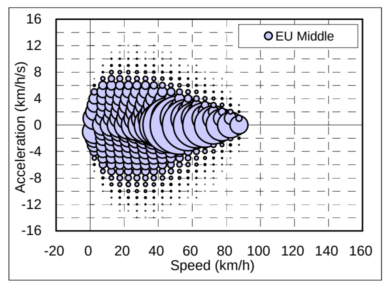
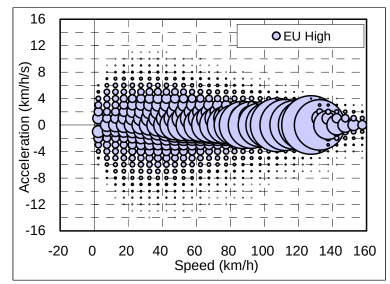
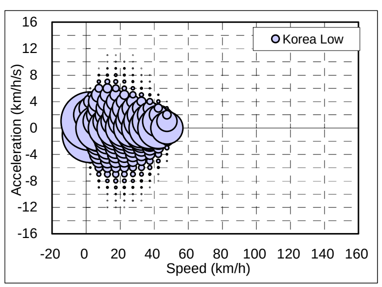
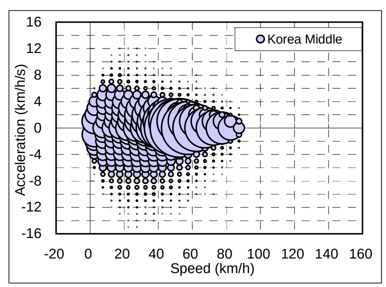
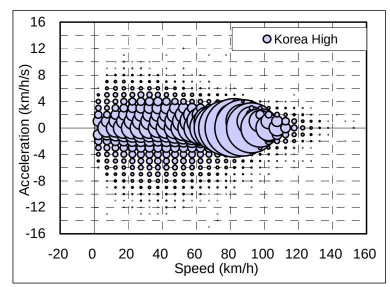
The segments that composed of ST and IDLE move into L/M/H categories with the compensated WF.

(*) Calculation formula of the compensated WF are shown in Appendix.

3.3.1. Develop the speed-acceleration distribution

- Develop the speed-acceleration distribution in each region

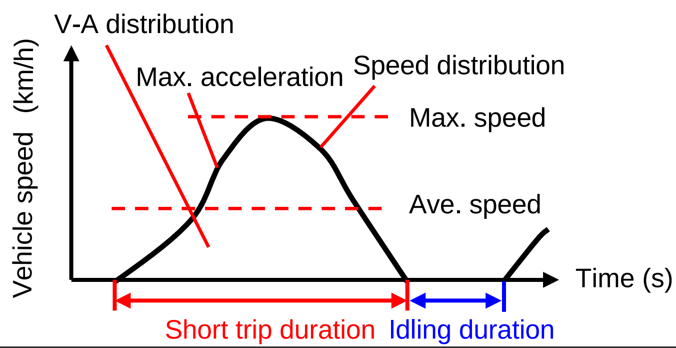
<Example>

	Low	Middle	High
Japan			
EU			
Korea			
US	:	:	:
India	:	:	:
China			

3.3.2. Analyze driving characteristics

➢To confirm the representativeness of the unified cycle, the following distributions and parameters will be analyzed.

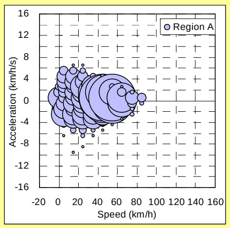
Distribution
ST speed-acceleration distribution
ST duration distribution
ST average speed distribution
ST maximum speed distribution
ST length distribution
ST cruise speed distribution
ST speed * acceleration distribution
Idling duration distribution



Parameter
Average speed (km/h)
Maximum Speed (km/h)
Maximum Acceleration (km/h/s or m/s^2)
Maximum Deceleration (km/h/s or m/s^2)
Relative Positive Acceleration (m/s^2)
Average short trip duration (s)
Average idling duration (s)
Number of idling per kilometer (#/km)
Number of idling per second (#/s)
Time accelerating (%)
Time decelerating (%)
Time cruising (%)
Time stop (%)

➢ Develop the unified speed-acceleration distribution

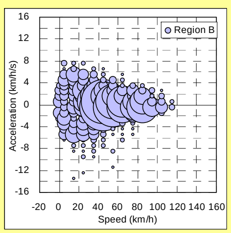
ex.: speed-acceleration distribution in Low phase



Low speed-acceleration distribution in region A

× $RW_{Low,A}$

WF Low in region A

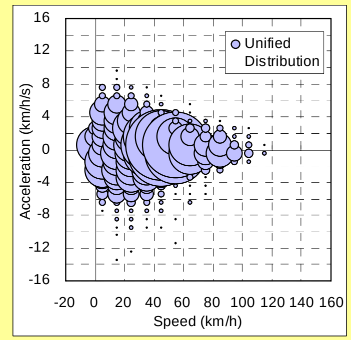


Low speed-acceleration distribution in region B

× $RW_{Low,B}$

WF Low in region B

⋮ ⋮



Unified speed-acceleration distribution in Low phase

<u>RW = Regional Weight</u>

✓ Unified distributions for the following parameters will be generated.

- ➢Short trip duration distribution, Short trip average speed distribution, Idling duration distribution, others

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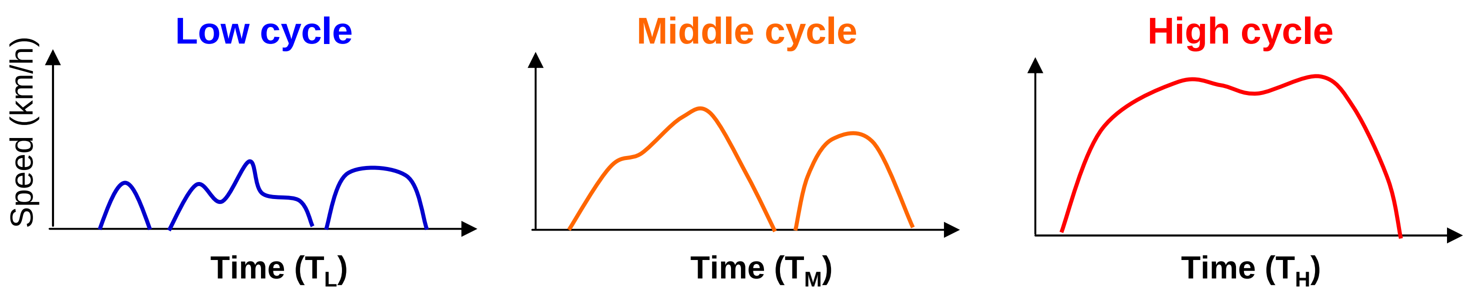
4.1.1. Determination of the number of idle and short trip

- Determine the test cycle duration

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



- Determine the number of idle and short trip in each phase
  - ✓ Calculate the number in each phase (Low, Middle, High)
    - number of short trip ($N_{ST,\,i}$)

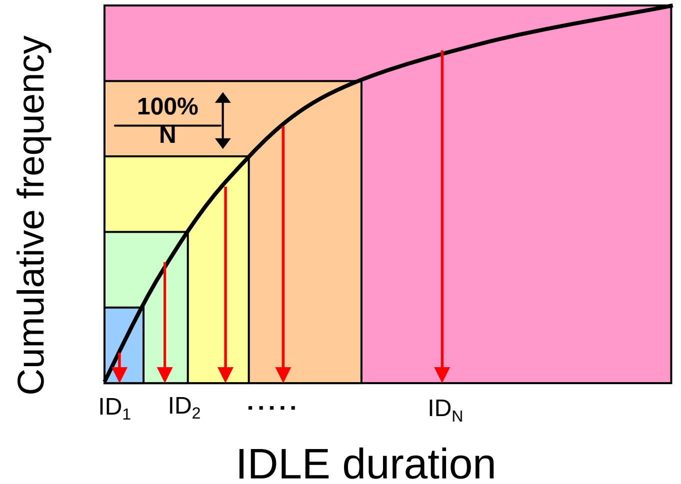
$$= \frac{\text{drive cycle duration in each phase } (T_i) - \text{average idling duration}}{\text{average short trip duration} + \text{average idling duration}}$$

- number of idle ($N_{I,\,i}$) = number of short trip ($N_{ST,\,i}$) + 1

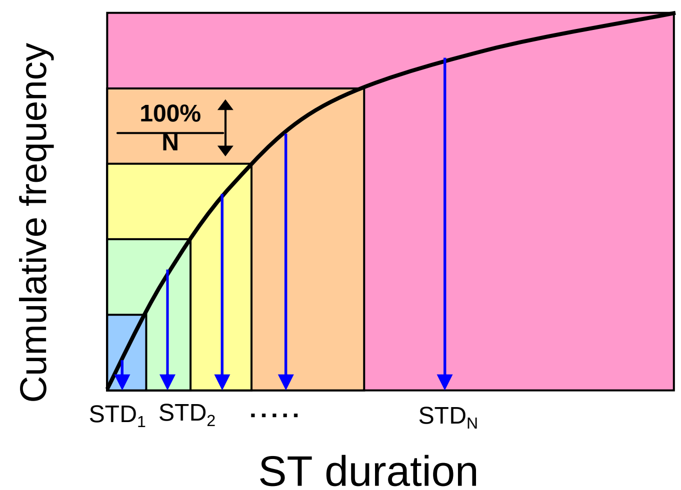
<example> T_L = 600 sec, average low short trip duration = 60 sec,
average low idling duration = 20 sec,
number of short trip ($N_{ST,L}$) = (600 – 20) / (60 + 20) = 7.25 => 7
number of idling ($N_{I,L}$) = 7 + 1 = 8

4.1.2. Determination of the idle and short trip duration

- Determine the $N_{I,\,i}$ units of idling duration in each phase
  - ✓ Generate the cumulative frequency graph based on idling data base
  - ✓ Divide into “$N_{I,\,i}$” equally in Y axis
  - ✓ Select the average duration in each class
  - ✓ $N_{I,\,i}$ units of idling duration (ID_1, ID_2, .., $ID_{NI,\,i}$) in each phase are decided

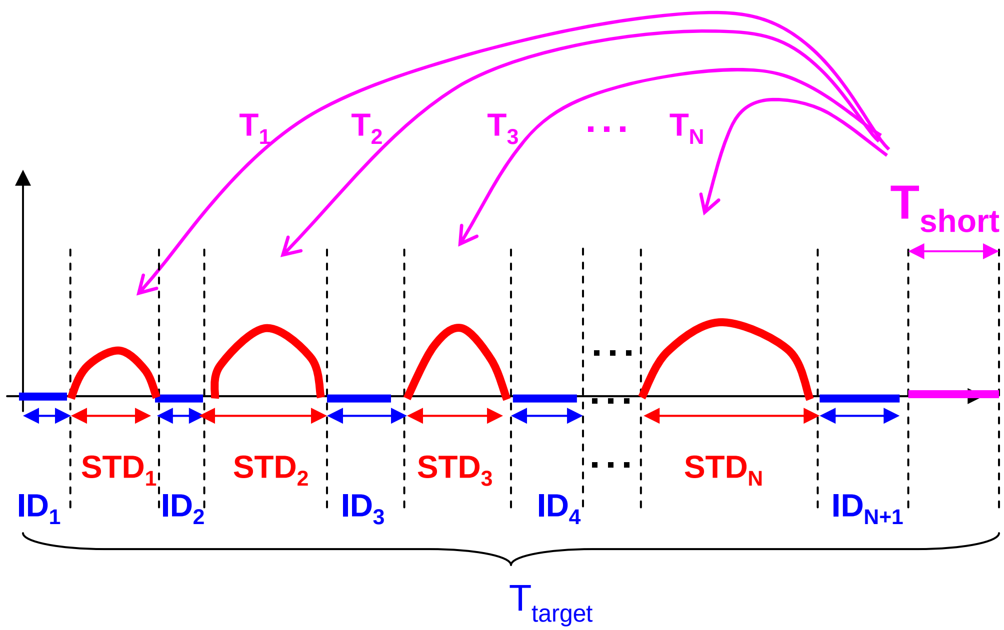


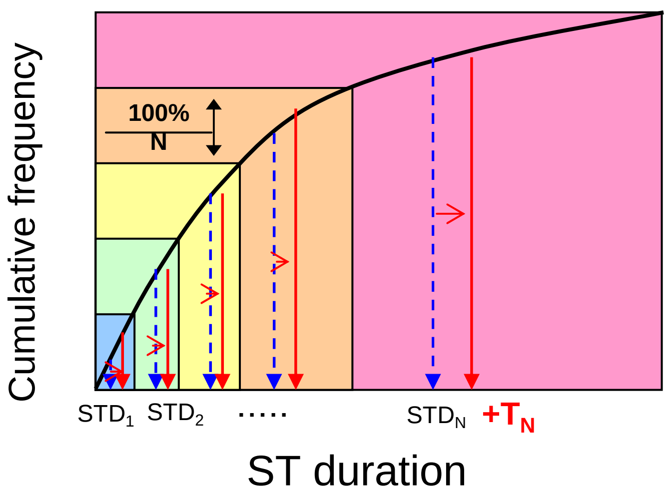
- Determine the $N_{ST,\,i}$ units of short trip duration in each phase
  - ✓ Generate the cumulative frequency graph based on short trip data base
  - ✓ Divide into “$N_{i,\,ST}$” equally in Y axis
  - ✓ Select a average duration in each class respectively. if necessary, adjust the duration to match the target cycle duration
  - ✓ Pick the candidate short trips which duration are STD_1, STD_2, .., $STD_{NST,\,i}$



4.1.3. Determination of the idle and short trip duration

- Select the ST which duration is adjusted by the following formula (T_n) to match the target cycle duration.
  - Compensate duration $T_N = STD_N / \Sigma STD_i * T_{short}$
- Same adjustment for idle duration will be taken, if necessary.



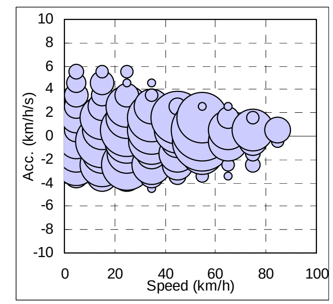


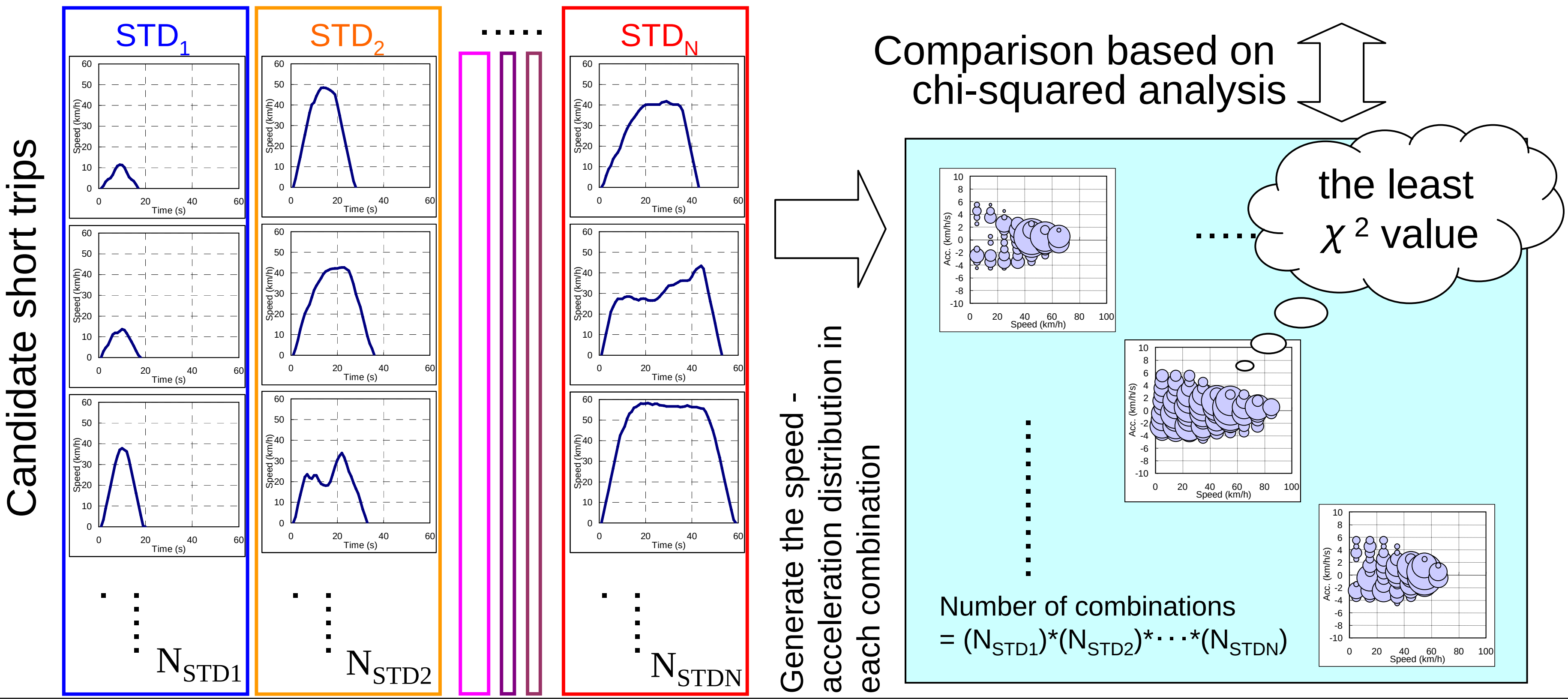
(*) $T_N = STD_N / \Sigma STD_i * T_{short}$

4.1.4 Determination of the short trip combination

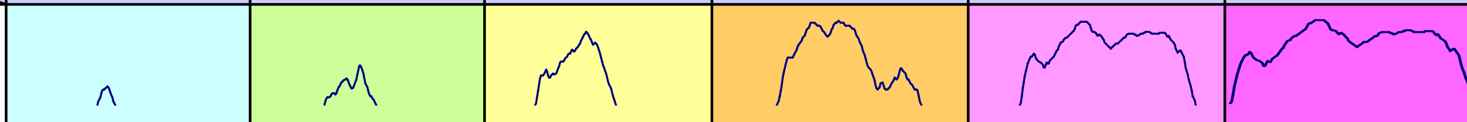
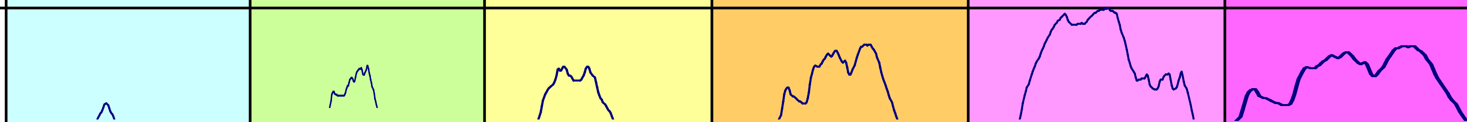
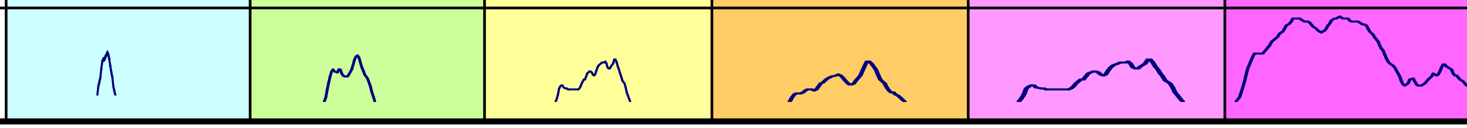
- Determine the short trip combination in each phase
  - ✓ Generate the speed-acceleration distribution in each combination from candidate short trips
  - ✓ Compare with the unified distribution
  - ✓ Select the short trip combination with the least χ^2 value
  - ✓ Check other distributions and parameters (refer to Appendix 1)

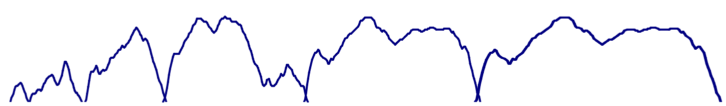
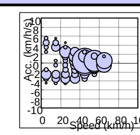
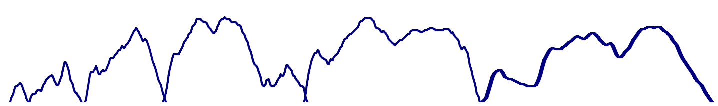
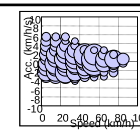
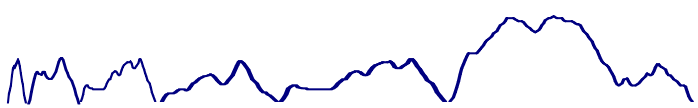
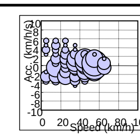
Unified speed - acceleration distribution





4.1.5. Sample of the ST combination

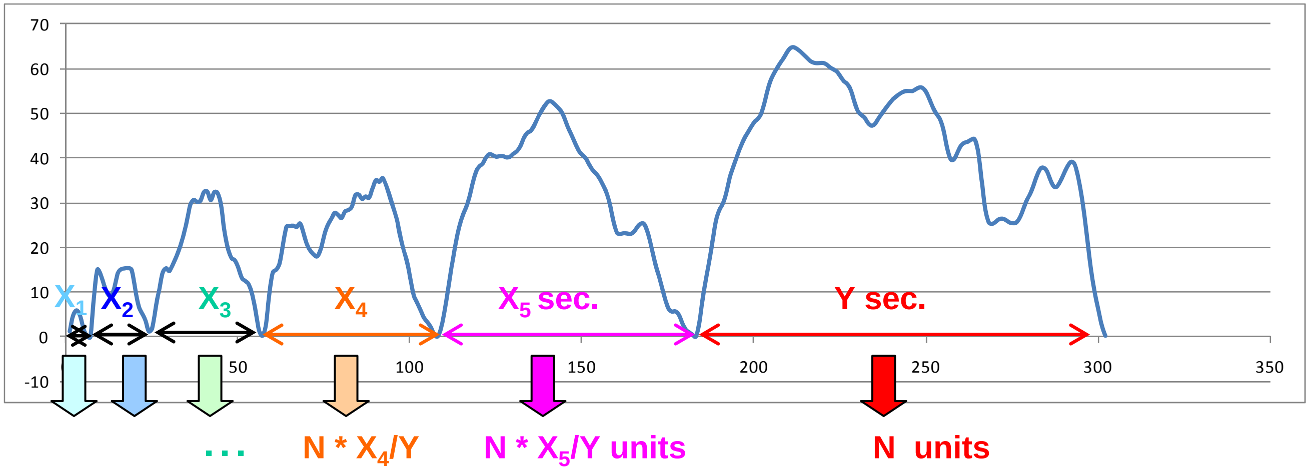
Duration (s) / No. of STD	STD1 10sec	STD2 15sec	STD3 18sec	STD4 24sec	STD5 38sec	STD6 60sec
1						
2						
.	.	.	.	.	.	.
N						

Combinations	Selected Short Trips	speed-acceleration distribution
1-1-1-1-1-1		
1-1-1-1-1-2		
…	…	…
N-N-N-N-N-N		

This analysis will be done for each phase.

4.1.6. Selection of each ST duration

- ST selection criteria
  - ST within average ±1σ in each ST duration
    - Average vehicle speed
    - Acceleration duration ratio
    - Deceleration duration ratio
  - Smaller chi-squared value is higher priority
- The number of potential STs in each ST duration
  - Longer ST has more potential STs since it has bigger influence on chi-square value.
  - Total number of combinations is less than $10^{7\sim8}$.
    - Approximately 3 days on Xeon X5492 (Quad core, 3.4GHz)



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4.2.1. Process of high-speed cycle development

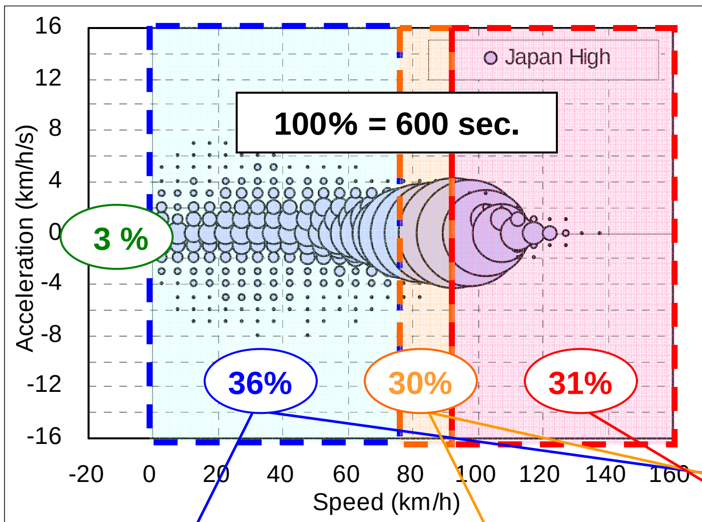
1. Determine the high-speed cycle duration (e.g. 600 sec.)
2. Determine the ST duration based on average ST duration and idling duration ratio of in-use data, the divide the ST into XX segments
   - 5 segments and 1 cruise
   - More than 5 segments and 2 cruise
   - Others

   <consider 2 phases (High-1 / High-2) cycle profile, if necessary >
3. Extract the driving data which meet each part's configuration from in-use STs.
4. Select the least chi-squared extracted driving data in each part, then combine the these data to develop the High-speed cycle.

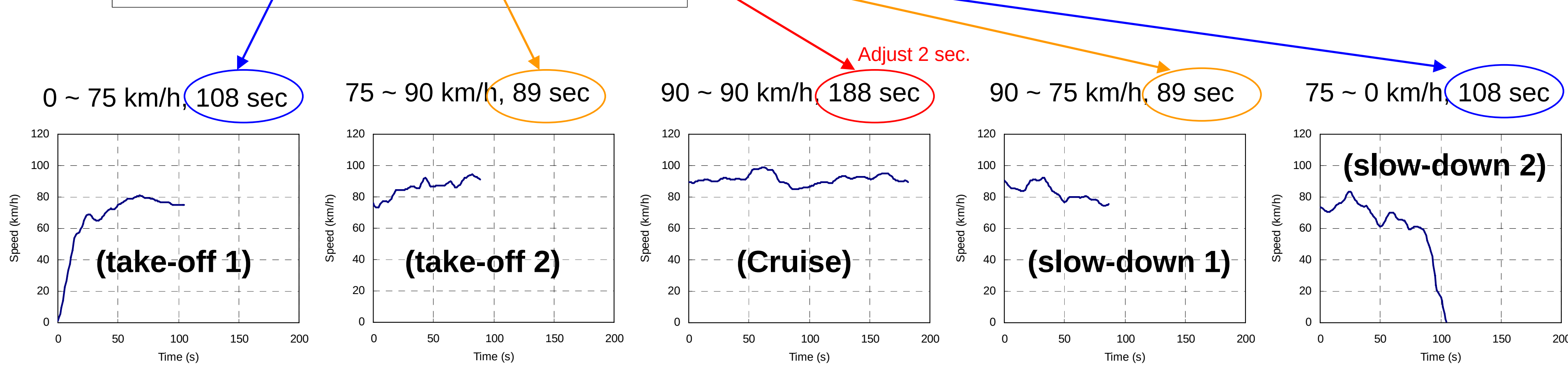
   (note) if the complete in-use ST is less chi-squared value than combined High-speed cycle, this specific ST can be used for High-speed cycle.

4.2.2. (Example) Divide into 5 parts of High-speed cycle

- Generate speed range and duration
  - Divide into 3 speed range based on dividing frequency distribution
    - Example: 0~75 km/h, 75~90 km/h, 90 km/h～
  - Decide target duration in each range, then divide into two portions (take-off and slow-down)
    - Example of 0~75km/h: 36% => 217 sec => take-off part 108 sec, slow-down 108 sec

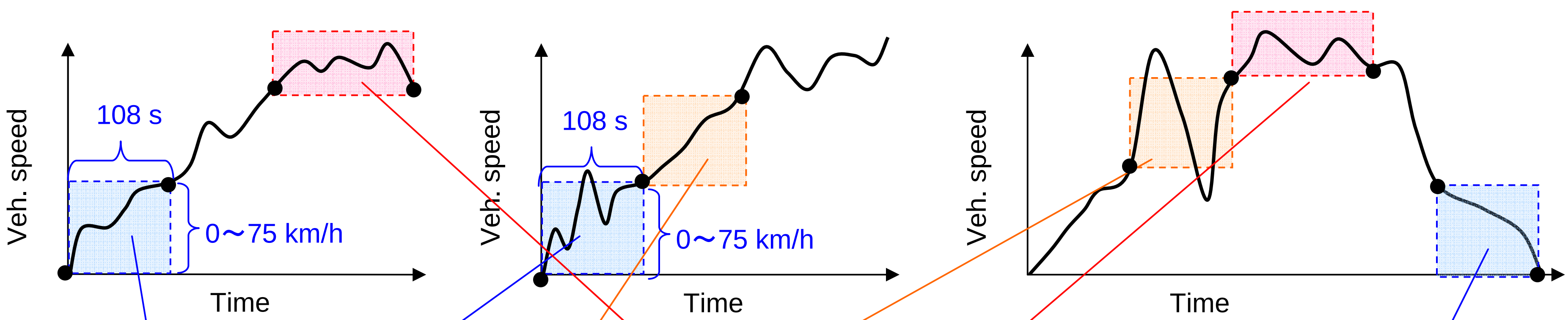


Speed range	Frequency (%)	Target duration	Divide part
Idling	3.1	18	9
0~75, 75~0	36.1	217	108
75~90, 90~75	30.0	179	89
90~	30.9	186	
Total	100	600	



4.2.3. Extraction of driving data

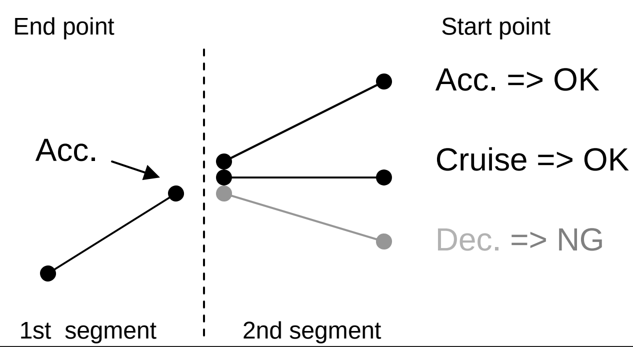
- Extract the driving data which meet each part's definition* from in-use ST.
  - Sample definition <Take-off 1 part>
    speed range : 0 ~ 75 km/h (with±0.5km/h), duration : 108sec.



0~75	75~90	90~90	・・・	75~0
			・・・	
			・・・	
			・・・	
			・・・	
			・・・	

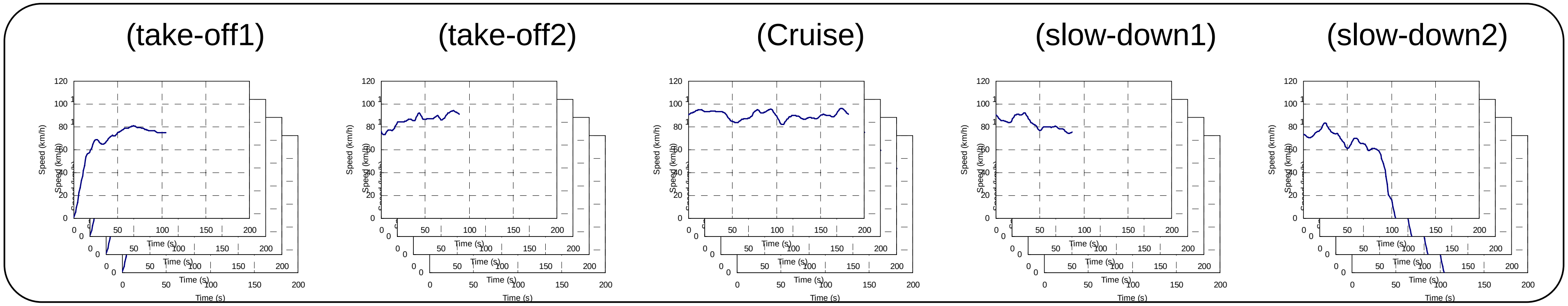
4.2.4. Connection conditions

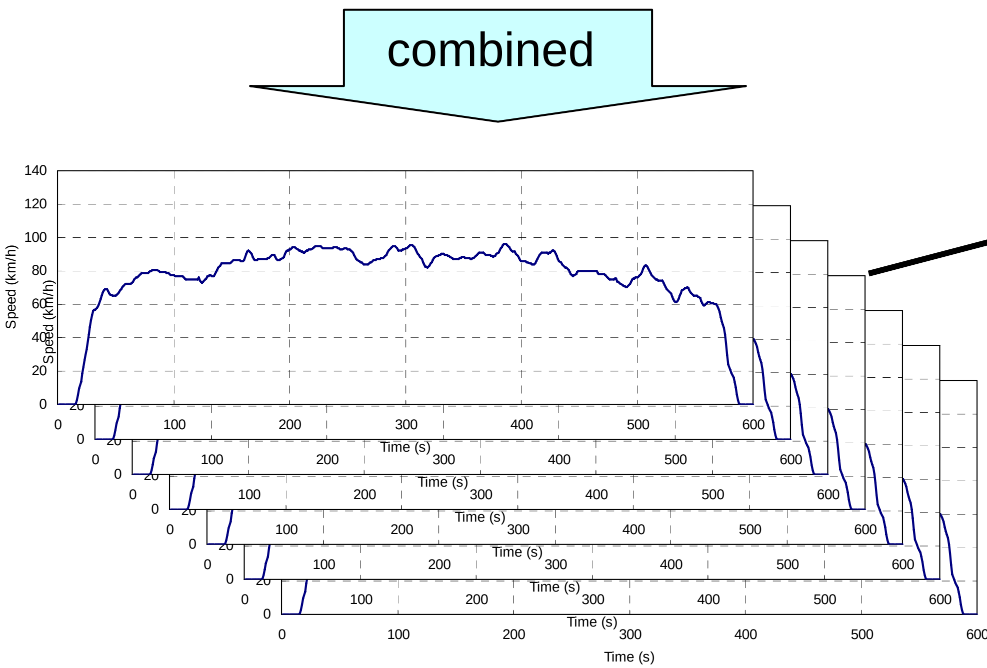
- Connection conditions:
  - Tolerance of the vehicle speed at connection point is ±0.5 km/h
    - example: 75 ± 0.5 km/h
  - The vehicle speed at connection point is adjusted to average of connected two points.
    - The vehicle speed of the end of first segment: 74.8km/h
    - The vehicle speed of the start of second segment: 75.2 km/h
    - The vehicle speed of connected point will be 75.0 km/h
  - Avoid the uncharacteristic connection
    - OK: “Acc. => Acc. or Cruise” or “Dec. => Dec. or Cruise”
    - NG: “Acc. => Dec.” or “Dec. => Acc.”

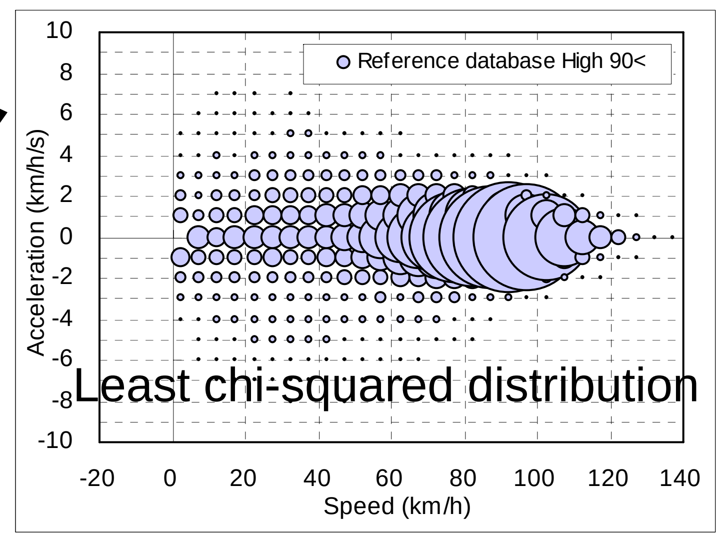


4.2.5. Method to develop High-speed cycle

Candidate driving data







Seek the combination cycle with least chi-square value compared with unified cycle

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(*) U/R/M: Urban/Rural/Motorway, L/M/H: Low/Middle/High

Compensated WF - 1

➢The collected data duration

road		vehicle		congestion	
urban	T_U	PC	$T_{U,PC}$	on peak	$T_{U,PC,ON}$
				off peak	$T_{U,PC,OFF}$
				weekend	$T_{U,PC,E}$
		LCV	$T_{U,LCV}$	on peak	$T_{U,LCV,ON}$
				off peak	$T_{U,LCV,OFF}$
				weekend	$T_{U,LCV,E}$
rural	T_R	PC	$T_{R,PC}$	on peak	$T_{R,PC,ON}$
				off peak	$T_{R,PC,OFF}$
				weekend	$T_{R,PC,E}$
		LCV	$T_{R,LCV}$	on peak	$T_{R,LCV,ON}$
				off peak	$T_{R,LCV,OFF}$
				weekend	$T_{R,LCV,E}$
motorway	T_M	PC	$T_{M,PC}$	on peak	$T_{M,PC,ON}$
				off peak	$T_{M,PC,OFF}$
				weekend	$T_{M,PC,E}$
		LCV	$T_{M,LCV}$	on peak	$T_{M,LCV,ON}$
				off peak	$T_{M,LCV,OFF}$
				weekend	$T_{M,LCV,E}$

➢Weighting factor matrix

road		vehicle		congestion	
urban	w_U	PC	$w_{U,PC}$	on peak	$w_{U,PC,ON}$
				off peak	$w_{U,PC,OFF}$
				weekend	$w_{U,PC,E}$
		LCV	$w_{U,LCV}$	on peak	$w_{U,LCV,ON}$
				off peak	$w_{U,LCV,OFF}$
				weekend	$w_{U,LCV,E}$
rural	w_R	PC	$w_{R,PC}$	on peak	$w_{R,PC,ON}$
				off peak	$w_{R,PC,OFF}$
				weekend	$w_{R,PC,E}$
		LCV	$w_{R,LCV}$	on peak	$w_{R,LCV,ON}$
				off peak	$w_{R,LCV,OFF}$
				weekend	$w_{R,LCV,E}$
motorway	w_M	PC	$w_{M,PC}$	on peak	$w_{M,PC,ON}$
				off peak	$w_{M,PC,OFF}$
				weekend	$w_{M,PC,E}$
		LCV	$w_{M,LCV}$	on peak	$w_{M,LCV,ON}$
				off peak	$w_{M,LCV,OFF}$
				weekend	$w_{M,LCV,E}$
sum	1	sum	1	sum	1

It is expected that the collected data volume in each matrix doesn’t match the weighting factor obtained based on vehicle statistical information.

Compensated WF - 2

➢Need to compensate the weighting factor of each matrix since the specific short trip is possible to move into different matrix.

(1) Calculate the compensated weighting factor (w_i')

road		vehicle		congestion	
urban	w_U	PC	$w_{U,PC}$	on peak	$w_{U,PC,ON}'$
				off peak	$w_{U,PC,OFF}'$
				weekend	$w_{U,PC,E}'$
		LCV	$w_{U,LCV}$	on peak	$w_{U,LCV,ON}'$
				off peak	$w_{U,LCV,OFF}'$
				weekend	$w_{U,LCV,E}'$
rural	w_R	PC	$w_{R,PC}$	on peak	$w_{R,PC,ON}'$
				off peak	$w_{R,PC,OFF}'$
				weekend	$w_{R,PC,E}'$
		LCV	$w_{R,LCV}$	on peak	$w_{R,LCV,ON}'$
				off peak	$w_{R,LCV,OFF}'$
				weekend	$w_{R,LCV,E}'$
motorway	w_M	PC	$w_{M,PC}$	on peak	$w_{M,PC,ON}'$
				off peak	$w_{M,PC,OFF}'$
				weekend	$w_{M,PC,E}'$
		LCV	$w_{M,LCV}$	on peak	$w_{M,LCV,ON}'$
				off peak	$w_{M,LCV,OFF}'$
				weekend	$w_{M,LCV,E}'$
sum	1	sum	1	sum	1

$$W_{U,PC,ON}' = \frac{W_{U,PC,ON}}{T_{U,PC,ON}} \times A_{U,PC}$$

$$W_{U,PC,OFF}' = \frac{W_{U,PC,OFF}}{T_{U,PC,OFF}} \times A_{U,PC}$$

$$W_{U,PC,E}' = \frac{W_{U,PC,E}}{T_{U,PC,E}} \times A_{U,PC}$$

where

$$A_{U,PC} = \frac{W_{U,PC,ON} + W_{U,PC,OFF} + W_{U,PC,E}}{\frac{W_{U,PC,ON}}{T_{U,PC,ON}} + \frac{W_{U,PC,OFF}}{T_{U,PC,OFF}} + \frac{W_{U,PC,E}}{T_{U,PC,E}}}$$

Same equation will be applied to others

Compensated WF - 3

- The collected data was converted into new categories.

  New weighting factors (w_L, w_M, w_H) are calculated as follows.

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

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

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

- This process will be done in each data collection CPs.