OICA contribution to PMP
28 Sep 2023

Content

- Overview and priorities
- Technical details to ANNEX-C and GTR-24
- Implementation of multiple sampling
- GTR-24 Testing boundaries for Light weight discs (see separate file)
- Correlation: WLTP Brake / WLTP-Exhaust
- Friction share family building
- Axle specific friction share coefficients

Priorities for GTR-24 Amendment and Beyond

Timing of amendments to Annex-C

Topic	ToDo	Jan 24	2025+
Technical points for Annex-C	Accept revisions: rotational speed; WLTP-Exhaust Brake events; Pressure threshold; integration method; Cp, and Ce calculation;	X	
Friction share family building	Text proposal for Annex-C	X	
Front / Rear axle friction shares	Presentation at PMP; ANNEX-C text; GTR-24 text	X	
Direct torque measurement	Add specifications (6.2.1.1); delete 6.2.1.2. (strain gauge), move strain gauge to 2. amendment (2025)	X	X
Electromechanical brakes	Accept revision; measurement of I_idle o.k? 6.2.3. to be completed. Supplier to review and add if necessary	X	
Pressure method	Specs for pressure sensors	X	
Equivalance criterion	Parameters for chap 7.3	X	
Correlation factor for ctrip10	Agree on factor	X	
c(WLTP-Exh) / c(WLTC-Brake)	Clear statement that c(WLTP-Brake) is decisive ADD: In case of discrepancy the c-factor determined on the WLTP-Brake is decisive	X	

Timing of amendments to GTR-24

Topic	ToDo	Jan 24	2025+
Technical points GTR-24	Tab 13.1; Annex B; OICA is collecting technical details; PMP stakeholders welcome to contribute	X	
Multi sampling	Implementation in GTR-24 to enable data collection and improve quality	X	
Enclosure	Specification of enclosure		X
Light-weight discs	Reduction of temp limits	X	
Bedding procedure	Collect more bedding data; alternative bedding procedure/duration		X
Parking brake	Amend text in GTR-24 for clarification „8.4.2. Calliper Orientation (…)The parking brake shall be dismounted for carrying out a brake emissions test. Alternatively, a calliper without the parking brake feature shall be selected for the test. “	X	

Technical Details to ANNEX-C and GTR-24

Technical Details & Comments

Usage of rotational Wheel Velocity

Relevant Section:

Annex C, all Section

Question:

Currently most formulas using the translatory vehicle velocity. This does not consider an eventually difference at each wheel and introduces additional computations. Usually the sensors on dynos or cars measure the rotational velocity.

Impact:

- Multiple forward/backward conversion of velocity with r_{dyn}
- Not exact values per wheel/axle and potentially incorrect values if **translational** CAN-Bus Signals are used (offset)
- But **rotational** CAN-Bus Signals are without offset so they might be used

Details

Usage of rotational Wheel Velocity instead of translational Vehicle Velocity?

- Usually all velocities are computed from the rotational velocity sensors ($v = \omega \cdot r$)
- Most of the formulas are using torque signals
- → It would be more meaningful to stick to the rotational velocity directly
- → this is also defined per wheel and not just for the whole vehicle

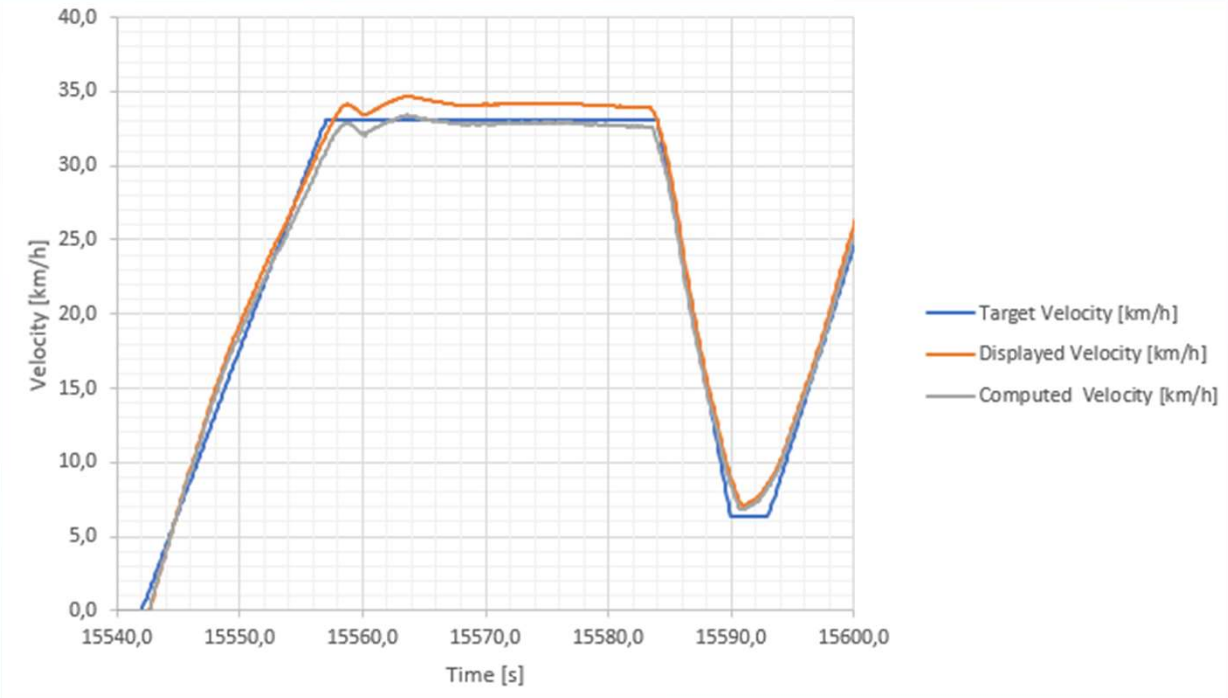
$$W_{brake} = \frac{1}{r_{dyn}} \int \tau_{brake} \cdot v \ \mathrm{d}t \quad \rightarrow \quad W_{brake} = \int \tau_{brake} \cdot \omega \ \mathrm{d}t$$

Measurement at Roller:

$$\omega_{Wheel} = \frac{r_{Roll}}{r_{dyn}} \omega_{Roll}$$

Measurement at Wheel:

$$\omega_{Wheel}$$



Take Away:

Modify formulas to use measured rotational wheel velocity.

Technical Details & Comments

Brake Events in WLTP **<u>Exhaust</u>**

Relevant Section:

Annex C, Section 8.2

Question:

How are the brake events or phases of deceleration defined if the WLTP **Exhaust** should be used for the computation of the friction share factor?

Impact:

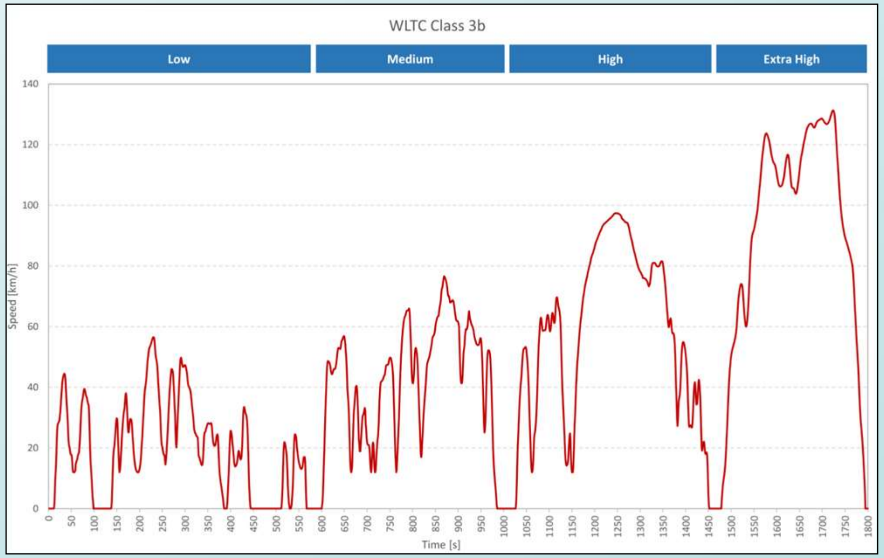
- Unclear integration intervals
- Different results in each house

Details

Only Deceleration Phase maybe not applicable:

- The WLTP Exhaust has not the same clear „braking phases“ as the WLTP Brake
- Rather very „smooth“ deceleration
- Also use following condition for integration:

$$a_{ref}(t) < 0$$



Take Away:

It is necessary to define the brake events.

Technical Details & Comments

Consideration of Pressure

Relevant Section:
Annex C, Section 5.2

Question:
Currently no pressure threshold for the computation of torque (friction power → friction work) is given. Hence mechanical threshold and sensor noise might introduces artificial friction work.

Impact:
- Significant overestimation of friction brake work

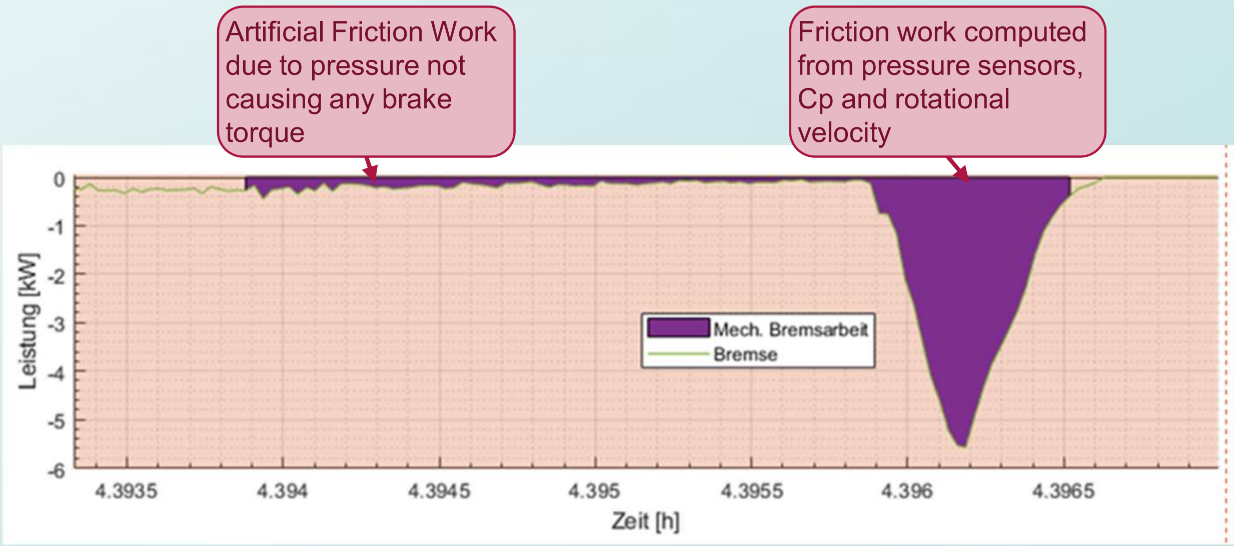
Details

Consideration of Pressure Threshold and Torque Threshold respectively:

- As stated in section 3.1.19 of the GTR a “Threshold Pressure” exists which is the minimum hydraulic pressure to overcome the internal friction and seal forces to move the brake calliper piston or drum wheel cylinder and onset brake torque output.
- Hence there will be no brake torque if the brake pressure is below this threshold. This must be considered for the computation of the friction brake power:

$$P_{brake,i} = \begin{cases} \omega_i \cdot C_p \cdot p_i & p_i > p_{threshold} \\ 0 & \text{otherwise} \end{cases}$$

- Pressure threshold is already defined in GTR



Take Away:
The pressure threshold for the signals as stated in table 8.1 of GTR24 main text shall be applied.

Technical Details & Comments

Consideration of Threshold for Torque

Relevant Section:
Annex C, Section 5.2, 6.1

Question:

Currently two methods to measure torque are described, i.e. Piezo Sensor and Strain Gauge method. How to deal with zero-offset and drift of zero line?

Impact:

There could be a false zero torque reading, which would be integrated during brake events.

Details

- Two methods have different accuracy and stability
- Strain gauge method requires weakening of caliper/bracket- which require expert knowledge
- Strain gauge method appears to have higher deviation- suitability?
- Base line correction and procedure is currently unclear
- Need a clear description, if and how base line torque may be corrected
- High accuracy is particularly needed for highly recuperating vehicles

Take Away:
- Two torque methods have very different sensitivity. Accuracy and stability is currently unclear and needs to be further elaborated
- A threshold torque might be needed

Technical Details & Comments

Definition of Brake Event Start/End Time and Intervals

Relevant Section:
GTR, Section 13.1
Annex C, Section 5.2

Question:
Which intervals are relevant for the integration and analysis of the brake stop event?

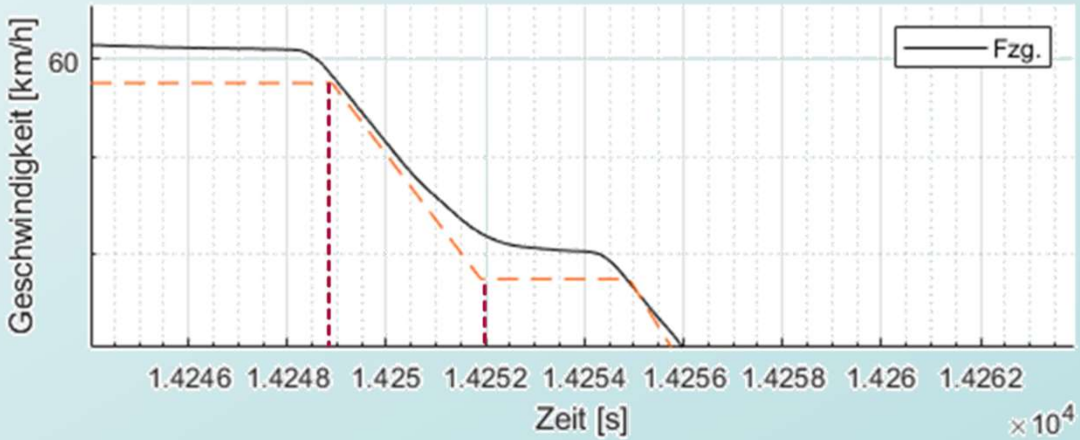
Impact:
- Unclear intervals of integration or analysis in different houses
- Different results and inconsistency of data

Details

Text from GTR:
"The brake event start time is the time stamp when the deceleration setpoint is above zero. The brake event end time is the time stamp when the deceleration setpoint is back to zero or a negative value."

- ➢ Setpoint means the reference/target value of the cycle?
- ➢ Instead of using start and end time of each brake event (multiple integral ranges) one could consider the friction power only where the acceleration of the **reference/target** is below zero?:

$$P_{frc,b}(t) = \begin{cases} \tau_{frc,b}(t) \cdot \omega_b(t) & \text{for} \quad a_{ref}(t) < 0 \\ 0 & \text{otherwise} \end{cases}$$



Take Away:
Add the above mentioned formula to the GTR.

Technical Details & Comments

Numeric Implementation of Integration

Relevant Section:
Annex C, Section 5.2

Question:
How should the integration be done?

Impact:
- Different methods for numerical integration used in different houses
- Deviation of results

Details

- Currently it is not defined how the integral should be computed

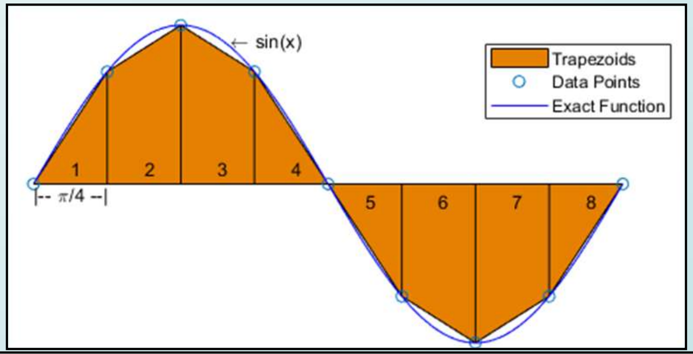
$$W = \int_{t_0}^{t_1} P(t)\, dt$$

- It is suggested to use the most easy one, the trapezodial method:

$$W \approx \frac{\Delta t}{2} \sum_{t_i \in [t_o, t_1]} (P(t_i) + P(t_{i+1}))$$

- Implementation e.g. in Excel:

$$W_i = \frac{\Delta t}{2} (P(t_i) + P(t_{i+1}))$$



=(((K195-K194)/2)*(AD194+AD195))

K	L	M	N	O	P	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH
TARGET						COMPUTED									
Time [s]	Target Velocity [km/h]	Trip ID [1]	Velocity [m/s]	Acceleration [m/s^2]	Delta Kin. Energy [J]	Computed Velocity [km/h]	Computed Velocity [m/s]	Computed Acceleration [m/s^2]	Computed Brake Torque Sum [Nm]	Computed Drag Force [N]	Computed Brake Power [W]	Computed Drag Power [W]	Computed Delta Kin. Energy [J]	Computed Brake Energy [J]	Computed Drag Energy [J]
18,3	19,7	1	5,5	-1,0	-998,4	18,3	5,1	-0,3	0,0	188,5	0,0	958,6	-283,6	0,0	95,6
18,4	19,3	1	5,4	-1,0	-980,7	18,2	5,1	-0,4	0,0	188,4	0,0	952,6	-346,3	0,0	94,9
18,5	19,0	1	5,3	-1,0	-963,0	18,1	5,0	-0,6	0,0	188,3	0,0	945,1	-557,7	0,0	93,9
18,6	18,6	1	5,2	-1,0	-945,3	17,9	5,0	-0,7	0,0	188,1	0,0	933,1	-661,6	AD195))	92,6
18,7	18,3	1	5,1	-1,0	-927,7	17,6	4,9	-0,8	352,7	187,8	5409,4	918,7	-735,3	603,1	91,1
18,8	17,9	1	5,0	-1,0	-910,0	17,3	4,8	-1,0	440,9	187,5	6653,0	902,5	-877,4	684,1	89,3

Take Away:
The exact numerical integration of the measured values shall be defined precisely.

Technical Details & Comments

Suggestion for reworked formulas/computation

Relevant Section:

Annex C, Section 5

Question:

There were plenty of topics regarding the formulas. Is a general rework possible?

Impact:

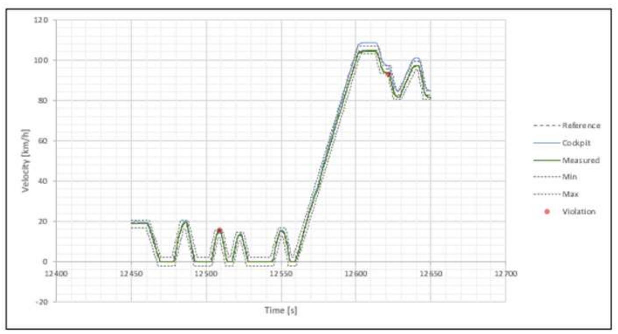
- Better readability and precise implementation in each house

BMW could provide Excel Template on request

Vehicle Parameters	Parameter	Value	Unit
Mass	m	1924,000	kg
Drag Coeffs	F0	178,200	N
	F1	0,055	N/(km/h)
	F2	0,028	N/(km/h)^2
Brake Const	CpF	32,460	Nm/bar
	CpR	14,890	Nm/bar
Wheels	r(dyn) FA	0,319	m
	r(dyn) RA	0,319	m
Distr.	FAF	0,685	1
	RAF	0,315	1
Tr. Press.	p_thr	1,500	bar

Plot Range		
t Start	12450	124500
t End	12650	2000

Key Results	Value	Unit
Overall Work		
W total, theor.	15,98	kJ/kg
W total, real	14,52	kJ/kg
W Brake	2,22	kJ/kg
W Drag	1,86	kJ/kg
Brake Friction Share C		
W total, theor. - 13%	16,0%	%
W total, theor. - W Drag	15,8%	%



FRICTION SHARE ANALYSIS

Overall Energy [kJ]	30758
Overall spez. Energy [kJ/kg]	15,986

Overall Energy [kJ]	27929	4280	3581
Overall spez. Energy [kJ/kg]	14,516	2,224	1,861

TARGET						COMPUTED															
Time [s]	Target Velocity [km/h]	Trip ID [1]	Velocity [m/s]	Acceleration [m/s^2]	Delta Kin. Energy [J]	Computed Velocity [km/h]	Computed Velocity [m/s]	Computed Acceleration [m/s^2]	Computed Brake Torque FL [Nm]	Computed Brake Torque FR [Nm]	Computed Brake Torque RL [Nm]	Computed Brake Torque RR [Nm]	Computed Brake Torque Sum [Nm]	Computed Drag Force [N]	Computed Brake Power F [W]	Computed Brake Power R [W]	Computed Brake Power [W]	Computed Drag Power [W]	Computed Delta Kin. Energy [J]	Computed Brake Energy [J]	Computed Drag Energy [J]
0,0	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,1	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,2	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,3	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,4	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,5	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,6	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,7	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,8	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
0,9	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,0	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,1	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,2	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,3	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,4	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,5	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,6	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,7	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,8	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1,9	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,0	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,1	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,2	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,3	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,4	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,5	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,6	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,7	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,8	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
2,9	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,0	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,1	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,2	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,3	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,4	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,5	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,6	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,7	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,8	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
3,9	0,0	1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0
4,0	0,0	1	0,0	1,0	8,8	0,0	0,0	2,9	0,0	0,0	0,0	0,0	0,0	178,2	0,0	0,0	0,0	0,0	80,4	0,0	2,6
4,1	0,3	1	0,1	1,0	26,5	1,0	0,3	0,9	0,0	0,0	0,0	0,0	0,0	178,3	0,0	0,0	0,0	51,5	61,3	0,0	6,0

Take Away:

An overall rework of the sections regrading the computation of individual C-Factors is necessary.

Technical Details & Comments

Misleading Computation of Average Friction Work

Relevant Section:
GTR, Table 13.1
(Event Based Results File)

Question:
In the table 13.1 of the main GTR the average friction work should be computed based on the time averaged friction brake torque and wheel rotational speed. This is mathematically incorrect but might be needed for sake of simplicity?

Impact:
- Wrong sum of friction work
- Confusion and inconsistency when comparing values

Details

Text from GTR:
"The actual specific friction work applied to the brake in the given deceleration event calculated from parameters in columns D, K, and O using Equation 10.1"

- ➢ The referenced Equation 10.1 is probably not the correct one?
- ➢ Column D,K and O are
  - Stop Duration
  - Time Average Rotational Speed
  - Time Average Brake Torque
- ➢ Formula probably (which is wrong):

$$\overline{W}_{brk} = T \cdot \overline{\omega} \cdot \overline{M}_{brk}$$

- ➢ Correct formula:

$$\overline{W}_{brk} = T \cdot \overline{M_{brk} \cdot \omega}$$

- ➢ Key Problem:

$$\overline{\omega} \cdot \overline{M}_{brk} \neq \overline{M_{brk} \cdot \omega}$$

$$\frac{1}{N}(M_1\omega_1 + M_2\omega_2 + M_3\omega_3) \neq \frac{1}{N^2}(M_1 + M_2 + M_3)(\omega_1 + \omega_2 + \omega_3)$$

$$\frac{1}{3}(1 \cdot 5 + 2 \cdot 6 + 3 \cdot 7) \neq \frac{1}{3^2}(1 + 2 + 3)(5 + 6 + 7)$$

$$\frac{1}{3}(5 + 12 + 21) \neq \frac{1}{3^2} 6 \cdot 18$$

$$\frac{1}{3} 38 \neq \frac{1}{9} 108$$

$$12{,}7 \neq 12$$

Take Away:
One of the following options must be implemented: A) Introduce a power signal which can be averaged over time B) Exclude this value from the results data

Technical Details & Comments

Mismatch in theoretical Spec. Kin. Energy

Relevant Section:
GTR, Annex B

Question / Problem:
In the Annex B of the main GTR the specific kinetic energy, given in column „Specific KE“ deviates from the theoretical value.

Impact:
- Wrong sum of specific kinetic energy for normalization of friction share → different / wrong calculation of c-Factors
- Bad reputation

Details

- ➢ Formula for computation of specific energy

$$\Delta e_{kin} = \frac{1}{2}(v_2^2 - v_1^2)$$

$$\Delta e_{kin} = \left(\frac{m}{2}v_2^2 - \frac{m}{2}v_1^2\right) \cdot \frac{1}{m}$$

- ➢ If applied to start and end velocity (in m/s) there are slightly different results obtained using Excel.

As currently written in GTR

Annex B

WLTP-Brake Cycle Brake Events

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s²]	Event Distance [m]	Specific KE (Decel only) [J/kg]
1	1	18	24	6.0	20.7	0.0	0.958	17.24	16.52
1	2	58	65	7.0	23.1	5.6	0.695	27.88	19.39
1	3	85	89	4.0	15.4	4.4	0.760	11.01	8.37
1	4	103	109	6.0	25.7	7.2	0.857	27.47	23.55
1	5	129	132	3.0	24.8	16.7	0.748	17.28	12.92
1	6	140	149	9.0	18.7	0.0	0.577	23.36	13.48
1	7	177	183	6.0	32.5	0.0	1.506	27.11	40.83

Recommendation for improvement

TARGET EVENTS

Event time start [s]	Event time end [s]	Trip [#]	Event Index	Duration [s]	Speed at start [km/h]	Speed at end [km/h]	Deceleration Rate [m/s^2]	Event Distance [m]	Specific KE (Decel only) [J/kg]	Real Specific KE (Decel only) [J/k
18	24	1	1	6	20,7	0,0	0,96	17,24	16,52	16,53
58	65	1	2	7	23,1	5,6	0,70	27,88	19,39	19,38
85	89	1	3	4	15,4	4,4	0,76	11,01	8,37	8,40
103	109	1	4	6	25,7	7,2	0,86	27,47	23,55	23,48
129	132	1	5	3	24,8	16,7	0,75	17,28	12,92	12,97
140	149	1	6	9	18,7	0,0	0,58	23,36	13,48	13,49
177	183	1	7	6	32,5	0,0	1,51	27,11	40,83	40,75

Take Away:
The correct values shall be given in the table!

Implementation of multiple sampling

Implementation of multi-sampling

Justification:

- It is crucial for the validation of emission testing and to characterise the success of bedding of the brake systems. Together with an adaption of the filter handling time it significantly enhances the usage time of emission test benches and the quality of the measurement results.
- Furthermore, only if the systems are allowed to be installed, it is possible to collect data for further evaluations.
- This topic was brought up by OICA already in summer 2022 and an according paragraph was proposed for discussion and implementation to the GTR. While JRC was generally open to the topic, the implementation was postponed due to lack of available instruments.
- There are now at least two systems commercially available.
  During the EUROBRAKE 23, one manufacturer showed an according system and at least two others showed presentations / prototypes of such systems with availability dates in 2023 and very early 2024.
- As stated in the general comment document, OICA recommends the adaption of the GTR as proposed on the next slide.

Implementation of multi-sampling

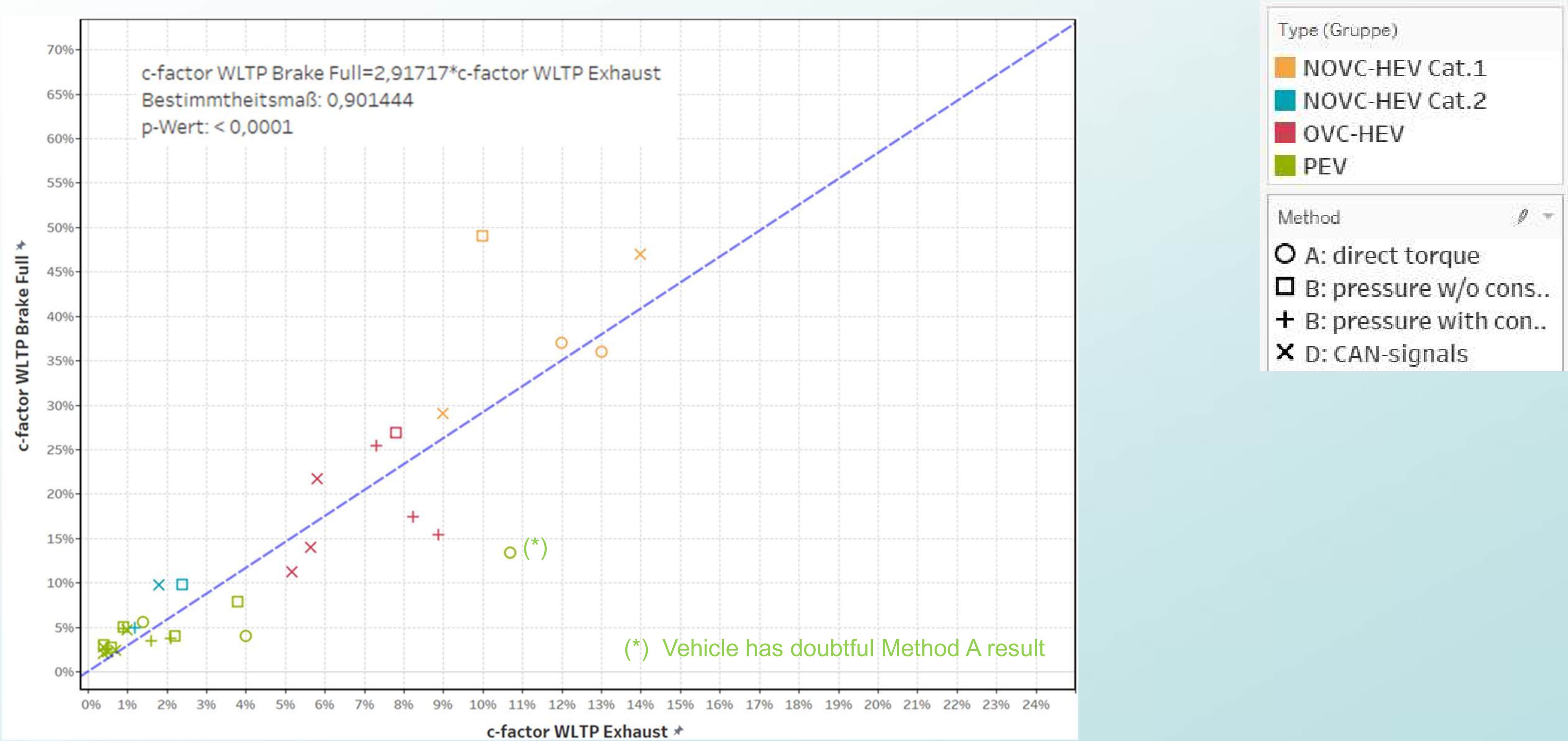
12.1.3.2. (new)	Multi filter-holders may be used to improve the measurement quality and statistics during bedding and emission testing. The filter holders shall fulfil the requirements of 12.1.3.1. Additionally, the following requirements apply: (a) The system-manufacturer shall provide information that no adverse effect on PM emission factors exist. This shall be done by correcting losses or provide according and appropriate measurement data. (b) All filter-holders shall be mounted in the same device under the same conditions within a closed housing to avoid contamination. (c) The same flow shall be used for the sampling on different filters (d) Only one filter shall be used at a time (e) All parts in contact with the aerosol or filters shall be electrically conductive (f) [additional provisions to be discussed with equipment manufacturers]	Proposal for addition: Justification: - It helps to check if bedding is completed and determine the stability of the emission measurement - The current description of the procedure does not allow an adequate utilization-time of the equipment. If is not possible to start a test later than Wednesday afternoon to finish it before the weekend - Multifilter holders allow the sampling during bedding or for additional emission measurement tests. - Possible issues with particle loss have not been observed and can be overcome by design or loss correction. - According systems are available on the market
12.1.4	(e) Post-sampling conditioning and weighing – ~~Take the filters to the conditioning room within 8 hours after testing is completed.~~ Store the filter in a closed petri dish (or equivalent) or sealed filter holder after testing. Place the filter in the weighing chamber (or room). within 1h of its removal from the filter holder. Use a closed petri dish (or equivalent) or sealed filter holder to transfer the filter to the conditioning room. Alternatively, transfer the filter without removing it from the filter holder ensuring that filter holders are not tilted during transfer. Condition/stabilise the filters at (22 ± 2) °C and (45 ± 8) per cent RH for a minimum of 2 hours. Weigh the filter at the end of the stabilisation period following the procedure described in (g) of this paragraph and register its weight in all relevant test sheets. No deviation from the conditions specified in this paragraph is permitted during the weighing operation. Store the filter in a closed petri dish (or equivalent) or sealed filter holder; (f) Ensure that the conditions for the filters are stable from the installation to the test bench until the removal from the test bench	Request for clarification: Justification: If the filters are installed in the test bench with the climate control running there should be no effect on the final results. As far as OICA knows, there was a presentation about this topic by an instrument manufacturer in the past. The installation time of 8h does not allow the usage of test rigs in automated mode over the weekend. There is no definition of “after testing”. Does it mean, after the emission measurement section is completed or does it mean, after the test bench is switched of? Please delete the sentences and use definition of (d) in the same chapter. We recommend to allow the filter to be left in the test bench as long as it is stored properly and limit the transfer time between test bench and weighing room/chamber.

GTR24 Temperature limits for non-gray cast iron rotors

See separate file

Correlation: WLTP Brake / WLTP-Exhaust

Correlation: WLTP Brake / WLTP-Exhaust



- OICA data does not support universal correlation of c(WLTP-Exhaust) and c(WLTC-Brake)

Correlation: WLTP Brake / WLTP-Exhaust

- The relationship between WLTP Exhaust and WLTC-Brake is dependent on several parameter, i.e. recouperation technology, powertrain capability, battery, …
- Due to the uncertainty OICA suggests to delete Chapter 8.2.
- At minimum, it must be clearly stated that WLTC-Brake, or Trip10 are decisive.
  "As an alternative to derive the friction braking share coefficient from WLTP-Brake cycle, the manufacturer may choose to calculate it from WLTP-Brake-Trip10 cycle or from WLTC (Exhaust). …. "
  Proposal ADD: "In case of discrepancy the c-factor determined on the WLTP-Brake is decisive "
- To deal with the testing demands on WLTC-Brake, or Brake-Trip10 a friction share family concept is mandatory

Friction braking share coefficient families

Need Friction braking share coefficient families

Table 5.1.
Friction braking share coefficients for all vehicle types

Brake type	*Vehicle Type*	*Friction Braking Share Coefficient (c)*
Full-friction braking	ICE and other vehicle types not covered in the non-friction braking categories in this Table	1.0
Non-friction braking	NOVC-HEV Cat.1	0.63
	NOVC-HEV Cat.2	0.45
	OVC-HEV	0.30
	PEV	0.15

Note: A detailed testing methodology to determine vehicle-specific friction braking share coefficients will be included in the first amendment to this UN GTR.

- In the current GTR it is stated that a methodology for the determination of vehicle-specific friction braking share coefficient will be developed.
- OICA concern is that without a clear definition of what “vehicle-specific” means, each and every vehicle variant, version and option configuration shall be tested.
- The resulting high testing burdens have been demonstrated to JRC

Vehicle specific friction data share

Example: BMW i4, available in three versions: i4 eDrive35, eDrive40, m50 Gran Coupé

- iX xDrive40 available with 12 different colors, 6 different tyres, and a multitude of costumer selectable optional equipment
  e.g. leather seats vs. textile seats (18 variants)
  with or without glass roof, different sound systems, ….

=> several thousand combinations (12x6x18x2x….) of possible user choices possible

⇒ resulting in different vehicle masses, but without any influence to the recuperation principle

⇒ is it common understanding, that the above mentioned variants are already combined in **IP-families (Interpolation families) from the „exhaust world“)?** Therefore, vehicle high of **individual IP-families** is the starting point, and not the individually configured vehicle ?! (see next slides)

⇒ Therefore, **several IP-families** can be **clustered** according to their **similar recuperation behaviour**?

Identification of friction braking share family parameters

Definition of IP-Families for exhaust emissions => in yellow: suggestion of parameters for friction braking share families

IP Interpolation family definition for NOVC-HEVs and OVC-HEVs

Only vehicles that are identical with respect to the following vehicle/powertrain/transmission characteristics may be part of the same interpolation family:

a) Type of internal combustion engine: fuel type (or types in the case of flex-fuel or bi-fuel vehicles), combustion process, engine capacity, full-load characteristics, engine technology, and charging system, and also other engine subsystems or characteristics that have a non-negligible influence on CO_2 mass emission under WLTP conditions;

b) Operation strategy of all CO_2 emission influencing components within the powertrain

c) Transmission type (e.g. manual, automatic, CVT) and transmission model (e.g. torque rating, number of gears, number of clutches, etc.);

d) n/v ratios (engine rotational speed divided by vehicle speed). This requirement shall be considered fulfilled if, for all transmission ratios concerned, the difference with respect to n/v ratios of the most commonly installed transmission type is within 8%;

e) Number of powered axles

f) Type and number of electric machines: construction type (asynchronous/ synchronous, etc.), type of coolant (air, liquid) and any other characteristics having a non-negligible influence on CO_2 emission and electric energy consumption under WLTP conditions

g) Type of traction REESS (type of cell, **capacity**, nominal voltage, **nominal power**, type of coolant (air, liquid));

h) Type of electric energy converter between the electric machine and traction REESS, between the traction REESS and low voltage power supply and between the recharge-plug-in and traction REESS, and any other characteristics having a non-negligible influence on CO_2 emission and electric energy consumption under WLTP conditions.

i) The difference between the number of charge-depleting cycles from the beginning of the test up to and including the transition cycle shall not be more than one

IP Interpolation family definition for PEVs

Only PEVs that are identical with respect to the following electric powertrain/transmission characteristics may be part of the same interpolation family:

a) Type and number of electric machines: construction type (asynchronous/synchronous, etc.), type of coolant (air, liquid) and any other characteristics having a non-negligible influence on electric energy consumption and range under WLTP conditions;

b) Type of traction REESS (type of cell, **capacity**, nominal voltage, **nominal power**, type coolant (air, liquid));

c) Transmission type (e.g. manual, automatic, CVT) and transmission model (e.g. torque rating, number of gears, numbers of clutches, etc.);

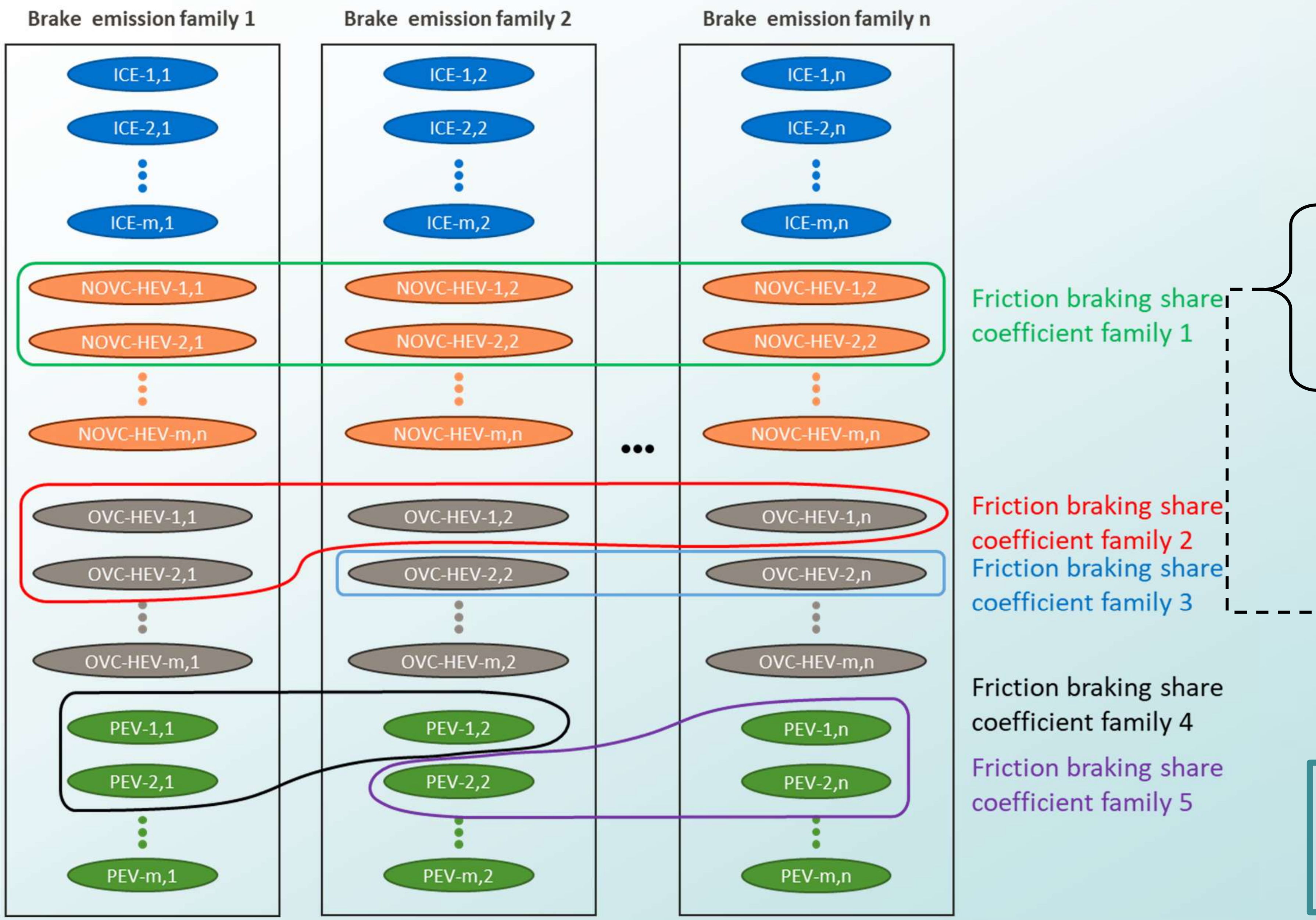
d) Number of powered axles;

e) Type of electric energy converter between the electric machine and traction REESS, between the traction REESS and low voltage power supply and between the recharge-plug-in and traction REESS, and any other characteristics having a non-negligible influence on electric energy consumption and range under WLTP conditions;

f) Operation strategy of all components influencing the electric energy consumption within the powertrain

g) n/v ratios (engine rotational speed divided by vehicle speed). This requirement shall be considered fulfilled if, for all transmission ratios concerned, the difference with respect to the n/v ratios of the most commonly installed transmission type and model is within 8%.

Identification of family parameters



Only electrified vehicles (OVC-HEVs, NOVC-HEVs, PEVs) that are identical with respect to the following powertrain characteristics may be part of the same friction braking share coefficient family:

- Type and number of electric machines
- Traction REESS nominal power
- Type of electric energy converter between the electric machine and traction REESS
- Number of powered axles

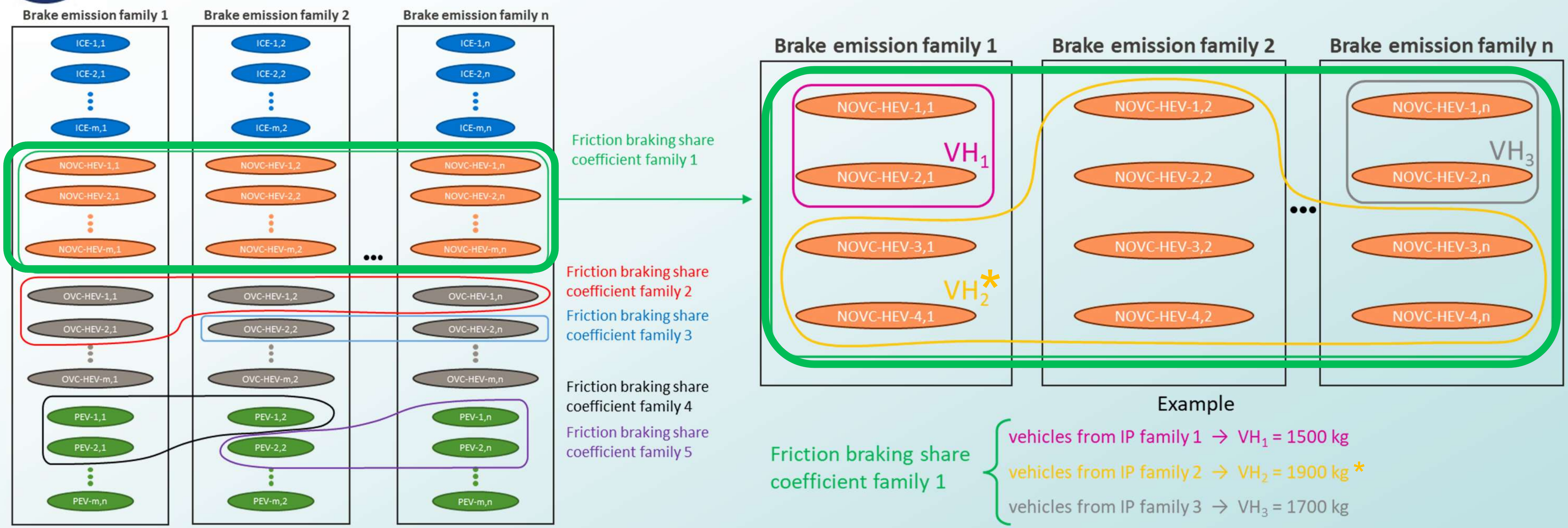
- Brake control system (Regen. strategy needs to be the same). To be further detailed

Sub-set of the Interpolation (IP) Family parameters.

Note: Different REESS capacities can be in different families

A friction braking share coefficient family is a group of several IP families

Identification of the family head



The Vehicle High with the highest test mass of a friction braking share coefficient family shall be selected for testing (**VH_2*** in the above example).

In case of same vehicle mass the one with the highest battery capacity shall be selected.

Text Proposal for Annex-C

6.1 Vehicle Selection

The vehicle shall be selected as described in the following paragraph 6.1.1. ~~The c-factors determined for this vehicle shall apply to all vehicles belonging to the same category and shall be used in Eq. 12.9, Eq. 12.10, Eq. 12.13, and Eq. 12.14 in the GTR.~~ The friction braking share coefficients determined for the selected vehicle shall apply to all vehicles belonging to the same group and shall be used for:

a) the selection of the brake emission family parent according to paragraph 5.2.2 of this GTR

b) the PM and PN emission factor calculation according to Eq. 12.9, Eq. 12.10, Eq. 12.13, and Eq. 12.14 of this GTR

6.1.1 Definition of friction braking share coefficient type (families)

For the purpose of the friction braking share coefficient determination, only electrified vehicles (OVC-HEVs, NOVC-HEVs, PEVs) that are identical with respect to the following powertrain characteristics may be grouped together, each group consisting of several Interpolation Families as defined in GTR 15:

a) Type and number of electric machines

b) Traction REESS nominal power

c) Type of electric energy converter between the electric machine and traction REESS

d) Number of powered axles

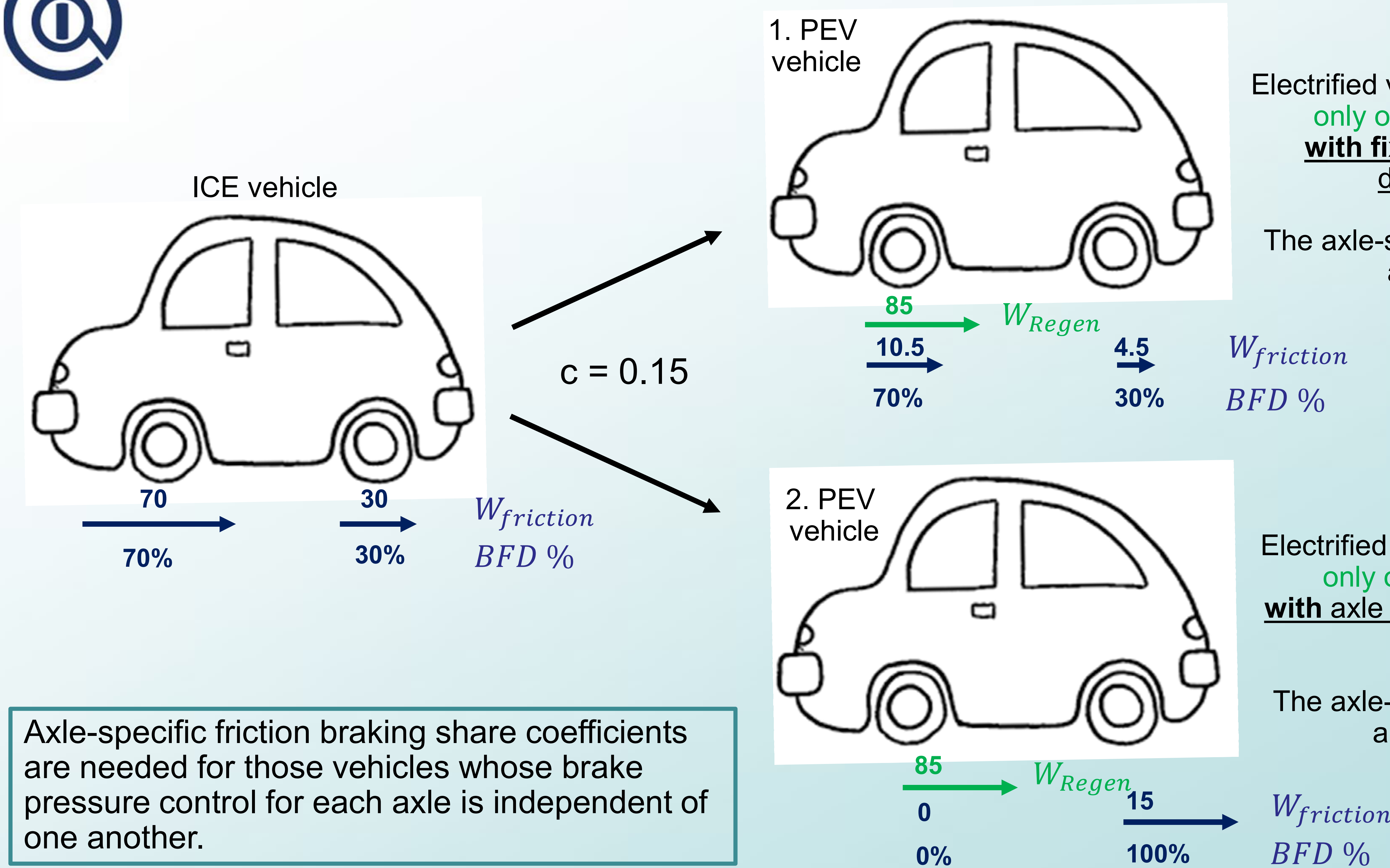
e) [Braking control system (Regen. strategy needs to be the same). Other par.]

The Vehicle High, as defined in GTR 15, having the highest test mass among all the Vehicle High in the group, shall be selected for the determination of the friction braking share coefficients [for the front axle and the rear axle respectively].

In the case of two or more Vehicle High in the group having [the same test mass] [a test mass difference lower than x%] , the Vehicle High having the highest traction REESS capacity shall be selected for testing.

Axle-specific friction braking share coefficients

Need for axle-specific friction braking share coefficients



Electrified vehicle recuperating only on the front axle **with fixed** brake force distribution

The axle-specific coefficients are equal

Electrified vehicle recuperating only on the front axle **with** axle wise brake pressure control

The axle-specific coefficients are not equal

Axle-specific friction braking share coefficients are needed for those vehicles whose brake pressure control for each axle is independent of one another.

Wref=0.87·MVeh·wtotal,bc

Definition of axle-specific friction braking share coefficients

$$c_{FA} = \frac{W_{brake,FA}}{W_{ref}}$$

$$c_{RA} = \frac{W_{brake,RA}}{W_{ref}}$$

$$\longrightarrow \quad c = c_{FA} + c_{RA}$$

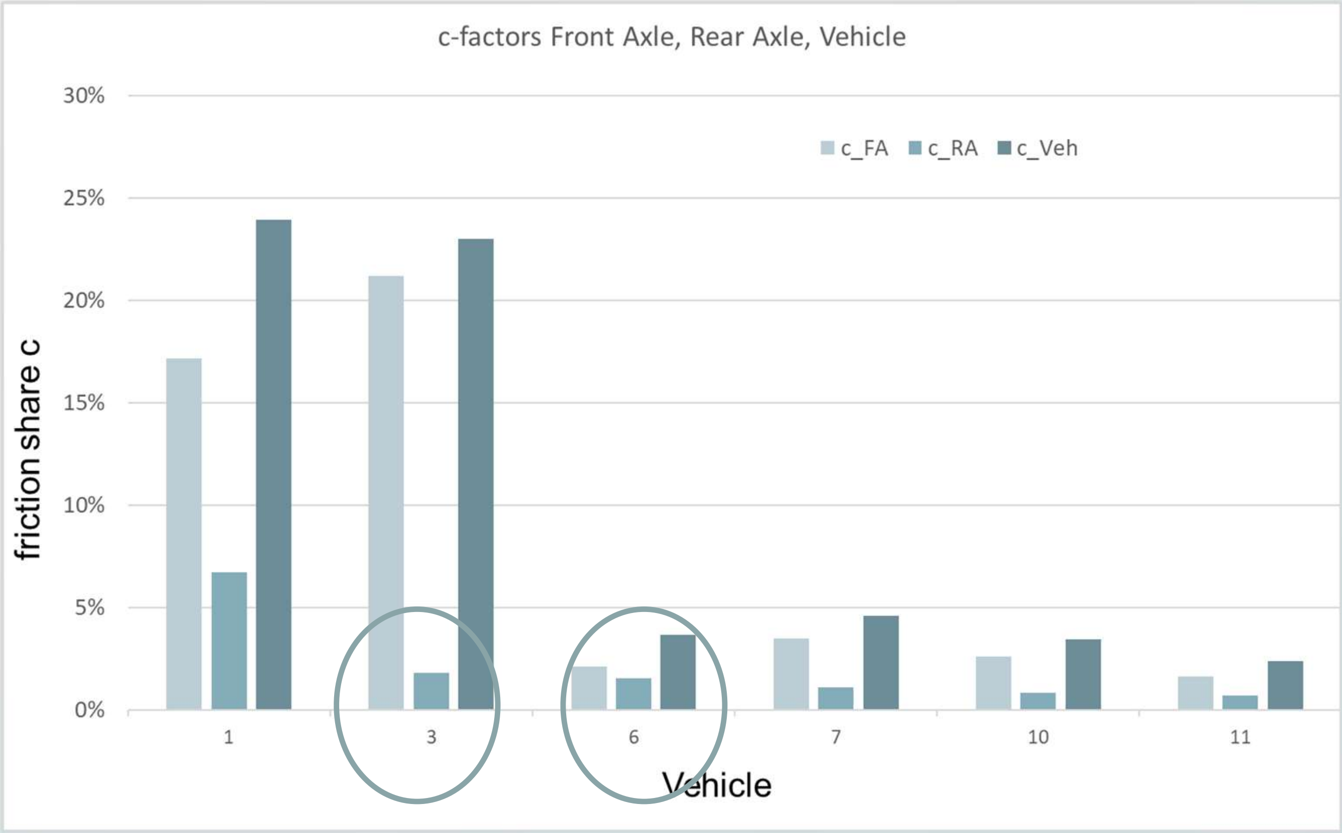
where:

c	is the vehicle friction braking share coefficient
c_{FA}	is the friction braking share coefficient of the front axle.
c_{RA}	is the friction braking share coefficient of the rear axle.
$W_{brake,FA}$	is the sum of the friction work dissipated in the friction brake systems of the front axle during all braking events in the used cycle.
$W_{brake,RA}$	is the sum of the friction work dissipated in the friction brake systems of the rear axle during all braking events in the used cycle.
W_{ref}	is the normalization reference for the cycle during which the friction work was measured. In case of WLTC-Brake $W_{ref} = 0.87 \cdot M_{Veh} \cdot w_{total,bc}$

By this definition the vehicle friction share coefficient (c) is the sum of front axle (c_{FA}) and rear axle c($_{RA}$) friction braking coefficient

Evidence from OICA test campaign

- OICA data collection show different braking behavior on front and rear axle
- Those vehicles need different c-factors for front and rear axle



Depending on the front and rear axle brake emissions, this might impact vehicle brake emission.

Modifications to the main section of the GTR

Due to the proposed definitions, the following equations in the main section of the GTR need to be modified

$$PM_{2.5}\ EF = PM_{2.5}\ EF_{ref} * c \quad \text{(Eq. 12.9)}$$

$$PM_{10}\ EF = PM_{10}\ EF_{ref} * c \quad \text{(Eq. 12.10)}$$

$$TPN10\ EF = TPN10\ EF_{ref} * c \quad \text{(Eq. 12.13)}$$

$$SPN10\ EF = SPN10\ EF_{ref} * c \quad \text{(Eq. 12.14)}$$

Example for Eq. 12.9:

$$PM_{2.5}EF = \begin{cases} PM_{2.5}\ EF_{ref} * c & \text{if Table 5.1 is used} \\ PM_{2.5}\ EF_{ref} * \frac{c_{FA}}{FAF} \text{ or } PM_{2.5}\ EF_{ref} * \frac{c_{RA}}{RAF} & \text{if axle} - \text{specific coefficients are used} \end{cases}$$

5.2.2. Brake Emissions Family Parent

For all vehicles with an identical brake assembly as described in paragraph 5.2.1., the vehicle with the highest product of friction braking share coefficient (c) and test wheel load as defined in paragraph 3.1.14. (WL_t*c) shall be selected as parent of the brake emissions family. The friction braking share coefficient for each vehicle type in the scope of this UN GTR is given in Table 5.1. If the product of the test wheel load and the friction braking share coefficient is the same for two or more vehicles of the same brake emissions family, the vehicle with the lowest dynamic rolling radius shall be selected as the brake emissions family parent.

The Brake Emissions Family Parent should be chosen considering for each vehicle of the family the following parameters:

$$\begin{cases} WL_T * c & \text{if Table 5.1 is used} \\ WL_T * \frac{c_{FA}}{FAF} \text{ or } WL_T * \frac{c_{RA}}{RAF} & \text{if axle} - \text{specific coefficients are used} \end{cases}$$

Integration with the Euro 7 implementing act approach

BRAKE FAMILIES
CALCULATION OF EMISSIONS – EXAMPLE

Identical front brake mounted in Vehicles A (ICE – M_{veh} = 1.5t – FAF = 70%) and Vehicles B (PEV – M_{veh} = 2.0t – FAF = 60%). ***Step 1.*** The parent of the brake emissions family is Vehicle A and is calculated as follows:

Vehicle A: $W_{t\text{-}f}$ = 0.87 x 0.5 x 1500 x 70% = 457 kg x **1.00** = 457 kg

Vehicle B: $W_{t\text{-}f}$ = 0.87 x 0.5 x 2000 x 60% = 522 kg x **0.15** = 78 kg

It can be either a measured axle-specific c-factor $\left(\frac{c_{FA}}{FAF} \text{ or } \frac{c_{RA}}{RAF}\right)$, or a default value as per Table 5.1

Step 2. The parent of the brake emissions family (Vehicle A) is tested for its emissions on the brake dynamometer following the GTR and gives e.g. PM10 of 5 mg/km. ***The final PM10 for this brake is calculated as follows:***

Vehicle A: PM10 = 5 mg/km x **1.00** = 5 mg/km

Friction braking coefficient for ICE

Step 3. The final PM10 for the member of the brake emissions family (Vehicle B) is calculated taking into account ***its testing wheel load vs. the parent's wheel load and the friction braking coefficient*** as follows:

Vehicle B: PM10 = 5 mg/km x $\frac{522}{457}$ x **0.15** = 0.85 mg/km

Friction braking coefficient for PEV

European Commission

NEW:

Vehicle B_{Front}: PM10 = 5 mg/km x $\frac{522}{457}$ x $\frac{c_{FA,B}}{FAF}$

Vehicle B_{Rear}: PM10 = 5 mg/km x $\frac{348}{457}$ x $\frac{c_{RA,B}}{RAF}$

348 kg = 0.87x 0.5 x 2000 kg x 40%