TF1 — Interlab Statistical Report

WLTP brake dyno test + ISO 5725 standards

Carlos **AGUDELO** + Theodoros **GRIGORATOS** + Jarek **GROCHOWICZ**

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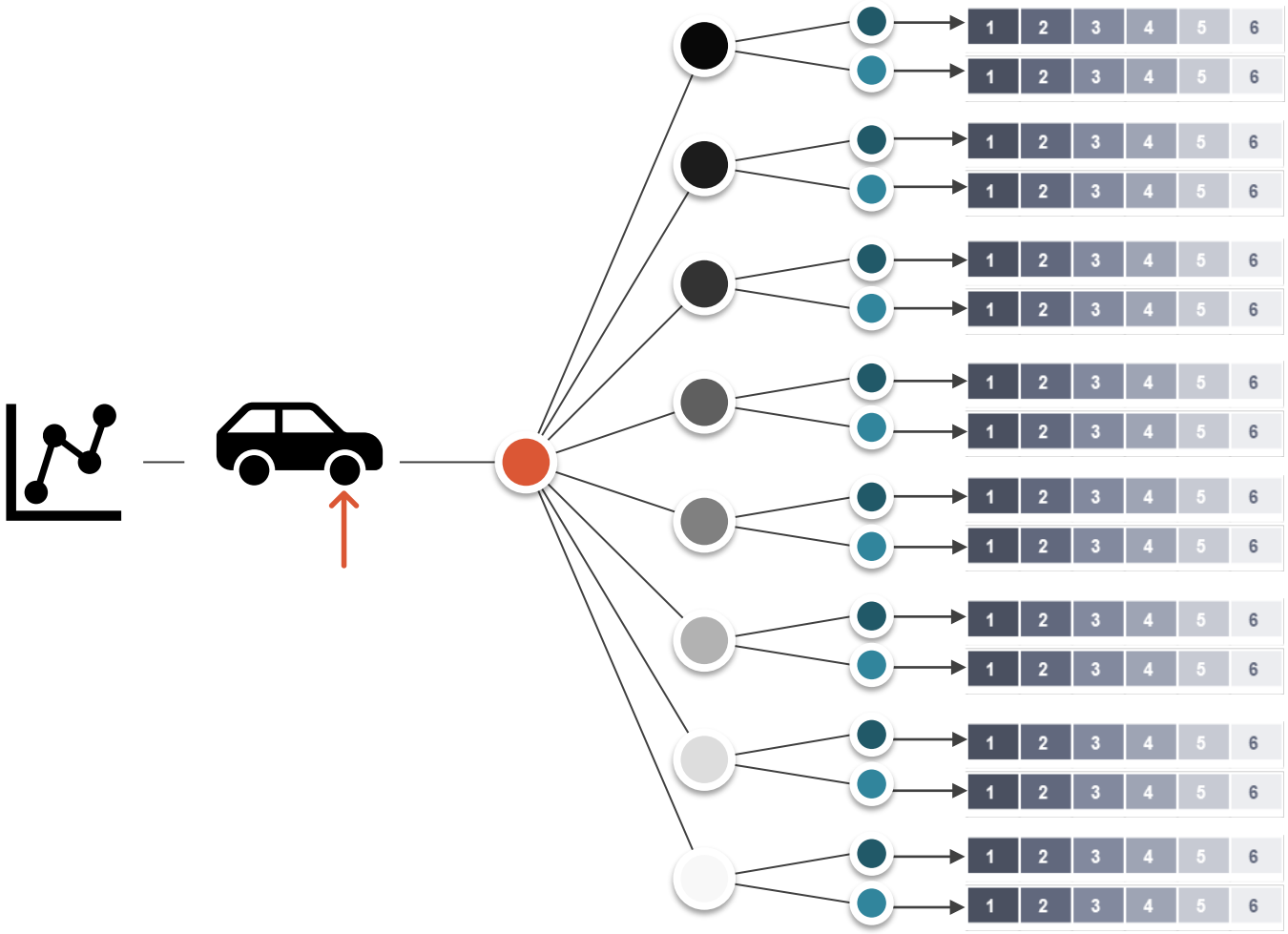
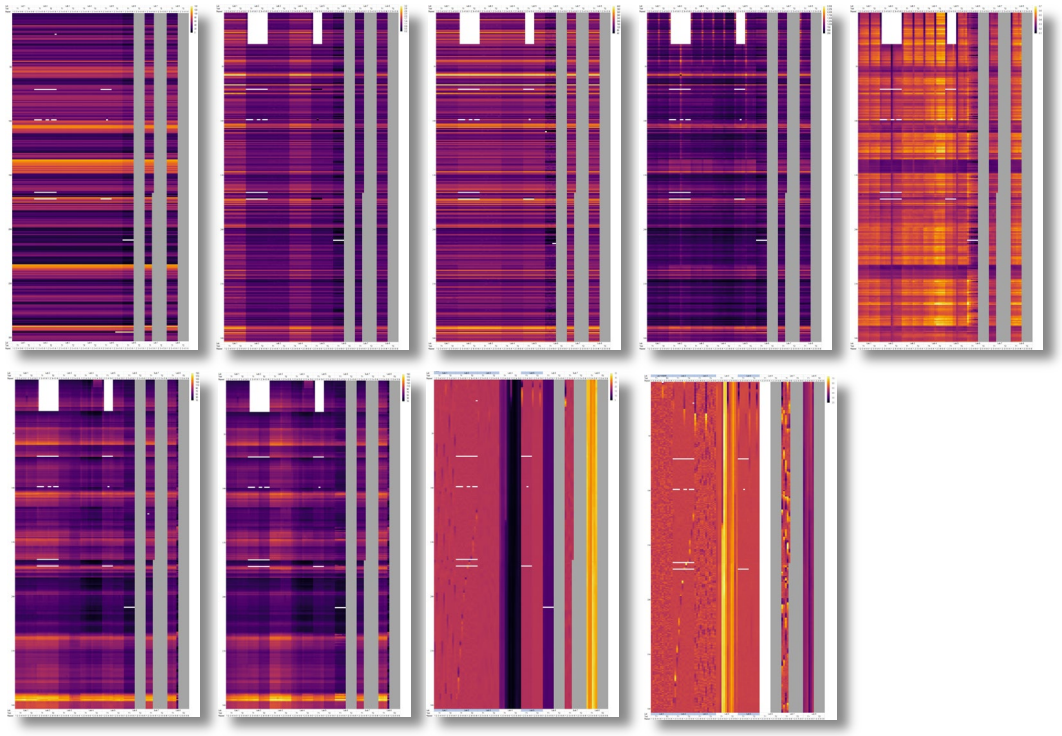
workflow to create the dataset for statistical assessments





WLTP Focus FA single setup 8 labs 2 tests each 6 x WLTP / test

~260k values

8 labs x 2 tests x 6 repeats x 303 events x 11 parameters:
braking speed, avg. dist. (torque, pressure, and COF), max. disc temps., cooling air temp. & cooling air RH

chapters and structure of the report

I. Rationale and justification

Introduction

Overview

Background of ILS-TF1

Main lab elements

Test cycle

10 %

II. General statistical evaluation

Aggregate stats on speed & deceleration

Temperature study

Special temperature assessment

~15 %

III. Statistics on time-resolved – EED

General concepts

VDA 305/EKB 3008

Speed control: violations & RMSSE

~10 %

IV. Statistics on event-based – EEC

VDA 305/EKB 3008

ISO 5725-5 elements

Repeatability, lab, sample, and total reproducibility std. dev.

Data scrutiny

Uncertainty on estimates s_r and s_R

20 %

Annexes (dataviz)

1. Heatmaps
2. Flowcharts
3. Std. dev. v avg.
4. Std. dev. v. event
5. Uncertainties (r & R)
6. Mandel's h^* (avg.)
7. Mandel's k^* (range)
8. Mandel's k^* (test)

45 %

interlaboratory accuracy study aims at determining the standard deviations for the main results

the assessment of brake emission measurements demands a deep understanding of test variability

main components include sample effect, lab effect, test repeatability, and total reproducibility

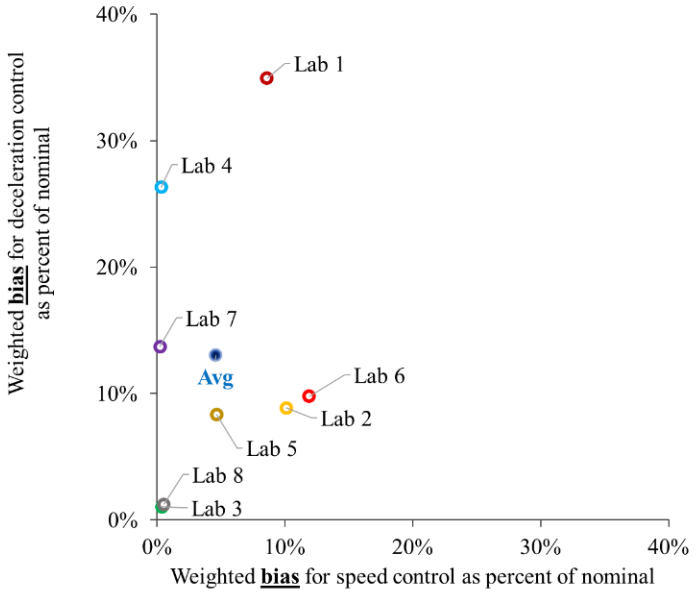
Table 1
Tabular summary of the applied hardware and testing conditions for R1 on each Laboratory – Cells in *green* indicate the Lab followed the recommended values; cells in *orange* indicate the Lab used a parameter or condition acceptable or equivalent; cells in *red* values indicate items with significant differences or deviations. (*) indicate data not available

Lab and test		Item or condition										
		Type of dynamometer [1 = Performance, 2 = NVH, 3 = Emissions]	**Climate Control** [1 = Temperature and RH Control, 2 = Temperature Control, 3 = Fresh]	**Script** – Control program [1 = Provided by Ford, 2 = Provided by Link US, 3 = Internal]	**Cooling air adjustment methodology** [1 = application of 2 curves, 2 = Alignment to trip 10, 3 = Other, including cooling rate]	**Application of test plan** [1 = Successful execution of two tests, 2 = Successful execution of one test, 3 = Other]	**Pads tested** [1= RR batch – New, 2 = RR batch – Used, 3 = Dummies/Other]	**Disc tested** [1= RR batch – New, 2 = RR batch – Used, 3 = Dummies/Other]	**Disc temperature measurement method** [1 = Rubbing TC, 2 = Embedded TC, 3 = Both, 4 = Other]	**Temperature control method for soak application** [1 = Rubbing TC, 2 = Embedded TC, 3 = Other]	**Output – VDA 305/EKB 3008 EEC** [1 = Lab specific, 2 = LINK modified, 3 = Not available]	**Output – VDA305/EKB 3008 EED** [1 = Lab specific, 2 = LINK modified, 3 = Not available]
Lab 1	T1	1	1	2	2	1	1	1	3	1	2	2
	T2	1	1	2	2	1	2	2	3	1	2	2
Lab 2	T1	2	1	1	1	1	1	1	3	1	2	1
	T2	1	1	2	1	1	2	2	3	1	2	1
Lab 3	T1	1	1	3	1	1	1	1	3	1	1	1
	T2	1	1	3	1	1	2	2	3	1	1	1
Lab 4	T1	1	3	2	1	1	1	1	3	1	2	2
	T2	1	1	2	2	1	2	2	3	1	2	2
Lab 5	T1	1	1	1	1	1	1	1	3	1	2	2
	T2	1	1	1	1	1	2	2	3	1	2	2
Lab 6	T1	2	2	3	3	1	1	1	3	1	1	2
	T2	2	2	3	3	1	2	2	3	1	1	2
Lab 7	T1	1	1	2	2	2	1	1	3	2	2	2
	T2	*	*	*	*	*	*	*	*	*	*	*
Lab 8	T1	3	3	3	1	2	3	3	3	1	1	1
	T2	*	*	*	*	*	*	*	*	*	*	*

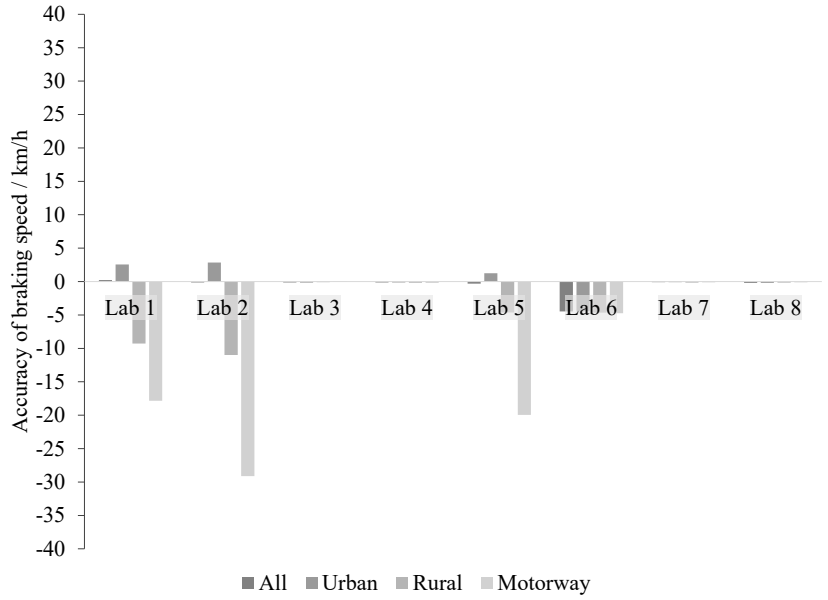
* Labs 7 and 8 did not execute T2 due to schedule constraints,

"Happy families are all alike; every unhappy family is unhappy in its own way."

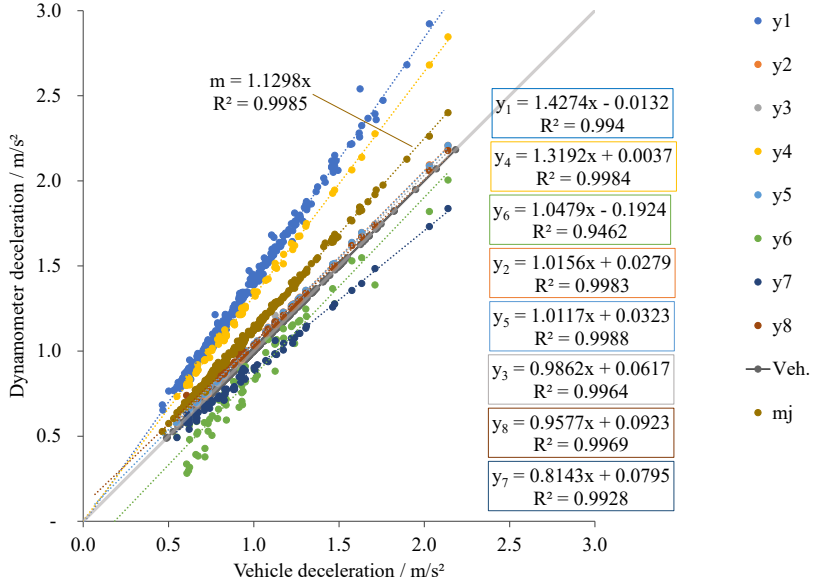
— Leo Tolstoy, Anna Karenina, 1877



scatter of bias/accuracy of deceleration v. braking speed



bias/accuracy of speed control by type of drive



scatter of dyno v. nominal deceleration level

extensive use of graphical and tabular presentation of data

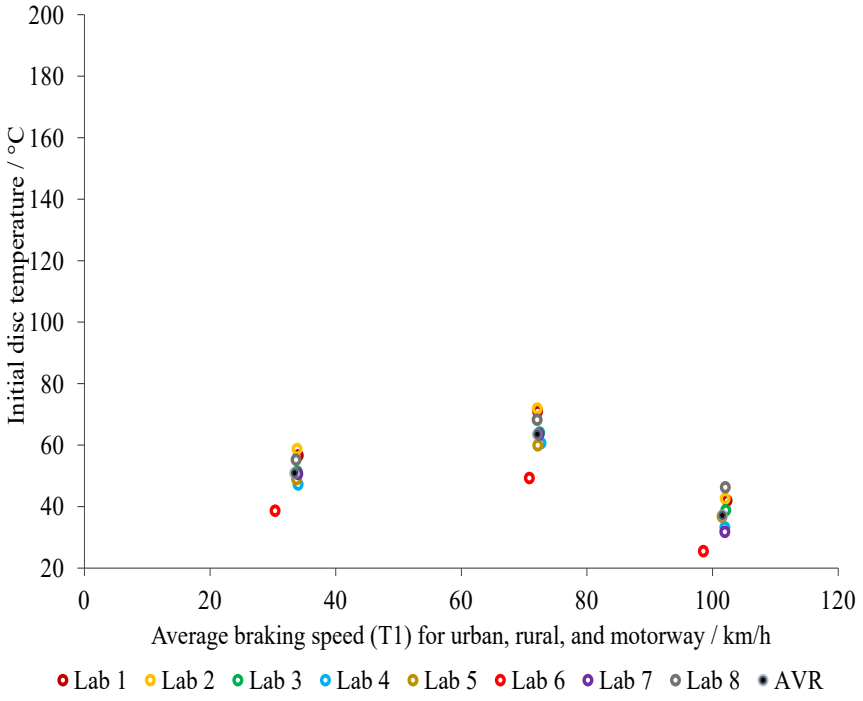


Table 6
Averaged initial, final and maximum disc temperature – The measurements include embedded (TC_{EMB}, *left half of the table*) and sliding (TC_{RUB}, *right half of the table*) TCs for all repetitions of T1 for all labs. Mean values (± 95 % confidence limits) represent the average temperature values for each parameter. (*) denotes missing data

Repeat	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8	Lab 1	Lab 2	Lab 3	Lab 4	Lab 5	Lab 6	Lab 7	Lab 8
	Average initial disc temperature TC_{EMB} / °C								**Average initial disc temperature TC_{RUB} / °C**							
1	57.9	59.7	52.4	48.2	49.8	39.3	51.5	56.5	50.8	54.8	64.2	51.5	45.5	40.0	52.3	61.3
2	57.8	56.6	52.3	44.2	46.4	37.3	51.3	54.9	51.4	52.1	64.1	47.4	43.4	38.9	52.1	59.3
3	57.5	56.8	52.3	44.1	46.5	36.7	51.2	53.3	52.9	52.6	64.1	47.2	43.6	38.5	52.3	57.6
4	57.2	57.2	52.6	42.5	46.9	39.5	50.9	57.4	54.1	53.0	64.1	44.9	44.0	41.3	52.2	61.4
5	56.8	57.3	52.3	38.5	48.9	36.2	*	55.8	55.1	53.4	63.7	41.2	46.3	38.3	*	59.5
6	57.1	56.6	52.3	36.8	48.9	35.4	*	*	53.1	52.7	63.9	39.0	46.5	37.7	*	*
Mean ± 95 % limit	57.38 ± 0.86	57.35 ± 2.33	52.38 ± 0.27	42.38 ± 8.19	47.9 ± 2.9	37.39 ± 3.25	51.21 ± 0.49	55.6 ± 3.13	52.92 ± 3.13	53.09 ± 1.84	64.01 ± 0.37	45.19 ± 8.91	44.89 ± 2.72	39.14 ± 2.57	52.25 ± 0.17	59.82 ± 3.14
	Average final disc temperature TC_{EMB} / °C								**Average final disc temperature TC_{RUB} / °C**							
1	66.9	72.2	60.4	56.5	62.4	51.4	60.8	65.7	57.3	62.6	75.7	62.3	53.4	50.8	59.0	75.4
2	66.1	67.1	59.8	52.6	56.7	47.6	59.7	64.5	56.8	59.4	75.8	58.1	50.7	49.6	58.5	72.7
3	65.7	67.2	59.6	52.9	56.2	46.7	59.5	62.9	58.5	60.0	75.9	57.3	50.9	49.0	58.8	70.8
4	65.6	67.3	59.8	51.6	56.2	49.2	59.1	66.9	60.3	60.6	75.8	54.8	51.3	50.4	58.9	74.5
5	65.3	66.9	59.2	47.8	58.9	45.8	*	65.3	61.4	61.2	75.6	51.1	54.4	47.6	*	72.0
6	65.5	66.2	59.0	46.3	58.8	45.3	*	*	59.1	60.6	75.7	48.7	54.5	47.4	*	*
Mean ± 95 % limit	65.84 ± 1.19	67.82 ± 4.25	59.65 ± 0.99	51.3 ± 7.25	58.19 ± 4.66	47.68 ± 4.52	59.8 ± 1.43	65.04 ± 2.91	58.88 ± 3.41	60.75 ± 2.15	75.77 ± 0.24	55.37 ± 9.73	52.55 ± 3.47	49.14 ± 2.79	58.8 ± 0.4	73.09 ± 3.59
	Maximum disc temperature TC_{EMB} / °C								**Maximum disc temperature TC_{RUB} / °C**							
1	171.1	166.7	159.5	150.1	164.7	166.9	160.8	151.5	145.8	167.8	192.5	149.6	140.5	174.0	150.9	193.4
2	176.2	164.3	159.5	156.7	158.2	162.0	161.0	143.5	148.4	172.7	194.5	144.5	139.8	175.6	157.3	187.9
3	177.1	164.6	158.9	161.2	154.8	160.0	162.9	144.3	157.1	175.6	194.8	142.6	139.8	175.9	163.4	185.0
4	181.1	164.5	154.6	160.4	153.2	161.0	166.6	149.1	166.9	183.5	197.9	133.1	137.8	168.4	168.0	187.2
5	185.9	163.3	156.2	160.5	157.6	159.8	*	148.1	167.8	183.8	193.4	130.6	146.6	169.5	*	185.4
6	188.9	163.6	153.9	159.7	156.8	158.6	*	*	168.9	182.8	194.6	128.7	145.0	165.3	*	*
Mean ± 95 % limit	180.04 ± 12.95	164.51 ± 2.32	157.1 ± 4.96	158.09 ± 8.31	157.58 ± 7.75	161.4 ± 5.76	162.81 ± 5.27	147.3 ± 6.57	159.16 ± 20.11	177.69 ± 13.13	194.62 ± 3.57	138.19 ± 16.69	141.57 ± 6.71	171.45 ± 8.49	159.91 ± 14.58	187.78 ± 6.6

integration of flowcharts and tabular data with step-by-step numerical examples

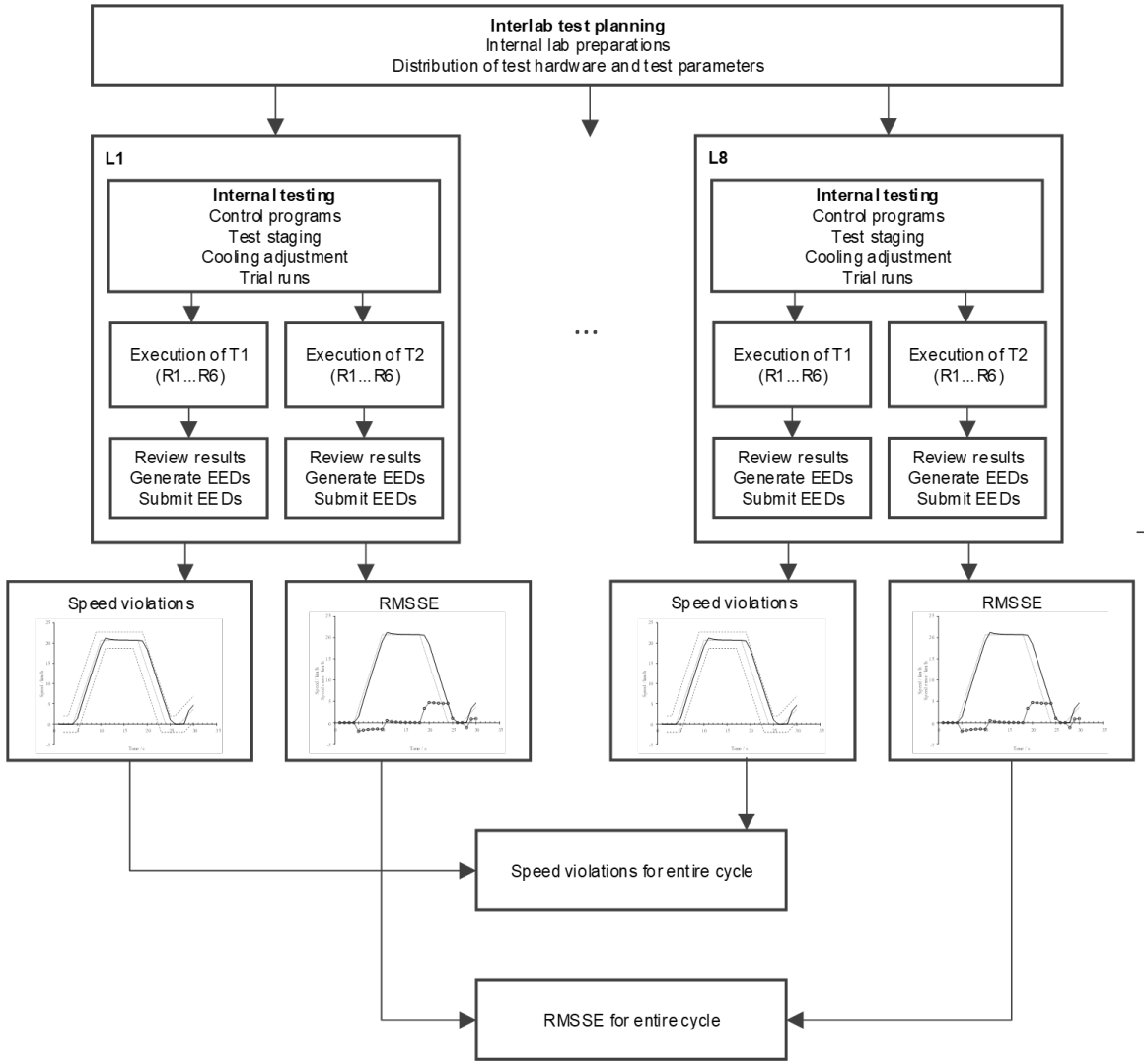


Table 10

Example of computation of speed violations for test 1, repeat 1, Lab 1 – Calculations in *bold, greyed cells* depicts values for time marker at 1124 s, using equations from paragraph 9.1. At 1124 s, the brake speed needs to be between 1.5 km/h and 12/4 km/h to not incur on a speed violation

Trip	Time / s	Speed / km/h				Speed difference from nominal / km/h			Speed violations		
		Nominal	Lower nominal	Upper nominal	Actual dyno	Lower nominal	Upper nominal	Actual dyno	Marker	Total / #	Total / %
		$S_{R0,t}$	$S_{R0,Lo,t}$	$S_{R0,Hi,t}$	$S_{R1,t}$	$S_{err,R0,Lo}$	$S_{err,R0,Hi}$	$S_{err,Ri,t}$	R1	R1	R1
1	1	0.0	—	—	0.0	0.00	0.00	0.00	—	—	0.00 %
1	2	0.0	-2.0	2.0	0.0	-2.00	2.00	0.00	—	0	0.00 %
1	3	0.0	-2.0	2.0	0.0	-2.00	2.00	0.00	—	0	0.00 %
1	4	0.0	-2.0	5.4	0.0	-2.00	5.45	0.00	—	0	0.00 %
1	5	3.4	-2.0	8.9	1.4	-5.45	5.45	-2.03	—	0	0.00 %
1	6	6.9	1.4	12.3	5.1	-5.45	5.45	-1.76	—	0	0.00 %
1	7	10.3	4.9	15.8	8.8	-5.45	5.45	-1.60	—	0	0.00 %
1	8	13.8	8.3	19.2	12.3	-5.45	5.45	-1.51	—	0	0.00 %
1	9	17.2	11.8	22.7	15.8	-5.45	5.45	-1.46	—	0	0.00 %
1	10	20.7	15.2	22.7	19.2	-5.45	2.00	-1.52	—	0	0.00 %
1	753	46.7	44.7	48.7	45.3	-2.00	2.00	-1.44	—	0	0.00 %
1	754	46.7	44.7	48.7	44.6	-2.00	2.00	-2.10	– 1	1	0.01 %
1	755	46.7	44.7	48.7	46.7	-2.00	2.00	-0.04	—	1	0.01 %
2	1 123	10.4	4.9	15.8	13.9	-5.46	5.46	3.50	—	2	0.01 %
2	**1 124**	**6.9**	**1.5**	**12.4**	**13.7**	**-5.46**	**5.46**	**6.77**	**1**	**3**	**0.02 %**
2	1 125	3.5	-2.0	8.9	10.6	-5.46	5.46	7.11	1	4	0.03 %
10	15 824	0.0	-2.0	2.0	0.9	-2.00	2.00	0.87	—	164	1.04 %
10	15 825	0.0	-2.0	2.0	0.5	-2.00	2.00	0.49	—	164	1.04 %
10	15 826	0.0	-2.0	2.0	0.5	-2.00	2.00	0.54	—	164	1.04 %
Total speed violations										164	1.04 %
Total speed violations below										160	
Total speed violations above										4	

$S_{R0,Lo,1124} = \min(10.4, 3.5) - 2 = 1.5$

$S_{R0,Hi,1124} = \max(10.4, 3.5) + 2 = 12.4$

$S_{err,R1,1124} = 13.68 - 6.9 = 6.77$

$S_{viol,1,1124} = +1, since \;\; 6.77 > 12.4 - 6.9$

For the entire cycle $S_{viol,1,\%} = 164 / 15\,826 = 1.04\ \%$

application of VDA 305/EKB 3008 with numerical examples for brake output data

Table 16
List of column identifiers, column headings, and applicable units for each parameter or measurand for each repeat – Rows in *grey* indicate the measurands used for the statistical assessments for standard deviations

Measurand	Identifier	Heading	Units	Description
M_1	–	Sect #	–	Trip # (1 to 10)
M_2	–	Stop #	–	Nominal event per WLTP (1 to 303)
M_3	–	Stop Stop	–	Internal dyno stop counter
M_4	–	Stop Time	sec	Duration of the brake event
M_5	–	Time of stop	hh:mm:ss am/pm	Clock time at the start of the brake event
M_6	–	Date of stop	mm:dd:yyyy	Calendar date
M_7	BrkSpd_SP	Brk Spd Setpoint	km/h	Target braking speed per WLTP
M_8	BrkSpd	Brk Spd	km/h	Braking speed (measured)
M_9	RelSpd_SP	Rel Spd Setpoint	km/h	Target release speed per WLTP
M_{10}	RelSpd	Rel Spd	km/h	Release speed (measured)
M_{11}	Dcl_SP	Decel Setpoint	m/s²	Target total deceleration rate per WLTP
M_{12}	Dcl	Decel avg–dist	m/s²	Average–by–distance deceleration
M_{13}	Tavg	Torque avg–dist	N·m	Average–by–distance braking torque
M_{14}	Pavg	pressure avg–dist	kPa	Average–by–distance brake pressure
M_{15}	Muavg	mu avg–dist	μ	Average–by–distance coefficient of friction (COF)
M_{16}	E_IRT	Initial Rotor	°C	Rotor temperature at braking speed with embedded TC
M_{17}	E_FRT	Final Rotor	°C	Rotor temperature at release speed with embedded TC
M_{18}	E_MRT	Max Rotor	°C	Maximum rotor temperature with embedded TC
M_{19}	R_IRT	Initial Rotor	°C	Rotor temperature at braking speed with rubbing TC
M_{20}	R_FRT	Final Rotor	°C	Rotor temperature at release speed with rubbing TC
M_{21}	R_MRT	Max Rotor	°C	Maximum rotor temperature with rubbing TC
M_{22}	OP_IRT	Initial Out pad	°C	Outer pad temperature at braking speed
M_{23}	OP_FRT	Final Out pad	°C	Outer pad temperature at release speed
M_{24}	OP_MRT	Max Out pad	°C	Maximum outer pad temperature
M_{25}	IP_IRT	Initial In pad	°C	Inner pad temperature at braking speed
M_{26}	IP_FRT	Final In pad	°C	Inner pad temperature at release speed
M_{27}	IP_MRT	Max In pad	°C	Maximum inner pad temperature
M_{28}	CASpd	ClSpdA	km/h	Average–by–time cooling airspeed
M_{29}	CATemp	Air Temp	°C	Average–by–time cooling air temperature
M_{30}	CArh	Humidity	%	Average–by–time cooling air relative humidity

Table 22
Example of the combination of test results for braking speed on the first six braking events on Trip #2 for Lab 1 and 2, both tests, and six repeats on each – Per paragraph 10.1.7. and Table 19

Trip	Trip event	Cycle event	Lab 1 / km/h											
			T1						T2					
			R1	R2	R3	R4	R5	R6	R1	R2	R3	R4	R5	R6
2	1	30	14.01	14.01	14.01	13.89	14.01	14.01	14.01	14.01	14.01	14.01	14.01	14.01
2	2	31	34.44	34.32	34.44	34.44	34.44	34.32	34.44	34.44	34.44	34.32	34.32	34.44
2	3	32	33.13	33.13	33.13	33.13	33.13	33.13	33.25	33.13	33.25	33.13	33.13	33.25
2	4	33	25.77	25.77	25.89	25.77	25.89	25.77	25.89	25.77	25.89	25.89	25.89	25.77
2	5	34	38.83	38.83	38.83	38.83	38.83	38.83	38.83	38.83	38.83	38.83	38.83	38.95
2	6	35	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.69	48.80
2	7	36	42.63	42.63	42.63	42.63	42.63	42.63	42.75	42.63	42.63	42.63	42.75	42.63
2	8	37	30.52	30.52	30.52	30.52	30.64	30.52	30.64	30.64	30.64	30.64	30.64	30.64
2	9	38	40.26	40.26	40.26	40.14	40.26	40.26	40.26	40.26	40.26	40.26	40.14	40.26
2	10	39	30.04	29.92	29.92	29.92	30.04	29.92	30.04	29.92	30.04	29.92	30.04	30.04
2	11	40	24.70	24.70	24.70	24.70	24.70	24.70	24.70	24.70	24.82	24.70	24.70	24.82
2	12	41	42.15	42.27	42.15	42.15	42.15	42.27	42.15	42.15	42.15	42.15	42.15	42.15
2	13	42	22.21	22.21	22.21	22.21	22.21	22.21	22.21	22.32	22.32	22.21	22.21	22.21
2	14	43	32.66	32.54	32.66	32.54	32.54	32.66	32.66	32.66	32.66	32.66	32.66	32.66
2	15	44	34.91	34.91	35.03	35.03	34.91	34.91	35.03	34.91	34.91	34.91	34.91	35.03
2	16	45	76.35	76.24	76.24	76.24	76.24	76.35	76.24	76.24	76.24	76.35	76.24	76.35
2	17	46	22.92	22.92	22.92	22.92	22.92	22.92	23.04	22.92	23.04	22.92	22.92	22.92
2	18	47	41.80	41.80	41.80	41.80	41.80	41.80	41.92	41.80	41.68	41.80	41.80	41.80
2	19	48	48.09	48.09	48.09	48.09	48.09	48.09	47.97	48.09	48.09	48.09	48.09	48.09
2	20	49	35.51	35.39	35.51	35.51	35.39	35.51	35.51	35.39	35.51	35.51	35.51	35.39

combination of tabular computations with step-by-step calculations per ISO 5725 math

Table 24 - Calculation of the sum of squares for laboratories' COF for Level 1

Including laboratory effects, degrees of freedom, and factors

Laboratory i	(Laboratory) cell average y_i	Number of test results n_{ij}	(Number of test results)² n_{ij}^2	Laboratory effect B_{ij}	(Laboratory effect)² B_{ij}^2	Factor K_{ij}
1	0.360	12	144	−0.014	0.000 20	72
2	0.240	1	1	−0.135	0.018 12	1
3	0.370	12	144	−0.004	0.000 02	72
4	0.456	12	144	0.082	0.006 78	72
5	0.358	7	49	−0.016	0.000 27	37
6	0.284	6	36	−0.090	0.008 12	36
7	0.342	5	25	−0.032	0.001 02	25
8	0.405	6	36	0.031	0.000 93	36

Applying [Eq.47] then gives:
Number of tests results for labs 5, 6, 7 $n_{51} = 1 + 6 = 7;\ n_{61} = 6 + 0 = 6;\ n_{71} = 5 + 0 = 5$

Applying [Eq.40] then gives:
Laboratory effect for lab 1 $B_{11} = 0.360 - 0.374 = -0.014$

Applying [Eq.48] then gives:
Factor K_{ij} for labs 5, 6, 7 $K_{51} = 1^2 + 6^2 = 37;\ K_{61} = 6^2 + 0 = 36;\ K_{71} = 5^2 + 0 = 25$

Applying [Eq.49] then gives:
Factor K_j $K_1 = 144 + 1 + 144 + 144 + 49 + 36 + 25 + 36 = 579$

Applying [Eq.50] then gives:
Factor K'_j $K'_1 = 72 + 1 + 72 + 72 + 37 + 36 + 25 + 36 = 351$

Applying [Eq.51] then gives:
Factor K''_j $K''_1 = 72/12 + 1/1 + \cdots + 25/5 + 36/6 = 41.3$

Applying [Eq.46] then gives:
Degrees of freedom for laboratories $v_{Lj} = 8 - 1 = 7$

Applying [Eq.43] then gives:
Sum of squares for laboratories $SS_{L1} = 12 \times 0.000\,20 + 1 \times 0.018\,12 + \cdots + 5 \times 0.001\,02 + 6 \times 0.000\,93 = 0.163\,3$

14.2.5 Applying [Eq.52] to [Eq.55] in [clause 5.9.k] then gives:

$s_{rj}^2 = SS_{rj}/v_{rj}$

$s_{r1}^2 = 0.250\,12/49 = 0.005\,105\ \mu^2$

so

$s_{r1} = 0.071\,4\ \mu$

and

$s_{Hj}^2 = \left[SS_{Hj} - v_{Hj} \times s_{rj}^2\right]/\left(n_j - K_j''\right)$

$s_{H1}^2 = [0.064\,39 - 4 \times 0.005\,105]/(61 - 41.3) = 0.002\,23\ \mu^2$

so

$s_{H1} = 0.047\,2\ \mu$

and

$s_{Lj}^2 = \left[SS_{Lj} - \left(K_j'' - K_j'/n_j\right) \times s_{Hj}^2 - v_{Lj} \times s_{rj}^2\right]/\left(n_j - K_j/n_j\right)$

$s_{L1}^2 = [0.163\,327 - (41.3 - 351/61) \times 0.002\,23 - 7 \times 0.005\,105]/(61 - 579/61) = 0.000\,938\mu^2$

so

$s_{L1} = 0.030\,6\ \mu$

and

$s_{R1} = \sqrt[2]{0.071\,4^2 + 0.030\,6^2}$

$s_{R1} = 0.077\,7\ \mu$

14.2.6 Applying the repeatability and reproducibility limits established in clause 4.1.4 from ISO 5725-6:1994, when comparing two single test results, the critical differences are, respectively, for level 1 (event 1):

— Critical difference for repeatability, $r = 2.8 \times s_r = 2.8 \times 0.071\,4 = 0.2\ \mu$

— Critical difference for reproducibility, $R = 2.8 \times s_R = 2.8 \times 0.077\,7 = 0.22\ \mu$

use of the ISO 5725 robust algorithms (*A* & *S*) to avoid bias and reduce sensitivity to extreme values

Figure 31 – (Example) of histograms for all COF (all labs, two tests with six repeats each)
Each histogram represents each repeat with 40 bins and without any data transformation

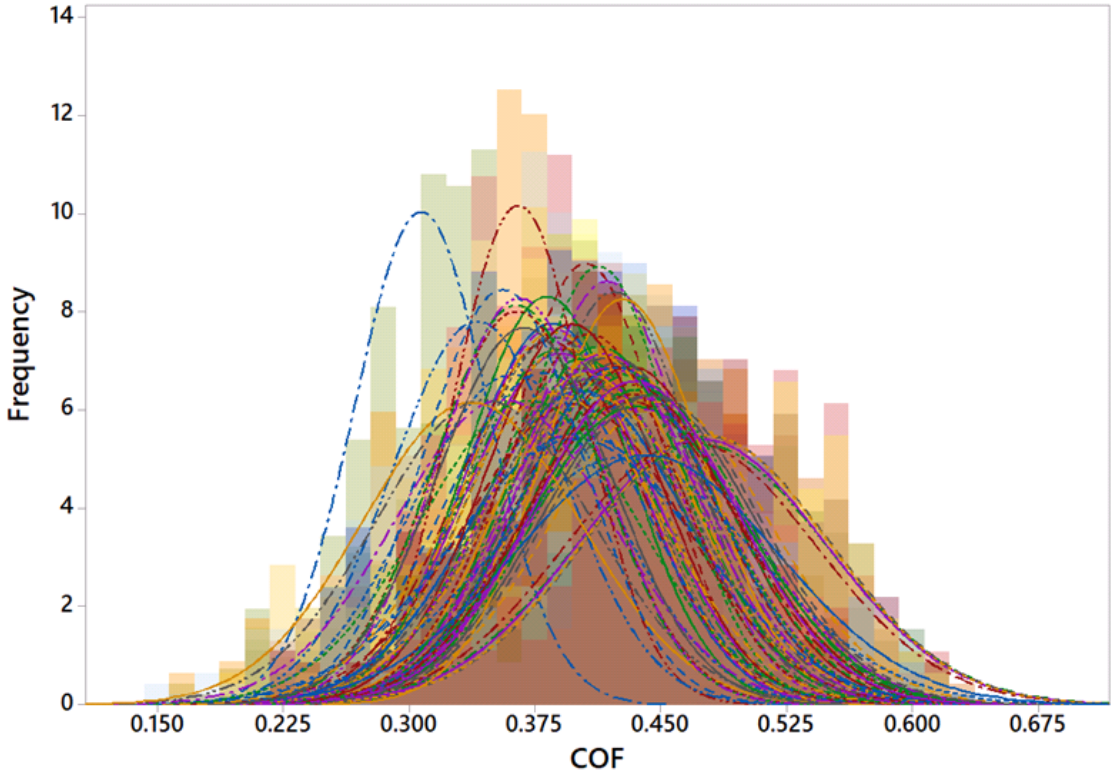
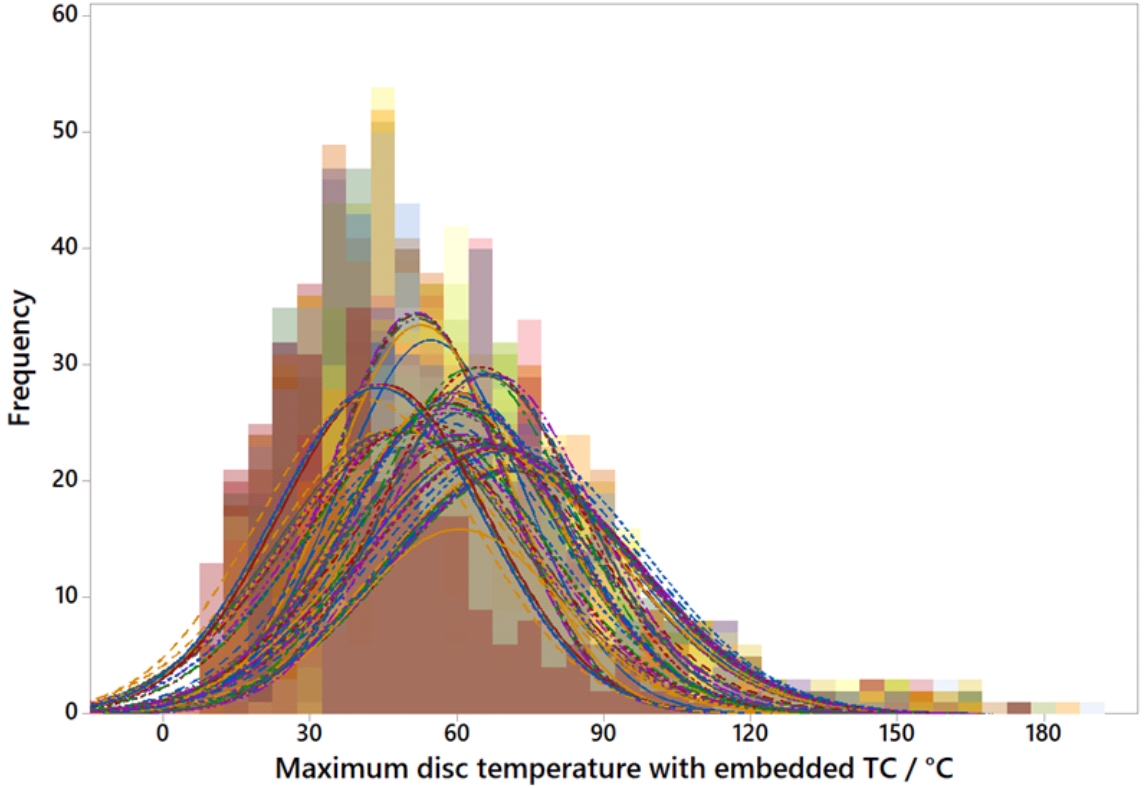


Figure 32 – (Example) of histograms for all maximum disc temperatures with embedded thermocouple
Each histogram represents each repeat with 40 bins and without any data transformation



tabular summaries of all standard deviations for 11 metrics on each trip

Table 32
Summary standard deviations for main measurands as a per cent of the average – Including metrics for standard deviations for repeatability s^*_{rj}, sample effect s^*_{Hj}, laboratory effect s^*_{Lj}, and reproducibility s^*_{Rj}. The statistics indicate values for all levels combined (303 brake events), for the 50th and the 95th percentiles, and each trip. The values are expressed as a per cent of the general average for all events, 50th percentile, and 95th percentile values. Also, the table provides the values as per cent of the general average for each trip. All values reflect the results after applying robust algorithms

Measurand	Metric	Mean	Percentiles		Trip									
					1	2	3	4	5	6	7	8	9	10
		Number of levels (brake events)												
		303	50th	95th	29	42	28	18	49	2	6	8	7	114
		Standard deviation / % of the mean for the applicable range of data												
Braking speed / km/h	s^*_{rj}	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.2	0.1
	s^*_{Hj}	0.0	0.1	0.1	0.1	0.0	0.0	-	0.0	-	0.0	0.0	0.1	0.0
	s^*_{Lj}	4.2	4.4	2.3	5.4	4.2	3.8	3.1	3.6	11.0	3.3	3.2	7.8	4.6
	s^*_{Rj}	0.4	0.4	0.3	0.5	0.4	0.3	0.3	0.3	1.7	0.3	0.3	0.9	0.5
Average–by–distance deceleration / m/s²	s^*_{rj}	0.3	0.3	0.3	0.4	0.3	0.3	0.2	0.3	0.4	0.2	0.3	0.3	0.2
	s^*_{Hj}	0.2	0.2	0.3	0.1	0.1	0.2	0.1	0.1	1.6	0.1	0.1	0.3	0.2
	s^*_{Lj}	17.6	16.1	16.9	19.4	18.1	17.4	16.8	17.0	14.9	18.0	16.7	17.7	17.1
	s^*_{Rj}	8.4	8.1	7.7	8.0	8.6	9.6	6.9	8.2	8.1	11.6	6.4	9.0	8.3
Average–by–distance torque / N·m	s^*_{rj}	0.3	0.2	0.3	0.4	0.3	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2
	s^*_{Hj}	0.1	0.1	0.2	0.1	0.0	0.1	0.0	0.1	0.3	0.0	0.1	0.2	0.1
	s^*_{Lj}	6.7	5.7	7.1	6.6	6.5	7.5	6.2	7.0	10.4	5.6	6.1	5.9	6.7
	s^*_{Rj}	3.8	3.4	4.2	3.0	3.3	4.0	4.5	3.7	7.9	4.9	4.4	3.5	3.9
Average–by–distance pressure / kPa	s^*_{rj}	5.9	2.5	8.2	15.6	5.7	4.0	2.6	2.4	2.8	2.2	2.5	2.5	1.9
	s^*_{Hj}	1.9	2.3	2.1	-	1.1	2.3	1.7	2.4	1.8	1.7	1.7	0.9	2.2
	s^*_{Lj}	9.2	8.4	8.7	9.8	10.1	9.5	9.2	9.4	11.0	8.7	9.1	7.7	8.4
	s^*_{Rj}	10.9	9.6	10.9	18.6	10.8	10.3	10.0	9.3	11.5	9.8	9.5	8.6	8.9
Average–by–distance COF / μ	s^*_{rj}	5.1	2.6	10.3	12.8	6.3	4.3	2.6	3.0	3.1	2.3	2.6	2.4	2.2
	s^*_{Hj}	2.5	2.2	4.5	0.8	2.2	2.8	3.0	3.0	1.9	1.6	2.1	1.6	2.5
	s^*_{Lj}	8.2	7.0	10.7	10.1	8.9	8.2	7.1	6.8	9.0	5.9	6.8	7.6	8.2
	s^*_{Rj}	9.8	8.3	13.8	17.0	11.1	9.7	7.0	7.4	10.8	6.6	6.4	8.8	8.5
Maximum temperature with embedded TC / °C	s^*_{rj}	1.8	1.6	1.7	2.7	2.2	1.9	1.7	1.6	2.1	1.3	1.6	1.5	1.4
	s^*_{Hj}	2.9	2.8	2.7	3.5	2.5	3.7	2.7	3.2	4.0	3.4	3.2	4.1	2.4
	s^*_{Lj}	15.8	16.2	11.9	14.4	15.7	16.5	13.2	15.9	29.3	13.6	13.8	25.0	16.1
	s^*_{Rj}	16.5	17.2	12.6	15.0	16.2	16.8	14.1	17.2	22.2	13.1	15.0	22.1	16.8
Maximum temperature with rubbing TC / °C	s^*_{rj}	2.2	2.0	2.2	3.4	2.4	2.2	2.1	2.0	2.1	1.8	1.6	1.6	1.9
	s^*_{Hj}	5.7	5.8	4.9	6.4	5.4	6.1	5.2	5.5	10.0	3.9	5.4	7.6	5.8
	s^*_{Lj}	18.6	19.0	15.6	24.6	17.8	19.1	14.7	17.9	25.8	18.1	16.3	25.4	18.4
	s^*_{Rj}	17.9	18.0	15.6	23.9	17.1	15.4	14.4	17.0	21.8	18.1	15.9	27.9	18.0
Cooling air temperature (controlled) / °C	s^*_{rj}	1.1	1.0	1.4	1.5	1.2	0.9	0.9	1.0	1.0	1.0	1.1	1.1	0.9
	s^*_{Hj}	0.6	0.7	1.1	-	0.4	0.5	0.4	0.6	0.9	0.6	0.1	0.7	0.7
	s^*_{Lj}	1.5	1.2	2.6	3.2	1.0	1.0	1.2	1.2	-	1.5	1.5	1.1	1.2
	s^*_{Rj}	1.6	1.4	2.4	2.5	1.4	1.3	1.6	1.6	1.0	1.5	1.8	1.5	1.5
Cooling air temperature (all) / °C	s^*_{rj}	1.4	1.1	2.0	2.7	1.2	1.0	1.0	1.2	1.1	1.2	1.2	1.3	1.1
	s^*_{Hj}	1.2	1.3	2.0	0.4	1.1	1.1	0.9	1.2	1.9	1.4	0.5	1.4	1.4
	s^*_{Lj}	31.5	31.7	32.1	29.7	30.6	30.8	30.7	31.6	31.9	33.2	32.3	32.6	32.4
	s^*_{Rj}	4.2	3.1	8.7	9.2	2.8	2.7	3.3	3.3	1.3	4.1	3.9	3.5	3.4
Cooling air relative humidity (controlled) / %RH	s^*_{rj}	3.5	2.9	6.6	7.1	3.5	2.4	2.2	3.1	2.8	3.3	2.6	3.3	2.9
	s^*_{Hj}	0.1	0.6	1.9	-	-	-	-	-	-	0.2	-	-	0.2
	s^*_{Lj}	1.1	1.0	2.8	2.5	1.2	0.7	0.6	0.8	1.8	0.5	0.6	0.7	0.9
	s^*_{Rj}	3.7	3.0	7.4	7.7	3.8	2.5	2.3	3.2	3.5	3.4	2.6	3.4	3.0
Cooling air relative humidity (all) / %RH	s^*_{rj}	4.1	3.5	7.1	7.3	4.1	3.3	3.2	3.7	2.8	4.0	3.5	4.1	3.3
	s^*_{Hj}	0.2	0.9	2.1	-	-	-	-	-	-	-	-	-	0.3
	s^*_{Lj}	8.7	8.8	9.9	7.0	7.4	7.6	8.1	9.2	9.4	10.0	9.7	10.0	9.3
	s^*_{Rj}	5.2	4.3	9.4	9.8	5.3	4.1	4.1	4.6	4.4	5.2	4.3	5.0	4.3

Table 32 - **Summary standard deviations for main measurands as a per cent of the average** – Including metrics for standard deviations for repeatability s^*_{rj}, sample effect s^*_{Hj}, laboratory effect s^*_{Lj}, and reproducibility s^*_{Rj}. The statistics indicate values for all levels combined (303 brake events), for the 50th and the 95th percentiles, and each trip. The values are expressed as a per cent of the general average for all events, 50th percentile, and 95th percentile values. Also, the table provides the values as per cent of the general average for each trip. All values reflect the results after applying robust algorithms

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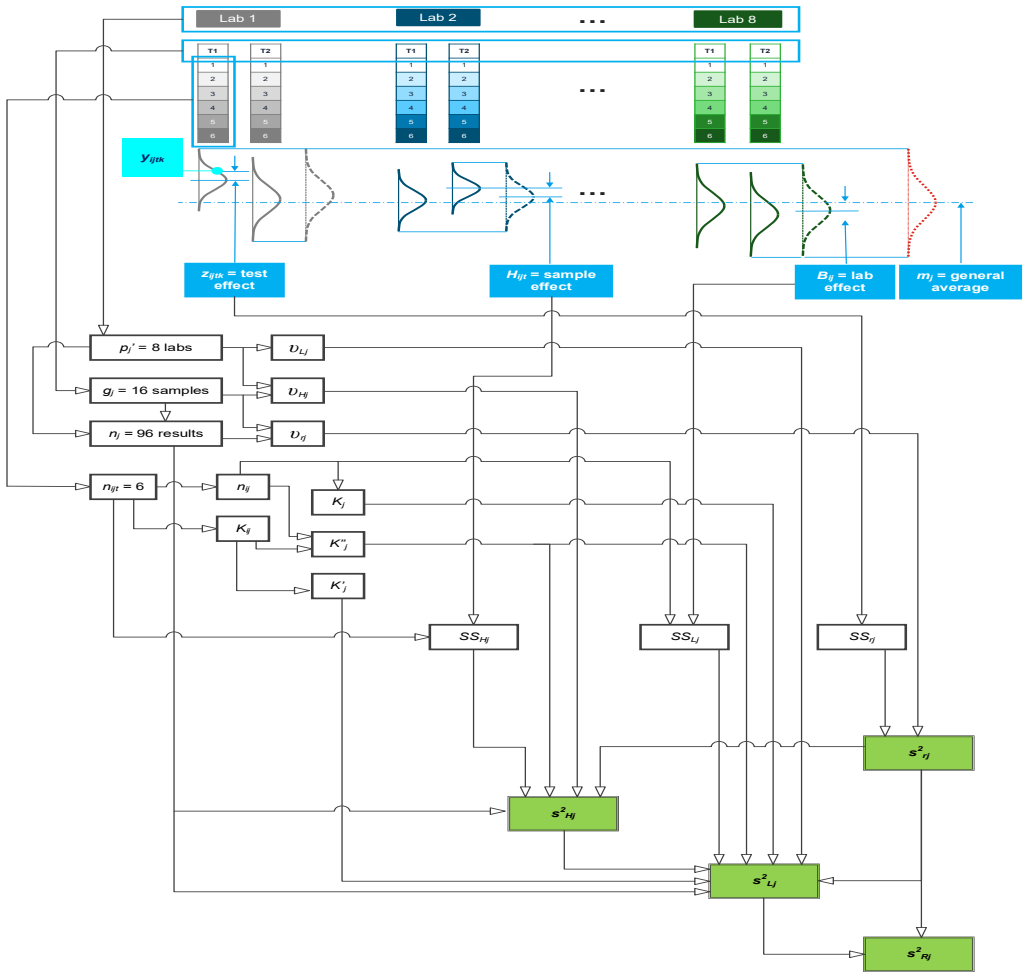
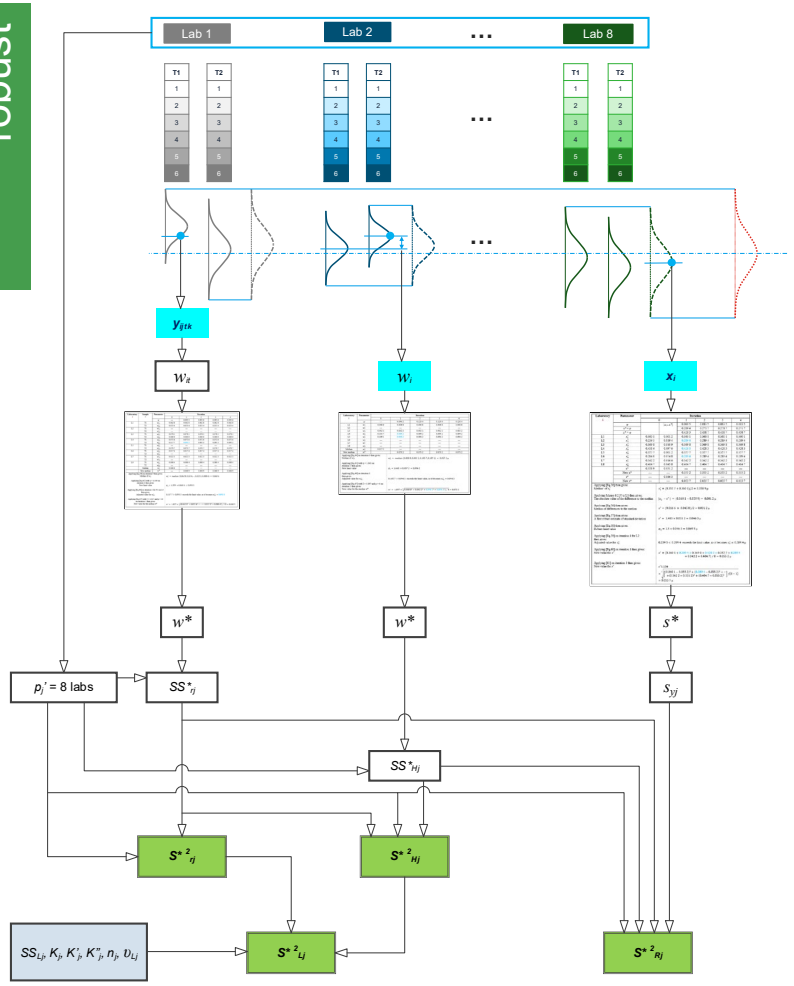
		Standard deviation / % of the mean for the applicable range of data												
Braking speed / km/h	s^*_{rj}	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.3	0.1	0.1	0.2	0.1
	s^*_{Hj}	0.0	0.1	0.1	0.1	0.0	0.0	-	0.0	-	0.0	0.0	0.1	0.0
	s^*_{Lj}	4.2	4.4	2.3	5.4	4.2	3.8	3.1	3.6	11.0	3.3	3.2	7.8	4.6
	s^*_{Rj}	0.4	0.4	0.3	0.5	0.4	0.3	0.3	0.3	1.7	0.3	0.3	0.9	0.5
Average–by–distance deceleration / m/s²	s^*_{rj}	0.3	0.3	0.3	0.4	0.3	0.3	0.2	0.3	0.4	0.2	0.3	0.3	0.2
	s^*_{Hj}	0.2	0.2	0.3	0.1	0.1	0.2	0.1	0.1	1.6	0.1	0.1	0.3	0.2
	s^*_{Lj}	17.6	16.1	16.9	19.4	18.1	17.4	16.8	17.0	14.9	18.0	16.7	17.7	17.1
	s^*_{Rj}	8.4	8.1	7.7	8.0	8.6	9.6	6.9	8.2	8.1	11.6	6.4	9.0	8.3

flowcharts for all mathematical relationships: input data → four components of test variability

non-robust

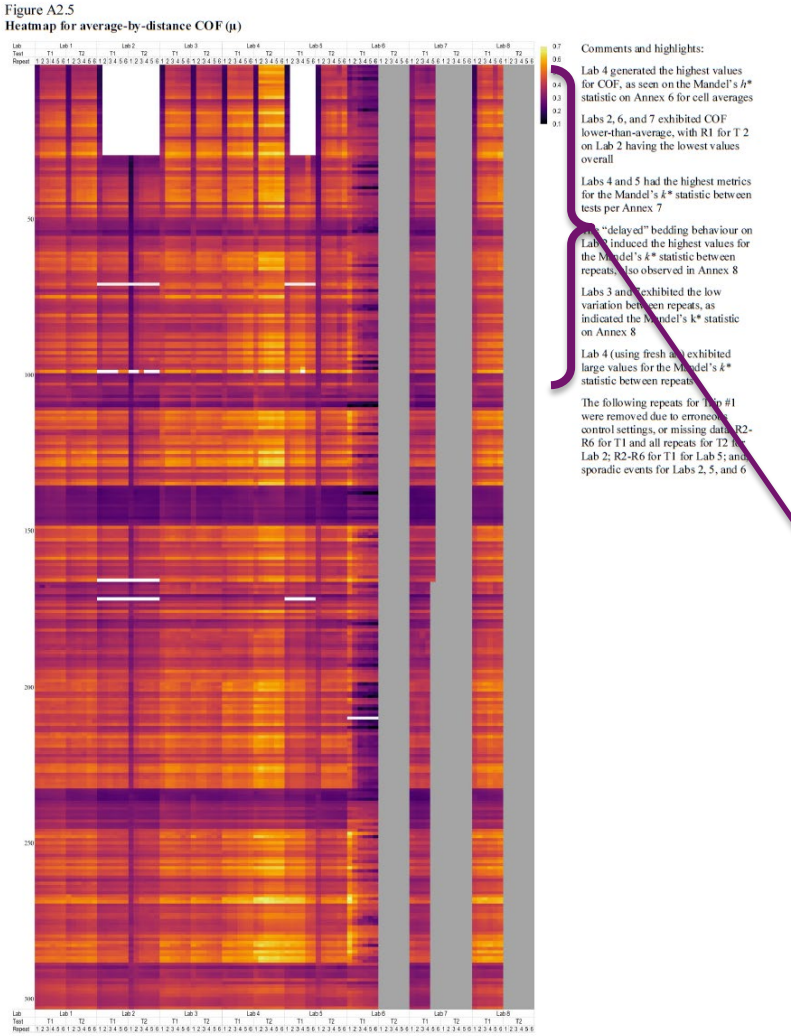


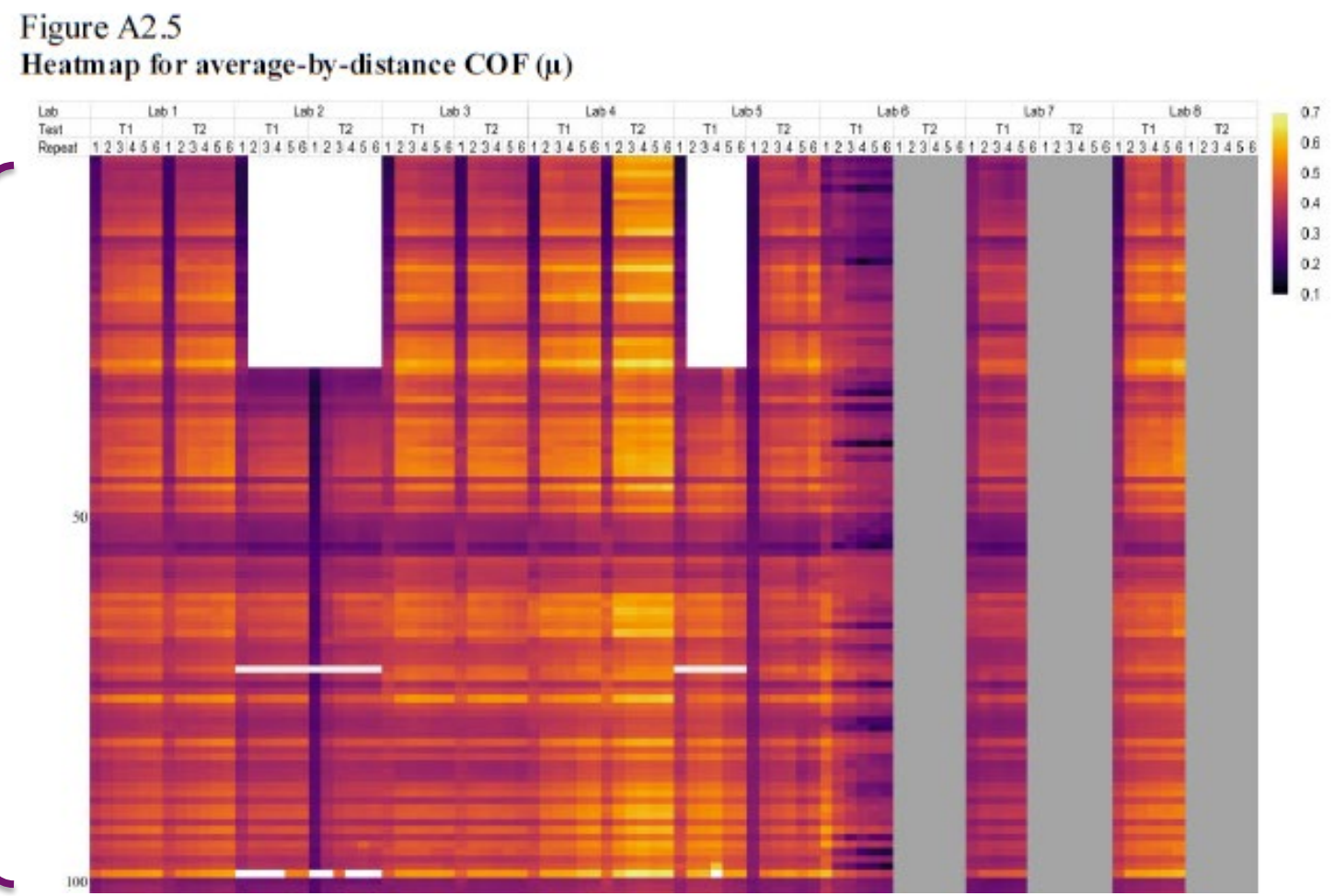
robust



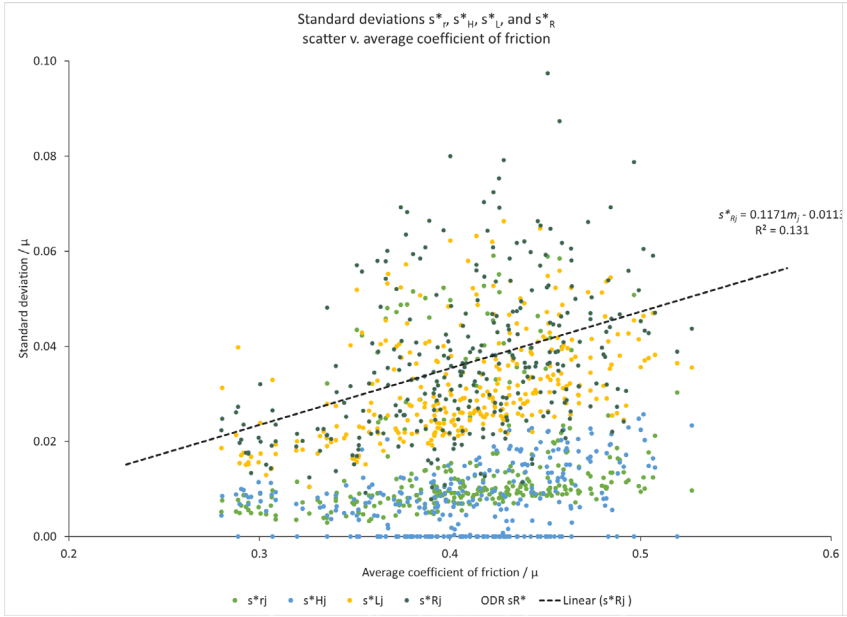
heatmaps (using inferno colormaps) with comments for all 11 metrics

a) perceptually uniform, b) colorblind-friendly, and c) non-biased conversion to grayscale

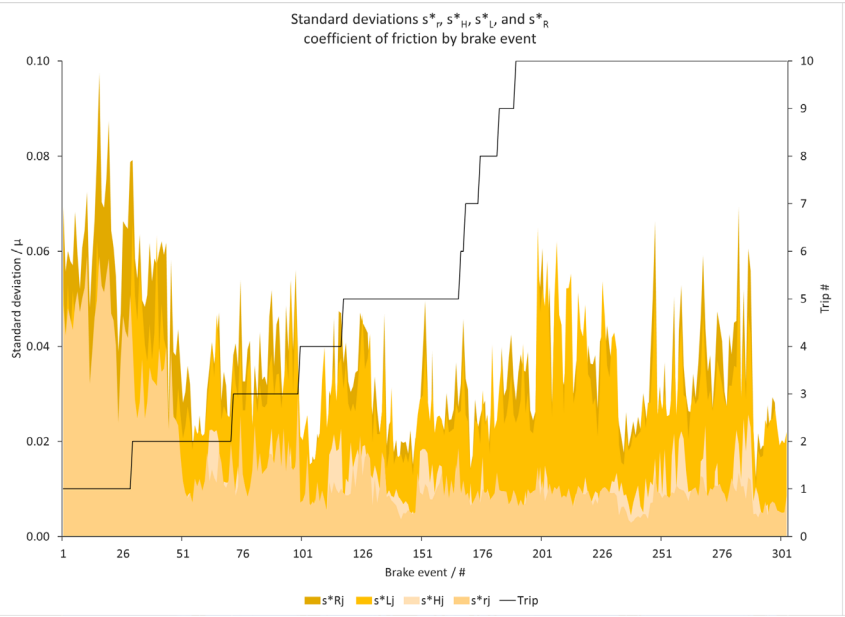




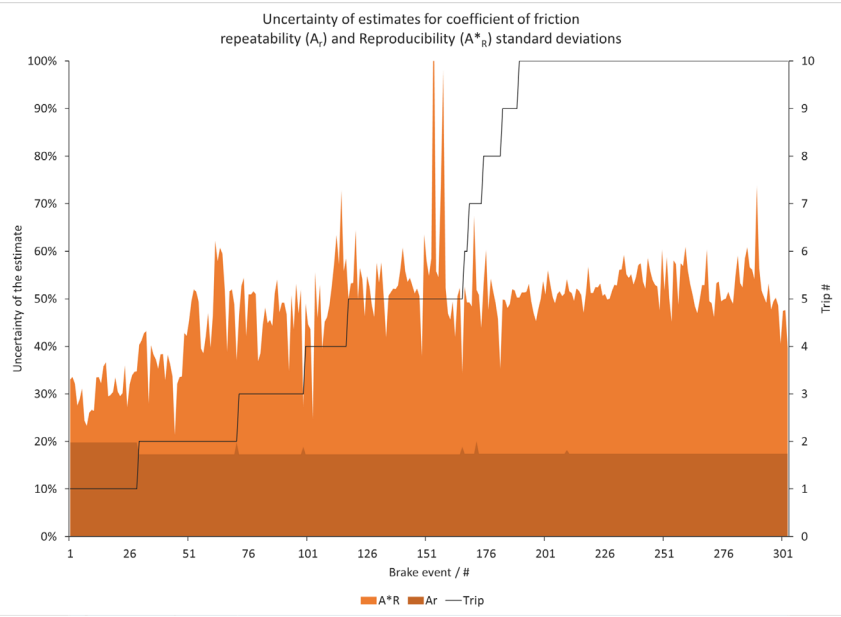
graphical representation of standard deviations and uncertainty for all 11 metrics



scatter of std. deviations
v. average for each event

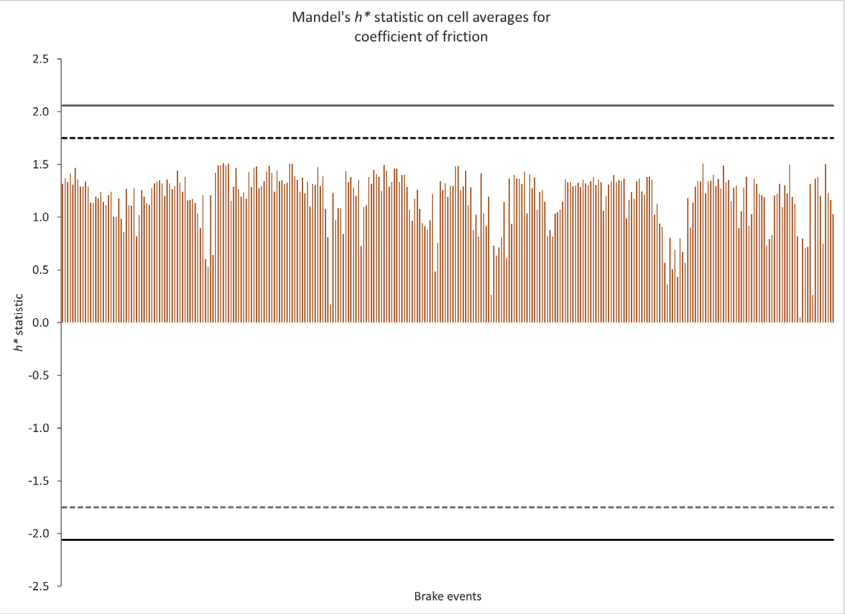


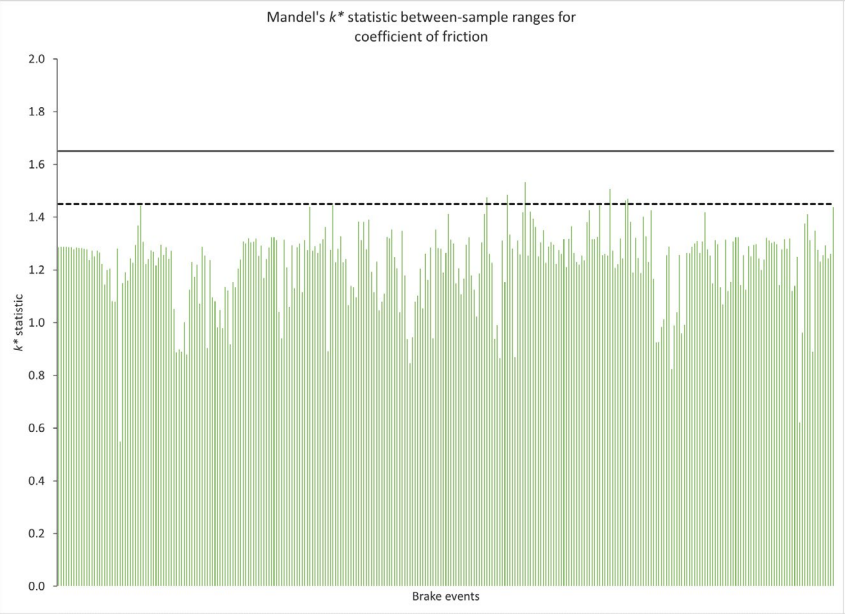
all std. deviations
v. event number

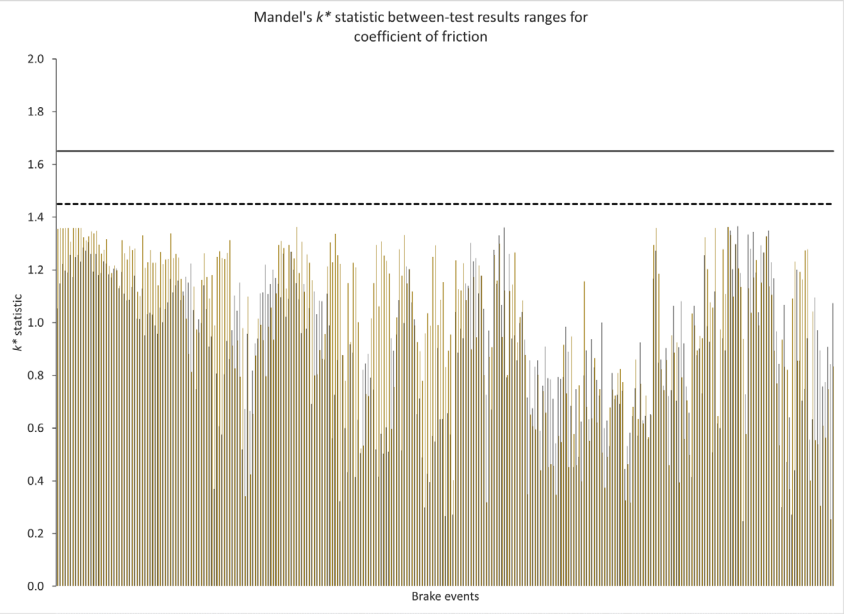


uncertainty for std. deviations
v. event number

graphical representation of stragglers (95 %) and outliers (99 %) per ISO 5725-2 for all 11 metrics







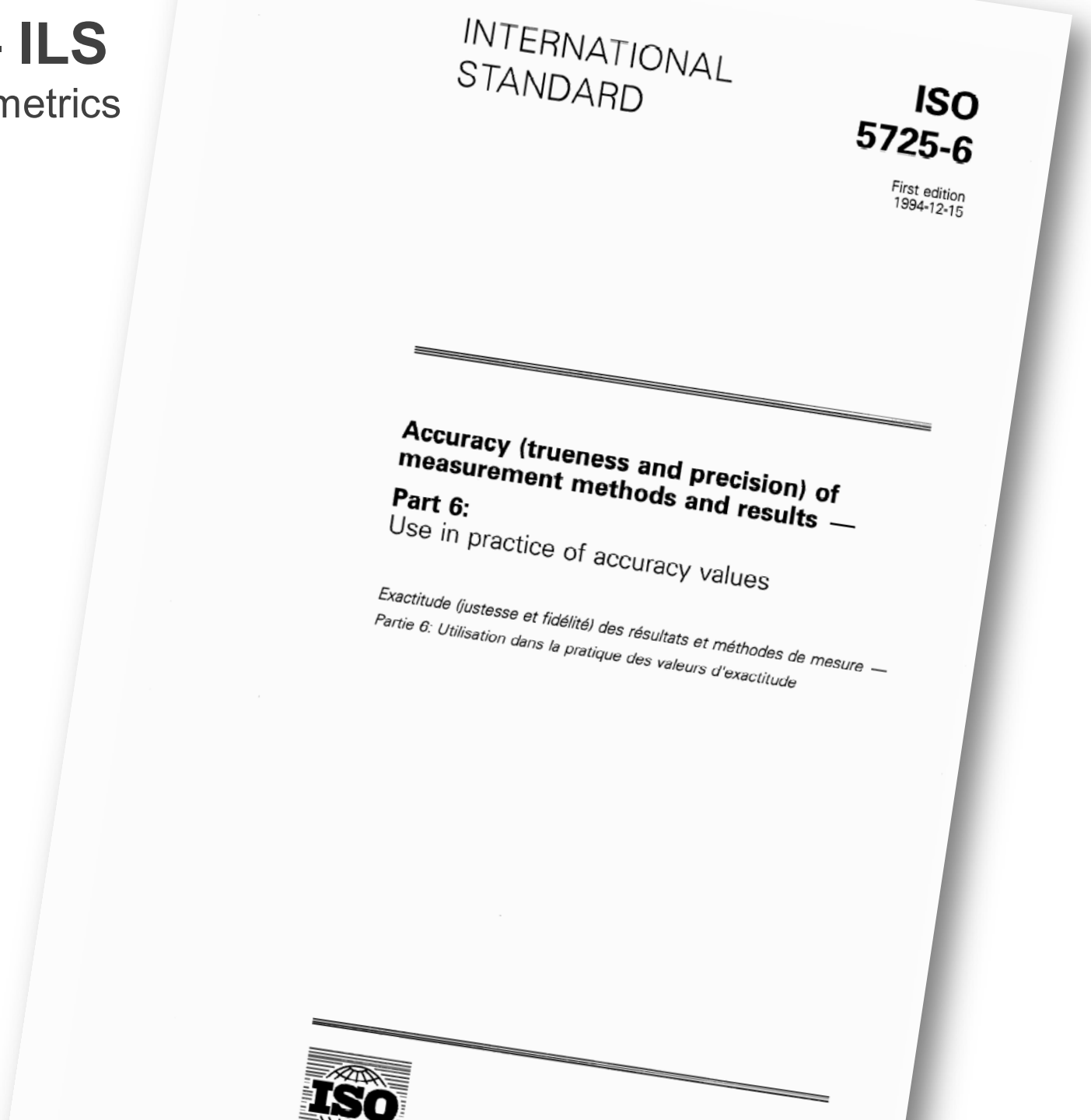
Mandel's *h** (between lab averages)

Mandel's *k** (between sample ranges)

Mandel's *k** (between test results)

…what is possible for TF3 – ILS

establish critical differences for key dyno metrics (speed, deceleration, cooling air)


INTERNATIONAL STANDARD

ISO 5725-6

First edition 1994-12-15

Accuracy (trueness and precision) of measurement methods and results —
Part 6:
Use in practice of accuracy values

Exactitude (justesse et fidélité) des résultats et méthodes de mesure —
Partie 6: Utilisation dans la pratique des valeurs d'exactitude

ISO

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RaviTeja **VEDULA** + Alejandro **HORTET**

"Statistical Assessment and Temperature Study from the Interlaboratory Application of the WLTP – Brake Cycle"

https://www.mdpi.com/2073-4433/11/12/1309

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