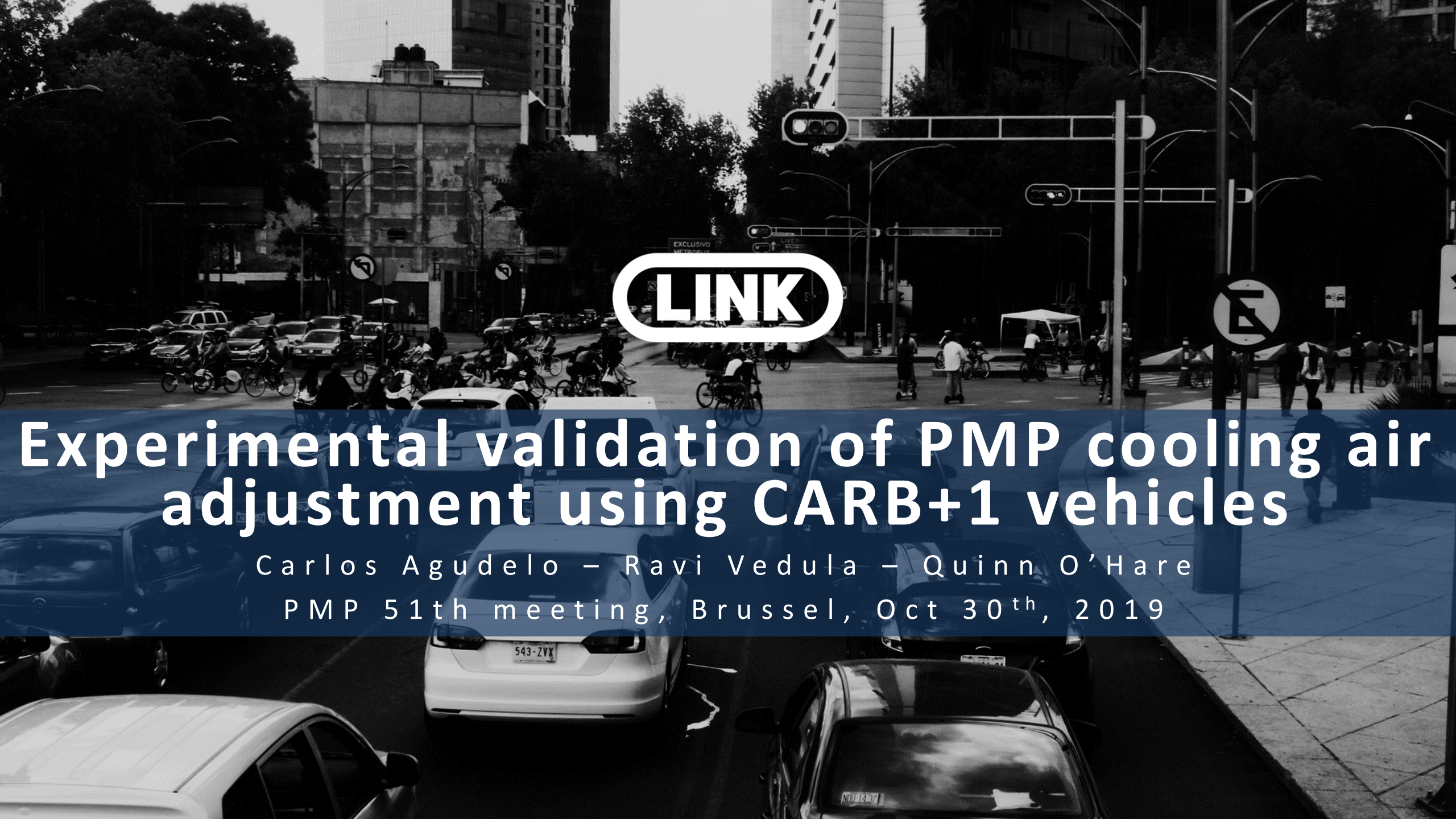


Experimental validation of PMP cooling air adjustment using CARB+1 vehicles

Carlos Agudelo – Ravi Vedula – Quinn O'Hare

PMP 51th meeting, Brussel, Oct 30th, 2019

Sonya Collier, Ph.D.
Contract 17RD016 – Project Leader
Climate Change Mitigation and Emissions Research

Seungju Yoon
Air Resources Supervisor
Climate Change and Emissions Mitigation Research Section

Alan Stanard
Staff Engineer
CARB Research Contract 17RD016

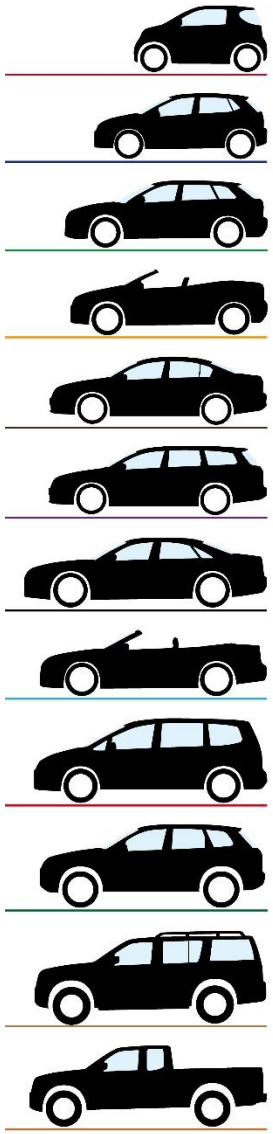
Jarek Grochowicz & Marcel Mathissen
WLTP-Brake novel cycle

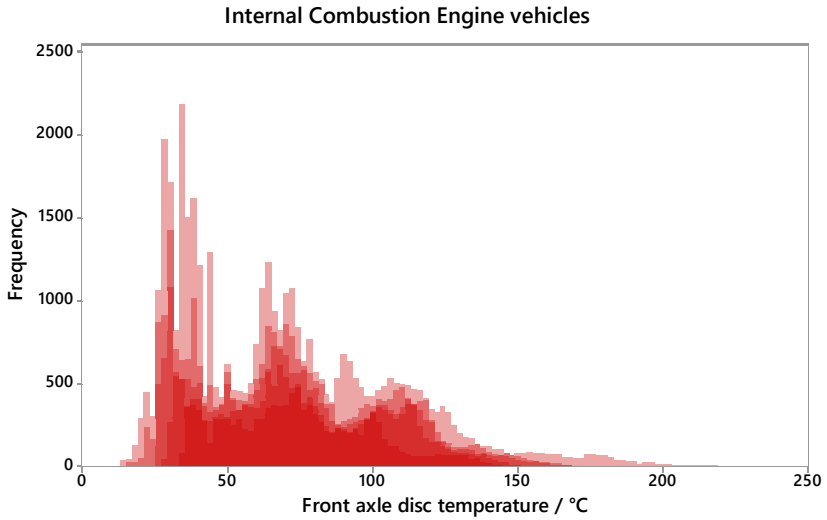
why cooling air?

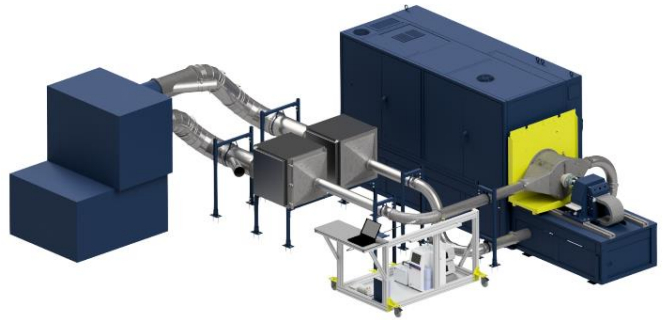
repeatability & Reproducibility

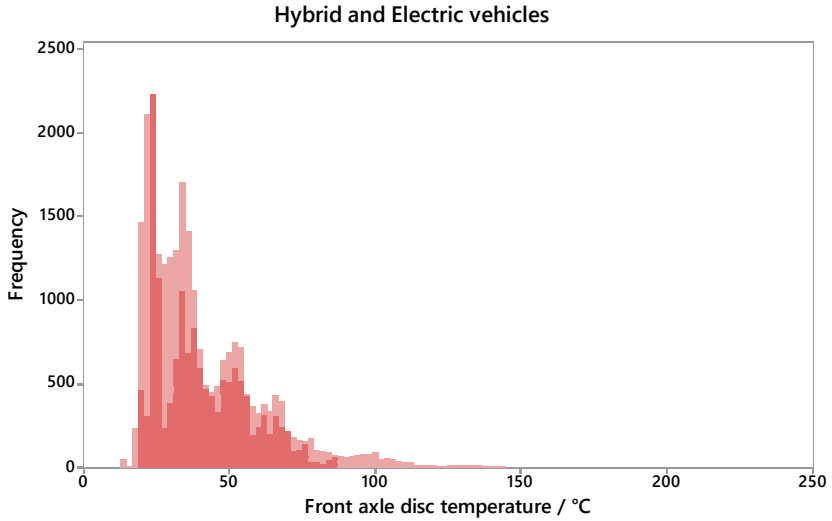
repeat & Reproduce

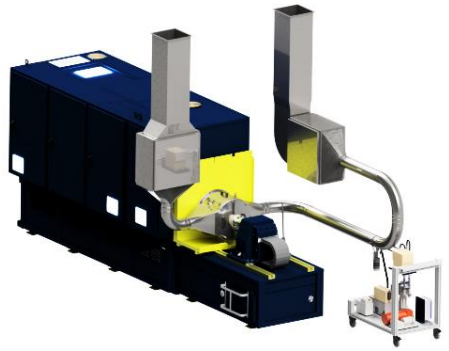
agnostic to the embodiment of the dynamometer and the detailed test setup











“If a test is not repeatable, it is only an anecdote”

Nature – International weekly journal of science

how did we use the metrics?

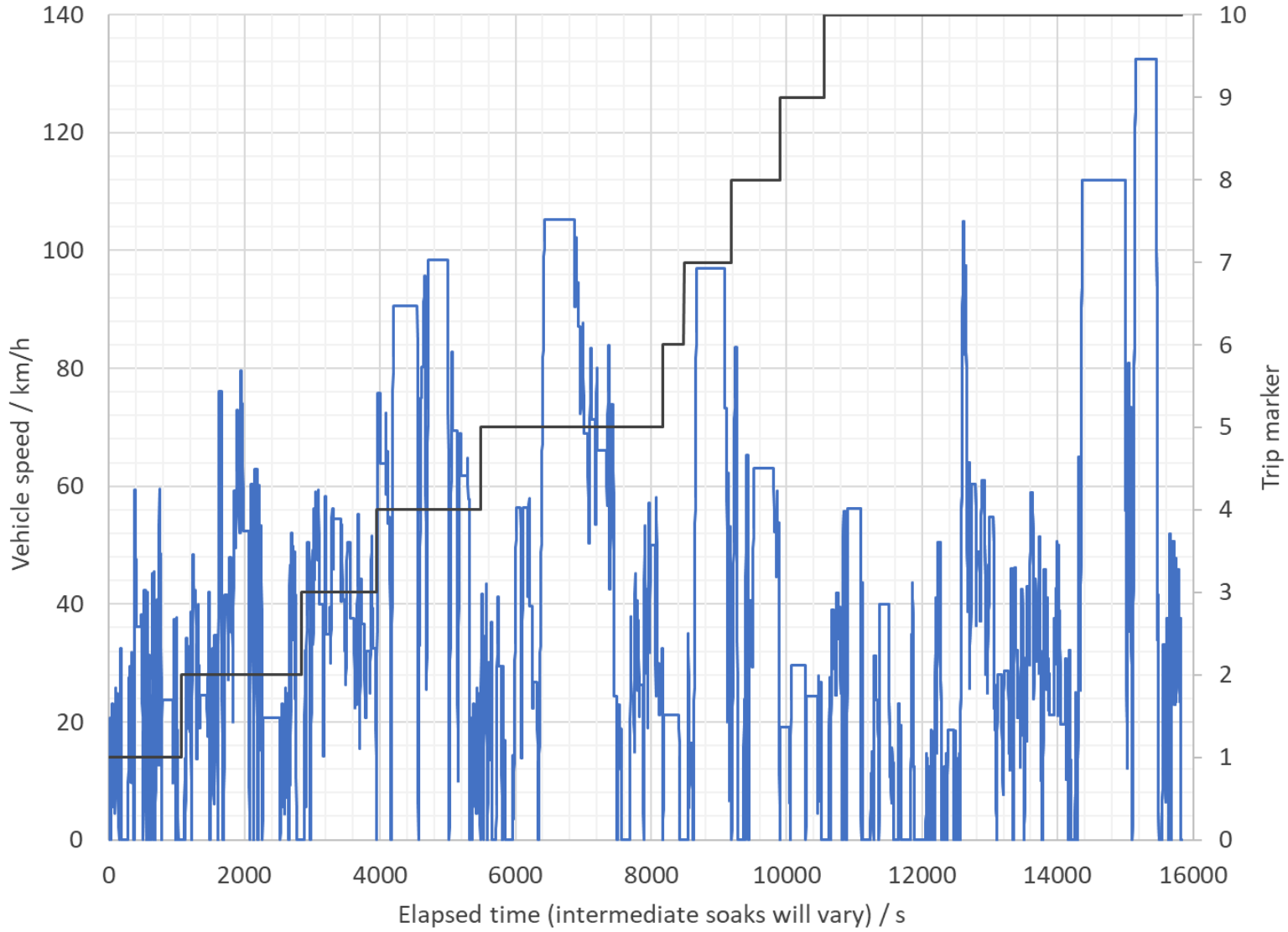
selecting a representative WLTP trip

using proving ground data as the benchmark

using and confirming PMP metrics

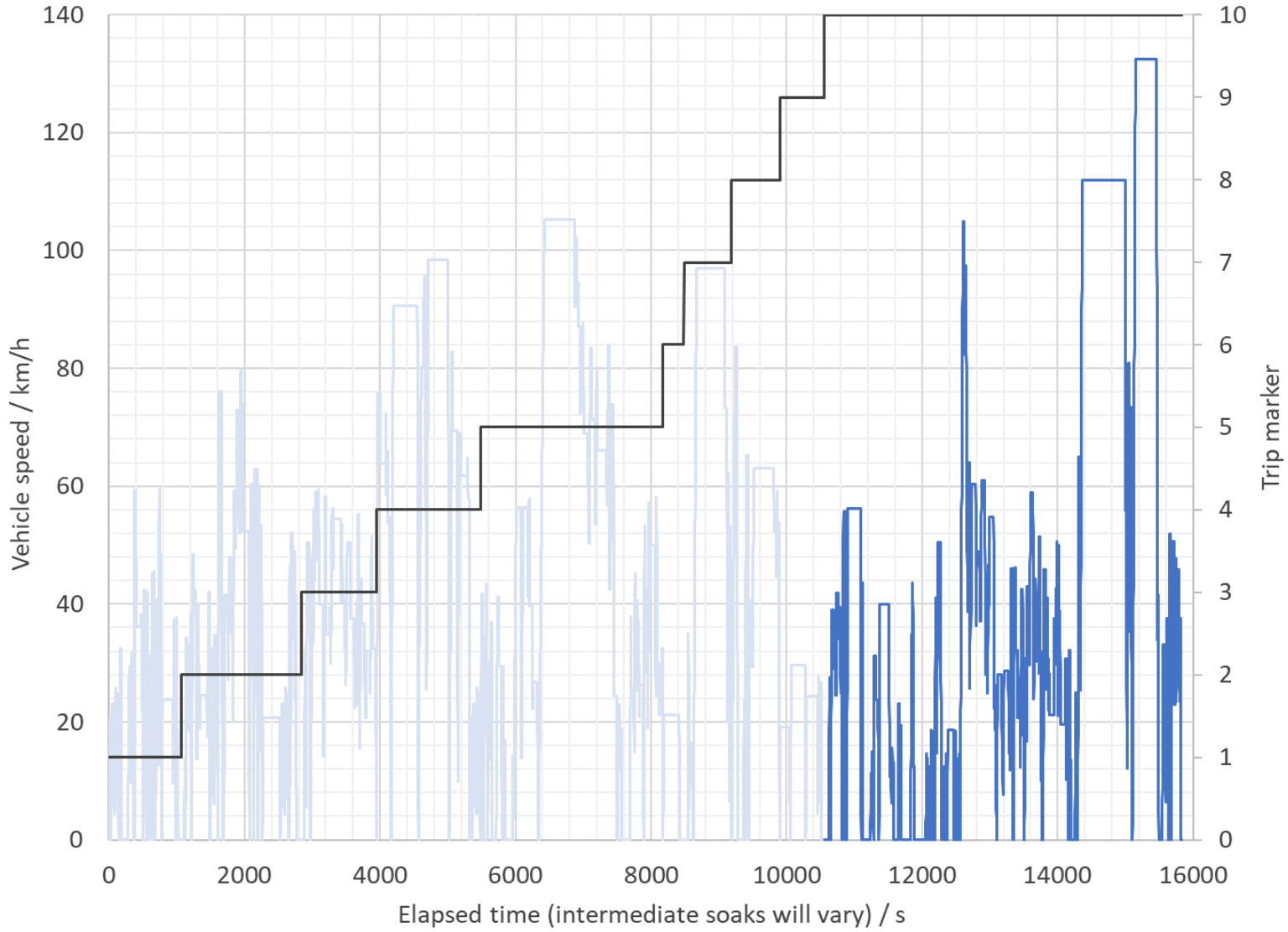
select a trip that can represent the WLTP-Brake cycle

the entire WLTP-Brake cycle takes 6.5-8 hour to run



Trip # 10 resembles the entire WLTP-Brake cycle

Most metrics for event mix, speed, and energy are within 20% of the entire cycle



Trip # 10 as a surrogate for entire WLTP-Brake

mix of events, speeds, braking frequency, and decelerations are comparable

Metric	units	All Trips	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Trip 9	Trip 10
type of event												
initial soak	%	1.5%	0.4%	2.5%	4.3%	0.1%	0.1%	0.6%	8.1%	0.3%	0.3%	1.4%
acceleration	%	15.8%	20.9%	20.1%	20.8%			3.9%	11.1%		6.9%	15.2%
cruise/steady drive	%	61.1%	43.6%	56.9%	63.7%		62.8%		71.6%	62.2%		55.9%
deeleration	%	10.8%			10.7%	9.0%	9.4%	2.9%	7.5%	8.3%	5.6%	11.9%
idling/standing still	%	9.3%		2.8%	0.4%	18%		0.0%	16%		0.9%	15.6%
final soak	%	1.4%	4.6%	3.9%	0.1%	0.3%	0.0%		0.1%	0.1%	6.1%	0.0%
speeds												
avg time-based	km/h	43.7	20.2	31.0	37.9		49.8	16.2		46.8	21.5	44.3
avg braking speed	km/h	41.6	32.4	42.5	45.3		48.4	15.3			22.2	37.2
95th percentile (1 Hz)	km/h	74.9	51.3	72.9		91.8	91.2	21.2	96.9	82.7	29.6	74.5
95th percentile braking speed	km/h	83.9	55.1	73.9		96.0	91.9	20.6	91.0	77.2	29.1	81.5
maximum	km/h	132.5		79.7		98.4	105.2	21.2	96.9	83.6	29.6	132.5
braking events												
total/km	#/km	1.58	4.83	2.76	2.39	0.61	1.32	1.44	0.45	0.86	1.79	1.76
Complete stops	%	30.4%		31.0%	7.1%	33.3%	20.4%		33.3%		42.9%	32.5%
Braking snubs	%	69.6%		69.0%	0.9	66.7%	79.6%		66.7%		57.1%	67.5%
deceleration only												
minimum	m/s²	0.49	0.58	0.64	0.63	0.64	0.63	0.65	0.82	0.70	0.58	0.49
50th percentile	m/s²	0.91	0.92	0.94	0.88	0.85	1.01	0.65		0.98	0.75	0.86
95th percentile	m/s²	1.35	1.50	1.67	1.27	1.70	1.34	0.66	1.66	1.54		1.44
maximum	m/s²	2.18	1.75	2.18	1.65	1.82	1.64	0.66	1.72	1.55		1.95

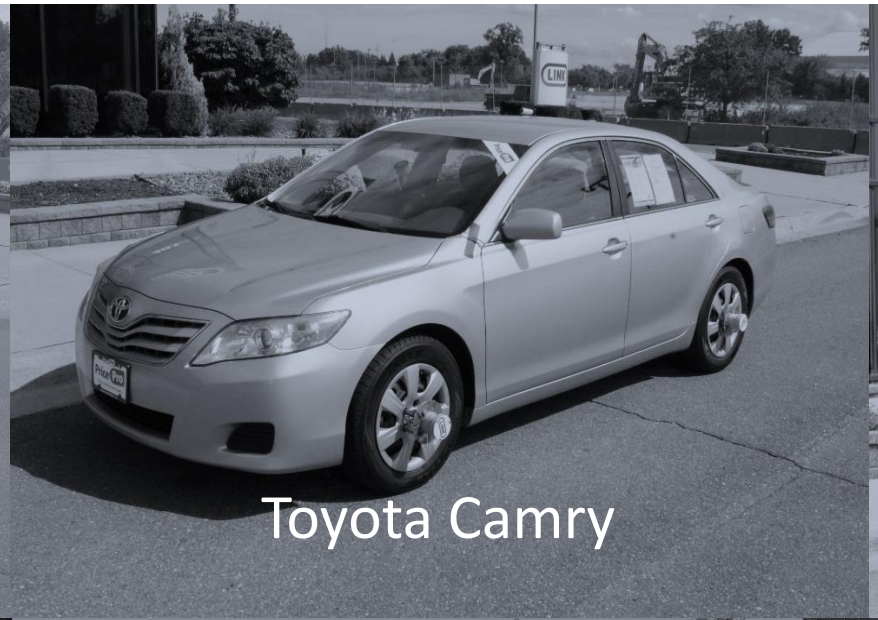
Trip # 10 as a surrogate for entire WLTP-Brake

metrics for braking events (duration, energy, and power) are comparable too

Metric	units	All Trips	Trip 1	Trip 2	Trip 3	Trip 4	Trip 5	Trip 6	Trip 7	Trip 8	Trip 9	Trip 10
Stop/Snub Duration												
minimum	s	2.0	3.0	3.0	3.0	3.0	2.0	4.0	5.0	3.0	4.0	2.0
50th percentile	s	5.0		5.0	4.0		5.0	4.5	8.5		5.0	5.0
95th percentile	s	11.0	10.0	11.0		15.0	10.0	5.0	12.3	14.0	7.0	11.0
maximum	s	15.0	10.0	13.0	7.0	15.0	13.0	5.0	13.0	15.0	7.0	15.0
Kinetic Energy deceleration												
minimum	J	25	78	96	203	108	97	45	136	284	55	25
50th percentile	J	455	404	500	510		680	112	1665	678	238	371
95th percentile	J	1442		1813		4337	1464	173	2365	3019	414	1832
maximum	J	8199		2896		4838	2614	180	2483	3497	438	8199
total/time	J/h	47129		57665		56993		2629			9143	49199
braking power												
minimum	kW	0.006	0.016	0.022	0.068	0.022	0.029	0.011	0.027	0.041	0.011	0.006
50th percentile	kW	0.095	0.077	0.105	0.115		0.103	0.024			0.051	0.078
95th percentile	kW	0.223		0.227	0.136	0.289	0.340	0.035	0.251	0.225	0.062	0.284
maximum	kW	0.547		0.247	0.194	0.323	0.373	0.036	0.252	0.233	0.063	0.547
total/distance	kW/km	0.176	0.367	0.313	0.294	0.092		0.034	0.069	0.127	0.078	0.175
total/time	kW/h	7.685		9.703	11.133	6.293	9.236	0.552	4.716	5.933	1.679	7.748

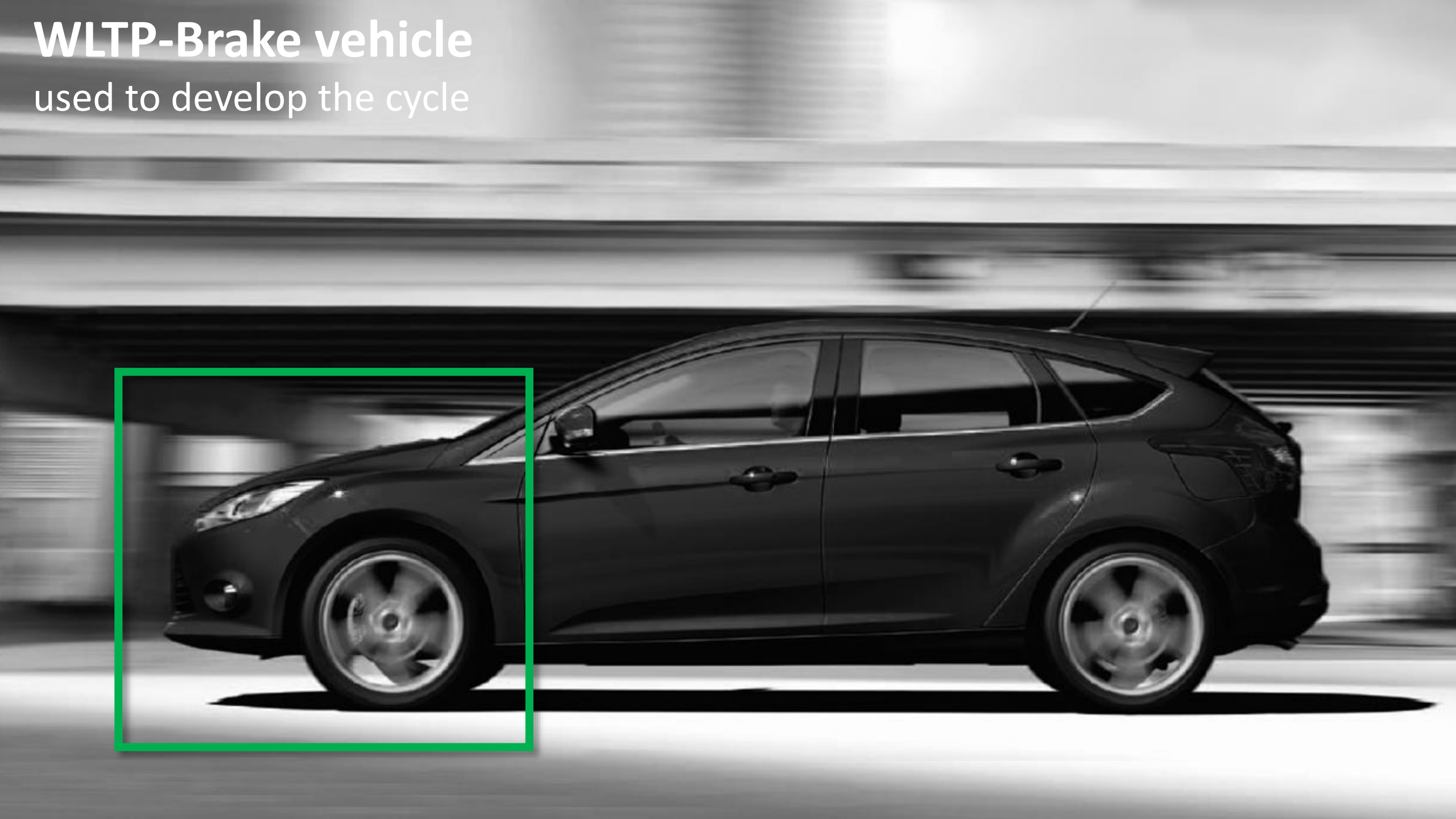
CARB vehicles

Based on vehicles in operation in CA, brake size, and replacement rates



WLTP-Brake vehicle

used to develop the cycle



test inertia per EPA exhaust test & SAE J2789:2018

test mass = LLVW + 136 kg

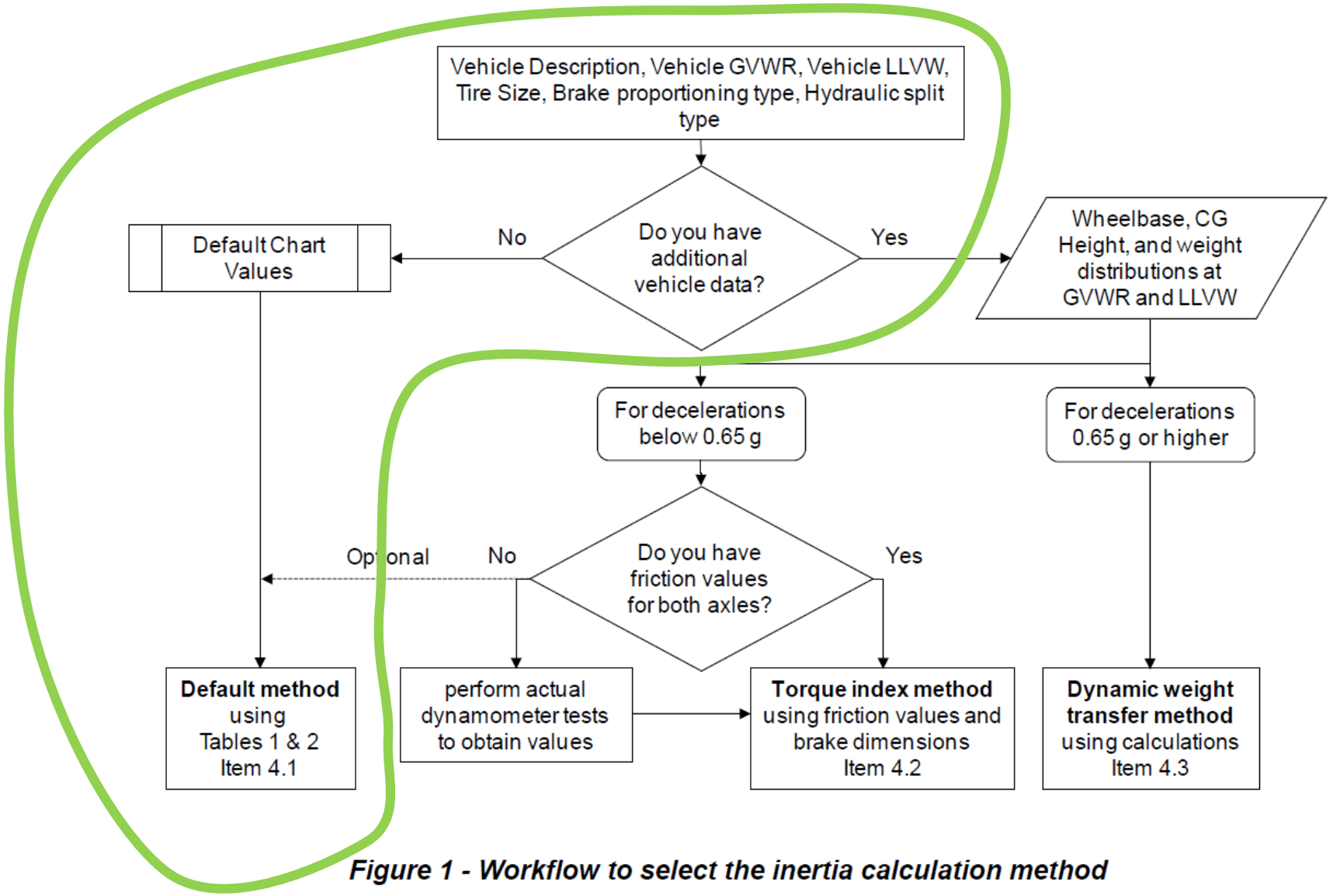
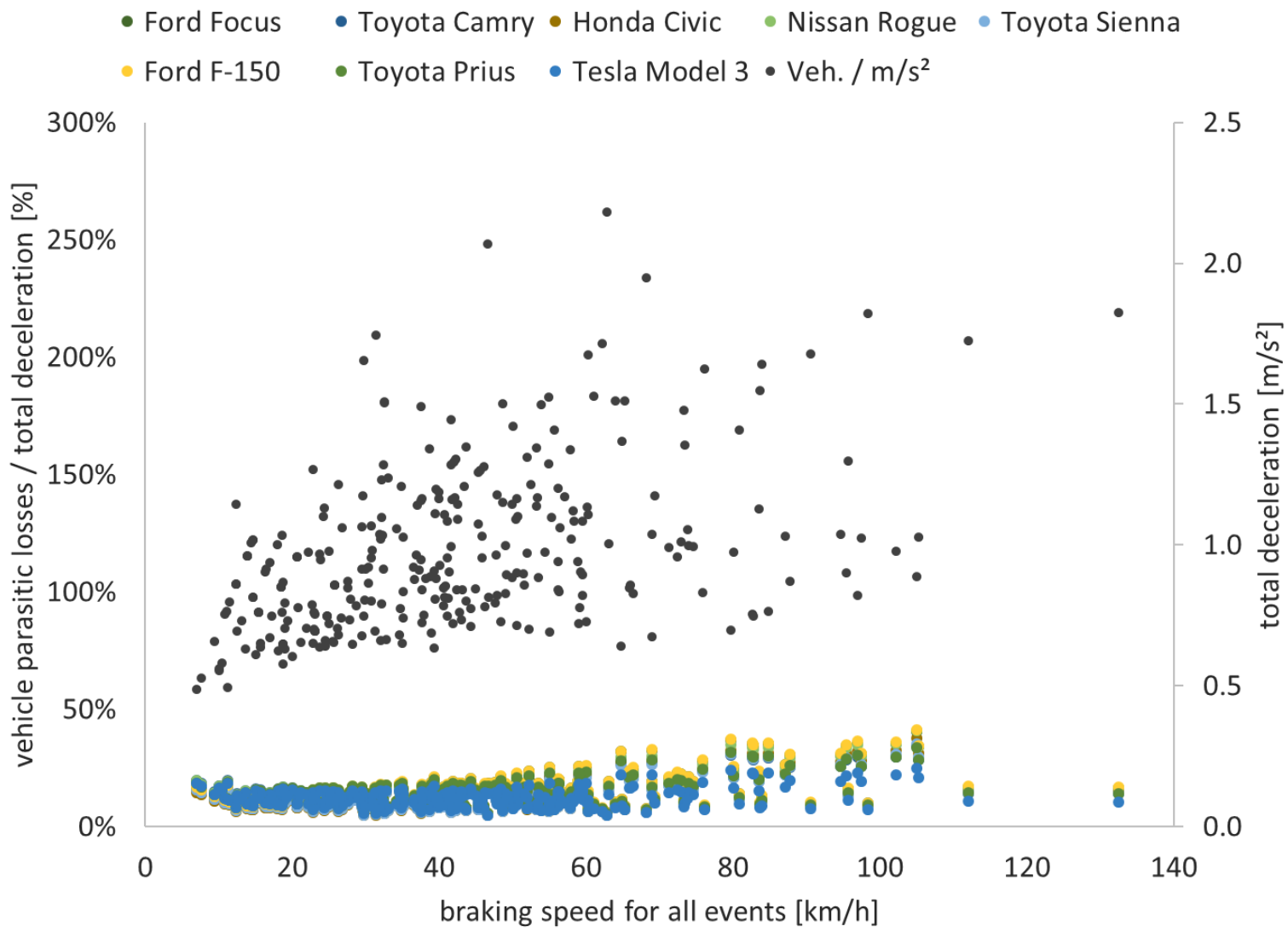


Figure 1 - Workflow to select the inertia calculation method

parasitic losses

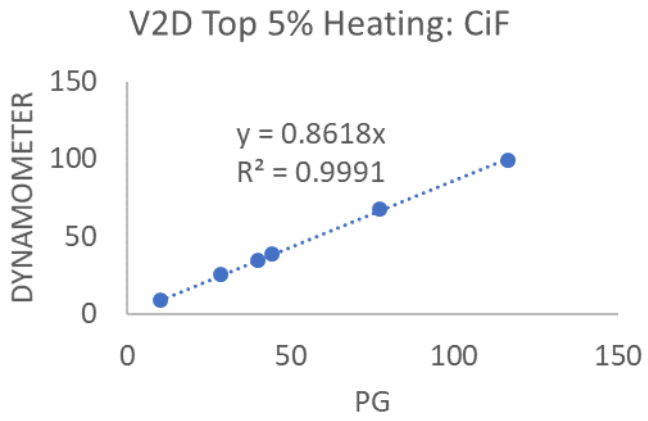
correction of foundation brake deceleration using nominal (EPA) A, B, C factors

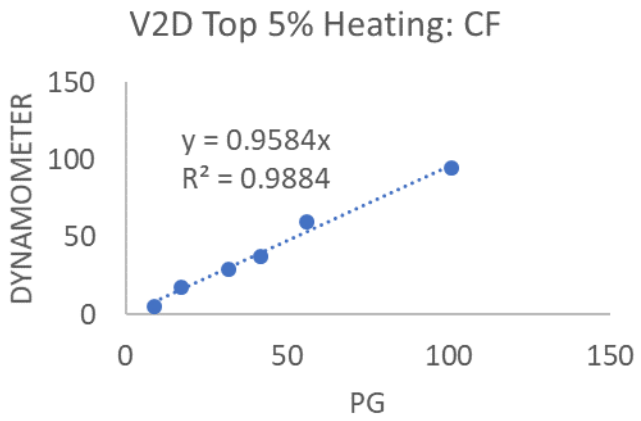


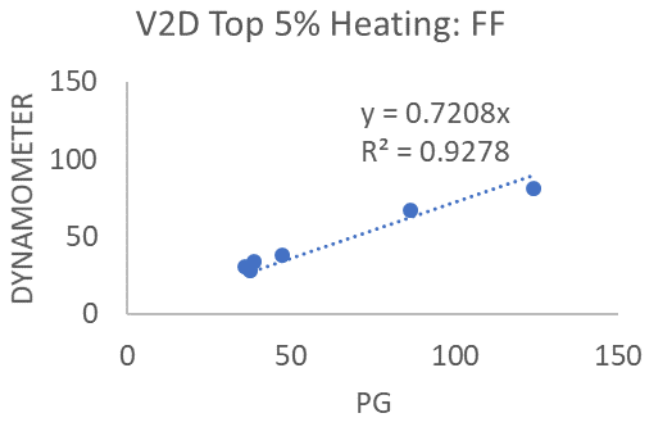
validation of test inertias and front-to-rear split

using temperature rise for brake events representing top 5% of braking power

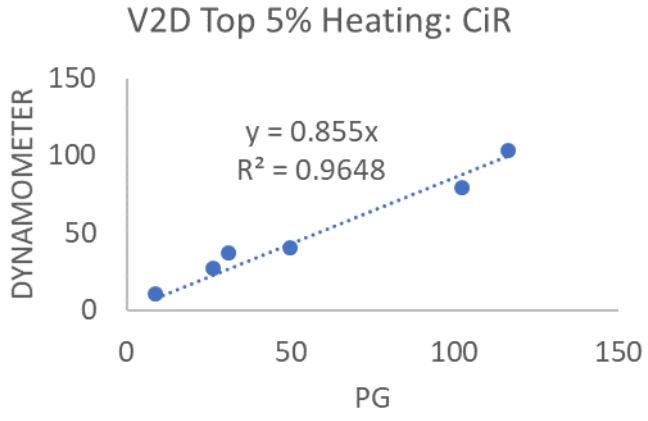
front axle

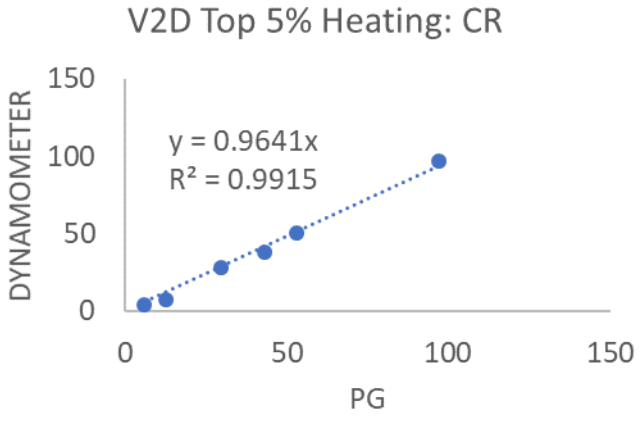


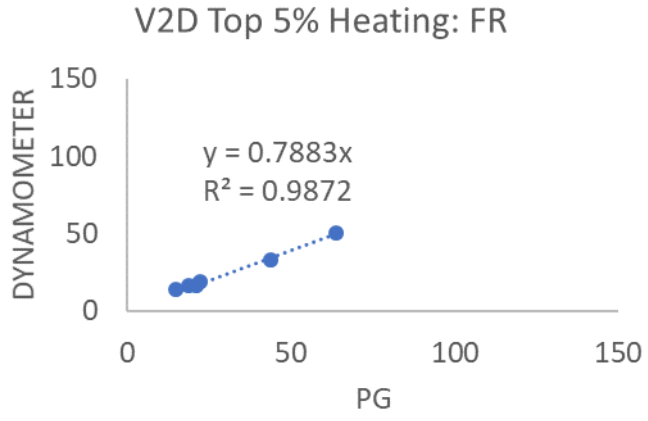




rear axle



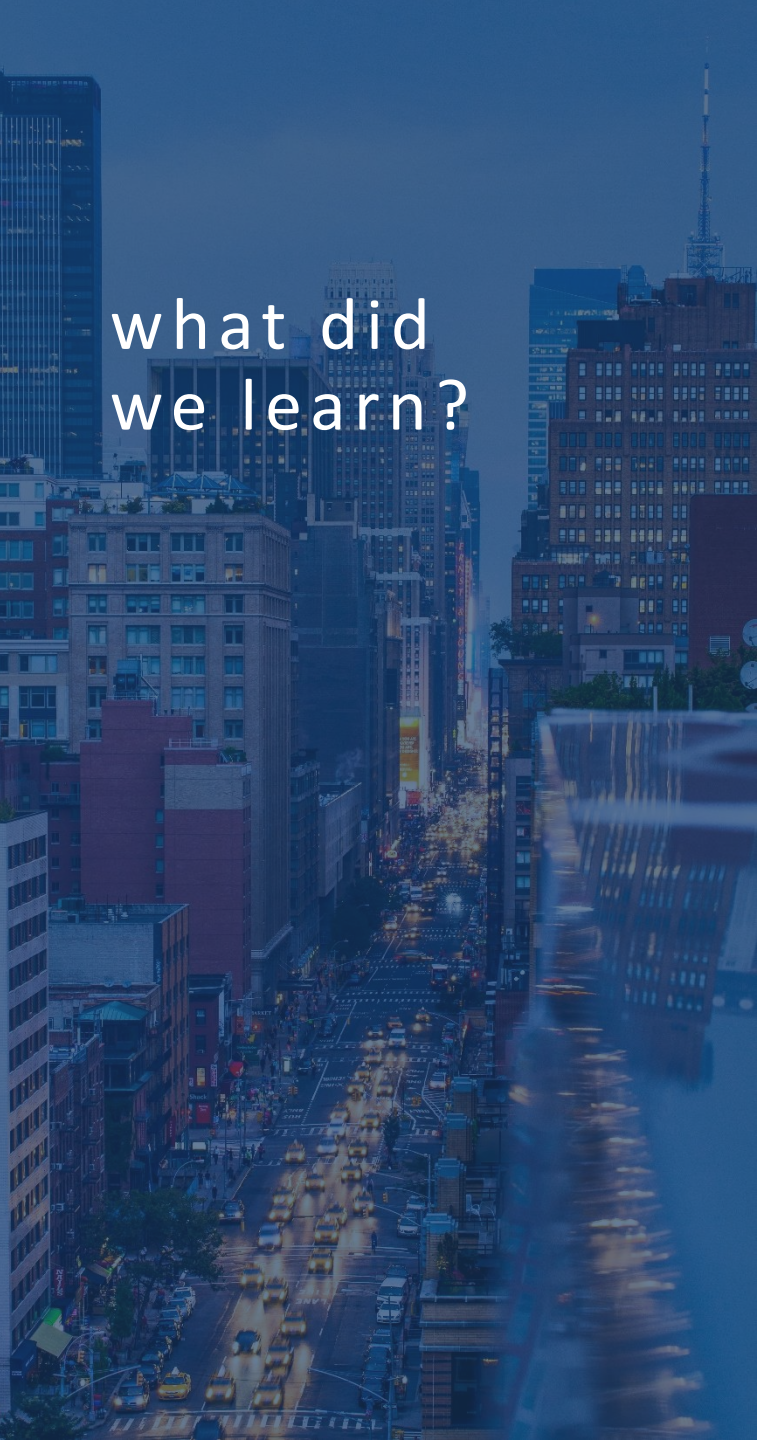




Honda Civic (1350 kg)

Toyota Camry (1660 kg)

Ford F150 (2620 kg)

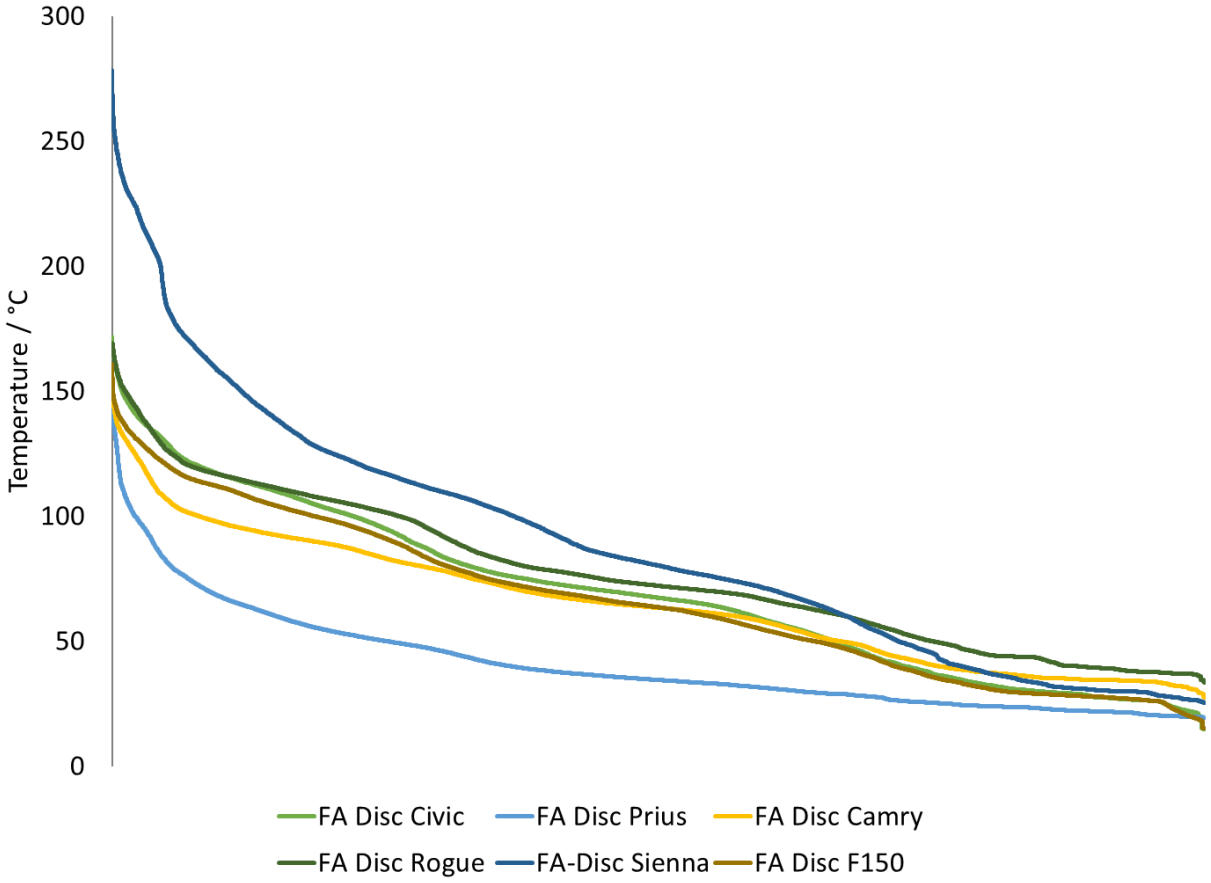


what did we learn?

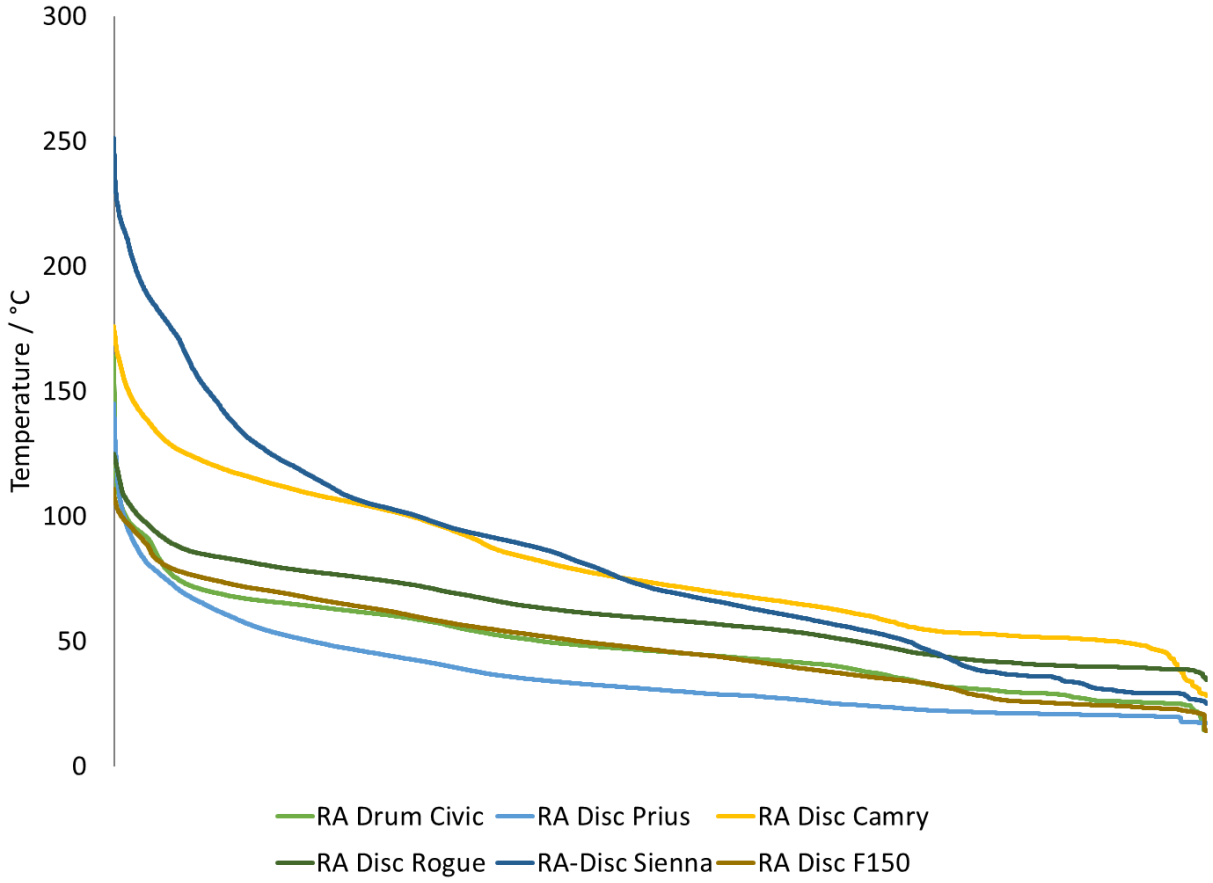
PMP metrics work, with proper engineering due diligence during cooling air adjustment

temperature collectives from proving ground measurements

prior to extracting trip # 10 to adjust the dynamometer air speed



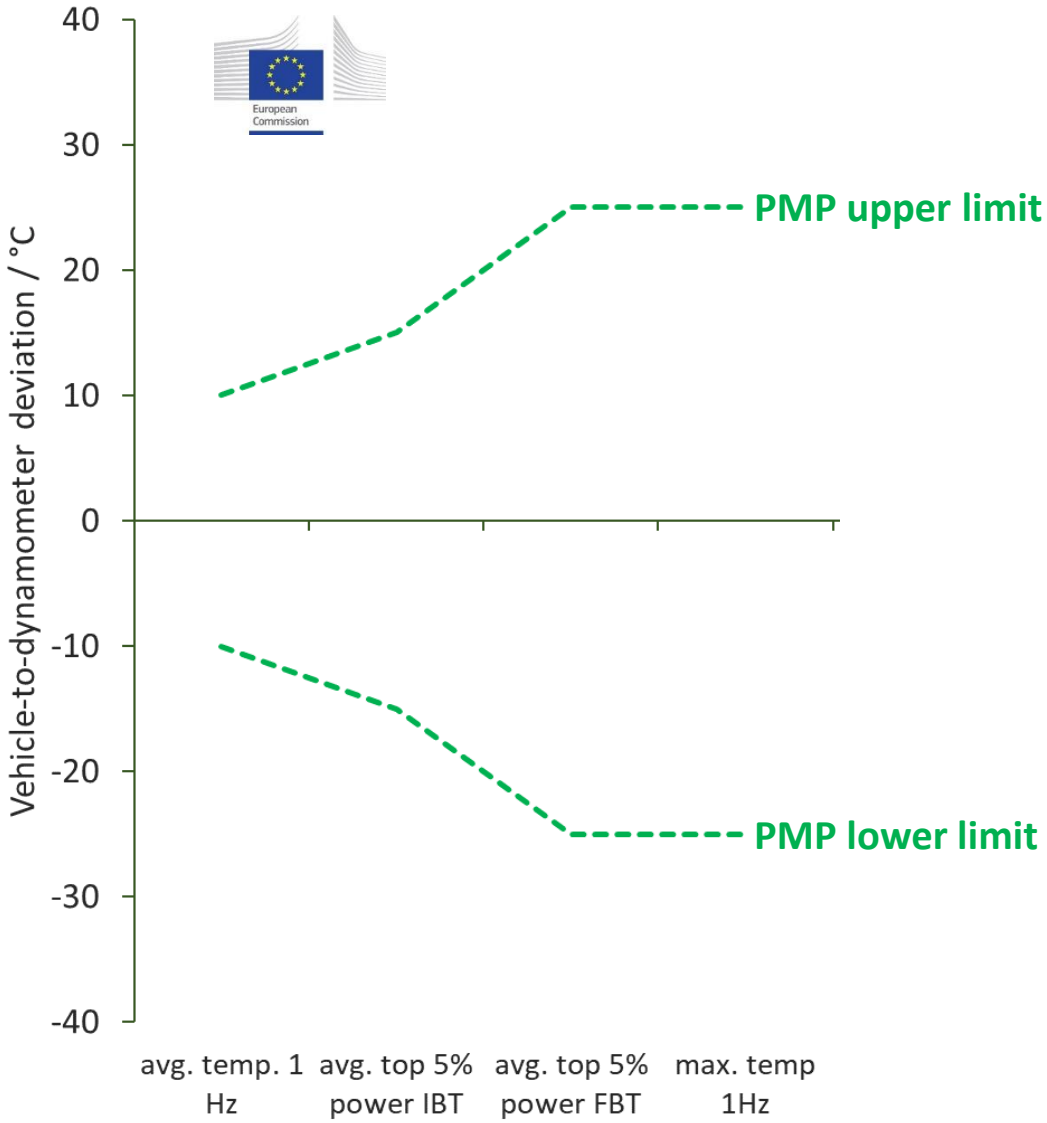
disc temperature on **front** axle



disc temperature on **rear** axle

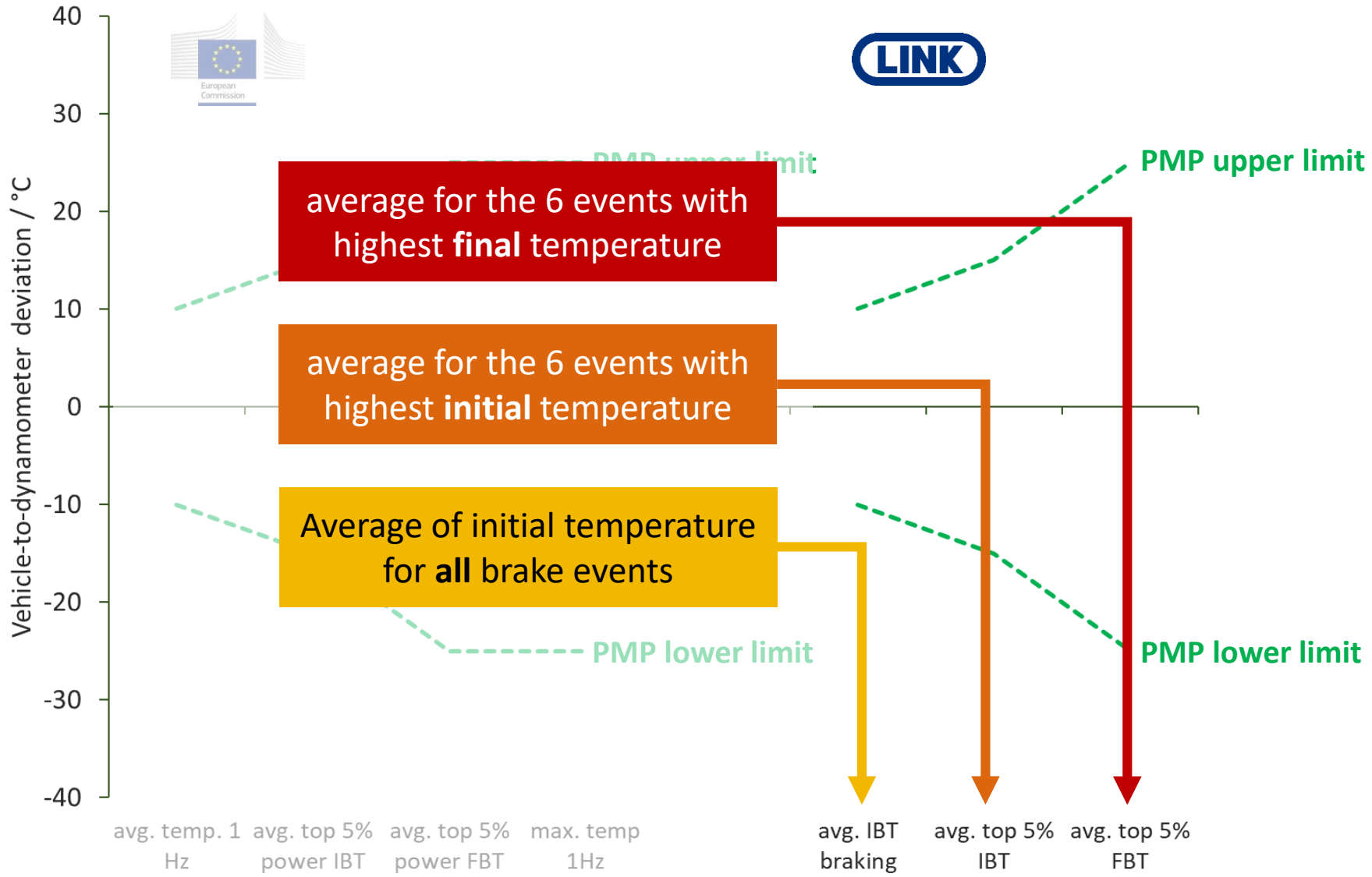
temperature deviations (PMP + LINK check-and-balance)

allowable deviation depends upon the specific metric



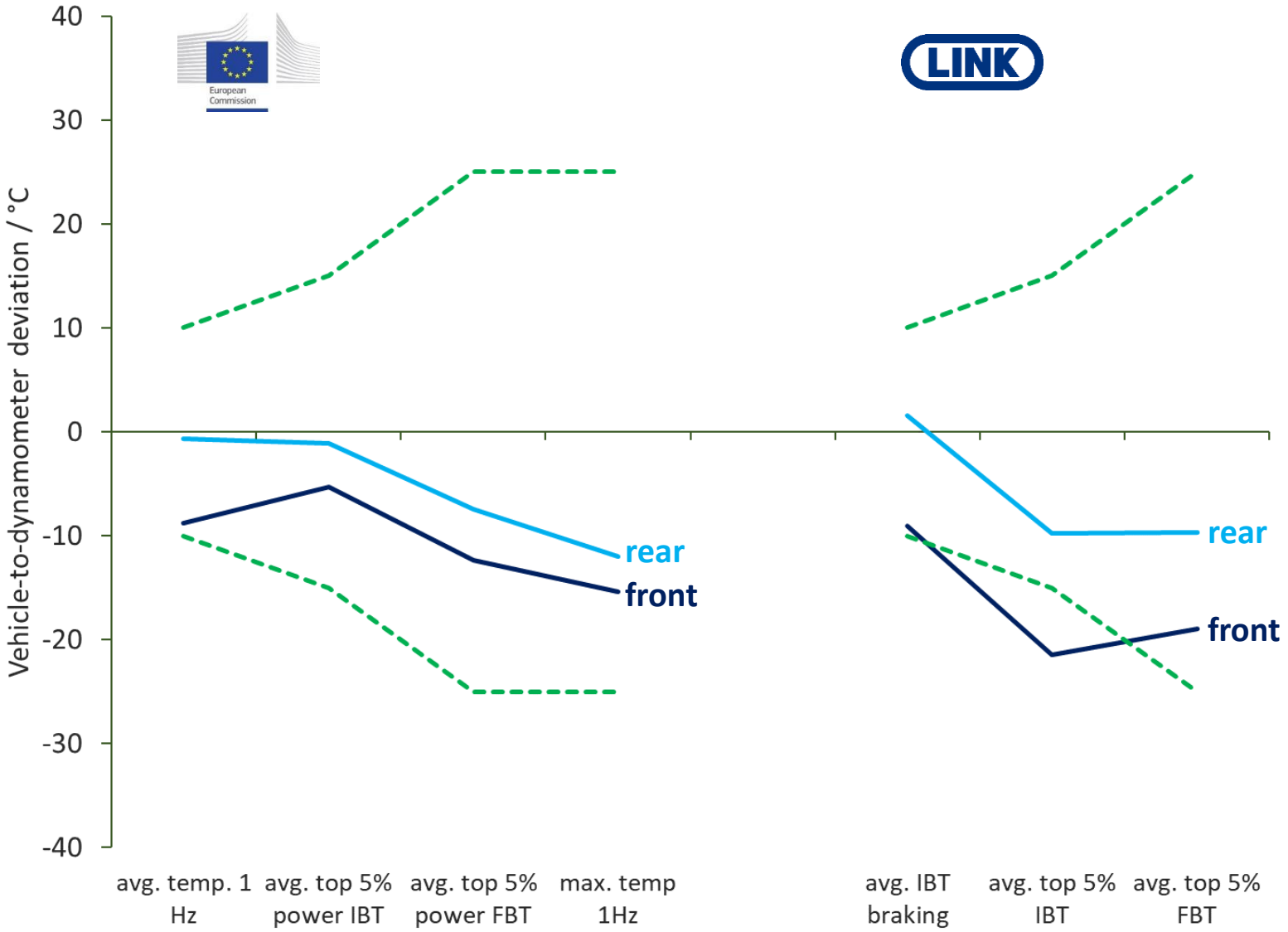
temperature deviations (PMP + LINK check-and-balance)

allowable deviation depends upon the specific metric



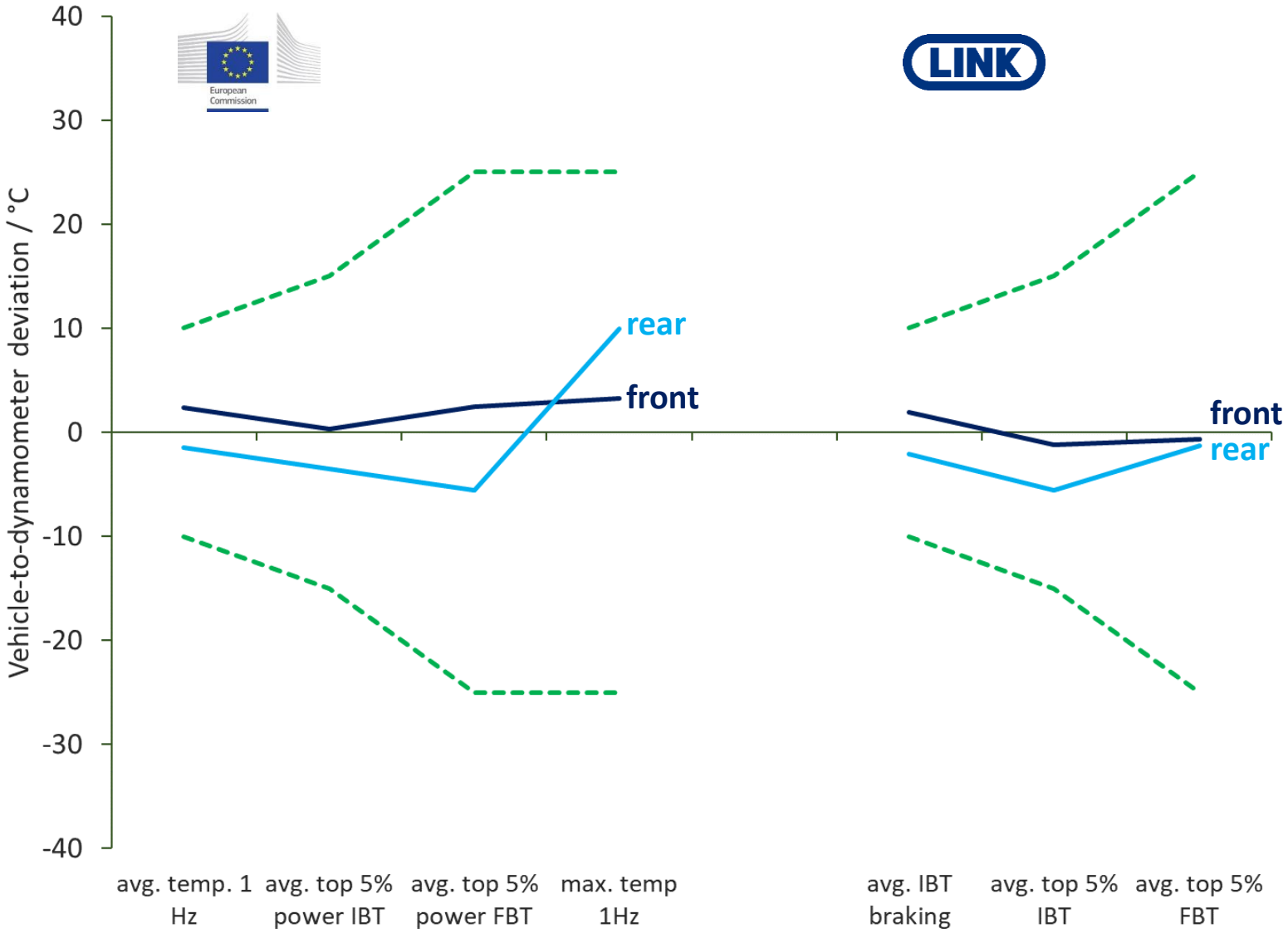
temperature deviations (PMP + LINK check-and-balance)

CARB – Honda Civic (1350 kg)



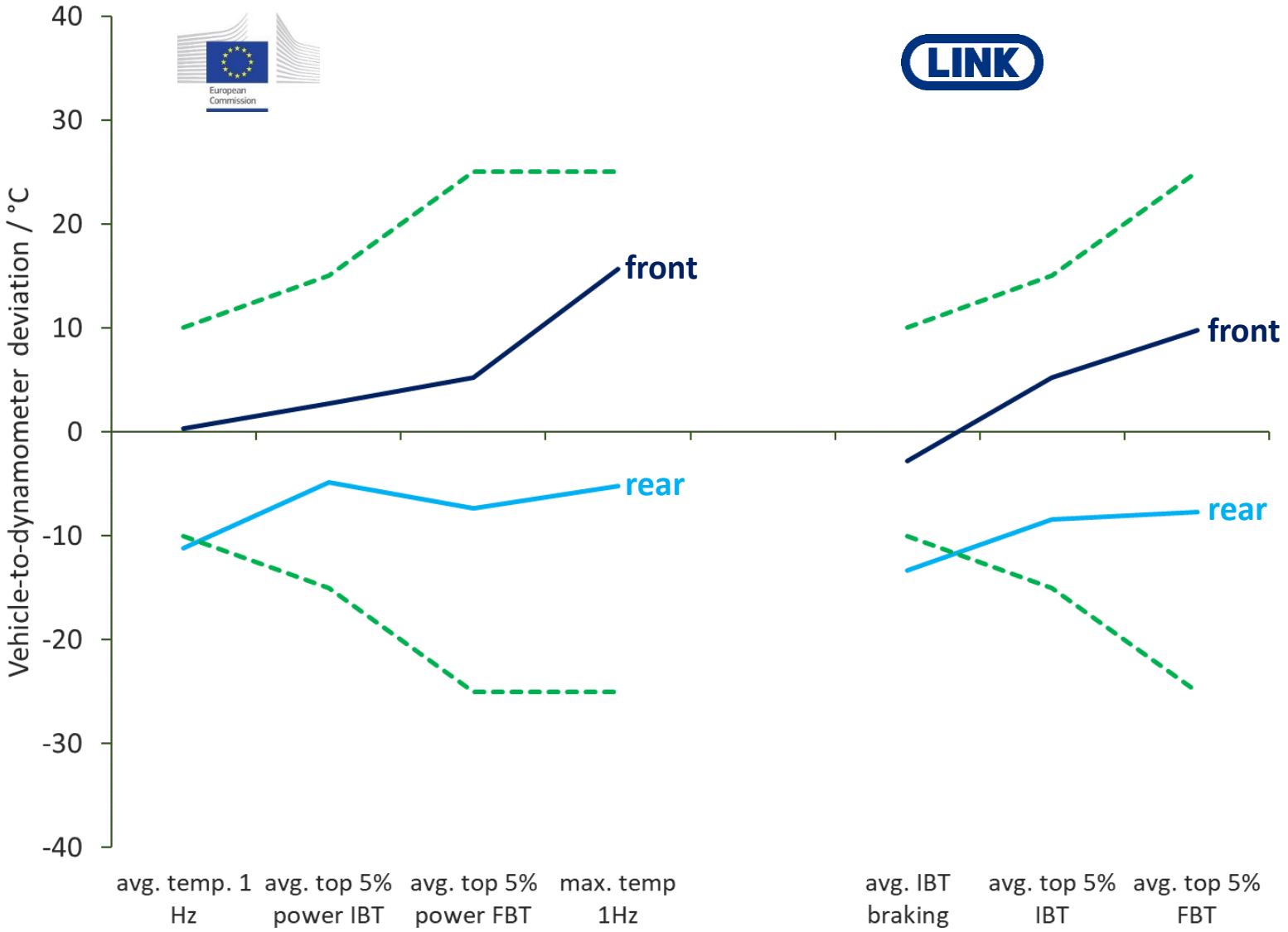
temperature deviations (PMP + LINK check-and-balance)

CARB – Toyota Prius (1590 kg)



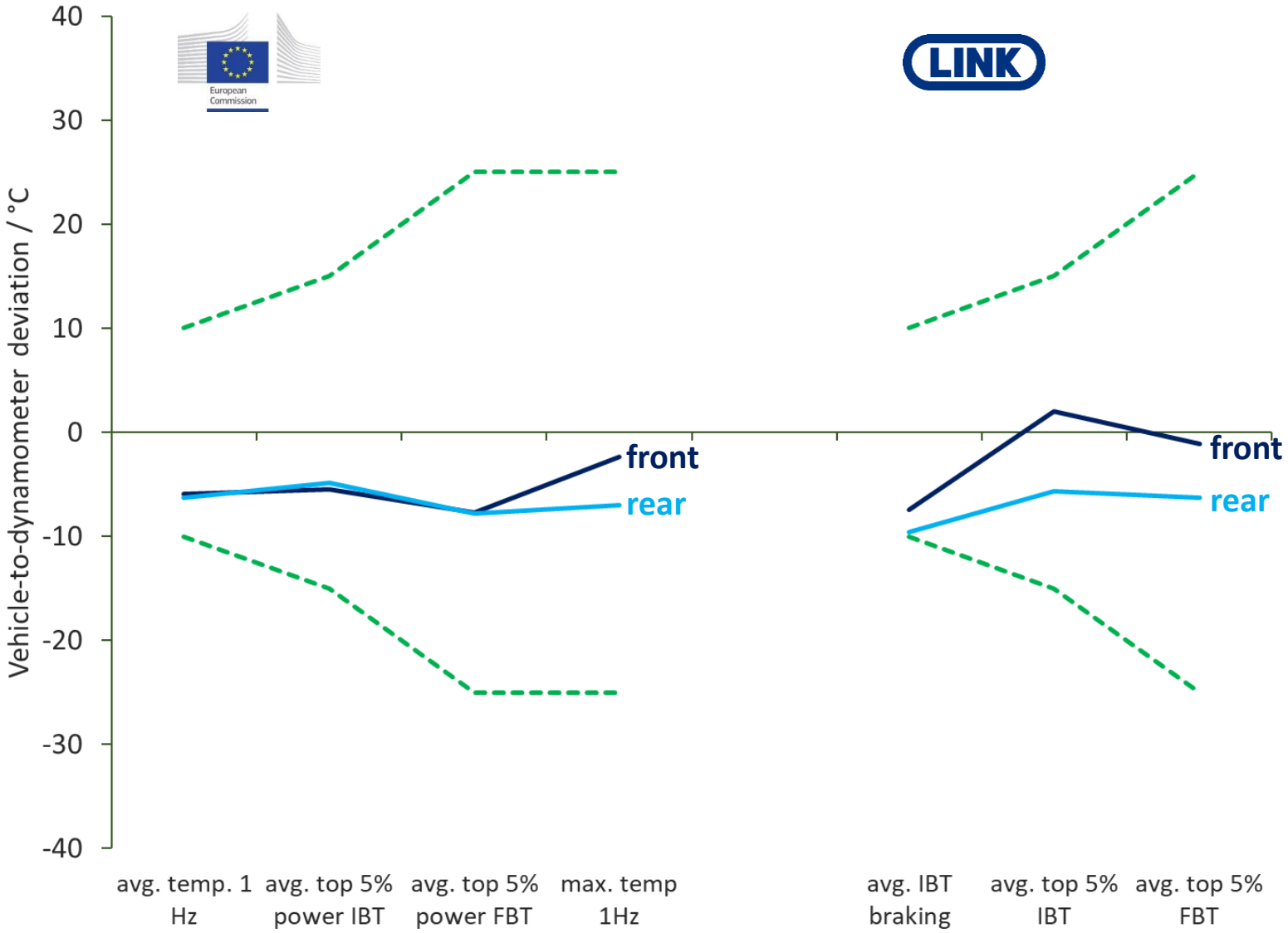
temperature deviations (PMP + LINK check-and-balance)

CARB – Nissan Rogue (1650 kg)



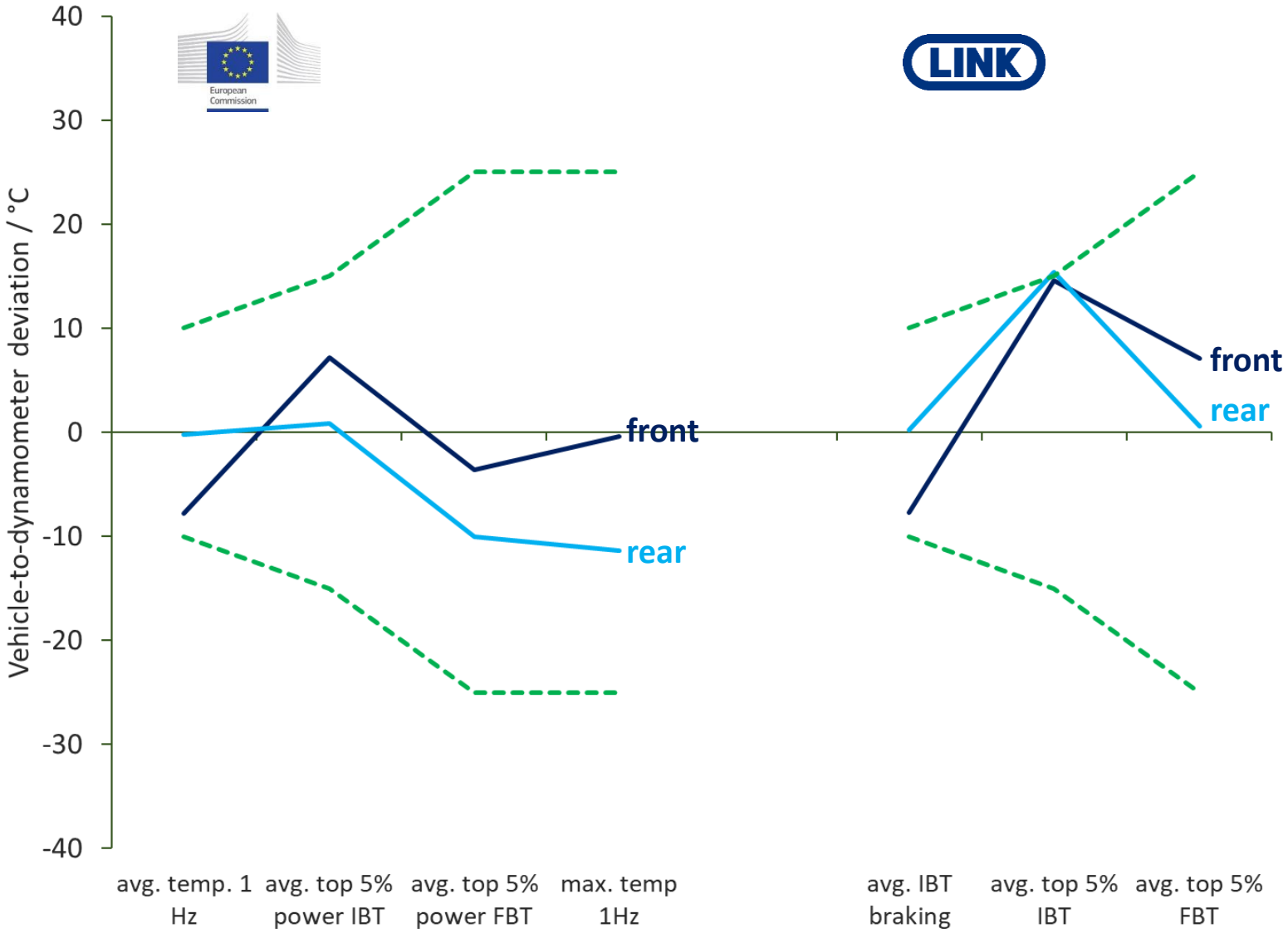
temperature deviations (PMP + LINK check-and-balance)

CARB – Toyota Camry (1660 kg)



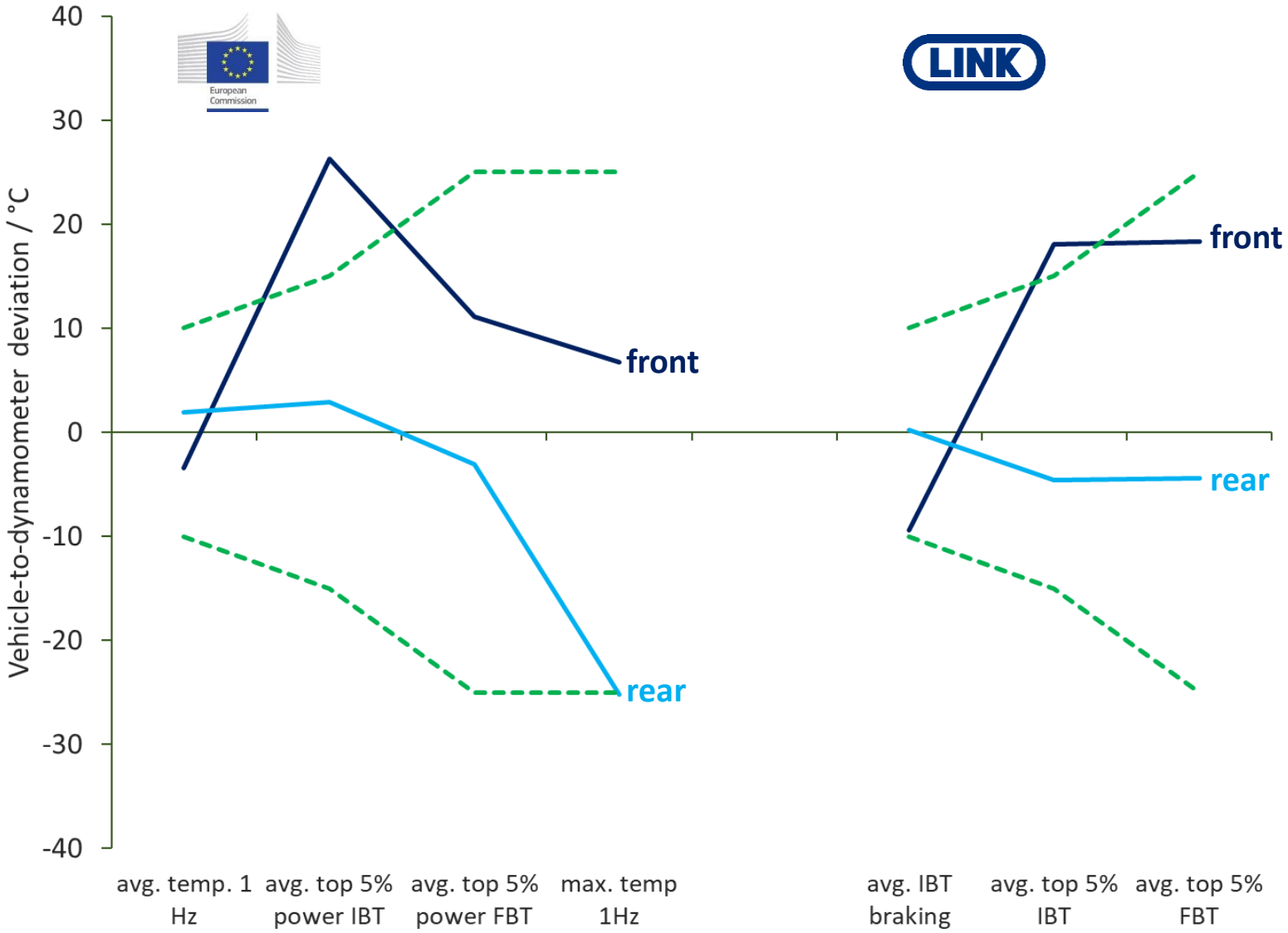
temperature deviations (PMP + LINK check-and-balance)

CARB – Toyota Sienna (2170 kg)



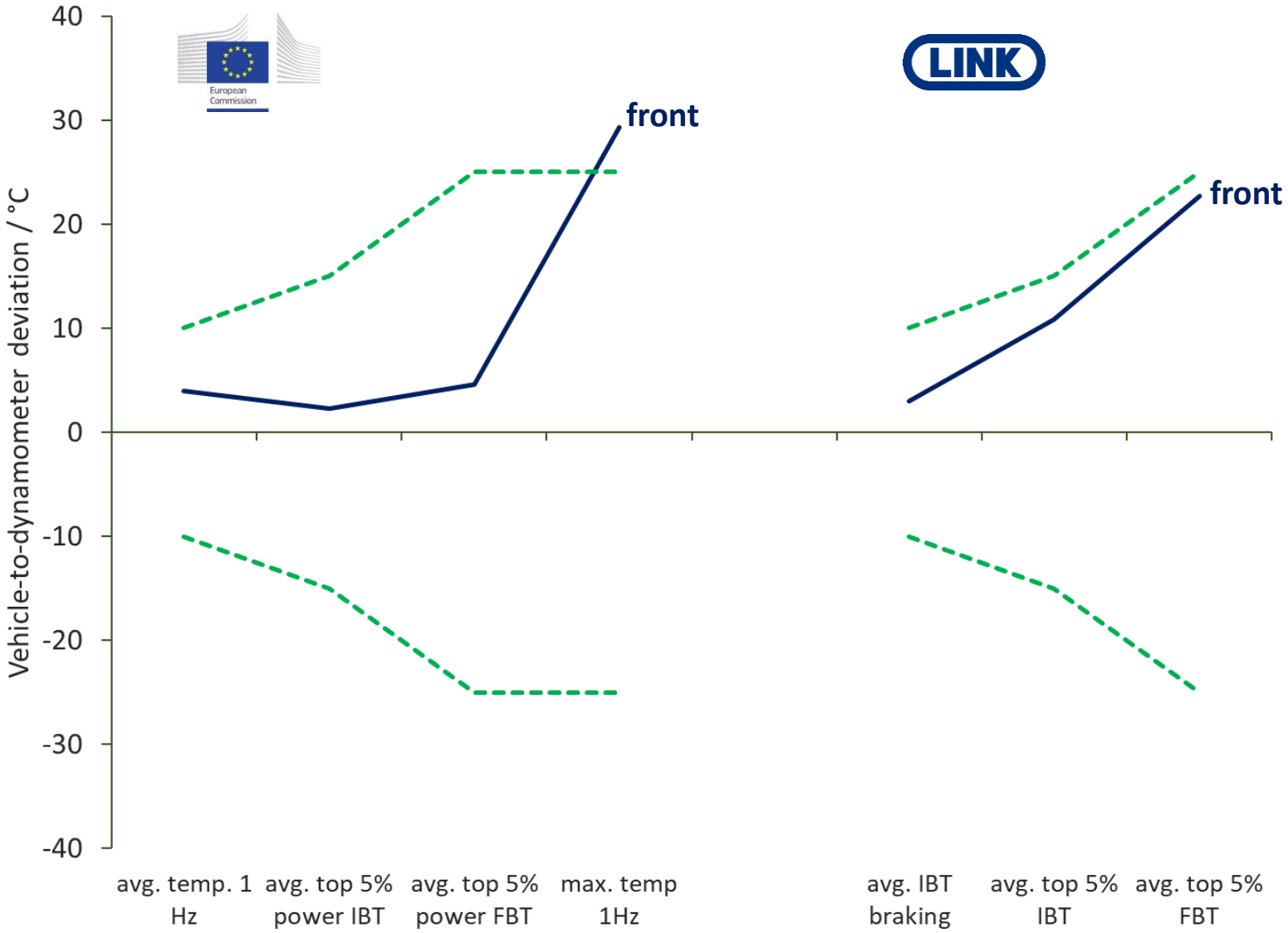
temperature deviations (PMP + LINK check-and-balance)

CARB – Ford F150 (2620 kg)



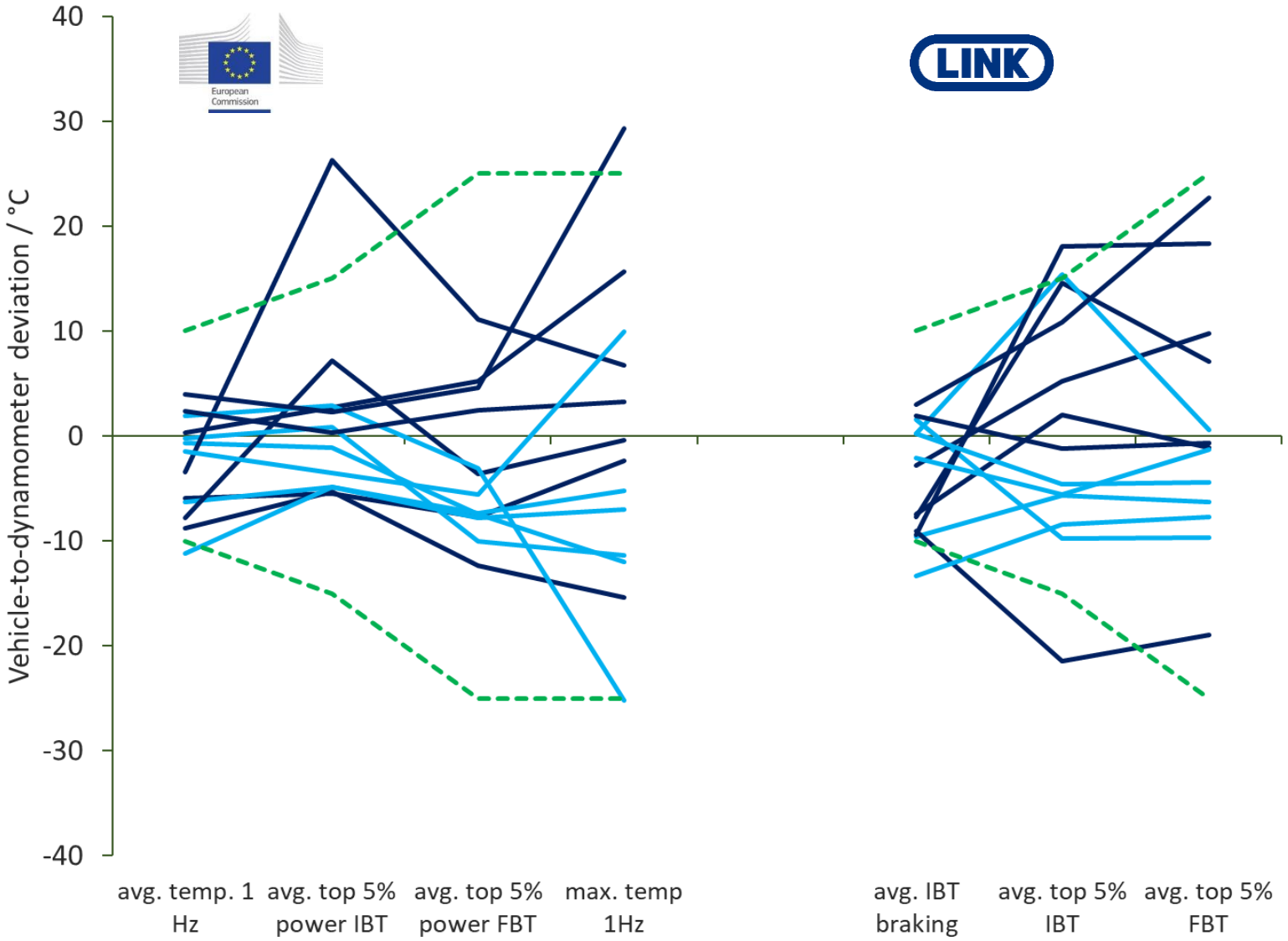
temperature deviations (PMP + LINK check-and-balance)

PMP – Ford Focus (1600 kg)



temperature deviations (PMP + LINK check-and-balance)

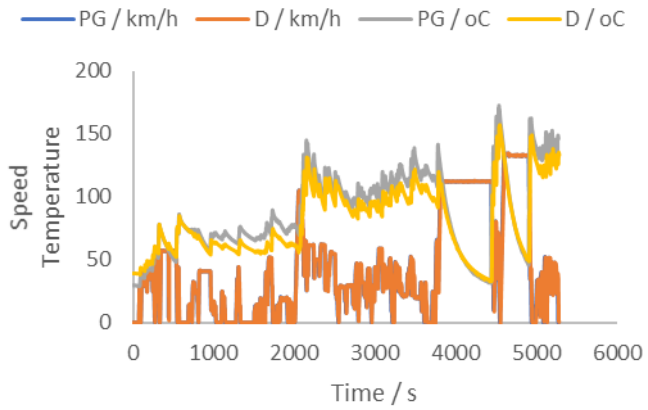
CARB + PMP

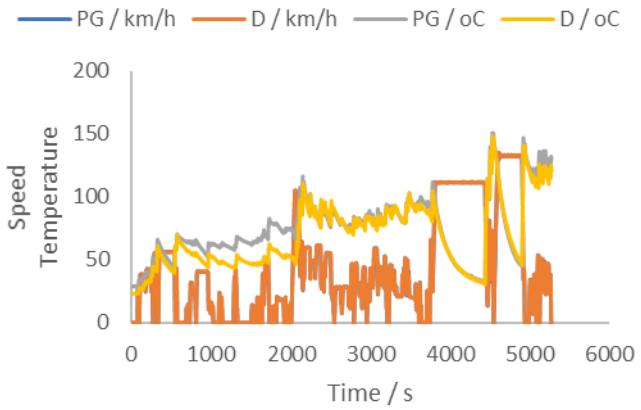


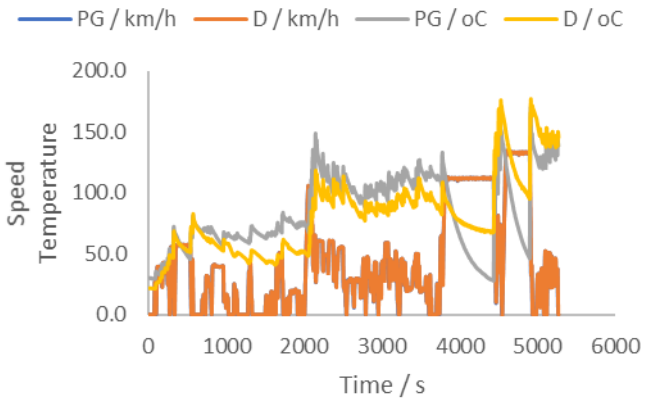
time-resolved comparison of vehicle v. dynamometer tests

with predictable exceptions on cooling behavior at high speed

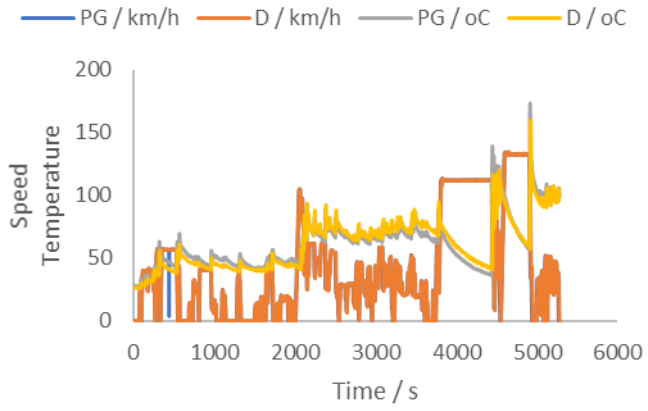
front axle

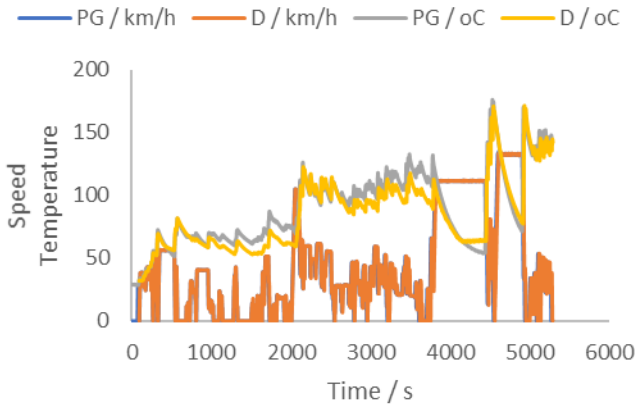


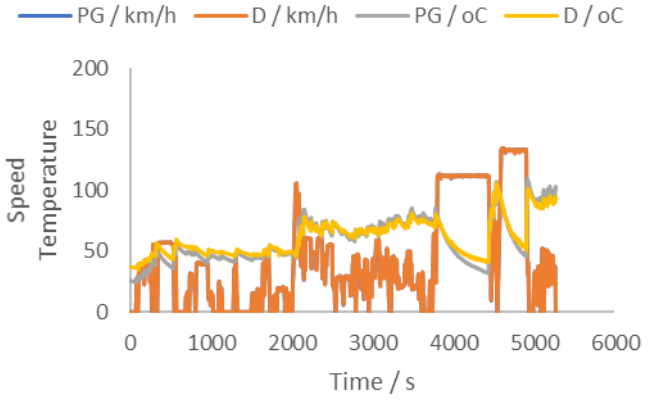




rear axle



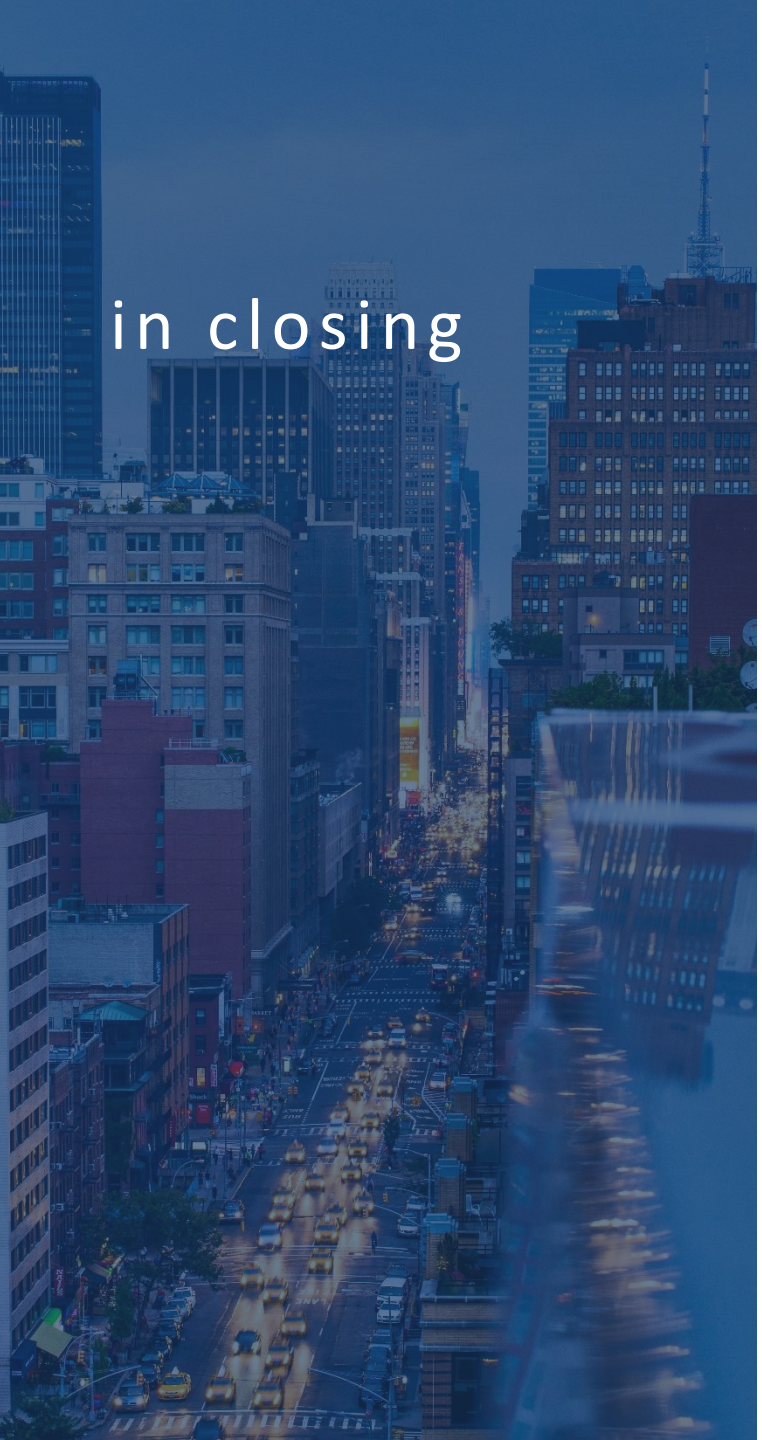




Honda Civic (1350 kg)

Toyota Camry (1660 kg)

Ford F150 (2620 kg)



in closing

PMP metrics work (set of four)

pay attention to setup and transport losses

future projects may provide further finetuning

Experimental validation of PMP cooling air adjustment using CARB+1 vehicles

Carlos Agudelo – Ravi Vedula – Quinn O'Hare