WLTC* Methodology

~ Initial Analysis Results & Modification on proposed methodology ~

Presented by Japan
GRPE/WLTP-IG/ DHC subgroup

14 October 2010

*) WLTC: Worldwide harmonized Light duty driving Test Cycle

Table of Contents

1. Purpose

1. Early studies
   - Japan and UK proposed the methodology to develop WLTC (WLTP-DHC-02-04/05/06 as U/R/M method)
   - Japan proposed the alternative technique to convert the in-use data to another categorization (WLTP-DHC-03-02 as L/M/H method)
     - The alternative technique was well recognized but need more clear explanation
2. Initial analysis
   - to make clear whether there is discrepancy in same road category or not
   - to derive the potential problem in the current methodologies
3. Validity of L/M/H method
   - to confirm that the alternative technique (L/M/H method) is valid to obtain similarity
   - to make a decision which methodology is more appropriate
4. Modification on proposed methodology
   - to improve the methodology based on the initial analysis

2.1.1. Definition of Road Type

It was agreed that each CP has its own unique definition of each road type (urban/rural/motorway) during 1st DHC meeting. This may lead the discrepancy on speed-acceleration distribution among CPs in same road category.

	Urban	Rural	Motorway
India	Paved roads in urban areas with a **speed limit ≤40 km/hour** (exclude mountain areas)	Paved non-motorways outside and inside urban areas with a speed limit **between 40 and 60 km/hour**	Paved motorways (multi-lane roads specifically constructed and controlled for fast traffic) with a speed **60 to 80 km/hour**
Korea	Arterial, collector and local road inside and/or near central business district (CBD). **Speed limit is from 40 to 80 km/h**, depends on road type	Arterial, collector and local road inside non-urban area. **Speed limit is from 50 to 80 km/h**, depends on road type	Motorway which is designed, constructed and controlled for faster traffic in urban and rural area. **Speed limit is from 100 to 120 km/h**, depends on area
Japan	Densely Inhabited District (DID) ・**Speed limit ≤ 60km/h** ・exclude mountain areas	・Non-Densely Inhabited District ・Non motorways ・**Speed limit ≤ 60km/h** ・exclude mountain areas	Motorways (within City and between Cities) ・**Speed limit ≤ 100km/h** ・exclude mountain areas
EU	The definition depends on EU countries	The definition depends on EU countries	The definition depends on EU countries
USA	?	?	?
China	?	?	?

2.1.2. Overview of Collected In-use Data

Country / Region	Area	No. of vehicles		Total driving duration(*) (hr)	Total driving distance(*) (km)
		Passenger car	Light duty commercial vehicle		
EU (*)ongoing	Germany, Italy, Slovenia, France, Belgium, Switzerland	67	6	Approx. 2,800	Approx. 145,000
Japan	12 prefecture: Tokyo, Osaka , Kyoto, Nagoya, Shizuoka, etc	11	13	Approx. 1,800	Approx. 55,000
Korea(**)	Seoul	6	2	Approx. 1,100	Approx. 35,000

(*) Exclude NG data

(**) Korea: Not exist Weekend data in Urban and Rural

2.1.3. Traffic Volume Weighting in Driving Conditions

Road type		Vehicle type	Driving period	Driving condition weighting factor					
				Japan	EU	Korea	US	India	China
Urban	Urban-1	PC	Peak	4.36%	2.98%	1.98%			
			Off peak	12.80%	8.93%	14.68%			
			Weekend	6.24%	4.76%				
		LDCV	Peak	1.04%	2.98%	1.98%			
			Off peak	3.13%	8.93%	14.68%			
			Weekend	0.56%	4.76%				
	Urban-2	PC	Peak	5.67%					
			Off peak	13.50%					
			Weekend	6.32%					
		LDCV	Peak	1.17%					
			Off peak	3.26%					
			Weekend	0.62%					
Rural	Rural	PC	Peak	6.64%	2.98%	1.98%			
			Off peak	14.05%	8.93%	14.68%			
			Weekend	6.63%	4.76%				
		LDCV	Peak	1.81%	2.98%	1.98%			
			Off peak	4.42%	13.69%	14.68%			
			Weekend	0.83%					
Motorway	Motorway-1	PC	Peak	0.68%	2.98%	1.98%			
			Off peak	1.72%	8.93%	9.92%			
			Weekend	1.73%	4.76%	4.76%			
		LDCV	Peak	0.18%	2.98%	1.98%			
			Off peak	0.39%	13.69%	9.92%			
			Weekend	0.12%		4.76%			
	Motorway-2	PC	Peak	0.32%					
			Off peak	0.89%					
			Weekend	0.52%					
		LDCV	Peak	0.10%					
			Off peak	0.24%					
			Weekend	0.05%					
Sum				100.00%	100.00%	100.00%	0.00%	0.00%	0.00%

Temporary weighting for initial analysis

◆EU and Korea

・Urban : Rural : Motorway = 1 : 1 : 1, PC : LDCV = 1 : 1

Weekday	5 days	Peak	EU: 7:00~10:00, 16:00~19:00	6 hours
			KOR: 7:00~9:00, 18:00~20:00	4 hours
		Off peak	Other time	18 / 20
Weekend	2 days			24 hours

2.2.1. Preparation for Data Analysis

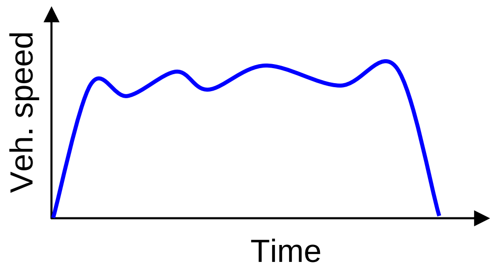
- Common points
  - Remove the noise by filtering process.（T4253H filter）
  - Find the acceleration by applying differential equation $\alpha_i = (V_{i+1} - V_{i-1}) / (T_{i+1} - T_{i-1})$
  - Generate the Speed-acceleration distribution, V：5km/h intervals, α ：1km/h/s intervals
  - Eliminate the ST with max speed 250km/h or higher
- Japanese data
  - Include incomplete ST that transfer to High phase (e.g. Vmax≧80, 90km/h)
  - (See the next slide for more details on incomplete ST）
- EU data（Pre-check methodology）
  - not_ok is set “true”, when failures or inconsistencies were found during data preprocessing and when the following indicators are set “true”,
  - not_ok_dv is set “true”, when the difference between the original vehicle speed v and the smoothed speed vg is < -7 km/h or > 7 km/h. This is typically the case, when there are gaps or jumps in the speed pattern.
  - not_ok_v_start_end is set to “true”, when v_start and/or v_end of a short trip is higher than 12.6 km/h.
  - not_ok_a_min_max is set to “true”, when the acceleration exceeds 4 m/s^2 or is less then -4.5 m/s^2.
  - Datasets and short trips, indicated with those not_ok indicators should be excluded from the further analysis.
- Korean data
  - Apply same method as Japanese data

2.2.2. Incomplete Short Trip

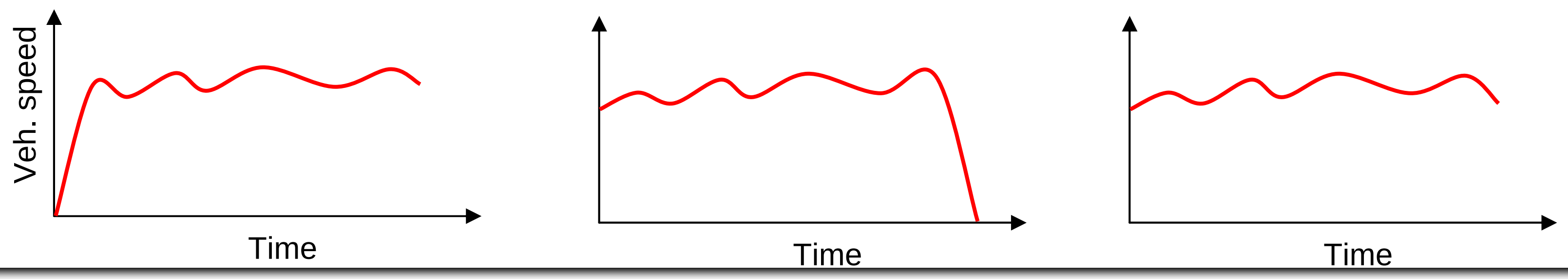
Both complete and incomplete in-use data that transfer to High phase are analyzed.

- Because of long driving duration at high speed, including the STs with no start acceleration phase or braking phase does not impact.
- If the data is excluded, the few remaining data might not represent actual driving conditions.

①Complete ST

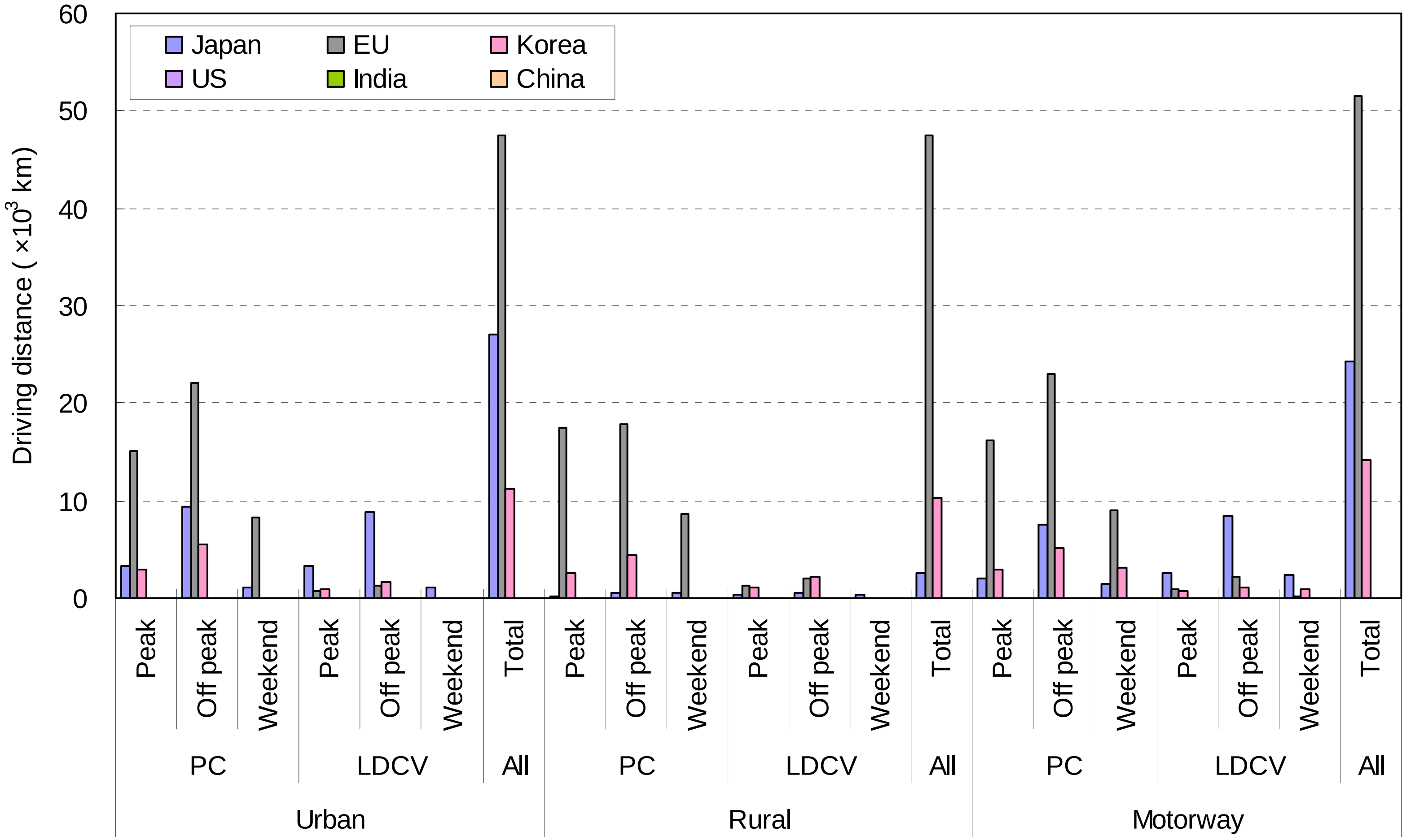


②Incomplete ST



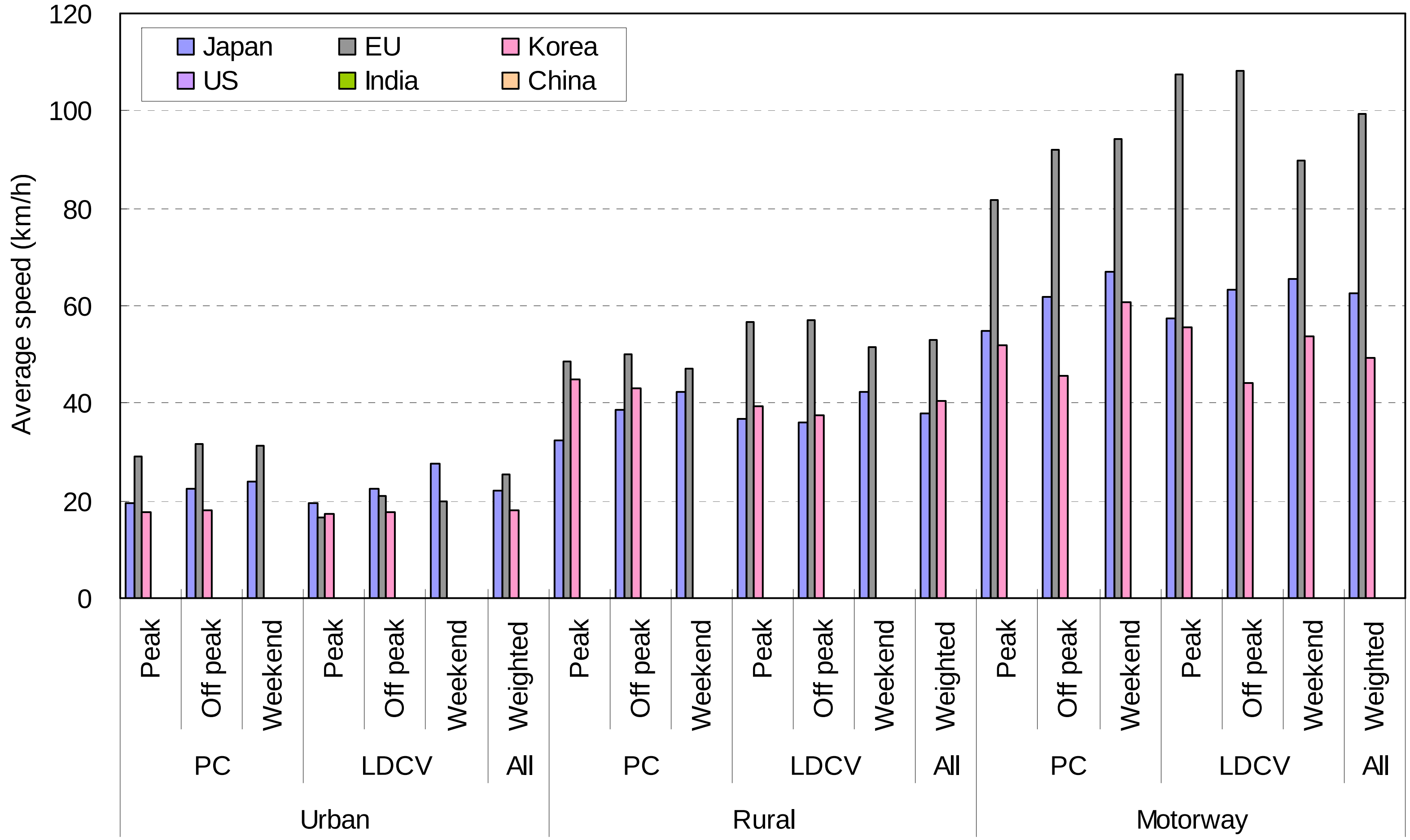
2.3.1. Parameter Comparison-1

◆Driving distance



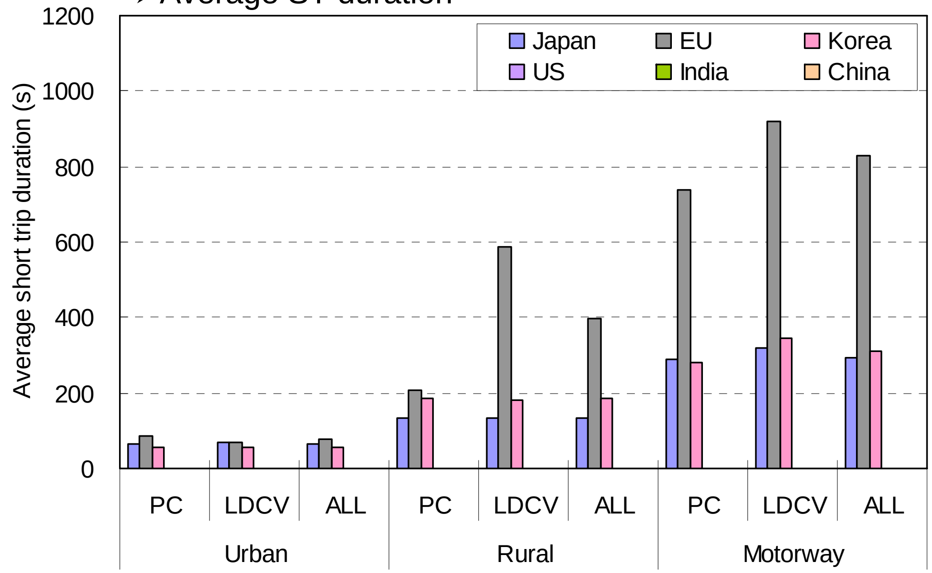
2.3.1. Parameter Comparison-2

◆Average speed

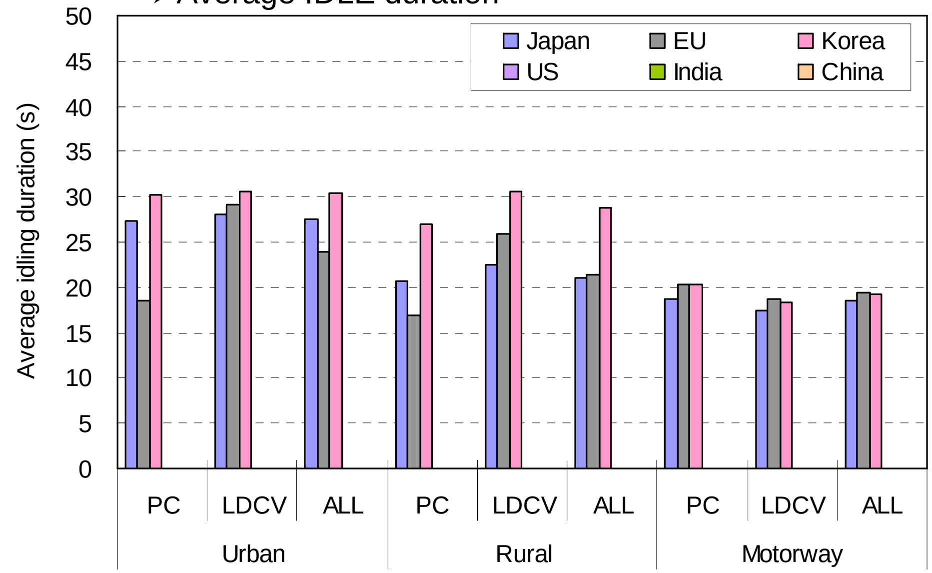


2.3.1. Parameter Comparison-3

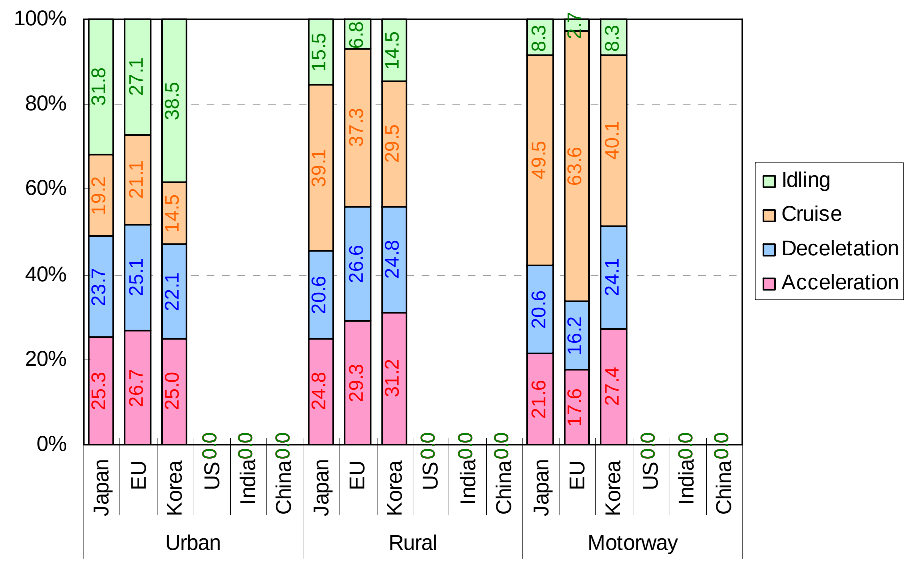
➤Average ST duration



➤Average IDLE duration

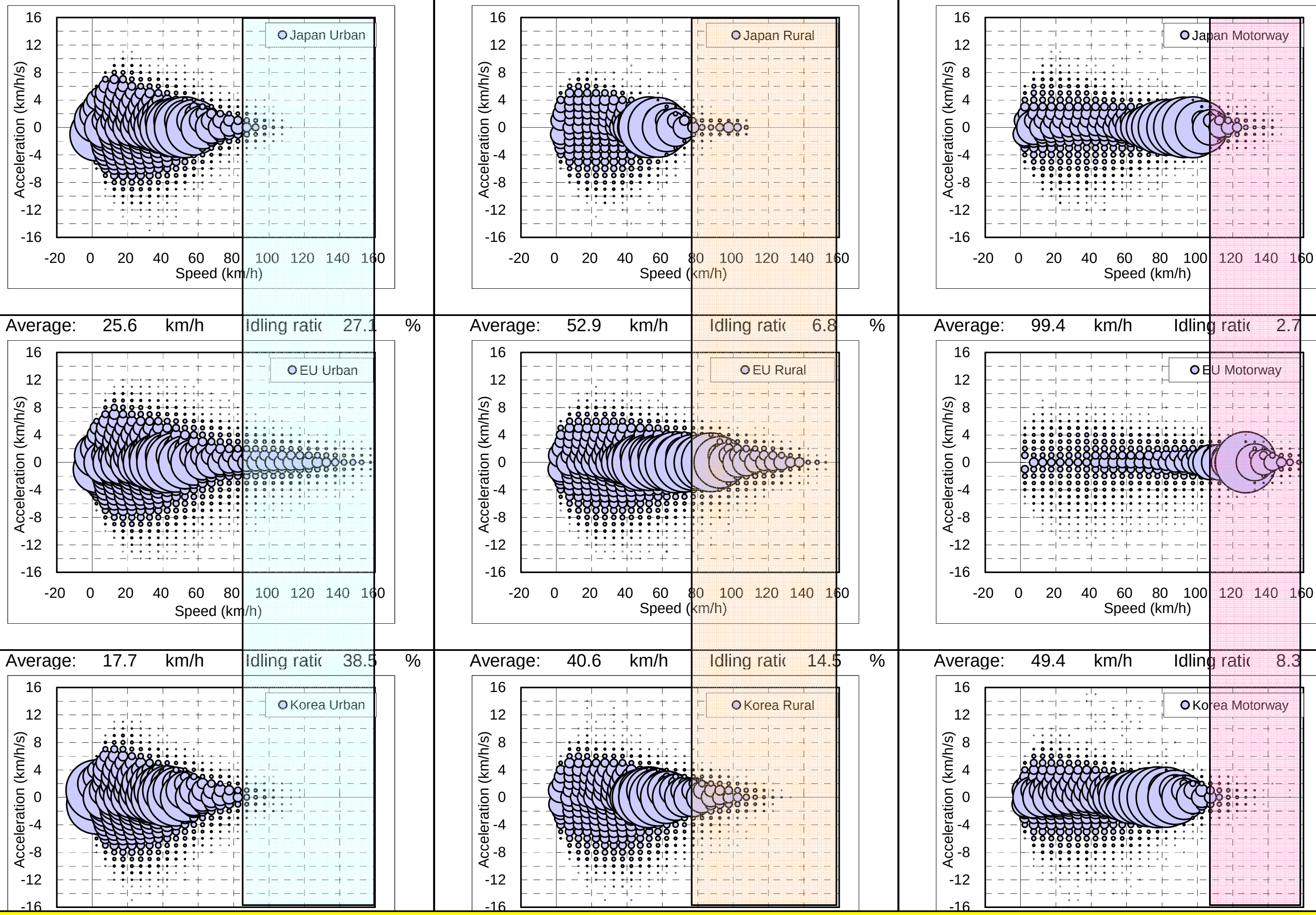


➤Ratio of 4 driving mode



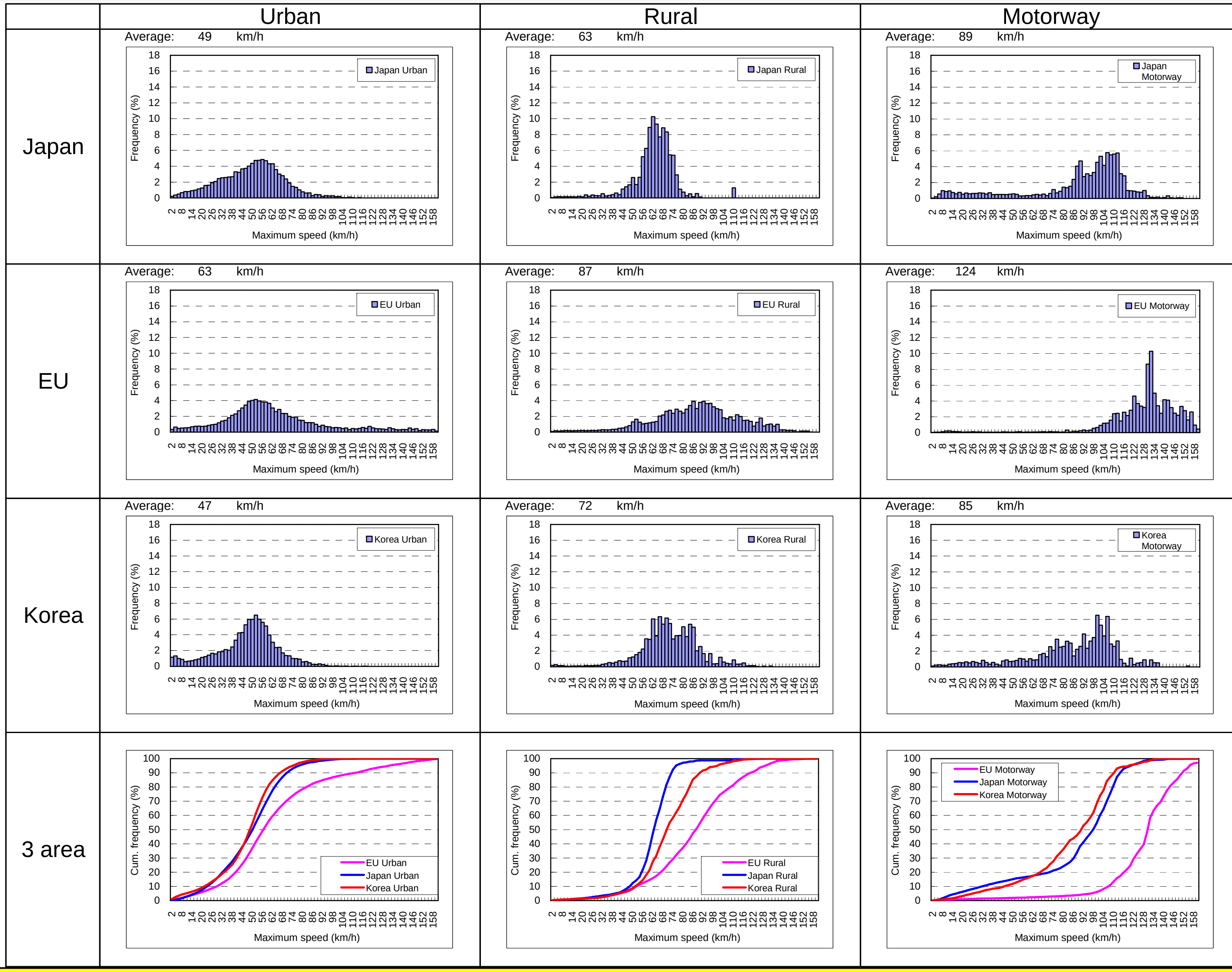
2.3.2. Speed Acceleration Distribution

	Urban	Rural	Motorway
Japan	Average: 22.3 km/h, Idling ratio 31.8 %	Average: 37.8 km/h, Idling ratio 15.5 %	Average: 62.5 km/h, Idling ratio 8.3 %
EU	Average: 25.6 km/h, Idling ratio 27.1 %	Average: 52.9 km/h, Idling ratio 6.8 %	Average: 99.4 km/h, Idling ratio 2.7 %
Korea	Average: 17.7 km/h, Idling ratio 38.5 %	Average: 40.6 km/h, Idling ratio 14.5 %	Average: 49.4 km/h, Idling ratio 8.3 %



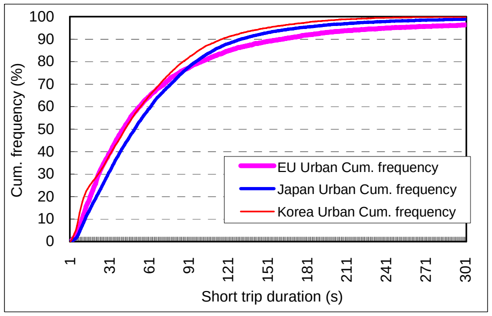
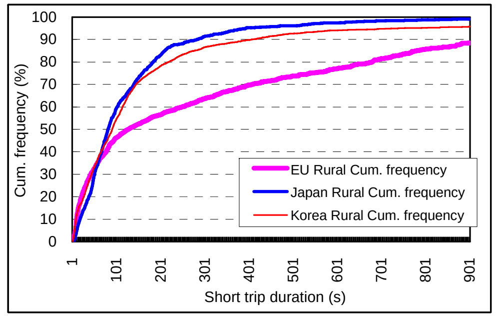
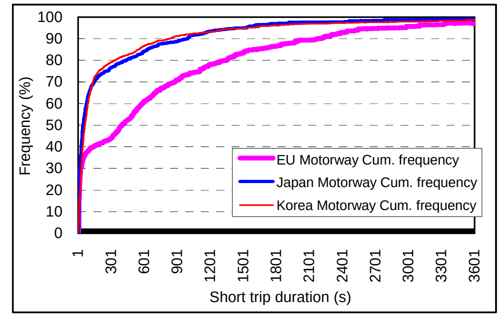
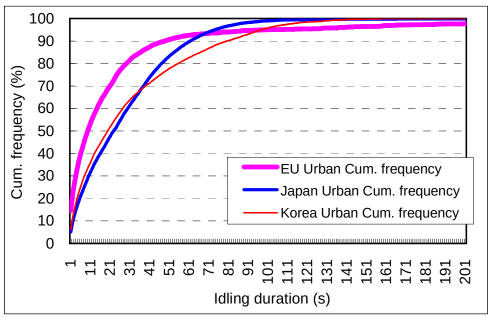
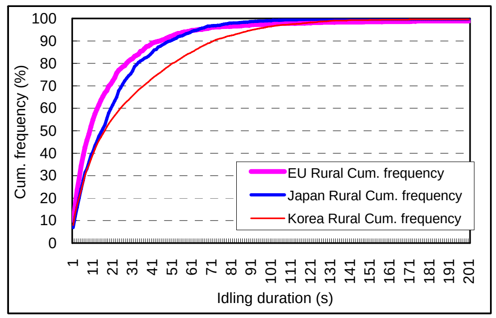
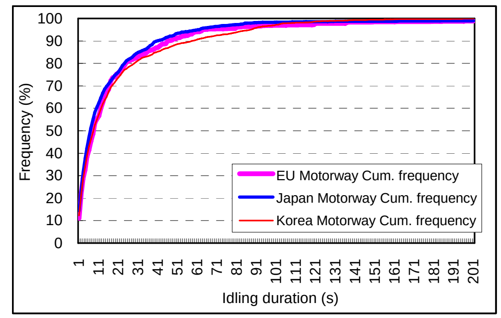
Discrepancy in speed-acceleration distribution was observed in each road category.

2.3.3. Frequency of ST Maximum Speed（Y axis：Frequency of driving duration）



Discrepancy in ST maximum speed distribution was observed.

2.3.4. Other Parameters

<table>
<tr><th></th><th>Urban</th><th>Rural</th><th>Motorway</th></tr>
<tr><td>Short trip duration</td><td>
</td><td>
</td><td>
</td></tr>
<tr><td>Idling duration</td><td>
</td><td>
</td><td>
</td></tr>
</table>

Discrepancy in ST/IDLE duration distribution was observed.

2.4. Conclusion of Initial Analysis

- It was observed that speed-acceleration distribution/driving characteristics in each region have discrepancy in same road categories.
- This discrepancy may mislead the representativeness when developing the harmonized driving cycle.

- Therefore, it is necessary to convert to another category where driving characteristics are similar in each region. L/M/H methods is one of countermeasures.

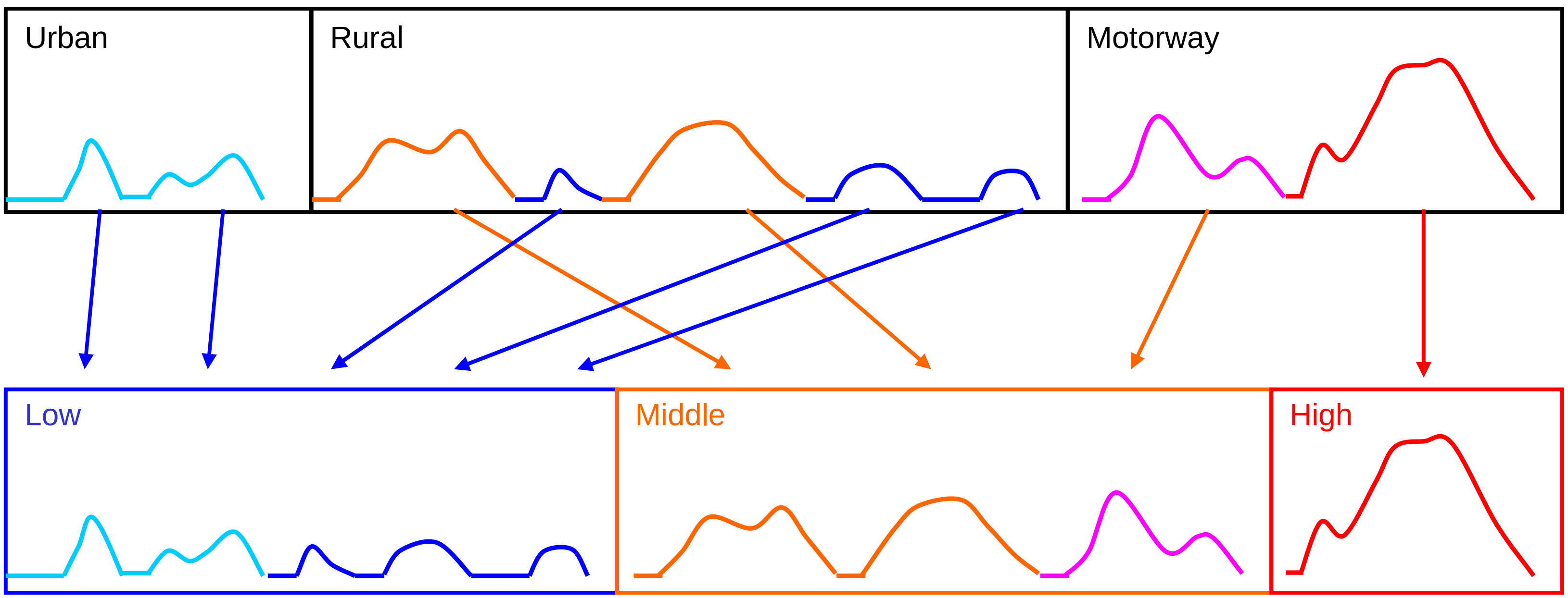
3. Validity of L/M/H Method

3.1. Overview of WLTP-DHC-03-02

WLTP-DHC-03-02 described the technique to convert the in-use data into vehicle speed oriented categories.

- Urban/Rural/Motorway -> Low/Middle/High

◆Image



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

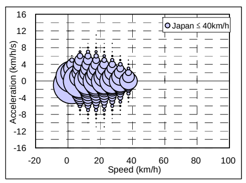
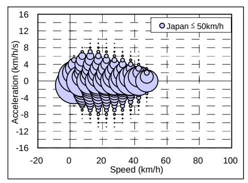
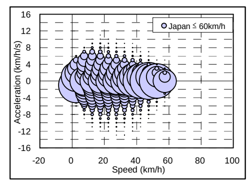
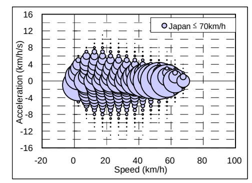
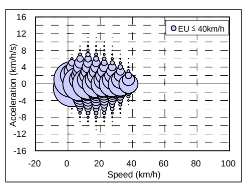
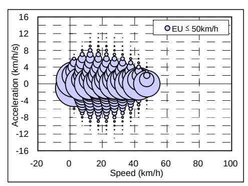
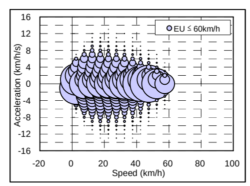
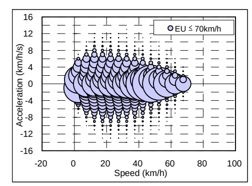
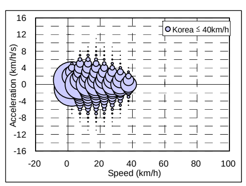
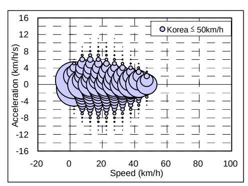
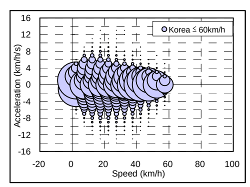
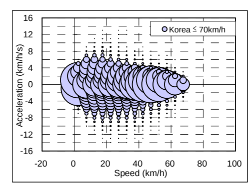
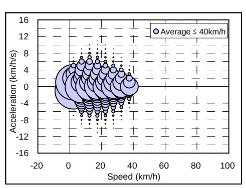
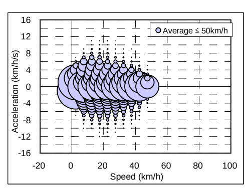
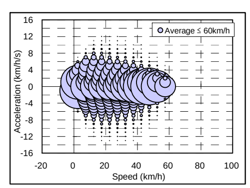
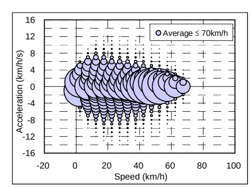
3.2.1. Detail of L/M/H Method

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

3.2.2. Consideration of Threshold Speed - 1

<Method1> Based on similarity of VA distribution

- The threshold of Low/Middle
  - Vmax ≤ 40 ?, Vmax ≤ 50 ?, Vmax ≤ 60 ?, Vmax ≤ 70 ?
- The threshold of Middle/High
  - $V_{L/M}$ < Vmax ≤70 ?, $V_{L/M}$ < Vmax ≤80 ?, $V_{L/M}$ < Vmax ≤90 ?, $V_{L/M}$ < Vmax ≤100 ?

	Low (Vmax≤40)	Low (Vmax≤50)	Low (Vmax≤60)	Low (Vmax≤70)
Japan				
EU				
Korea				
Average				

3.2.2. Consideration of threshold speed - 2

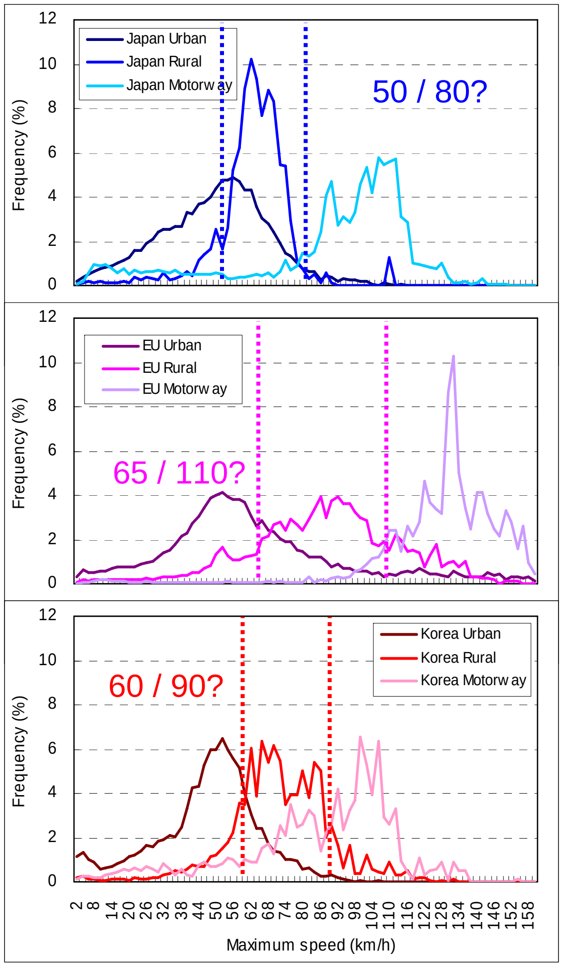
<Method2> Based on parameter value

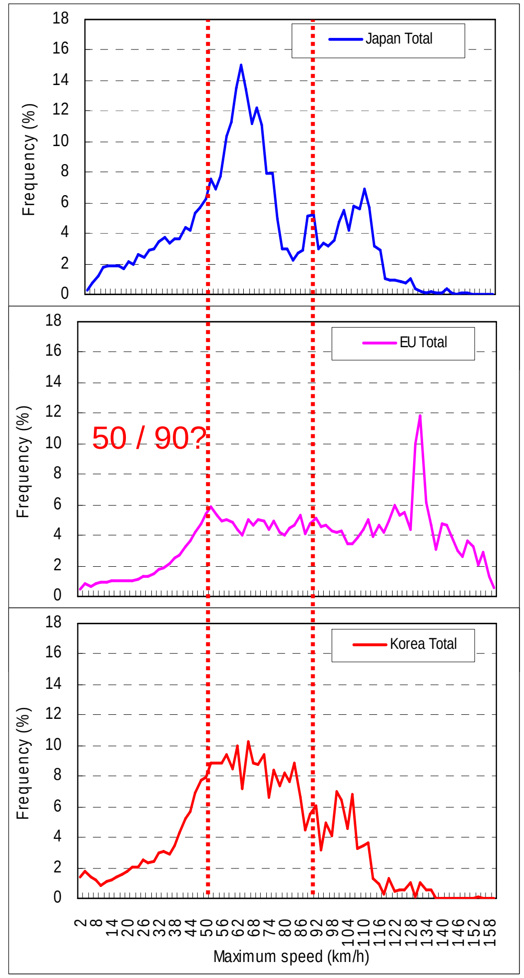
Road type Speed rage		Average speed				Relative positive acceleration				Idling ratio				Average short trip duration				Average idling duration			
		km/h				m/s^2				%				s				s			
		JPN	EU	KOR	Max−Min	JPN	EU	KOR	Max−Min	JPN	EU	KOR	Max−Min	JPN	EU	KOR	Max−Min	JPN	EU	KOR	Max−Min
Urban Low	Urban	22	26	18	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.

3.2.2. Consideration of threshold speed - 3

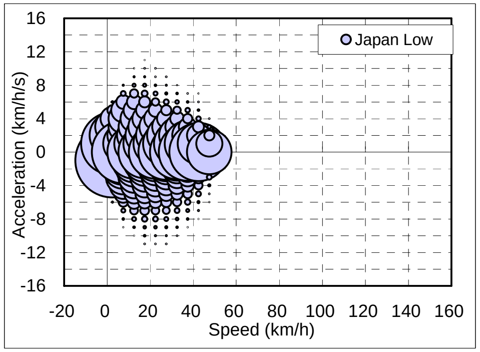
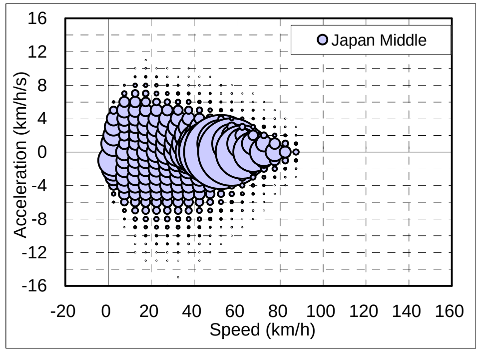
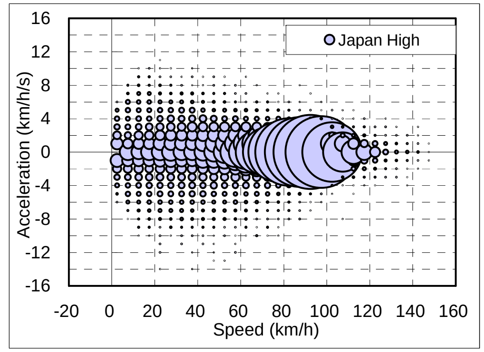
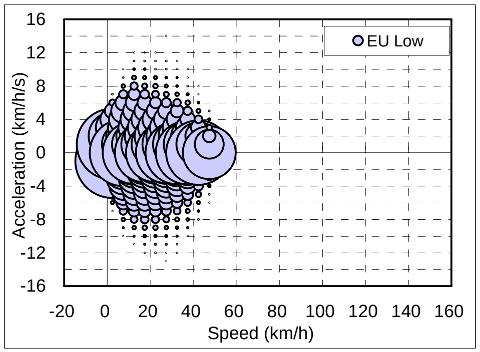
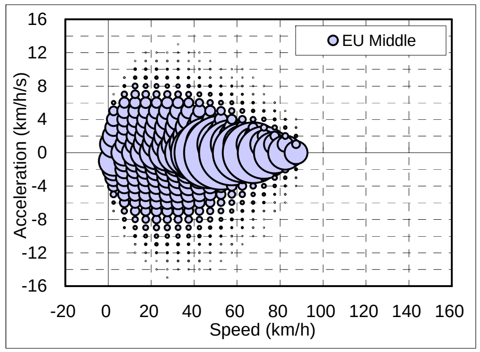
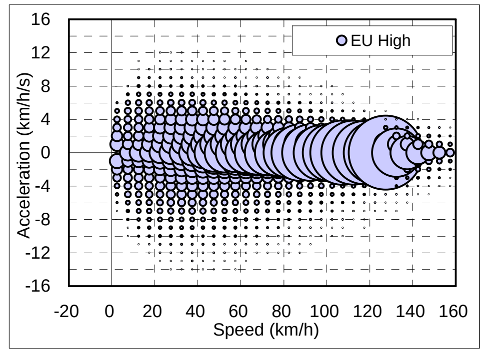
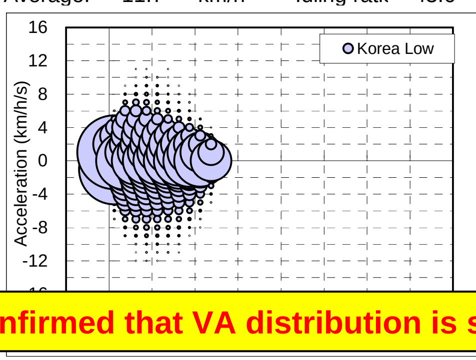
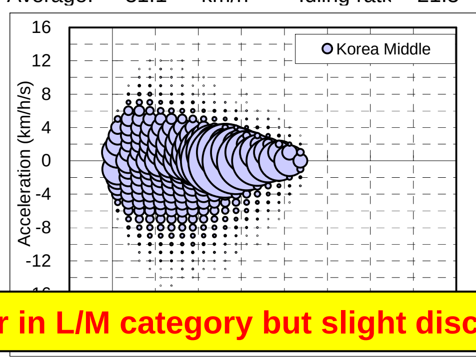
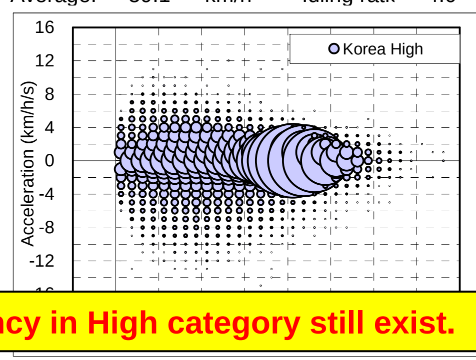
<Method3> Based on maximum speed distribution





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

3.3.1. Analysis Sample - VA distribution

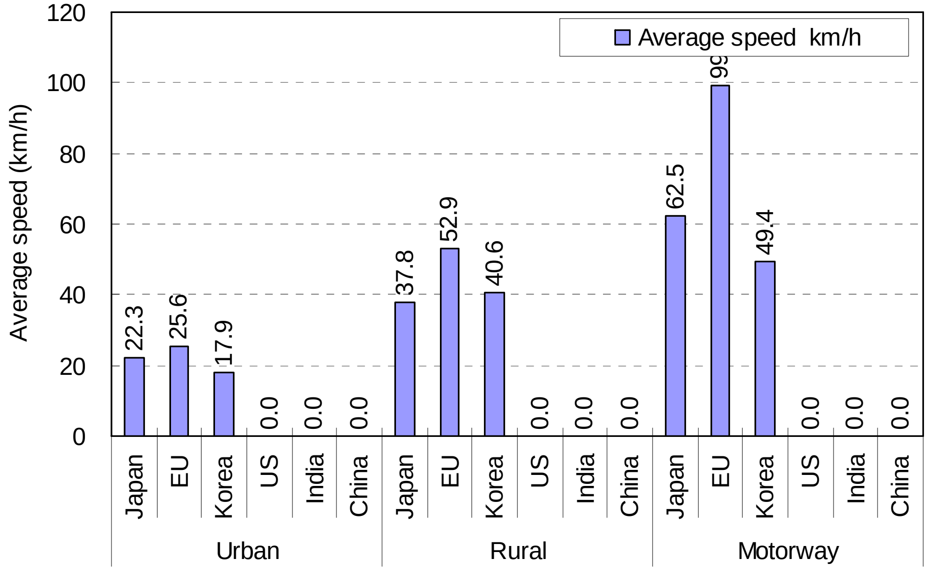
<table>
<tr><th></th><th>Low (Vmax≦50)</th><th>Middle (Vmax≦90)</th><th>High (90＜Vmax)</th></tr>
<tr><td>Japan</td>
<td>Average: 12.1 km/h Idling ratic 41.0 %

</td>
<td>Average: 32.2 km/h Idling ratic 21.6 %

</td>
<td>Average: 69.0 km/h Idling ratic 3.1 %

</td></tr>
<tr><td>EU</td>
<td>Average: 13.8 km/h Idling ratic 35.8 %

</td>
<td>Average: 37.9 km/h Idling ratic 10.1 %

</td>
<td>Average: 75.7 km/h Idling ratic 2.6 %

</td></tr>
<tr><td>Korea</td>
<td>Average: 11.7 km/h Idling ratic 43.6 %

</td>
<td>Average: 31.1 km/h Idling ratic 21.3 %

</td>
<td>Average: 59.1 km/h Idling ratic 4.0 %

</td></tr>
</table>

It was confirmed that VA distribution is similar in L/M category but slight discrepancy in High category still exist.

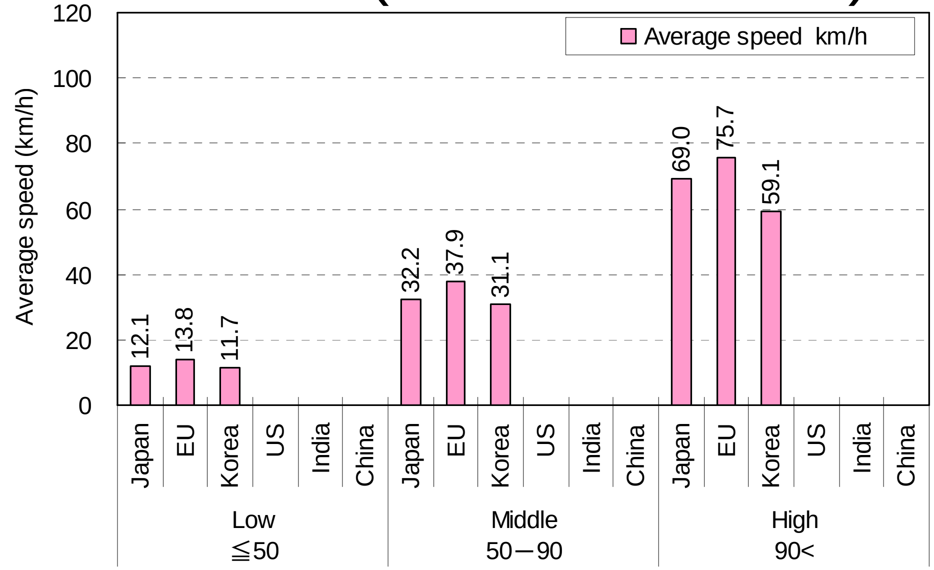
3.3.2. Analysis Sample - Average speed

As an example, convert into L/M/H at 50/90km/h

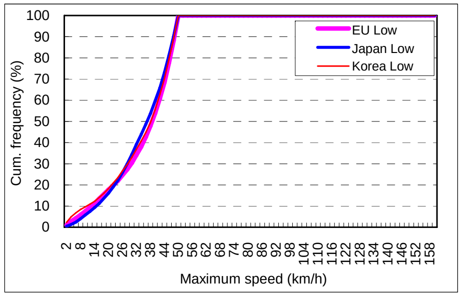
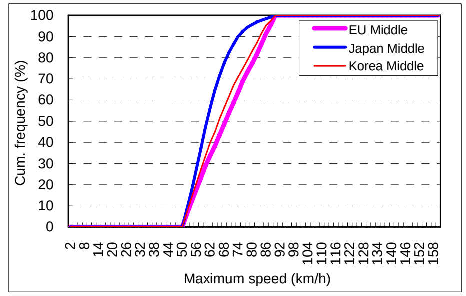
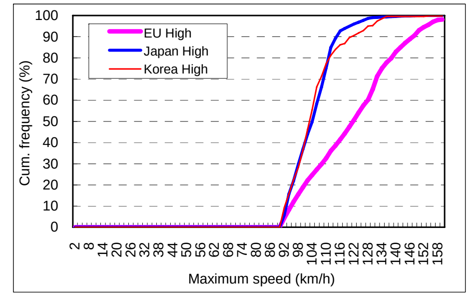
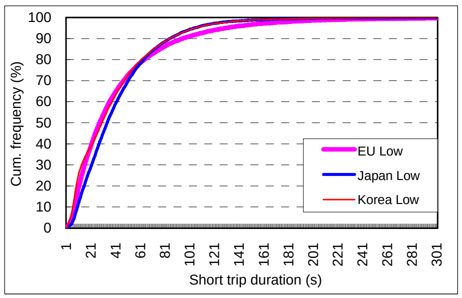
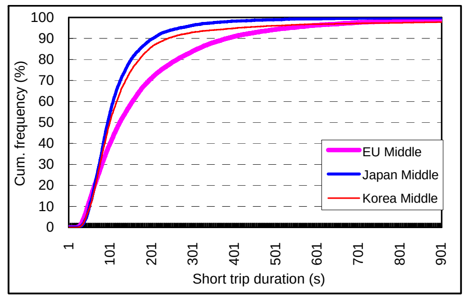
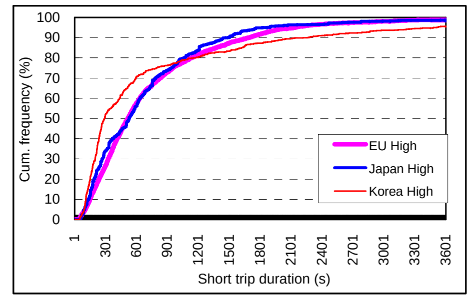
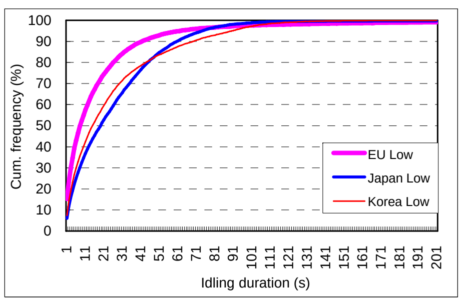
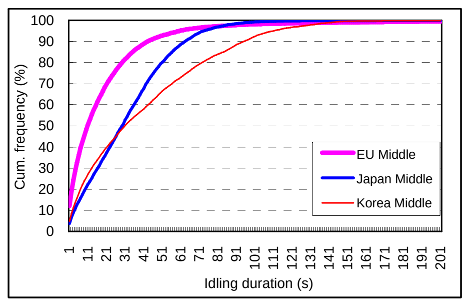
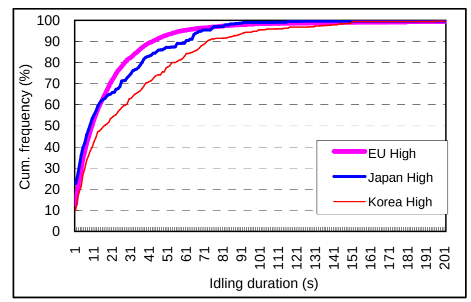
➢U/R/M



➢L/M/H (threshold: 50/90)



3.3.3. Analysis Sample - Parameters

<table>
<tr><th></th><th>Low (Vmax≦50)</th><th>Middle (Vmax≦90)</th><th>High (90＜Vmax)</th></tr>
<tr><td>Max. speed</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
<tr><td>Short trip duration</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
<tr><td>Idling duration</td>
<td>
</td>
<td>
</td>
<td>
</td></tr>
</table>

3.4. Summary of L/M/H Method

- It was observed that each region driving characteristics and VA distributions comparatively show similarity by converting into Low/Middle/High speed based on ST max speed.
- The appropriate threshold will be decided based on each countries’ traffic condition, driving characteristic and VA distribution after completion of all in-use data collection.

4. Modification on Proposed Methodology

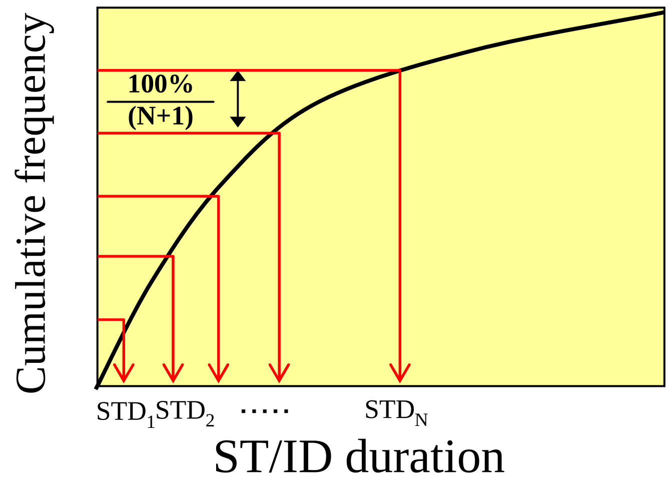
4.1. Modification Lists

- Based on the initial in-use data analysis, it was observed that the following items need to be revised for improvement of driving cycle development and for efficient work.

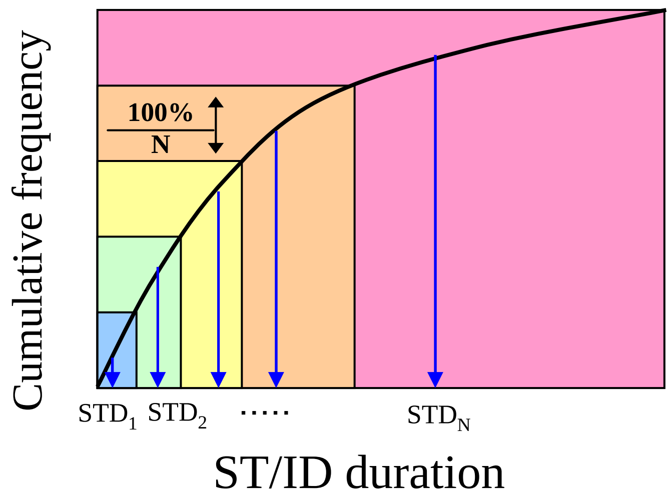
  - Method for ST/IDLE selection
  - Method for cycle development of high speed mode
  - Method for ST selection combination in each mode

4.2. Method for ST/IDLE Selection

- Original (Boundary)
  - Divide cumulative frequency distribution into "$N_{i,\ ST}$ +1"
  - Select the durations on each boundary (dividing) line



- Revised (Average)
  - Divide cumulative frequency distribution into "$N_{i,\ ST}$"
  - Select the average duration in each class

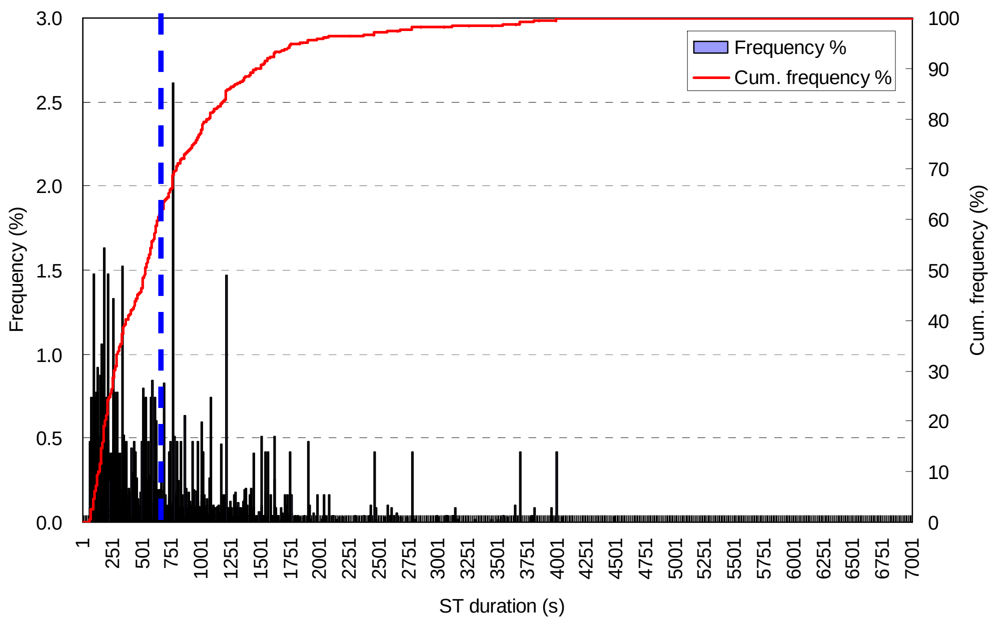


It is possible to develop more representative cycle by applying revised method

4.3.1. Concerns on High-speed Driving Cycle Development

Since most of ST duration（e.g. 696sec, Japan） in high-speed mode are longer than cycle duration, the number of potential STs will be dramatically reduced. This may lead the critical discrepancy in its representativeness.

Example) Japan High phase（90km/h < ）



- Average ST duration: 696 sec
- Average Idling duration: 20 sec
- Number of ST: (600 - 20) / (696 + 20) = 0
- Idling ratio: 3.1 %
- Driving ratio: 96.9 %

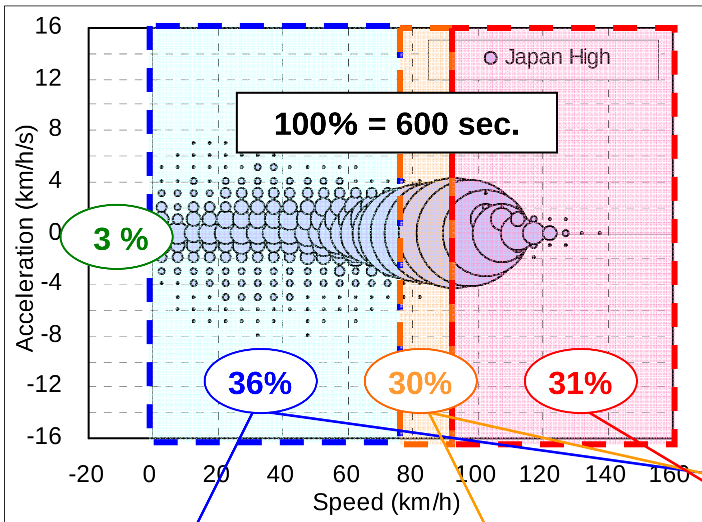
4.3.2. Process of high-speed cycle development

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 5 parts (take-off1, take-off2, cruise, slow-down1, slow-down2).
3. Extract the driving data which meet each part configuration from the complete in-use ST.
4. Select the least chi-squared extracted driving data in each part, then combine the selected data to develop the complete cycle.

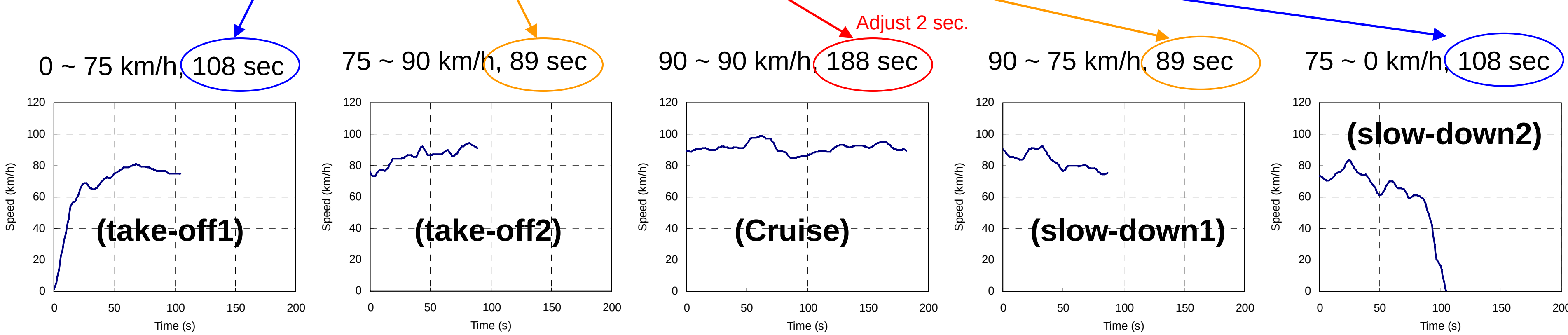
(note) if the complete in-use data is less chi-squared value than combined cycle, this specific data can be used for high-speed cycle.

4.3.3. 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

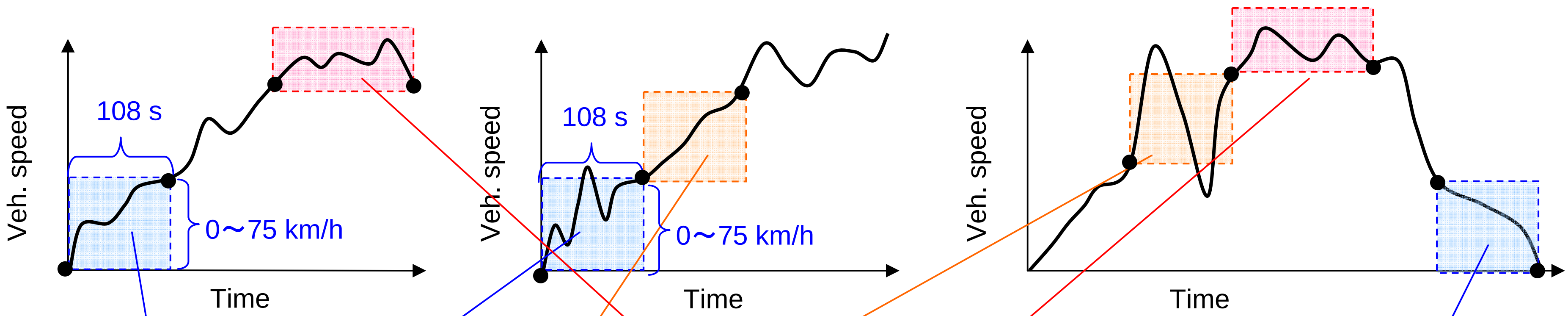


Speed range	Frequency (%)	Target duration	Divide part
Idling	3.1	18	9
0~75, 75~0	36.1	217	108
75~90, 90~75	30.0	179	89
90~	30.9	186	
Total	100	600	



4.3.4. Extraction of Driving Data

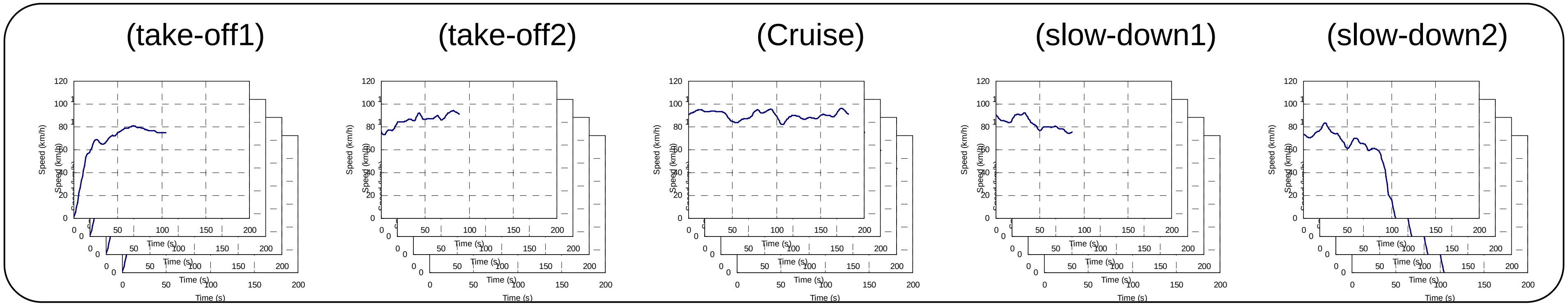
- Extract the driving data which meet each part definition* from complete ST.
  - Sample definition <Take-off 1 part>
    speed range : 0 ~ 75 km/h (with±0.5km/h), duration : 108sec.



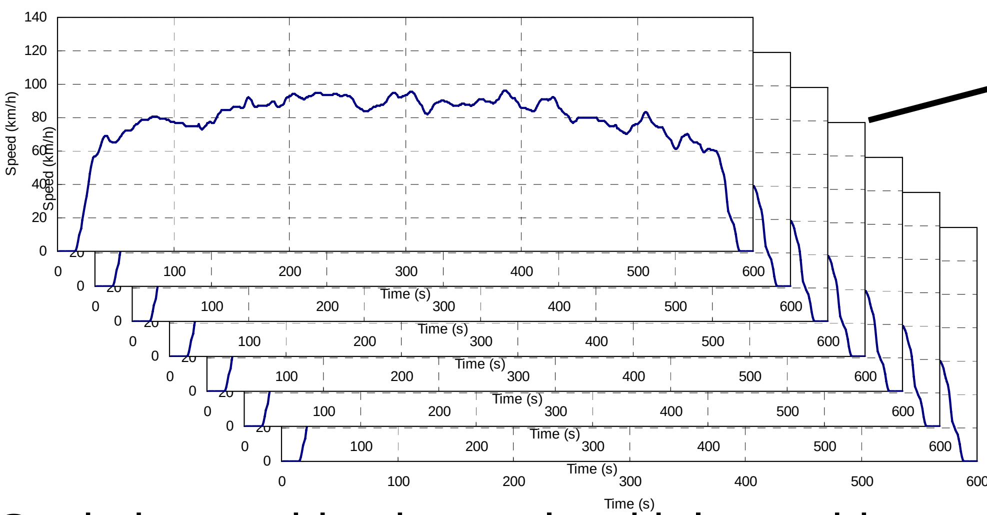
0~75	75~90	90~90	･･･	75~0
			･･･	
			･･･	
			･･･	
			･･･	
			･･･	

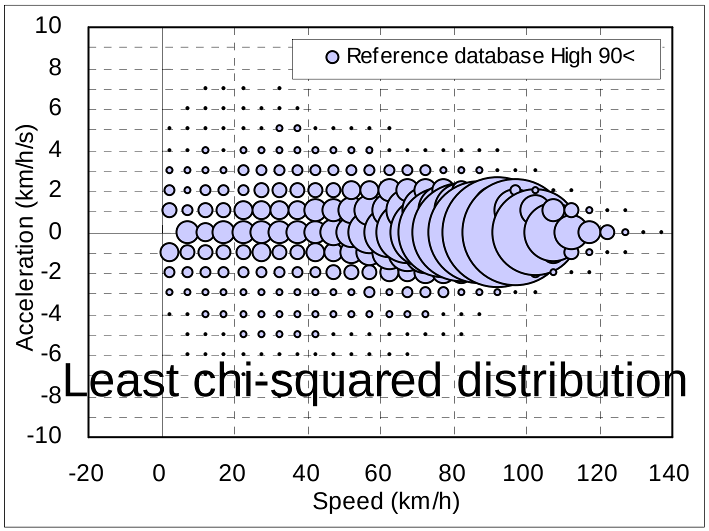
4.3.5. Method to Develop High-Speed Driving Cycle

Candidate driving data



combined

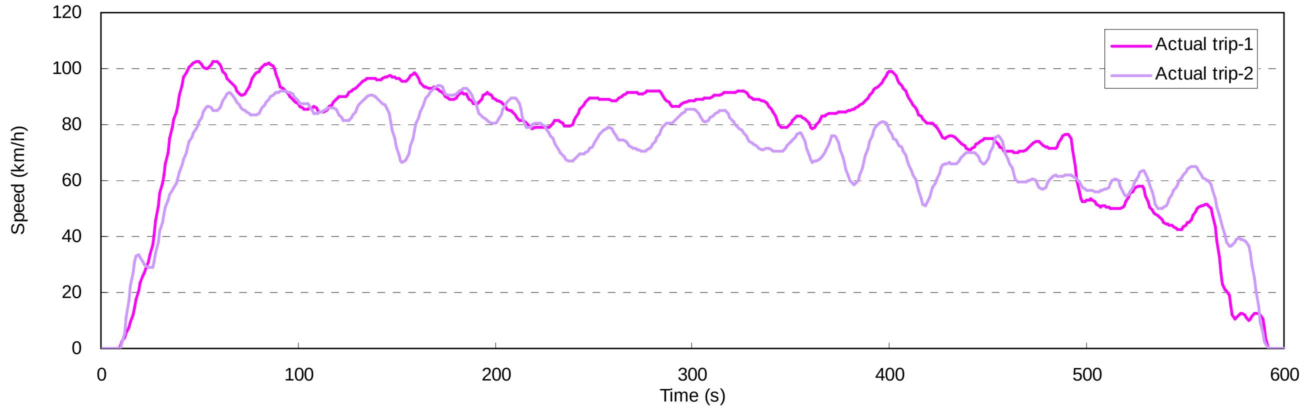




Seek the combination cycle with least chi-square value compared with unified cycle

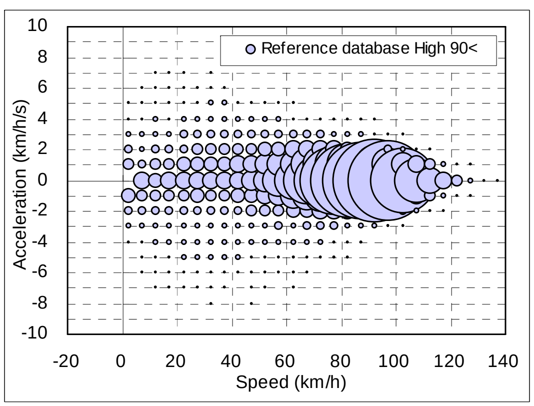
4.3.6. Selection of Complete Short Trip

◆There is only a few complete STs with target duration in Japan database

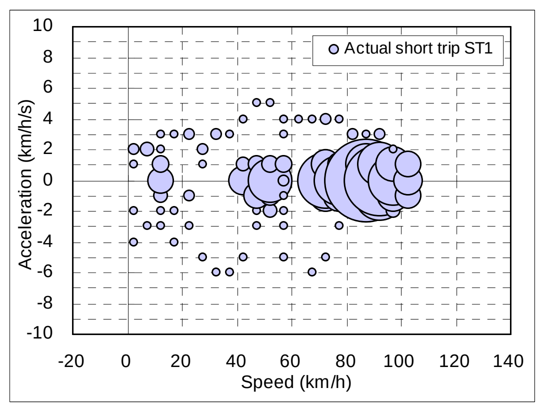


◆Comparison of VA distribution

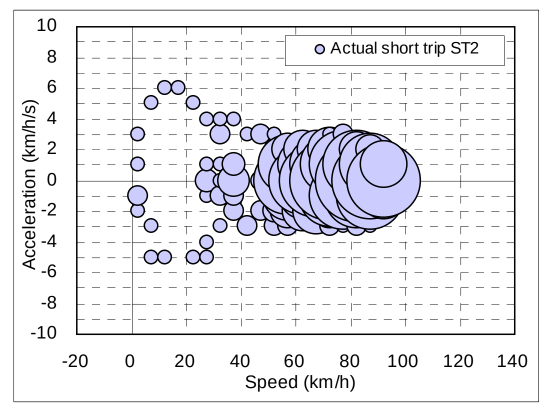
◆United VA distribution (90<)



◆complete short trip -1 (X^2=1.12)



◆complete short trip -2 (X^2=1.15)



Few possibility to find the complete in-use data to represent the unified cycle

4.4.1. Method for the ST Combinations

◆Short trip duration in Low phase (threshold: 50/90)

◆Japan reference database

✓Average ST duration: 42.7 sec

✓Average Idling duration: 26.5 dec

◆Test cycle

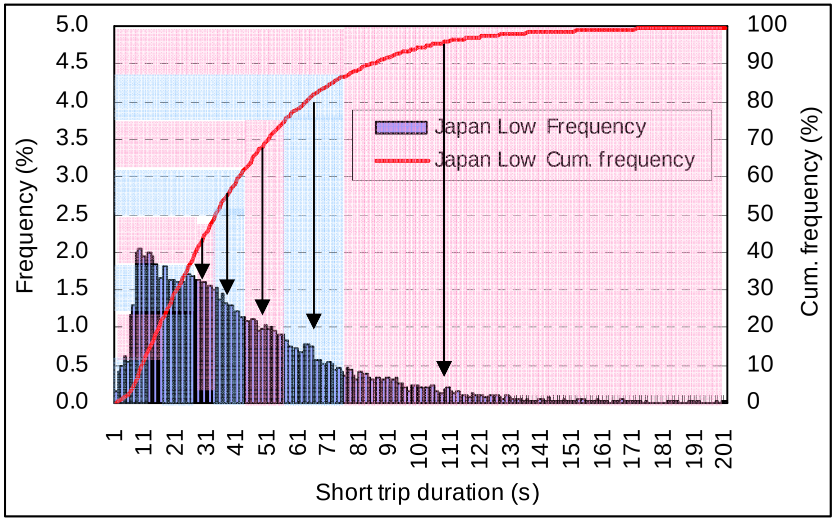
✓Desired cycle duration: 600 sec

✓N_{ST} = (600 - 26.5) / (42.7 + 26.5) = 8.3

✓Number of short trips N_{ST}: 8

✓T_{ST}: 8, 15, 22, 30, 39, 51, 67, 111 = 343 sec

✓ Average ST duration: 42.9 sec



◆The candidates for each short trip duration for the total combination numbers and short trip numbers

T_{ST}	8	15	22	30	39	51	67	111
N_{ST}	960	764	685	689	556	419	250	75

Combination number = 1.5×10^{21} (Only Japan data)

When it takes 0.1 sec for chi-square calculation per one combination, it takes 4.8×10^{12} Year (1.5×10^{20} Sec) for all possible combinations (only Japanese data). Therefore, it is necessary to reduce number of combinations for practical work.

4.4.2. 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)