

WLTP-28-16e

The 28th WLTP Meeting

A Study on the impact of Driving Trace Index(DTI) on fuel economy in Korea

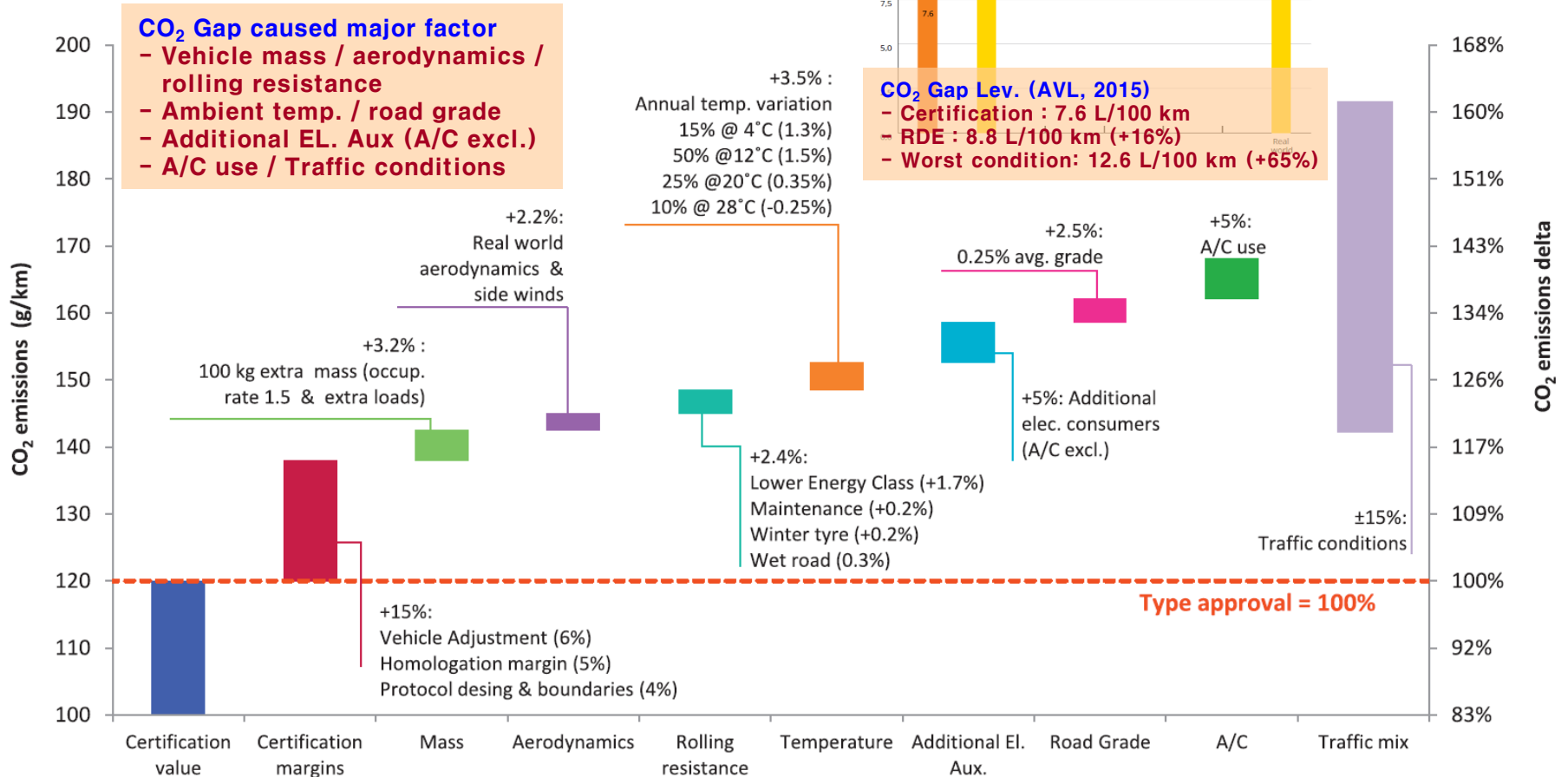
26 Sep. 2019

**KOTSA, The Republic of KOREA
(Korea Transportation Safety Authority)**

- 1. Background**
- 2. Definition of DTI(Driving Trace Index)**
- 3. Information of Test equipment**
- 4. DTI resulting from drive trace on F.E.**
- 5. Conclusions**

1. Background

CO₂ gap between Lab vs. RDE

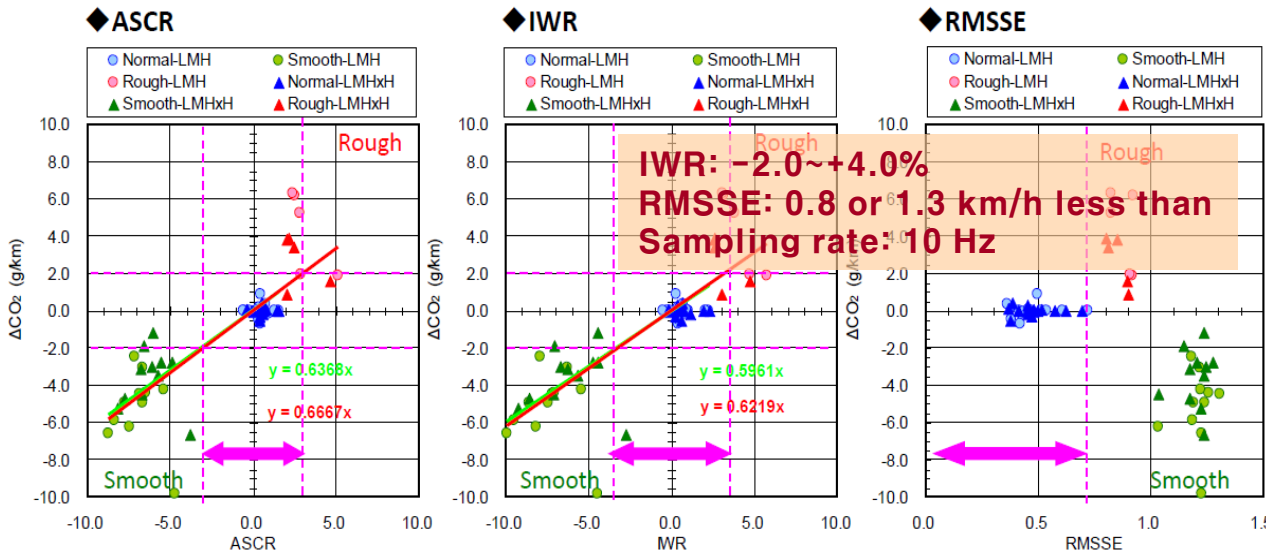


<Source : Progress in Energy and Combustion Science, 2017>

►► Need to establish a fuel economy criteria methodology for reducing Gap between CO₂ (fuel economy) certification and actual measurements

1. Background

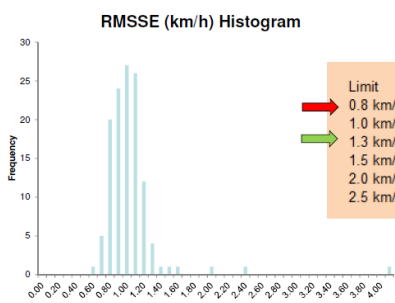
Driving cycle trace indices in WLTP (UNECE/WP.29/GRPE)



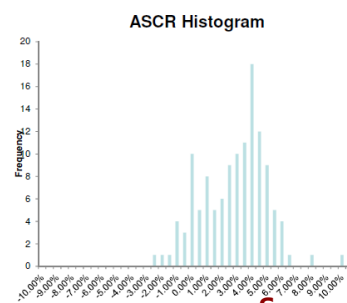
IWR: -2.0~+4.0%
RMSSE: 0.8 or 1.3 km/h less than
Sampling rate: 10 Hz

possible criterion

<Source : WLTP-11-21e, 2015>



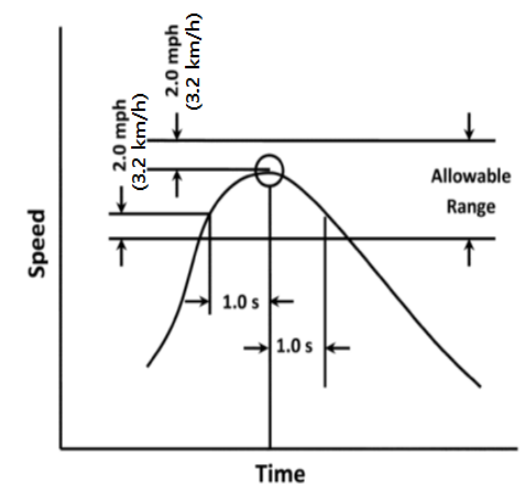
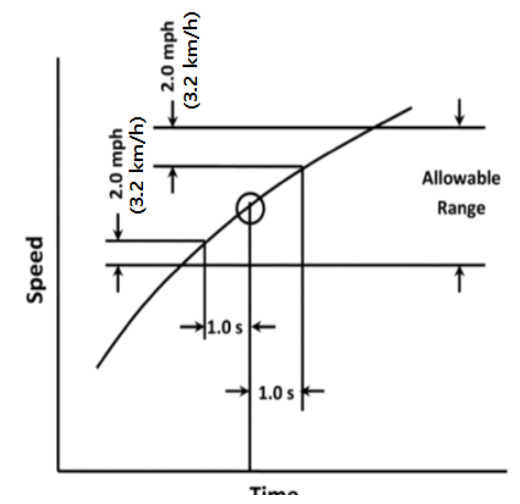
Limit	% Pass Rate	% Scrap Rate
0.8 km/h	20.80%	79.20%
1.0 km/h	61.60%	38.40%
1.3 km/h	95.20%	4.80%
1.5 km/h	96.80%	3.20%
2.0 km/h	98.40%	1.60%
2.5 km/h	99.20%	0.80%



Positive ASCR means actual driving contains more microtransients than on the original drive trace.

-2 to +4 % tolerance band takes valid test pass rate to >70%

<Source : WLTP-11-22e, 2015>



▶▶ Need to select indices and set criteria for Drive trace in line with international trends

2. Definition of DTI(Driving Trace Index)

● Driving quality evaluation (DQE) indices (SAE J2951)

☞ (SAE J2951 driving index) Energy rating (ER), Distance rating (DR), Energy economy rating (EER), Absolute speed change rating (ASCR), Inertial work rating (IWR), Root mean squared speed error (RMSSE)

Index	Evaluation	Brief description
Energy Rating (ER)	Change rate on the cycle energy	ER is defined as the percent difference between the total driven and target cycle energy.
Distance Rating (DR)	Change rate on the distance	DR is defined as the percent difference between the total driven and scheduled distance.
Energy Economy Rating (EER)	Change rate on the distance per energy	EER is defined as the percentage difference between the distance per unit cycle energy for the driven and target traces.
Absolute Speed Change Rating (ASCR)	Change rate on the integral of the absolute magnitude of acceleration	ASCR is defined as the percentage difference between the ASC for the driven and target traces.
Inertial Work Rating (IWR)	Change rate on the inertial work	IWR is defined as the percentage difference between the inertial work for the driven and target traces.
Root Mean Squared Speed Error (RMSSE)	Speed deviation	RMSSE provides the driver's performance in meeting the schedule speed trace throughout the test cycle in terms of the Root Mean Squared Speed Error.

$$ER = \frac{CE_D - CE_T}{CE_T} \cdot 100$$

$$CE_J = \sum_{i=1}^N [(1.015 \cdot ETW \cdot a_{Ji} + F_0 + F_1 V_{Ji} + F_2 V_{Ji}^2) \cdot d_{Ji}]^+$$

$$a_{Ji} = \frac{V_{Ji+1} - V_{Ji-1}}{0.2}$$

$$V_{Ji} = \frac{1}{5} \sum_{t=i-2}^{i+2} V_t$$

$$d_{Ji} = V_{Ji} \cdot 0.1$$

$$DR = \frac{D_D - D_T}{D_T} \cdot 100$$

$$D_J = \sum_{i=1}^N d_{Ji}$$

$$EER = \left[1 - \frac{DR/100 + 1}{ER/100 + 1} \right] \cdot 100$$

$$ASCR = \frac{ASC_D - ASC_T}{ASC_T} \cdot 100$$

$$ASC_J = 0.1 \sum_{i=1}^N |a_{Ji}|$$

$$IWR = \frac{IW_D - IW_T}{IW_T} \cdot 100$$

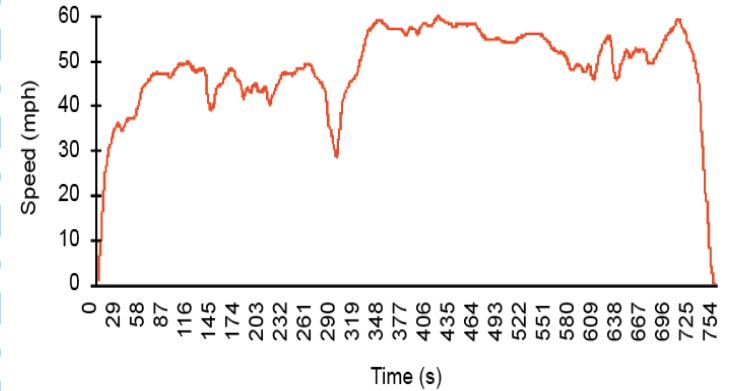
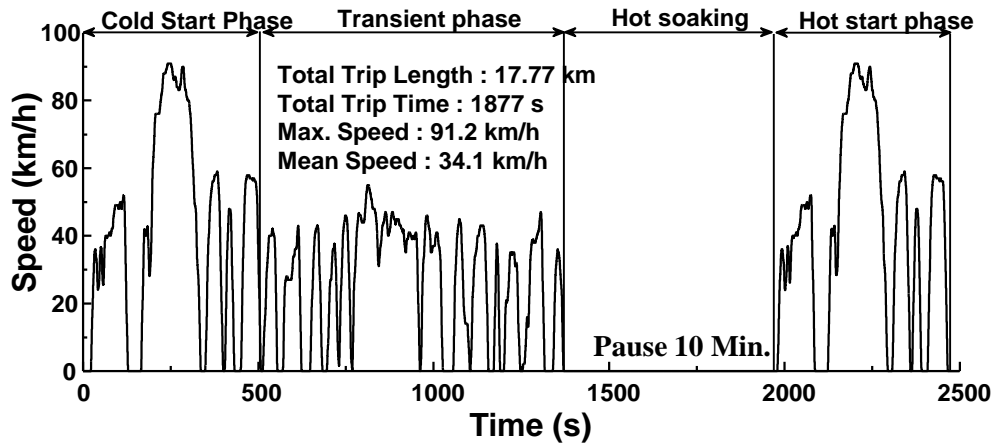
$$IW_J = \sum_{i=1}^N [\omega_{I-Ji}]^+$$

$$\omega_{I-Ji} = F_{I-Ji} \cdot d_{Ji} = 1.015 \cdot ETW \cdot a_{Ji} \cdot V_{Ji} \cdot 0.1$$

$$RMSSE = 3.6 \sqrt{\frac{\sum_{i=1}^N (V_{Di} - V_{Ti})^2}{N}}$$

3. Information of Test equipment

◆ Fuel economy test modes : FTP-75 (city) + HWFET (highway) mode

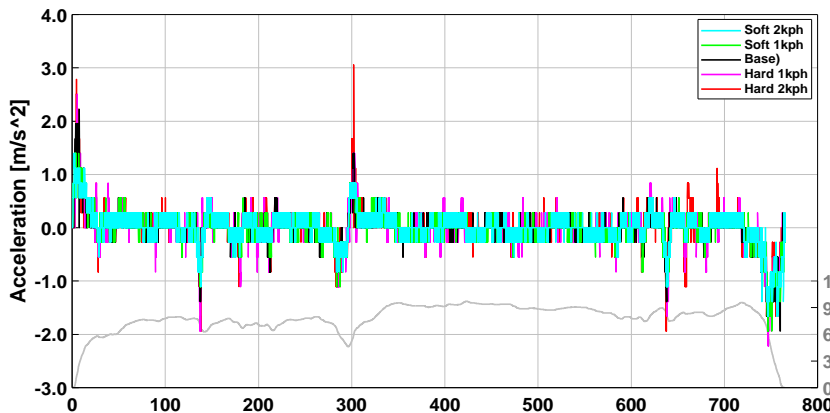


Cycle	Phase 1	Phase 2	Phase 3	FTP-75
Duration (sec)	505	867	505	1877
Distance (km)	5.78	6.21	5.78	17.77
Avg. speed (km/h)	41.2	25.9	41.2	34.1
Max. speed (km/h)	91.2	55.2	91.2	91.2
Max. acceleration (m/s ²)	1.48	1.48	1.48	1.48
Idle fraction (%)	19.6	18.4	19.6	19.1

Cycle	HWFET
Duration (sec)	765
Distance (km)	16.51
Avg. speed (km/h)	77.7
Max. speed (km/h)	96.4
Max. acceleration (m/s ²)	1.43
Idle fraction (%)	0.7

4. DTI resulting from drive trace on F.E.

Fuel economy (FE) variation depending on drive trace method

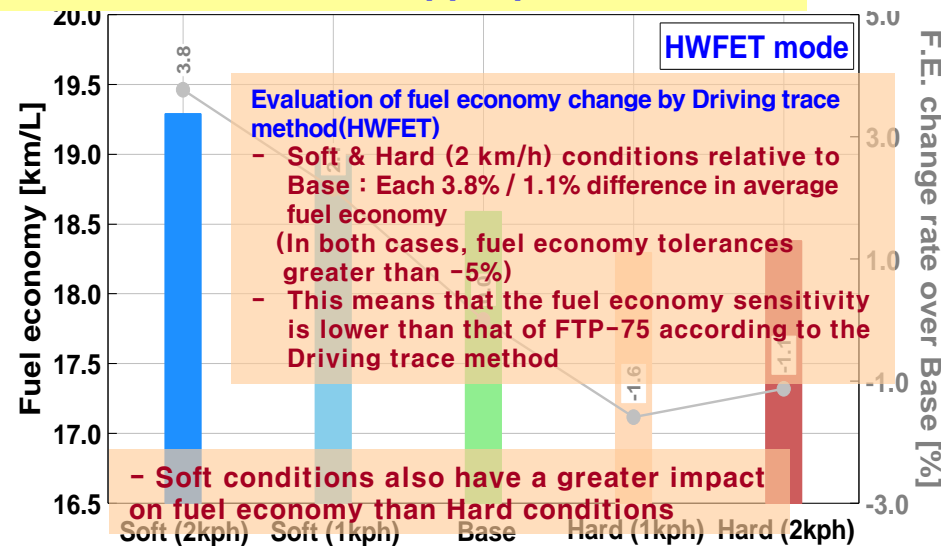
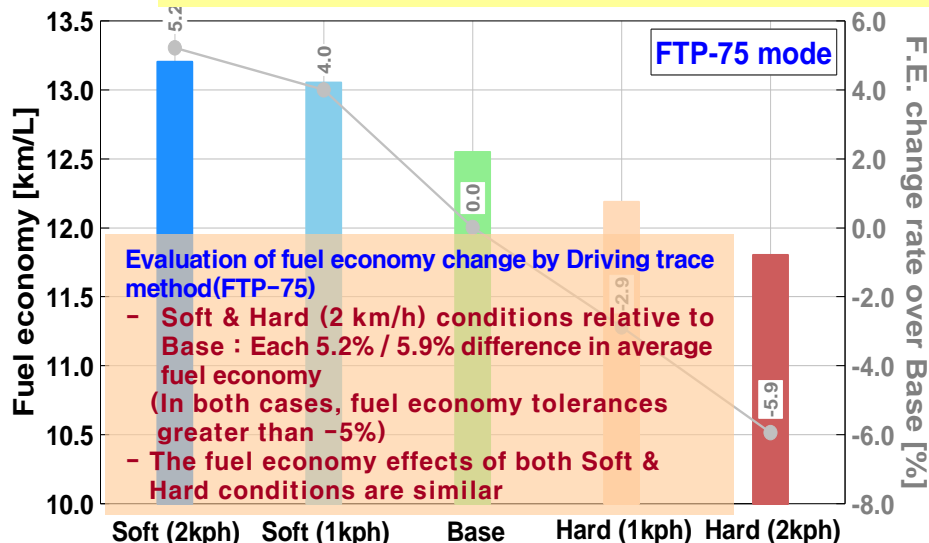


Test conditions by Driving trace method(Base, Soft & Hard)

- Base, Soft & Hard condition test times: each 5 / 3 / 3
- Speed tolerance range : Total of 5 separated by ± 1 km/h & ± 2 km/h
- DQE index calculation: 10 Hz measurement data / ETW / Road load data use

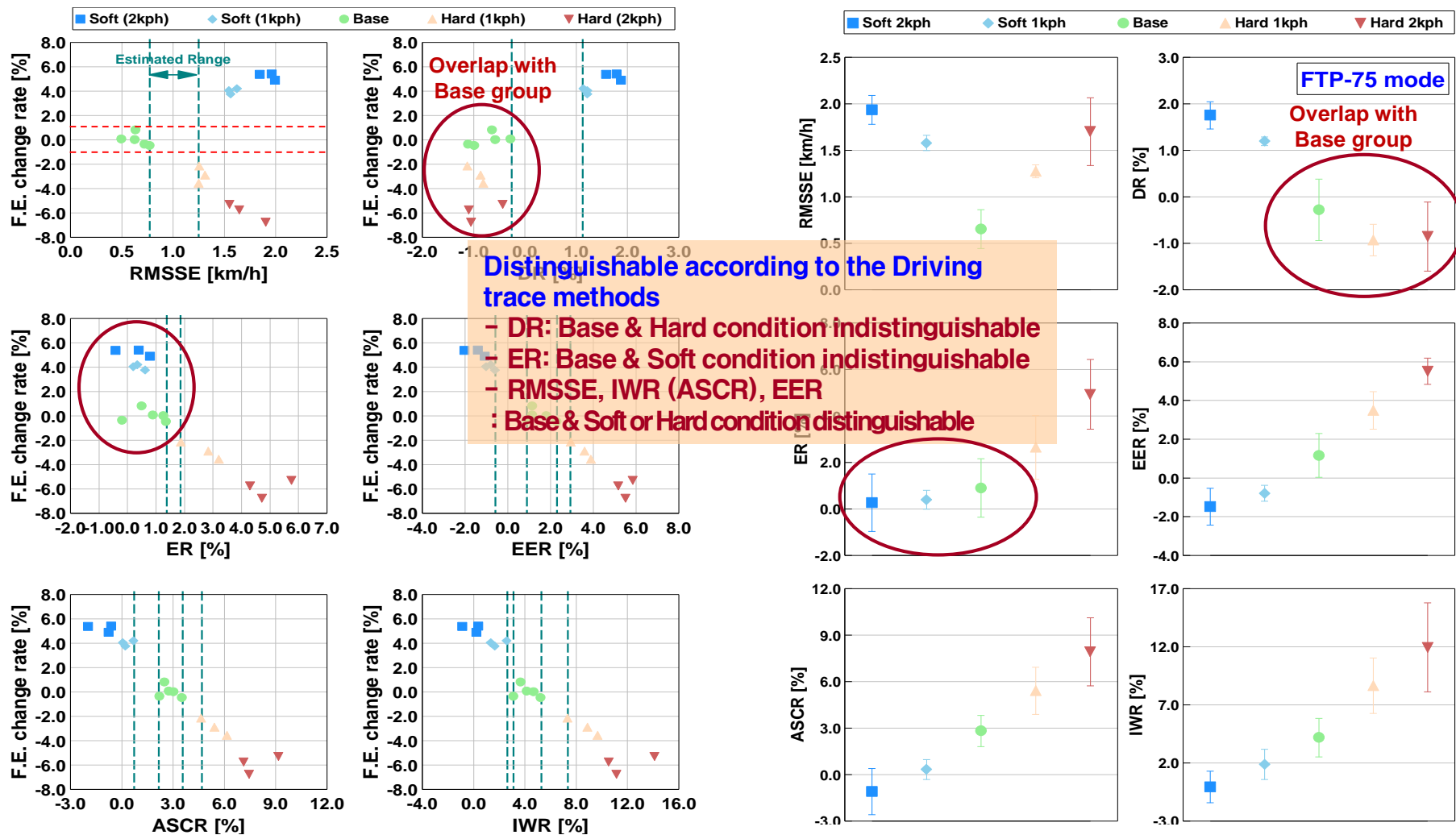
Test mode	Fuel economy change rate (%) over base driving condition				
	Soft (2 kph)	Soft (1 kph)	Base	Hard (1 kph)	Hard (2 kph)
FTP-75	5.2	4.0	0.0	-2.9	-5.9
HWFET	3.8	2.1	0.0	-1.6	-1.1

Need to selection of the DQE indices and introduction of appropriate criteria



4. DTI resulting from drive trace on F.E.

Analysis of DQE index and fuel economy depending on drive trace (FTP-75 mode)

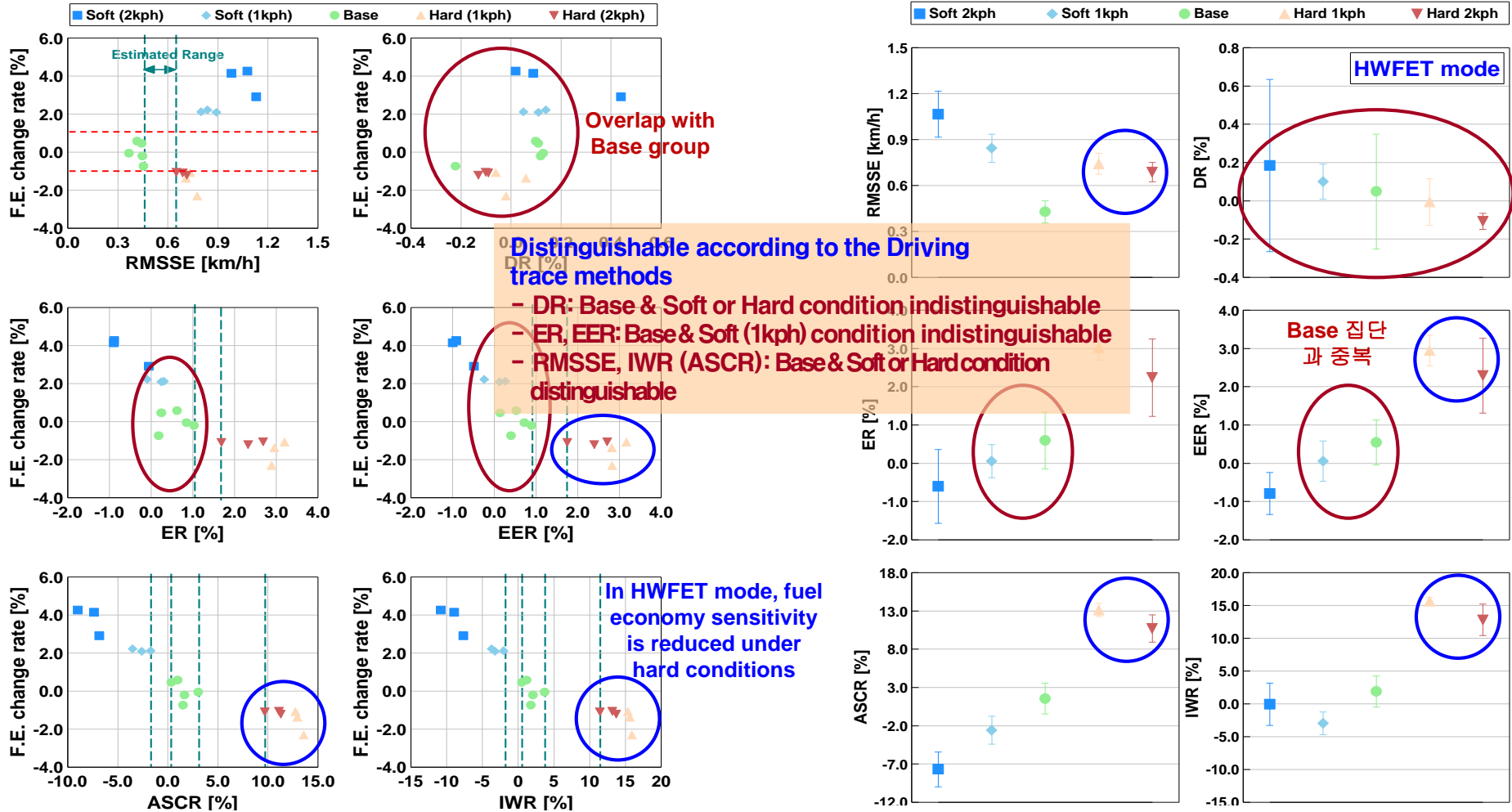


FE change rate (%) depending on the DQE indices

2σ Error bar graph for avg. value of DQE index

4. DTI resulting from drive trace on F.E.

Analysis of DQE index and fuel economy depending on drive trace (HWFET mode)



FE change rate (%) depending on the DQE indices

2σ Error bar graph for avg. value of DQE index

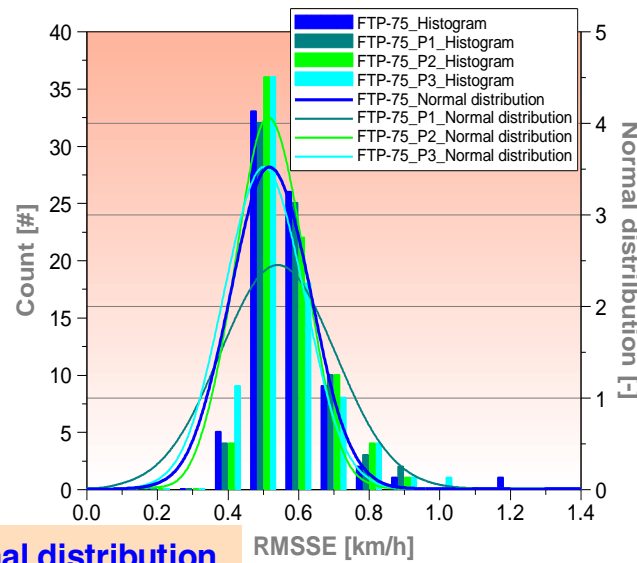
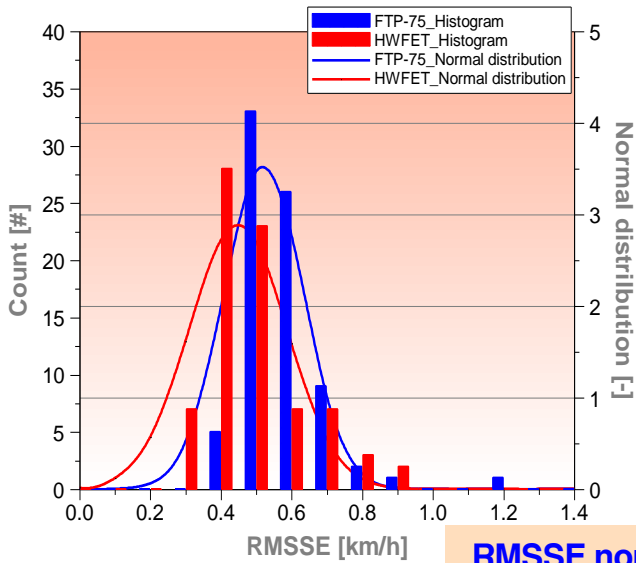
4. DTI resulting from drive trace on F.E.

Each DQE index variation depending on drive trace method in **FTP-75** and **HWFET** modes

Pattern	Index	RMSSE (km/h)	DR (%)	ER (%)	EER (%)	ASCR (%)	IWR (%)
FTP-75	Soft (2 kph)	1.85~1.99	1.59~1.88	-0.41~0.80	-2.01~-1.07	-1.96~-0.60	-0.86~0.39
	Soft (1 kph)	1.55~1.62	1.14~1.22	0.21~0.62	-1.01~-0.60	0.07~0.69	1.35~2.59
	Base	0.50~0.77	-1.10~-0.28	-0.18~1.35	0.92~2.29	2.22~3.53	3.12~5.23
	Hard (1 kph)	1.25~1.31	-1.12~-0.81	1.88~3.21	2.95~3.89	4.64~6.16	7.34~9.68
	Hard (2 kph)	1.55~1.90	-1.09~-0.43	4.3~5.76	5.17~5.85	7.13~9.17	10.54~14.12
HWFET	Soft (2 kph)	0.98~1.13	0.02~0.44	-0.89~0.05	-0.99~-0.48	-8.98~-6.82	-10.82~-7.62
	Soft (1 kph)	0.80~0.89	0.05~0.14	-0.09~0.31	-0.24~0.27	-3.52~-1.69	-3.70~-2.01
	Base	0.37~0.49	-0.22~0.13	0.19~1.03	0.14~0.90	0.37~3.07	0.58~3.73
	Hard (1 kph)	0.71~0.78	-0.06~0.06	2.89~3.20	2.82~3.17	12.76~13.59	15.37~15.93
	Hard (2 kph)	0.65~0.72	-0.13~-0.09	1.69~2.69	1.75~2.71	9.69~11.31	11.45~13.74

4. DTI resulting from drive trace on F.E.

Estimation of DQE index criteria through statistical analysis

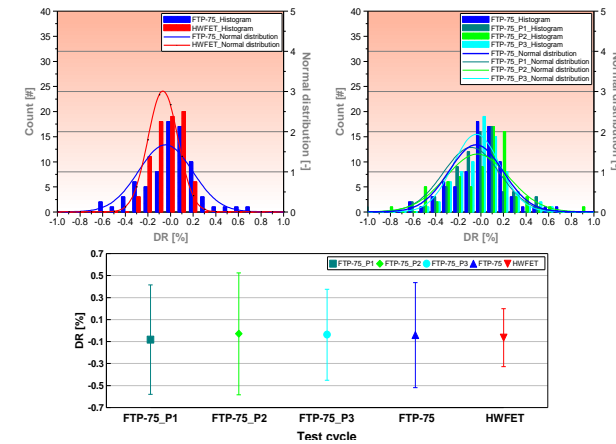
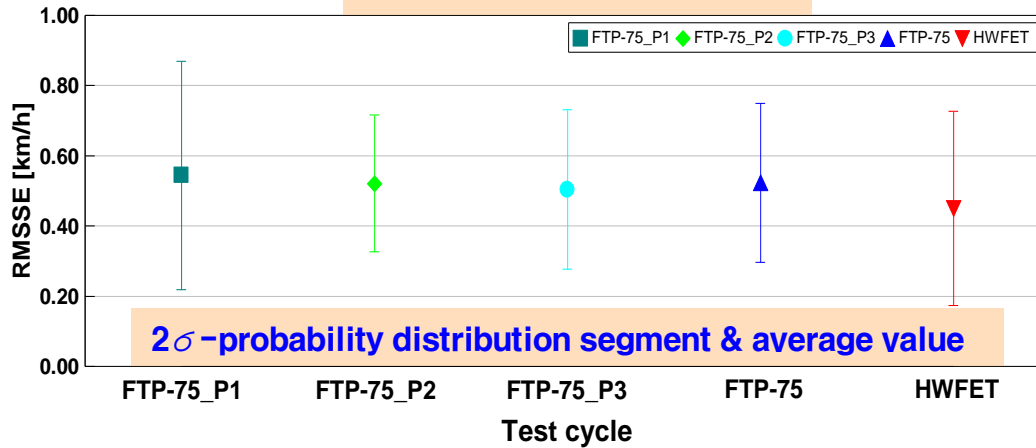


Analyze DQE Indices statistics

- Leverage a total of 77 Base driving data
- Setting the 2σ probability distribution interval of normal and average values
- FTP-75 mode: separated by phase

RMSSE regular distribution analysis

- In FTP-75 mode compared to HWFET, less dispersion and move to the right
- In FTP-75 mode, the average value and dispersion are large in P1 → Consider this to be due to a delay in response performance due to non-heating



⟨DR⟩

4. DTI resulting from drive trace on F.E.

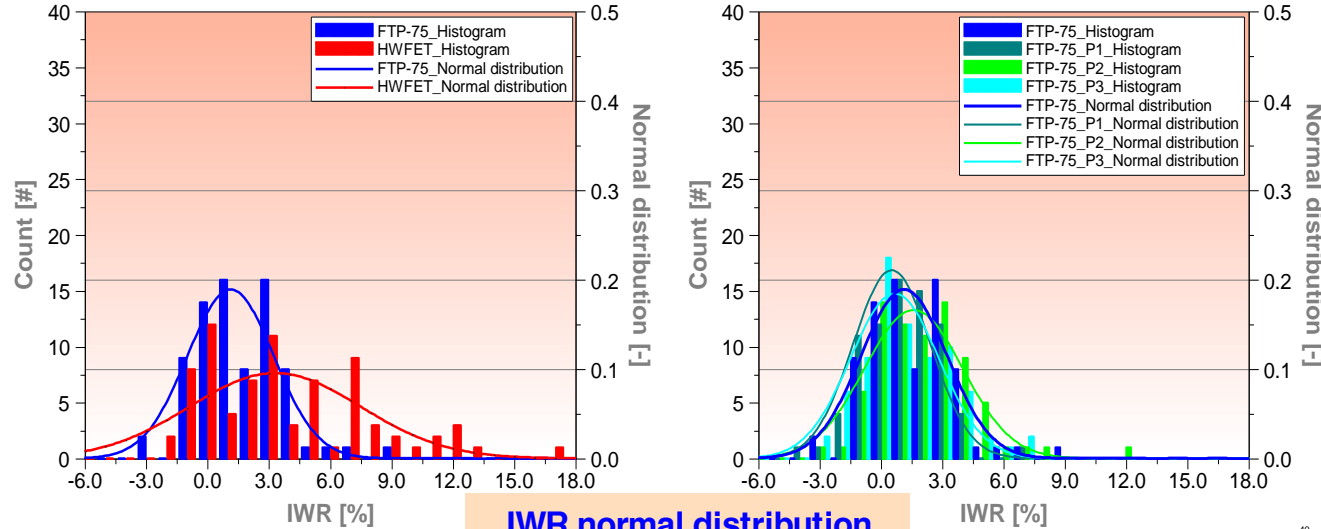
Estimation of DQE index criteria through statistical analysis

Analyze DQE Indices statistics

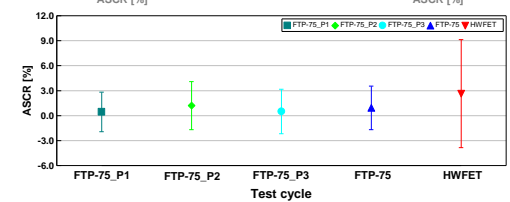
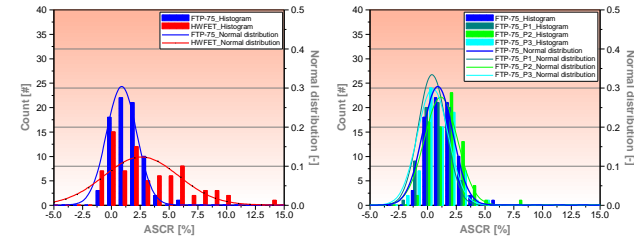
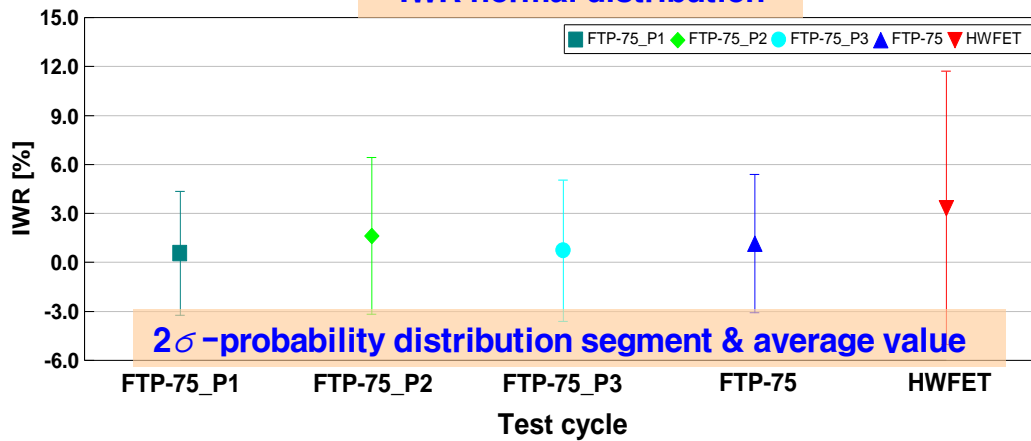
- Leverage a total of 77 Base driving data
- Setting the 2σ probability distribution interval of normal and average values
- FTP-75 mode: separated by phase

IWR (ASCR) regular distribution analysis

- Less dispersion in FTP-75 mode compared to HWFET (Excellent normality in FTP-75 mode)
- For FTP-75 mode, the mean value and dispersion → Judging by frequent acceleration and deceleration of P2 sections



IWR normal distribution

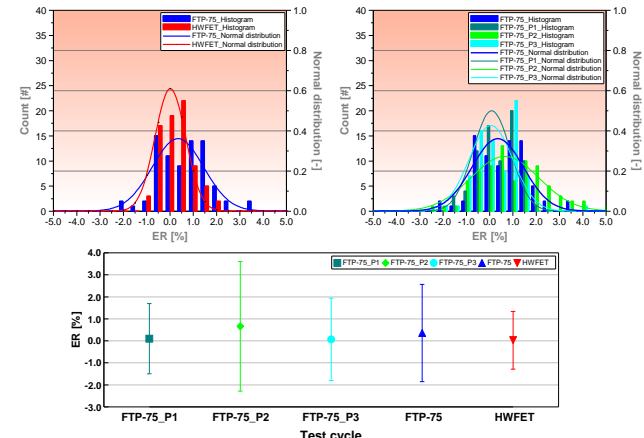
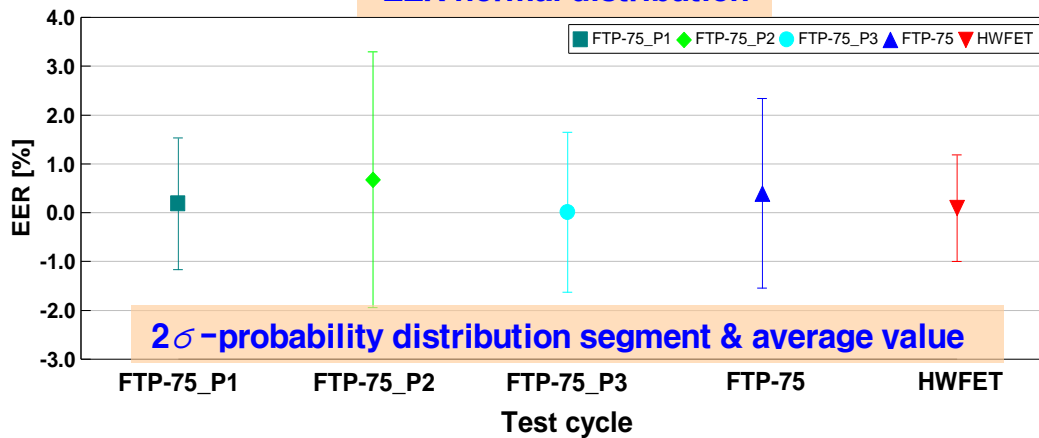
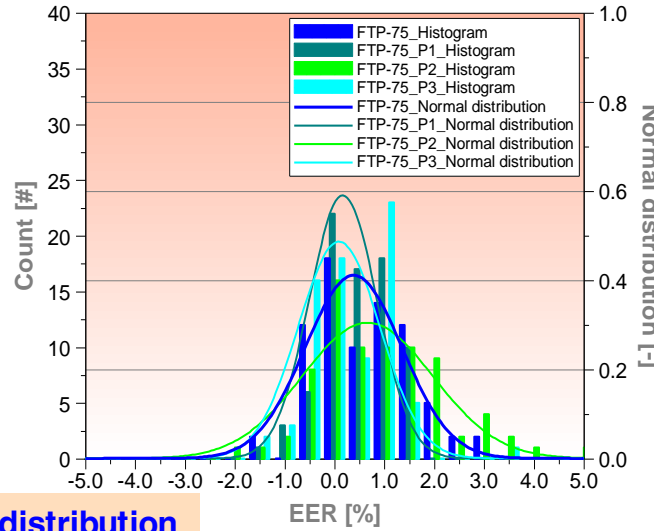
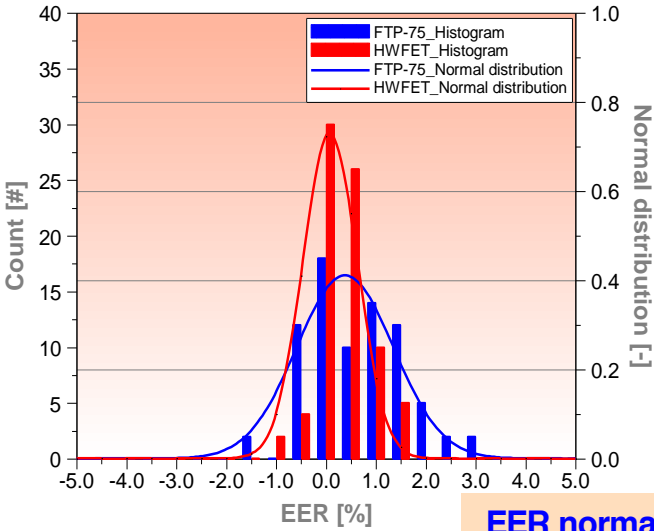


<ASCR>

4. DTI resulting from drive trace on F.E.

Estimation of DQE index criteria through statistical analysis

- Analyze DQE Indices statistics**
- Leverage a total of 77 Base driving data
 - Setting the 2σ probability distribution interval of normal and average values
 - FTP-75 mode: separated by phase
- EER regular distribution analysis**
- Less dispersion in HWFET mode compared to FTP-75 (Excellent normality in HWFET mode)
 - * Reverses the regularity characteristics of IWR (ASCR)
 - For FTP-75 mode, the mean value and dispersion \rightarrow Judging by frequent acceleration and deceleration of P2 sections



$\langle \text{EER} \rangle$

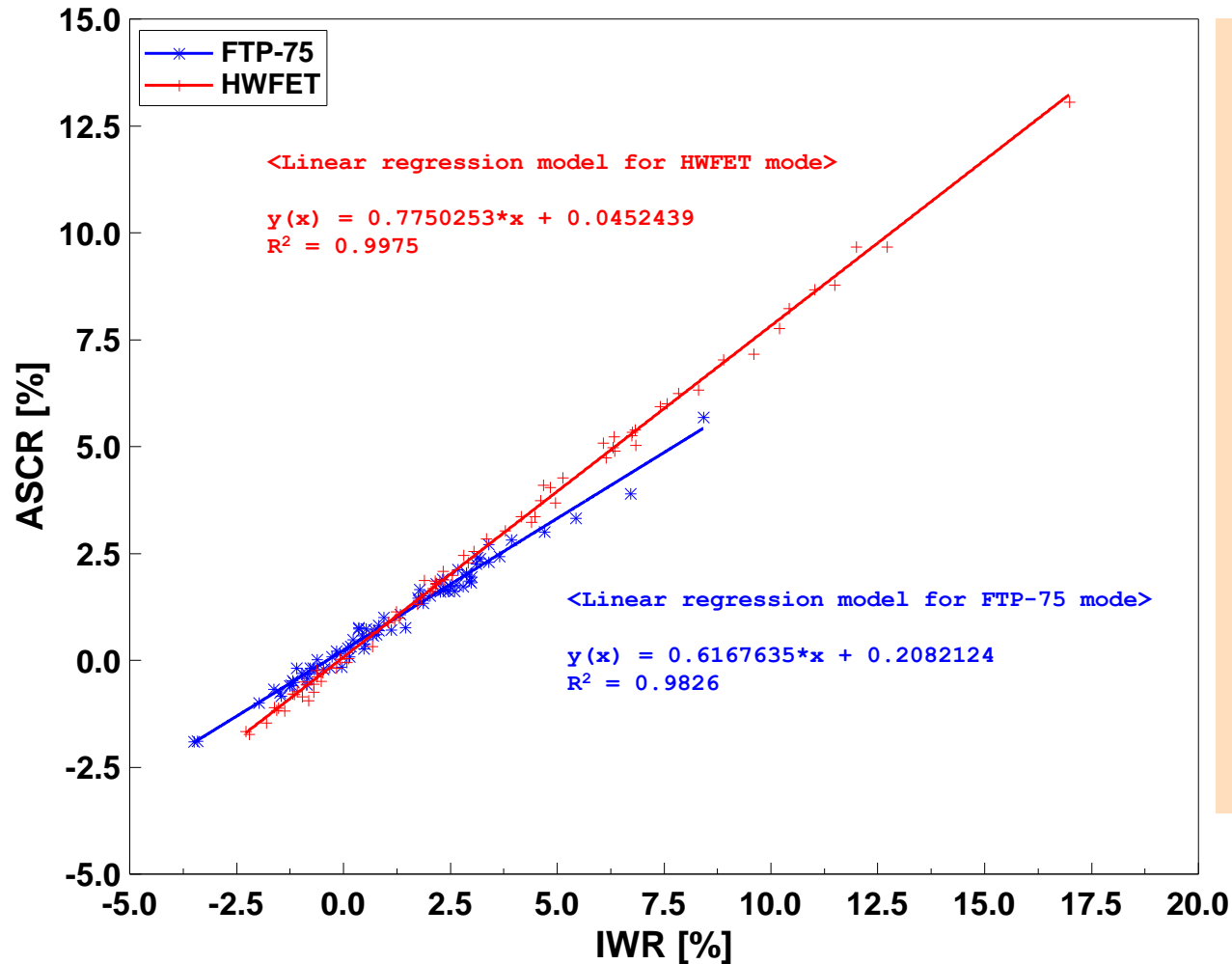
4. DTI resulting from drive trace on F.E.

Results of statistical analysis and suggestions of the appropriate criteria

		<u>RMSSE</u> (km/h)	<u>DR</u> (%)	<u>ER</u> (%)	<u>EER</u> (%)	<u>ASCR</u> (%)	<u>IWR</u> (%)	
FTP-75	77 vehicles data	<u>Nomal probability</u> (2σ)	0.75	-0.52~0.44	-1.86~2.57	-1.56~2.33	-1.72~3.54	-3.09~5.36
	Estimated range	(-)	0.77~1.25	-	-	-0.60~0.92	0.69~2.22	2.59~3.12
		(+)		-0.28~1.14	1.35~1.88	2.29~2.95	3.53~4.64	5.23~7.34
	Criteria proposal_strict		0.75	-	-	0.92~2.29	2.22~3.53	3.12~5.23
	Criteria proposal_flexible			-	-	-0.60~2.33	0.69~3.54	2.59~5.36
	HWFET	77 vehicles data	<u>Nomal probability</u> (2σ)	0.73	-0.33~0.20	-1.28~1.33	-1.00~1.18	-3.88~9.11
Estimated range		(-)	0.46~0.65	-	-	-	-1.69~0.37	-2.01~0.58
		(+)		-	1.03~1.69	0.90~1.75	3.07~9.69	3.73~11.45
Criteria proposal_strict			0.46	-	-	-	0.37~3.07	0.58~3.73
Criteria proposal_flexible			0.65	-	-	-	-1.69~9.11	-2.01~11.45

4. DTI resulting from drive trace on F.E.

Analysis of correlation between IWR and ASCR



Correlation Analysis between IWR and ASCR

- Leverage a total of 77 Base operating data
- When comparing determinant (R2) the correlation between the two Indexes is very large
 - FTP-75 Mode (R2): 0.9826
 - HWFET Mode (R2): 0.9975
- IWR provides a more quantitative driving quality scale compared to ASCR
 - ASCR does not detect changes in driving path as it represents the degree of change in speed
 - IWR, on the other hand, takes into account the effects of inertia work expressed in engine power.

- ❖ Impact of driving quality evaluation (DQE) indices resulting from drive trace on fuel economy
 - ❖ Driving quality evaluation (DQE) indices (ER, DR, EER, ASCR, IWR, RMSSE) depending on drive trace (soft, base, hard driving) in reference to SAE J2951 were evaluated and the impact of each index on fuel economy was analyzed
 - ❖ HWFET mode is less sensitive to fuel economy variation depending on drive trace than FTP-75 mode in Soft or Hard driving condition when compared with Base driving
 - ❖ The estimated range of DQE indices present between Base driving condition and Soft or Hard driving conditions is selected, and the area overlapping the 2σ -probability distribution segment of the population are approached from two different perspectives (strict and flexible) to **propose a range of appropriate criteria**
 - ✓ When **strict criteria** are applied, in FTP-75 and HWFET modes respectively, RMSSE (km/h) is 0.75 and 0.46; ASCR (%) 2.22~3.53 and 0.37~3.07; IWR (%) 3.12~5.23 and 0.58~3.73; and EER (%) 0.92~2.29 in only FTP-75 mode
 - ✓ When **flexible criteria** are applied, in FTP-75 and HWFET modes respectively, RMSSE (km/h) is 0.75 and 0.65; ASCR (%) 0.69~3.54 and -1.69~9.11; and IWR (%) 2.59~5.36 and -2.01~11.45
 - ❖ IWR and ASCR were confirmed to have a close correlation to each other ($R^2 \geq 0.982$) , and it was suggested that IWR is more reliable than ASCR as quantitative DQE index
- **The proposed criteria of each DQE index can be used for the amendment of domestic fuel economy regulation, and applied to reduce the gap between laboratory and real road by excluding the flexibility of the driver's skill.**

Thank you very much ! !



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