



Homologation test cycles worldwide

Status of the WLTP

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Introduction



- Road vehicles have to comply with limit values for their pollutant exhaust emissions and in future also for their CO2 emissions.
- The compliance with the limits is checked by test bench measurements using standardised test cycles.
- For heavy duty vehicles the engines are tested on an engine dynamometer test bench using normalised engine speed and engine load cycles.
- Light duty vehicles and motorcycles are tested on a chassis dynamometer test bench using standardised vehicle speed cycles.
- For heavy duty vehicle engines and motorcycles worldwide harmonised cycles (WHDC, WMTC) were developed under the UN ECE WP29 umbrella and are currently transposed into regional legislation (e.g. EU, Japan, USA).

Introduction



- For light duty vehicles the development work for a worldwide harmonised cycle (WLTP) and a corresponding test procedure is currently performed and will be finalised in 2014.
- Two main elements are important for the measurement results:
 - The test cycle,
 - The test procedure
- The test cycle defines the driving schedule for the test in terms of vehicle speed and gear use in case of manual transmission vehicles.
- The test procedure defines the conditions of the vehicle in terms of vehicle mass, road load, inertia, preconditioning, temperatures etc.
- Within the WLTP both elements are significantly changed compared to the current regional procedures, but this presentation will focus on the test cycle.

Worldwide test cycles for LDV



- The most important test cycles that are currently used for light duty vehicle type approval are
 - NEDC,
 - FTP 75,
 - JC08.
- The NEDC is used in Europe, the low powered vehicle version of this cycle is used in India. The FTP 75 cycle is used in the USA and the JC08 in Japan.
- The NEDC is a synthetic cycle while the other two are derived from real world in-use data.
- The EU commission plans to replace the NEDC by the WLTC in future and base its CO2 legislation on the WLTC and its test procedure.

Development steps for the WLTC



- The development of the WLTC was carried out in the following steps
 - Collection and analysis of in-use data from different regions of the world,
 - Collection of in-use mileage statistics to be used for the weighting of the in-use data,
 - Creation of the worldwide unified database,
 - Derivation of the WLTC from this database.
- The in-use data collected for the cycle development consists of 451 000 km from Europe, 98 000 km from India, Japan and Korea and 153 000 km from the USA.
- The major part of this data is M1 data but N1/M2 vehicles are well represented with 96 000 km.

Structure of the WLTC



- The data was separated into short trips and stop or idling phases, the short trips were binned into the following four phases according to their maximum speed
 - Low (up to 60 km/h),
 - Medium (> 60 km/h up to 80 km/h),
 - High (> 80 km/h up to 110 km/h)
 - Extra high (> 110 km/h).
- This classification was used instead of urban, rural and motorway, because it is more objective and makes it easier to consider regional differences, e.g. for the vehicle speed distribution (see figure 1).
- The disadvantage is, that the phases consist of contributions from different road categories (see figure 2).
- The mileage shares for the different road categories are shown in figure 3.

Vehicle speed distributions for different regions/countries

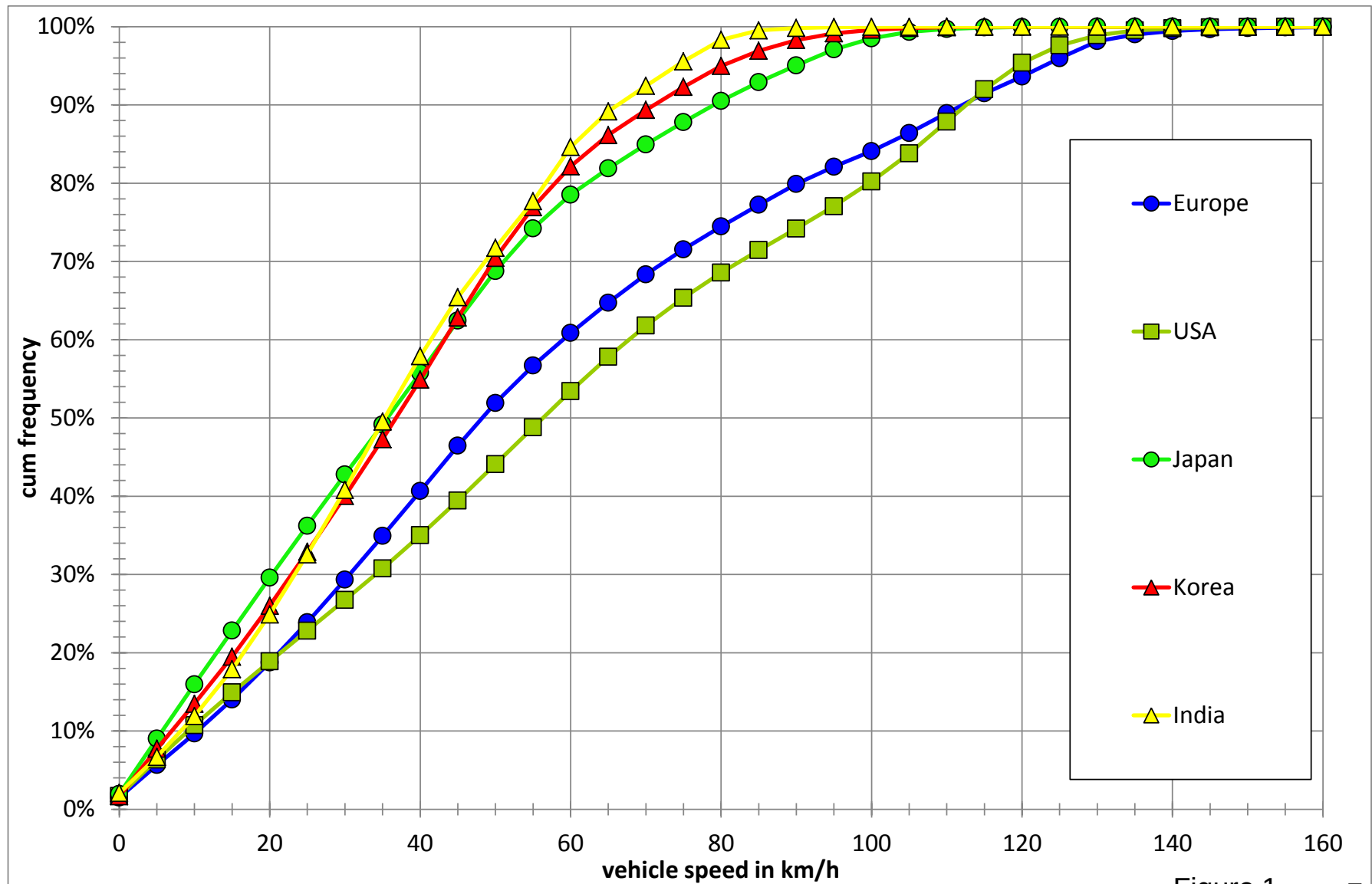


Figure 1

Comparison of road categorie shares of the WLTC for the 4 speed classes

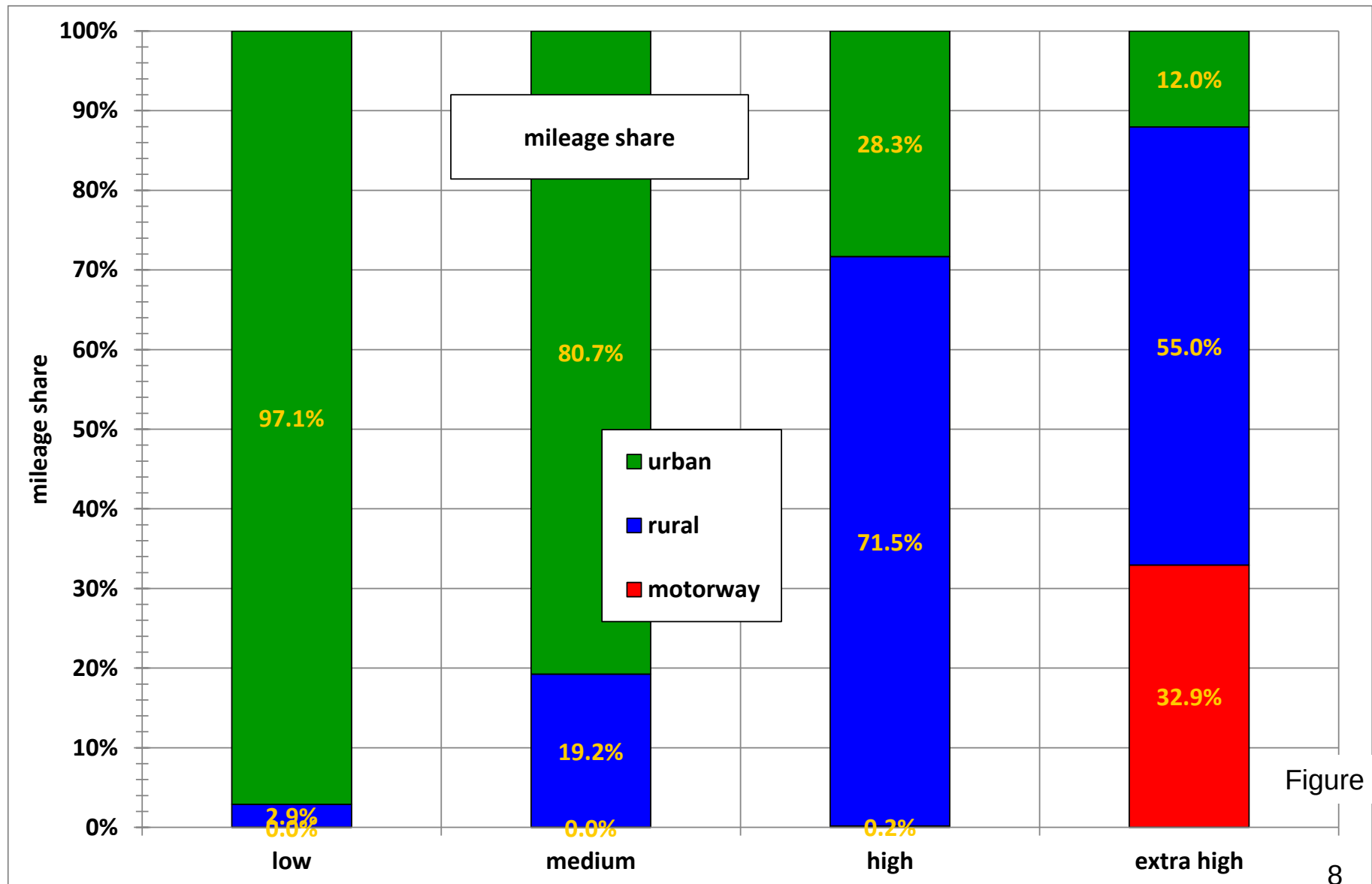


Figure 2

Comparison of road categorie shares of the WLTC for the 4 speed classes

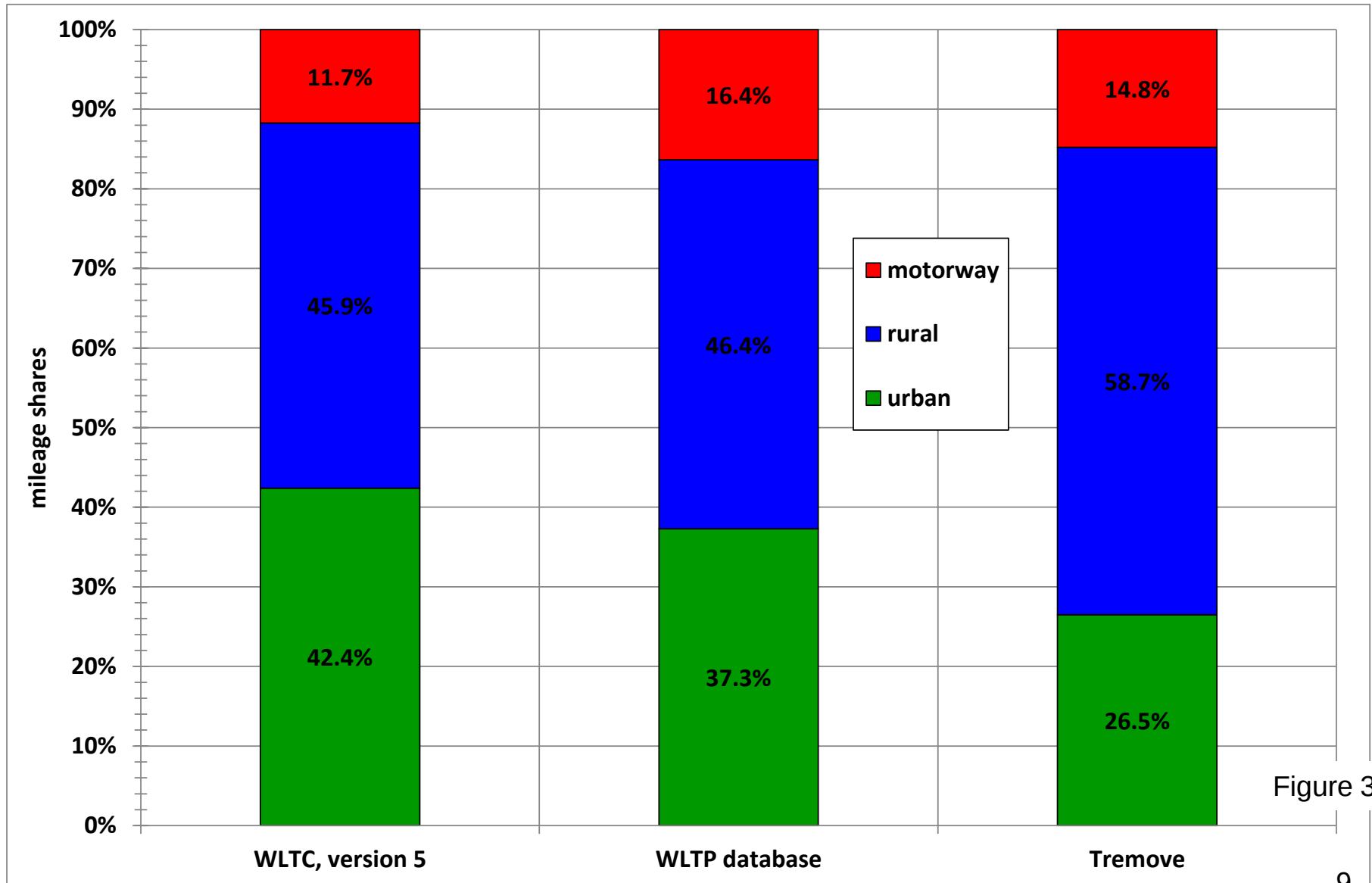


Figure 3

Structure of the WLTC



- The WLTC has a total duration of 1800 s. The durations of the four cycle phases are set in that way that it reflects the mileage distribution of the database and thus no weighting factors are necessary for the final result.
- The in-use database contains data for a broad variety of vehicles with respect to rated power to kerb mass ratio (pmr), ranging from 9 kW/t to 127 kW/t.
- The analysis of the in-use data showed that the driving dynamics for vehicles with $\text{pmr} > 34 \text{ kW/t}$ is more influenced by individual driving behaviour and traffic load rather than by technical vehicle parameter, but that the driving dynamics below this threshold decreases with decreasing pmr.
- This reflects the situation that the dynamics are limited by the limited power availability.

Structure of the WLTC



- Based on the analysis results the following three pmr classes are defined:
 - Class 1, $\text{pmr} \leq 22 \text{ kW/t}$,
 - Class 2, $22 \text{ kW/t} < \text{pmr} \leq 34 \text{ kW/t}$,
 - Class 3, $\text{pmr} > 34 \text{ kW/t}$.
- Cycles with different dynamics were developed for each vehicle class, adjusted to the acceleration potential of the vehicles.
- The key parameters of these cycles are shown in table 1.
- For Europe class 3 is of highest importance, at least for the current vehicle stock.
- But class 2 vehicles might become more important in future, especially in the context of electrified vehicles.

Key parameters of the WLTC



cycle phase	duration	stop duration	distance	p_stop	v_max	v_ave without stops	v_ave with stops	a_min	a_max	a_pos ave	v*a_pos ave	RPA
	s	s	m		km/h	km/h	km/h	m/s ²	m/s ²	m/s ²	m ² /s ³	kWs/(kg*km)
class 3, version 5.3												
low	589	156	3,095	26.5%	56.5	25.7	18.9	-1.47	1.47	0.47	3.04	0.2046
medium	433	48	4,756	11.1%	76.6	44.5	39.5	-1.49	1.57	0.42	4.36	0.1964
high	455	31	7,162	6.8%	97.4	60.8	56.7	-1.49	1.58	0.37	4.49	0.1322
extra high	323	7	8,254	2.2%	131.3	94.0	92.0	-1.21	1.03	0.30	6.21	0.1249
	1800	242	23,266			53.8	46.5					
class 2, version 2												
low	589	155	3101	26.3%	51.4	25.7	19.0	-0.94	0.90	0.34	2.25	0.1605
medium	433	48	4737	11.1%	74.7	44.3	39.4	-0.93	0.96	0.30	3.24	0.1236
high	455	30	6792	6.6%	85.2	57.5	53.7	-1.11	0.85	0.22	3.19	0.1218
extra high	323	7	8019	2.2%	123.1	91.4	89.4	-1.06	0.65	0.21	4.00	0.0913
	1800	240	22649			52.3	45.3					
class 1, version 2												
low	589	154	3330	26.1%	49.1	27.6	20.4	-1.00	0.76	0.22	1.26	0.0908
medium	433	48	4767	11.1%	64.4	44.6	39.6	-0.53	0.63	0.19	2.00	0.0743
	1022	202	8098			35.6	28.5					

Structure of the WLTC



- In order to consider the special situation of kei cars in Japan, two different versions of the class 3 cycle exist, version 5.1 to be used for vehicles with $v_{\max} \leq 120$ km/h and version 5.3 for vehicles with $v_{\max} > 120$ km/h.
- According to the importance for Europe, the presentation is restricted to the WLTC class 3 (version 5.3) cycle only.
- The driving pattern of this cycle is shown in figures 4 to 7.

WLTC, low phase

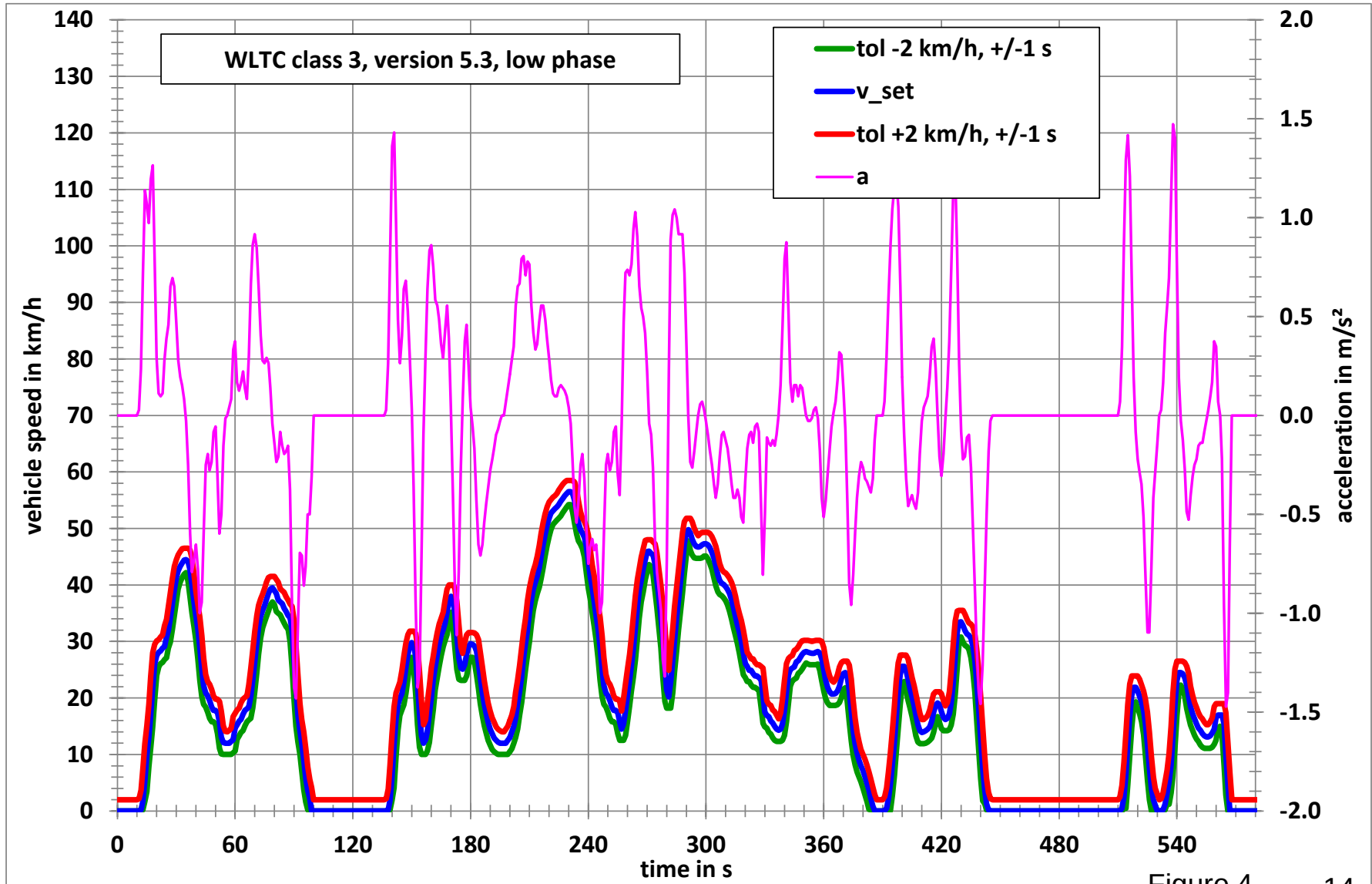


Figure 4

WLTC, medium phase

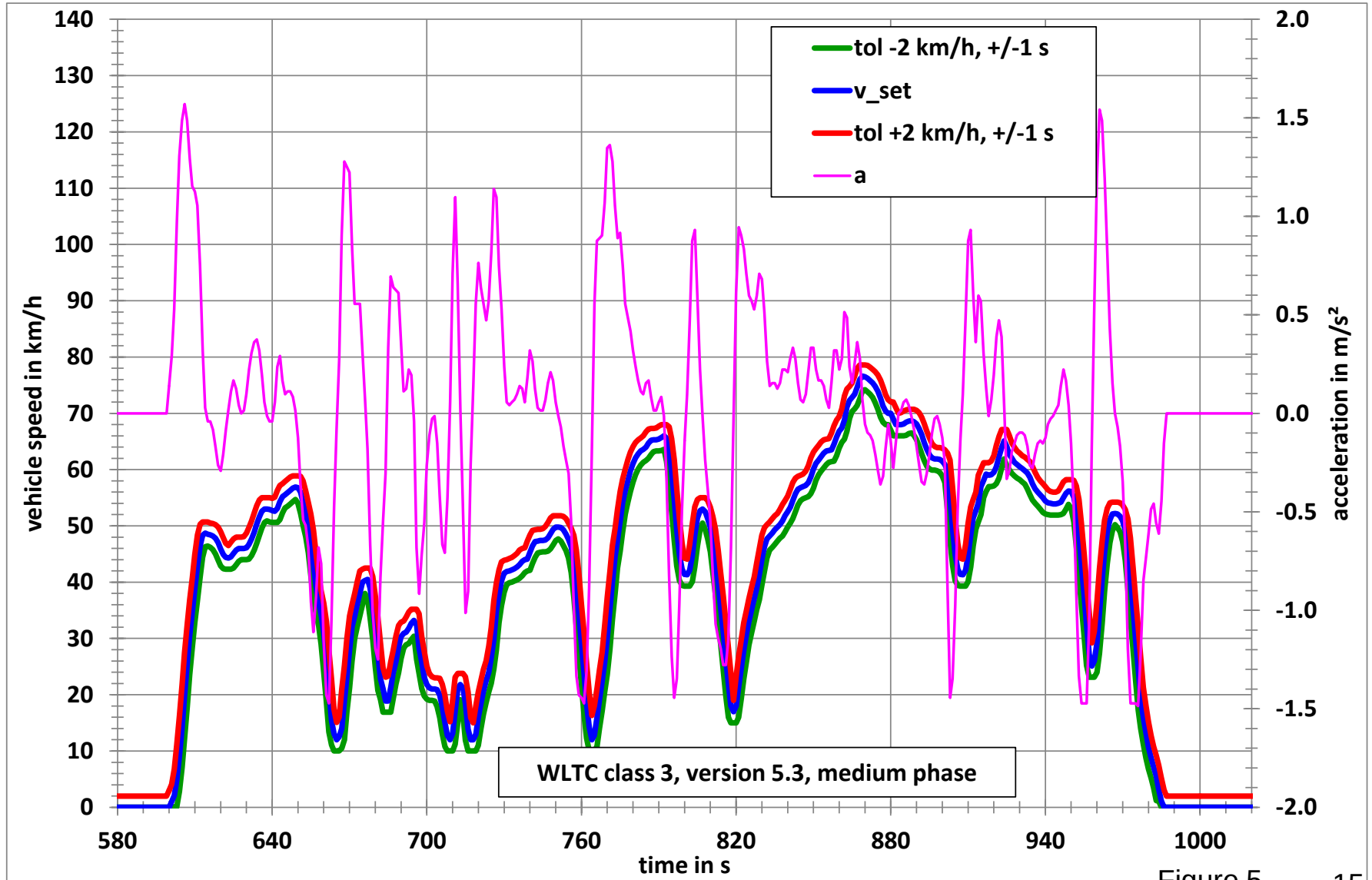


Figure 5

WLTC, high phase

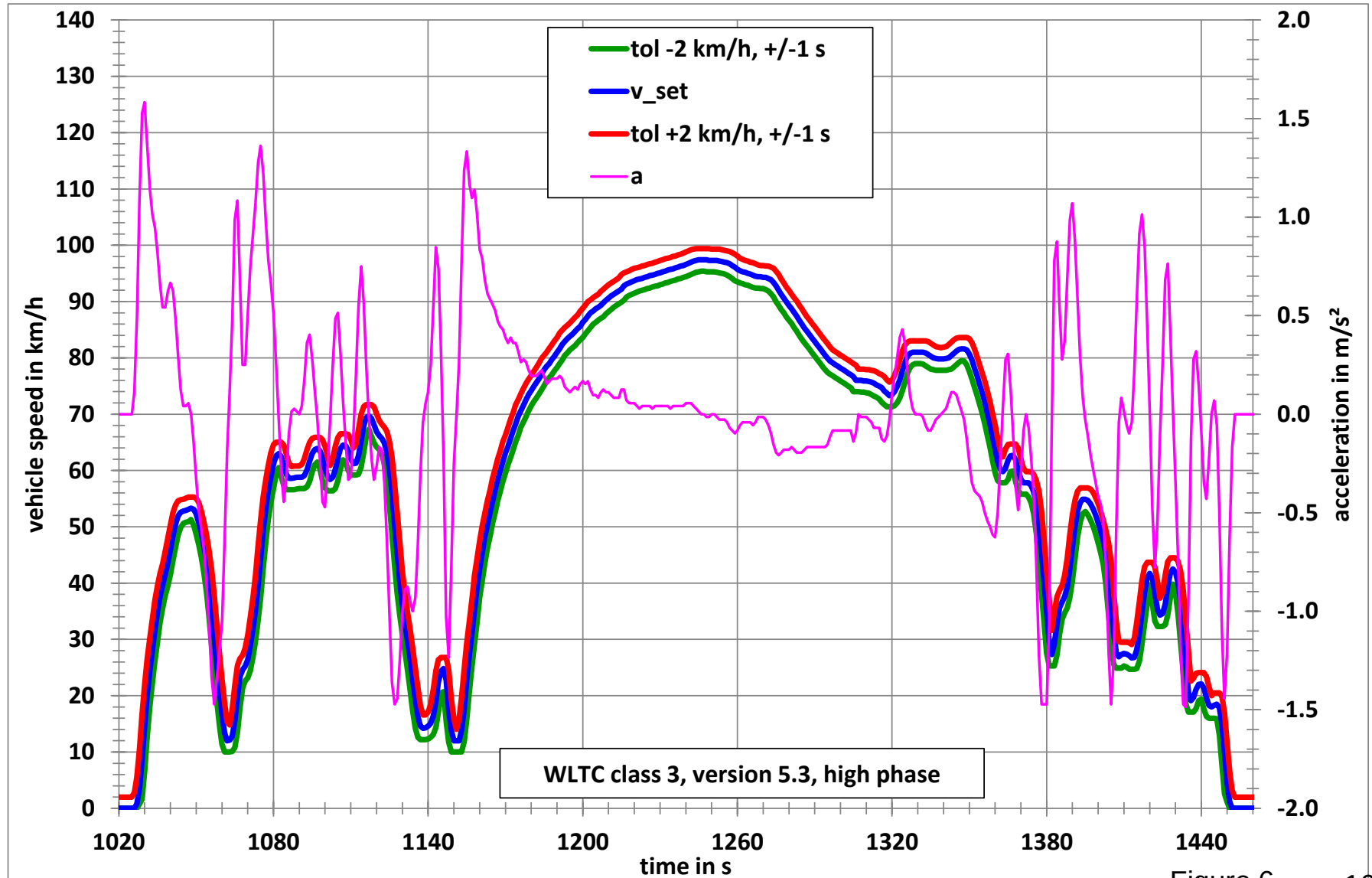


Figure 6

WLTC, extra high phase

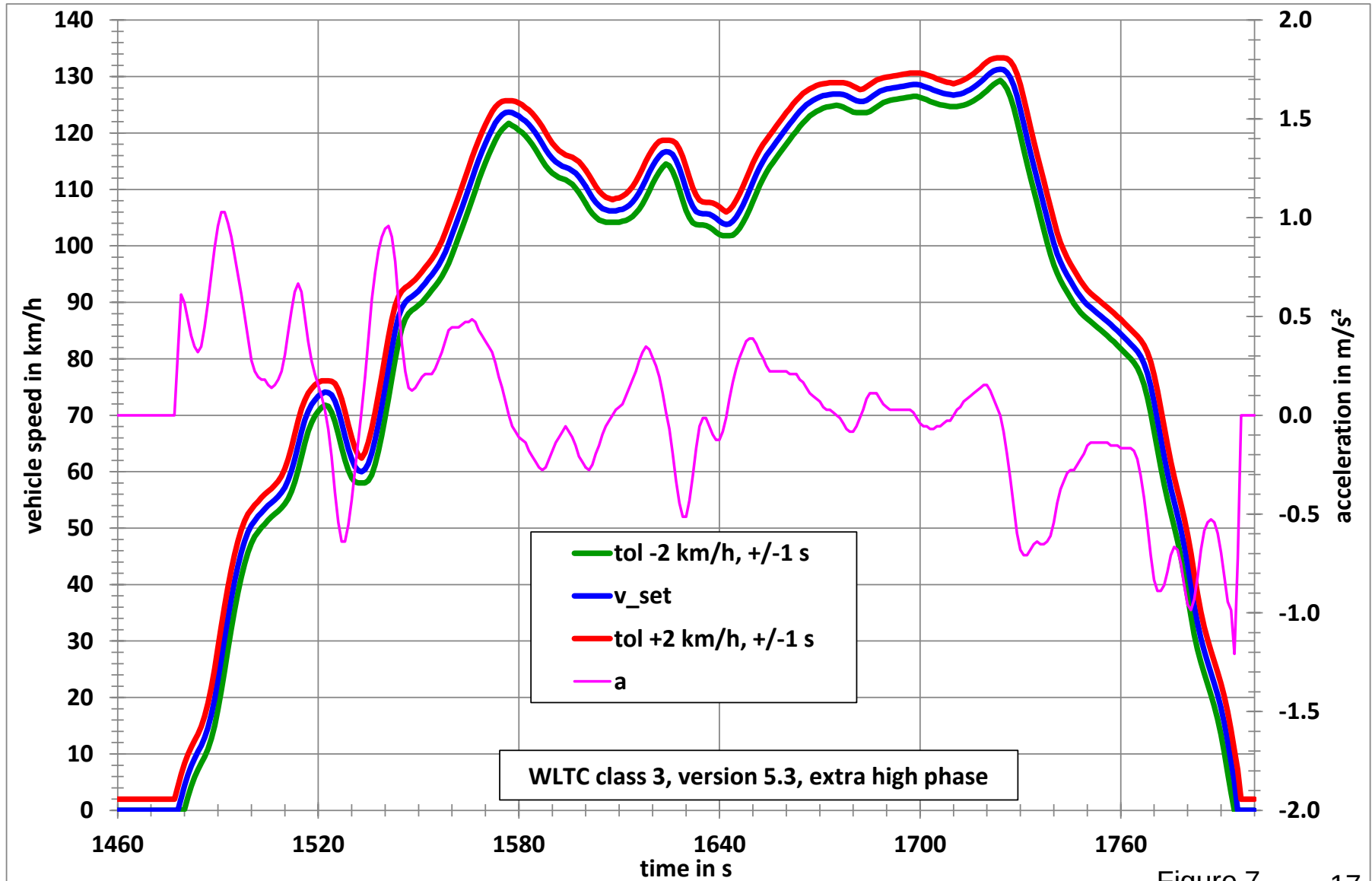


Figure 7

Comparison with NEDC, FTP 75 and JC08



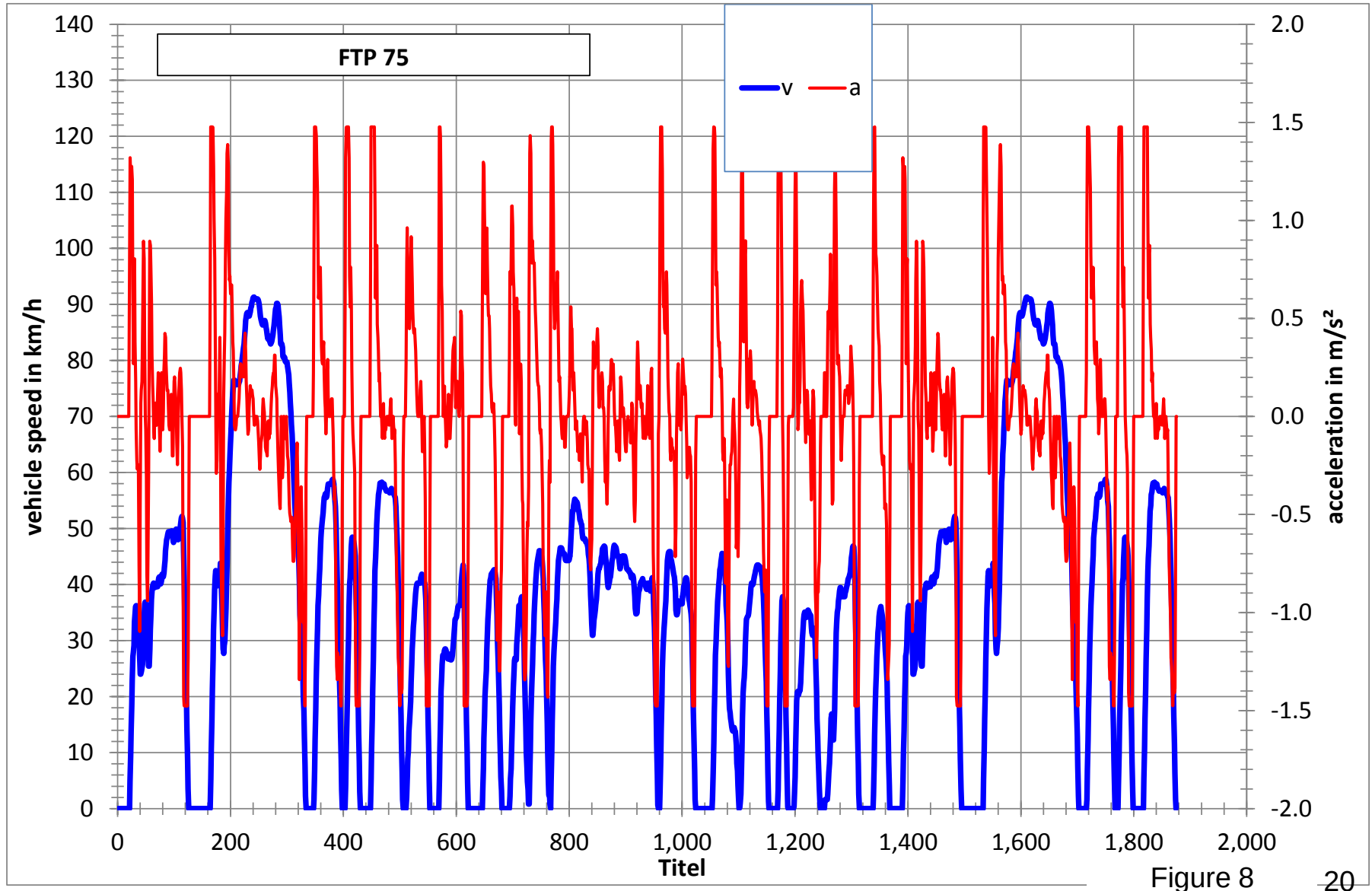
- Table 2 shows a comparison of the key cycle parameter for the WLTC, class 3, version 5.3 and the currently used type approval cycles FTP 75, NEDC and JC08.
- RPA is the relative positive acceleration. This is the sum of $v \cdot a \cdot dt$ for positive accelerations, divided by the cycle distance. It can be interpreted as acceleration as well as specific acceleration work. RPA is a good descriptor for the cycle dynamics.
- The time pattern of the current type approval cycles are shown in figures 8 to 10.
- The WLTC has lower stop percentages and higher speeds than the other cycles (see figures 11 and 12), the JC08 is the other extreme (highest stop percentages and lowest speeds).
- The NEDC has the lowest dynamics.

Key cycle parameter



cycle phase	duration	stop duration	distance	p_stop	v_max	v_ave without stops	v_ave with stops	a_min	a_max	a_pos ave	v*a_pos ave	RPA
	s	s	m		km/h	km/h	km/h	m/s ²	m/s ²	m/s ²	m ² /s ³	kWs/(kg*km)
WLTC class 3, version 5.3												
low	589	156	3,095	26.5%	56.5	25.7	18.9	-1.47	1.47	0.47	3.04	0.2046
medium	433	48	4,756	11.1%	76.6	44.5	39.5	-1.49	1.57	0.42	4.36	0.1964
high	455	31	7,162	6.8%	97.4	60.8	56.7	-1.49	1.58	0.37	4.49	0.1322
extra high	323	7	8,254	2.2%	131.3	94.0	92.0	-1.21	1.03	0.30	6.21	0.1249
all	1800	242	23,266	13.4%		53.8	46.5					0.1524
FTP 75												
1	507	101	5,783	19.9%	91.3	51.3	41.1	-1.48	1.48	0.52	5.14	0.1680
2	862	165	6,215	19.1%	55.2	32.1	26.0	-1.48	1.48	0.46	3.04	0.1751
3	507	101	5,783	19.9%	91.3	51.3	41.1	-1.48	1.48	0.52	5.14	0.1680
all	1876	367	17,780	19.6%		42.4	34.1					0.1704
NEDC												
urban	780	252	4,058	32.3%	50.0	27.7	18.7	-0.93	1.04	0.64	3.71	0.1426
extra urban	400	41	6,955	10.3%	120.0	69.7	62.6	-1.39	0.83	0.35	5.95	0.0932
all	1180	293	11,013	24.8%		44.7	33.6					0.1114
JC08												
1	651	129	5,322	19.8%	62.6	36.7	29.4	-1.13	1.53	0.40	3.39	0.1644
2	387	219	692	56.6%	33.8	14.8	6.4	-1.04	1.49	0.44	1.88	0.2286
3	166	9	2,158	5.4%	81.6	49.5	46.8	-1.08	1.17	0.35	3.97	0.1674
all	1204	357	8,172	29.7%		34.7	24.4					0.1707

FTP 75



NEDC

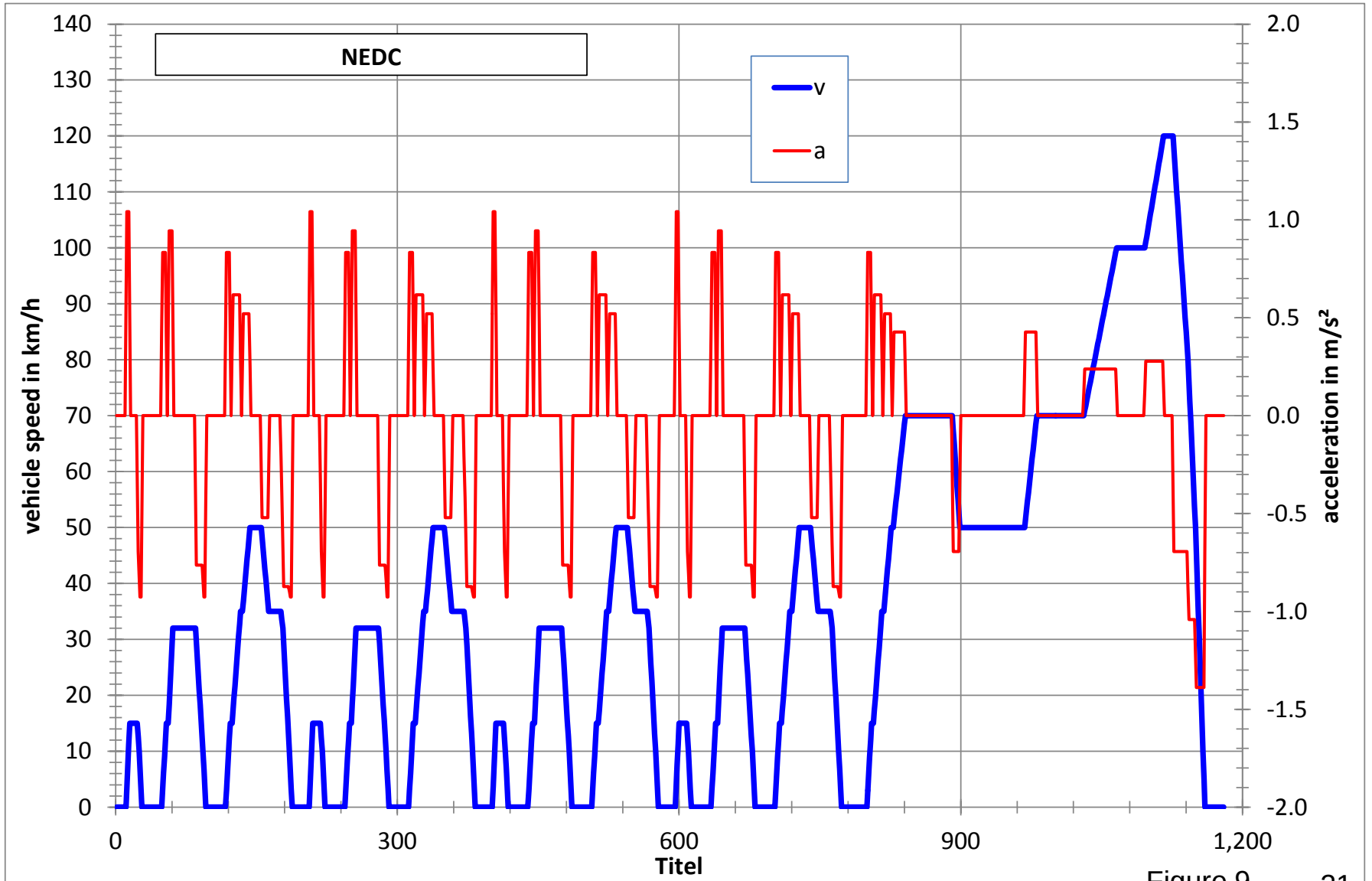


Figure 9

JC08

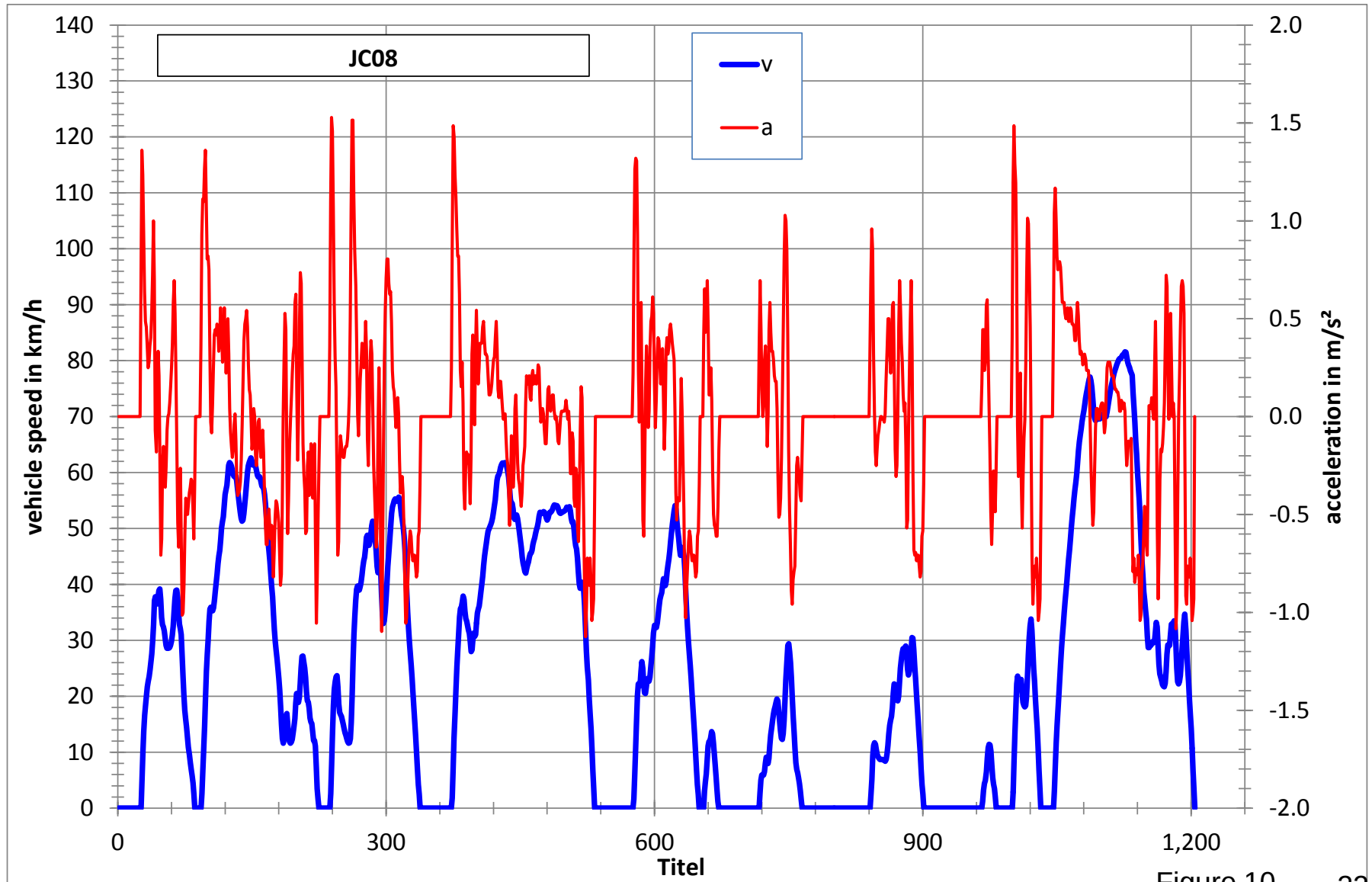


Figure 10

Average and maximum speeds

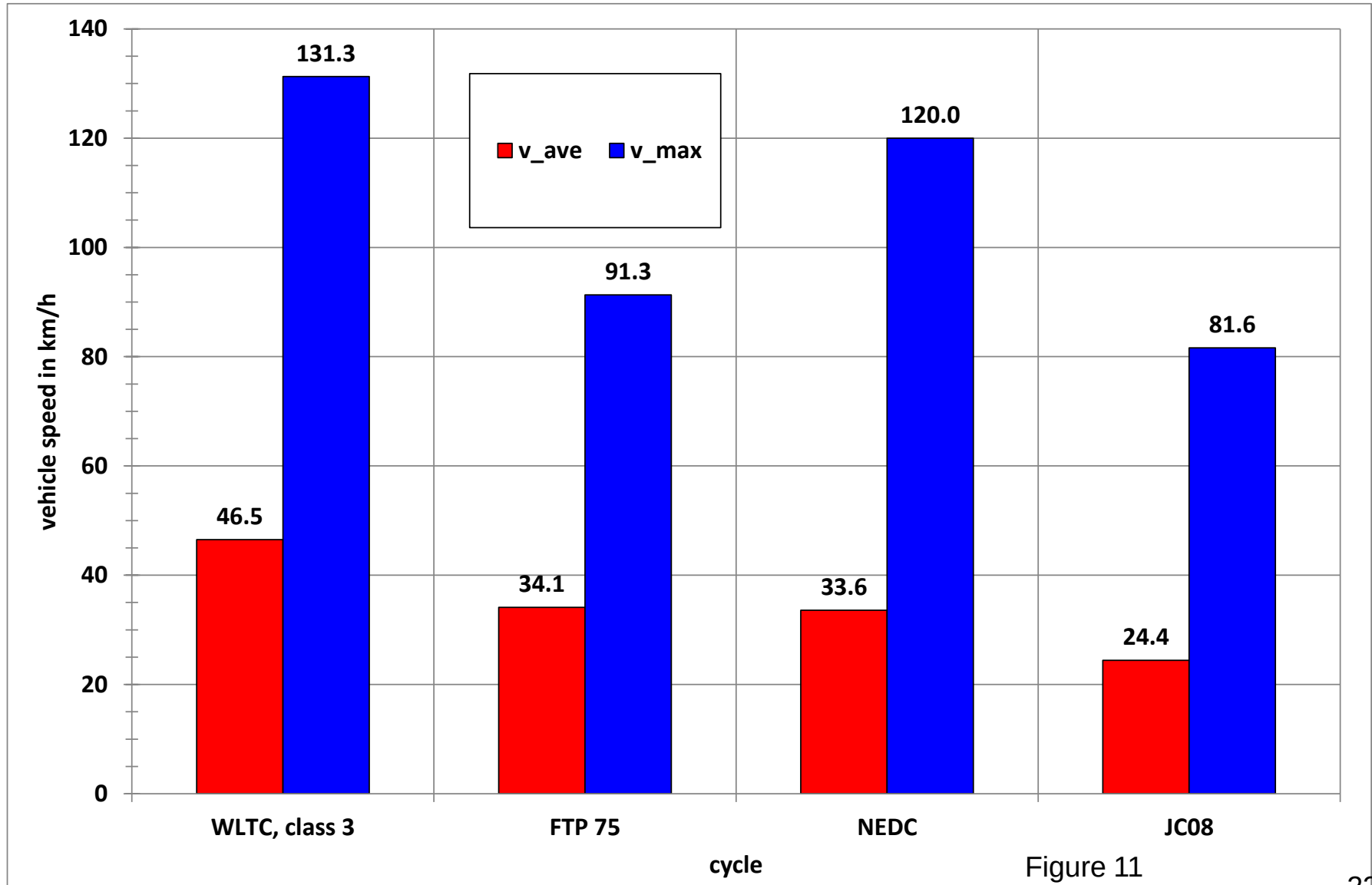
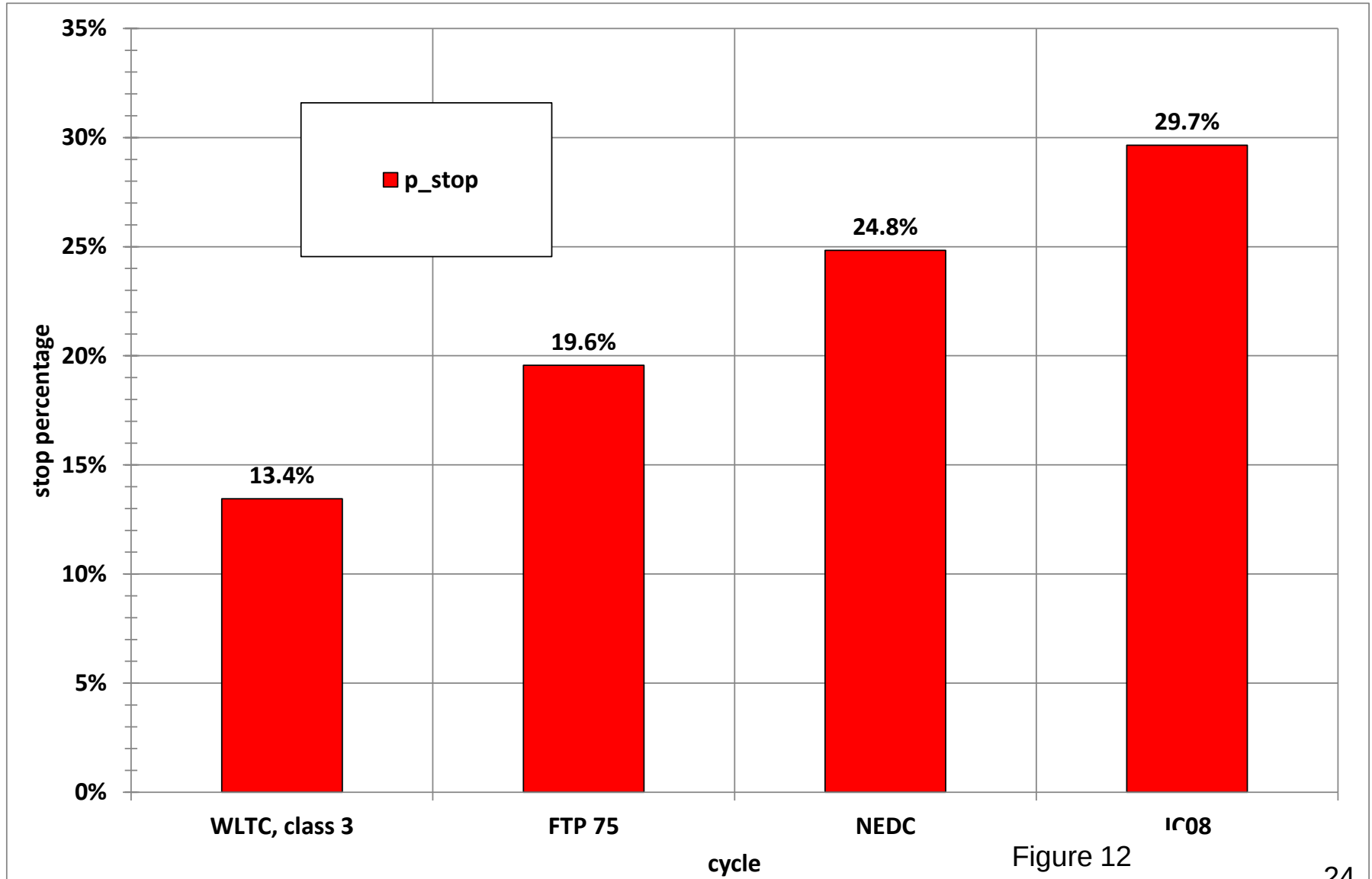


Figure 11

Stop percentages



Comparison with NEDC, FTP 75 and JC08



- The RPA values cannot be compared directly, they have to be assessed together with the average speed of a cycle without the stop phases.
- Figure 13 shows the percentiles (5%, 50% and 95%) of the RPA values from all short trips of the EU in-use database as function of the average speed of the short trips. The maxima of these curves are located between 15 km/h and 25 km/h.
- For higher average speeds the RPA values decrease with increasing speed.
- The RPA values of the different type approval cycles are also shown. They are located between the 5% and 50% curves. The WLTC is closest to the 50% curve, the NEDC is closest to the 5% curve, the values for the FTP 75 and JC08 are in between.
- This demonstrates that the WLTC has the highest and the NEDC the lowest dynamics.

RPA, in-use database percentiles

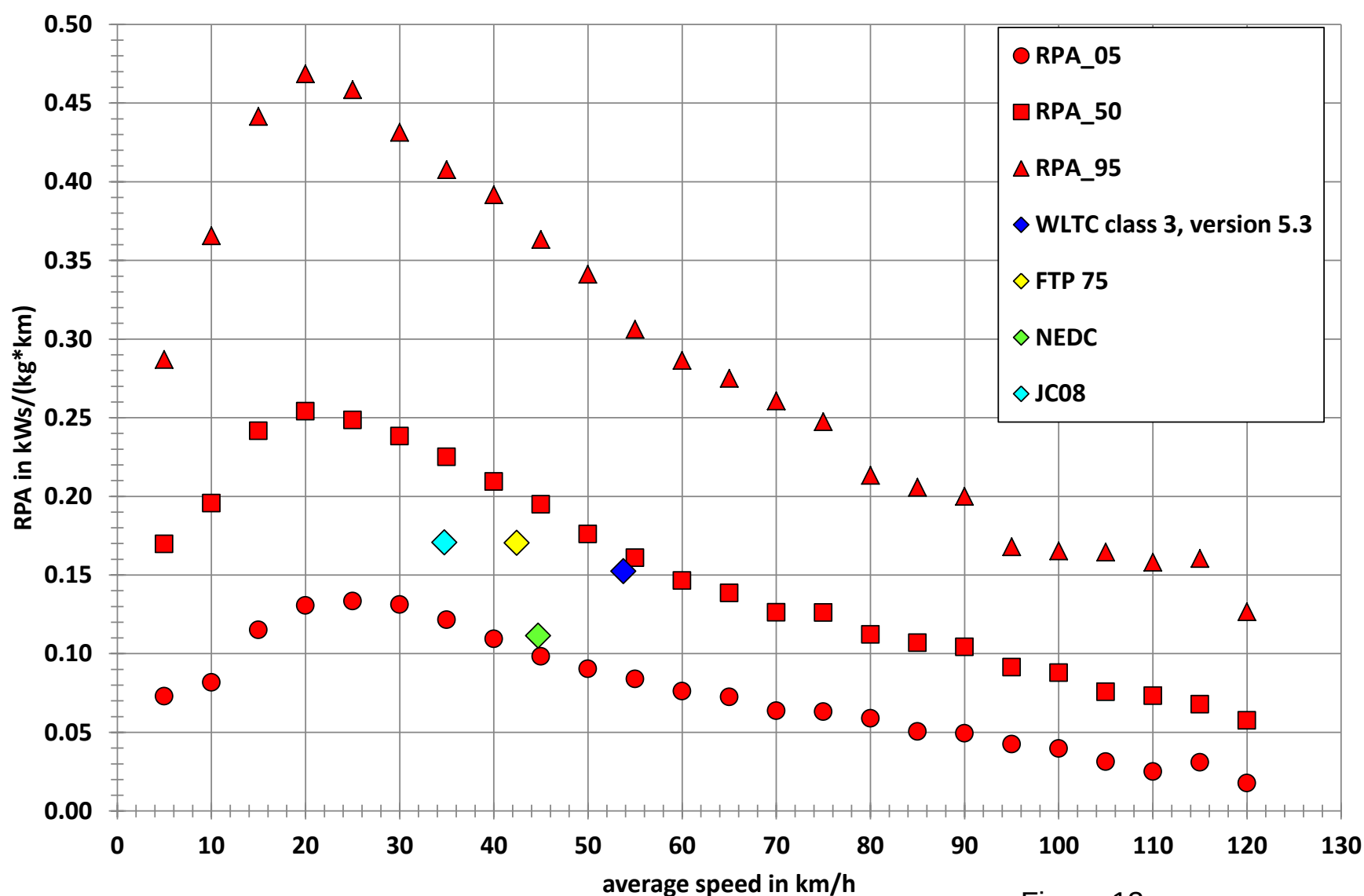


Figure 13

Comparison with NEDC, FTP 75 and JC08



- Figure 14 shows a comparison of the engine map coverage in terms of normalised engine speed and engine power for positive power values for a small Petrol car.
- Figure 15 shows corresponding results for a medium sized Diesel car.
- For a better comparison the WLTP gearshift prescriptions were used for all cycles.
- The engine speed range is correlated to the maximum cycle speed; the JC08 has the lowest and the WLTC the highest range.
- Concerning the engine load the NEDC is least and the WLTC most demanding.

Engine map comparison, small Petrol car

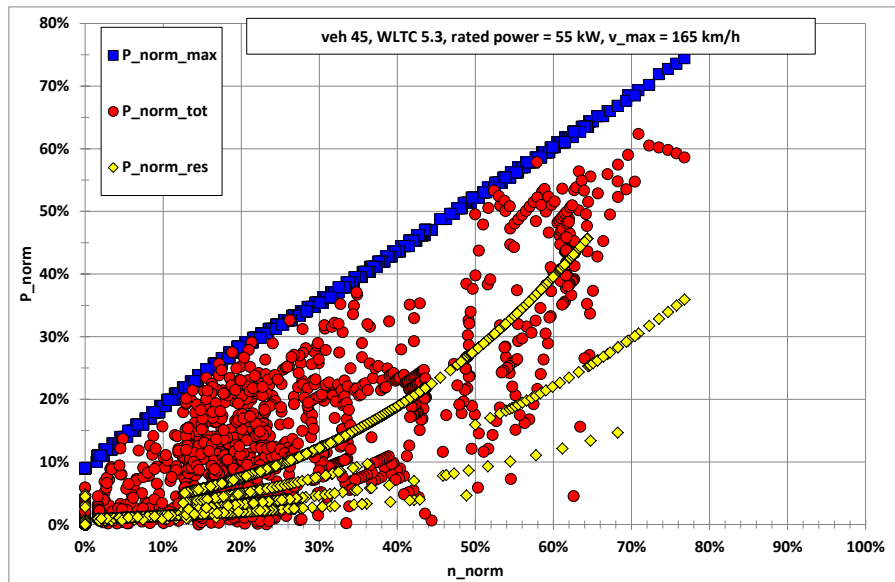
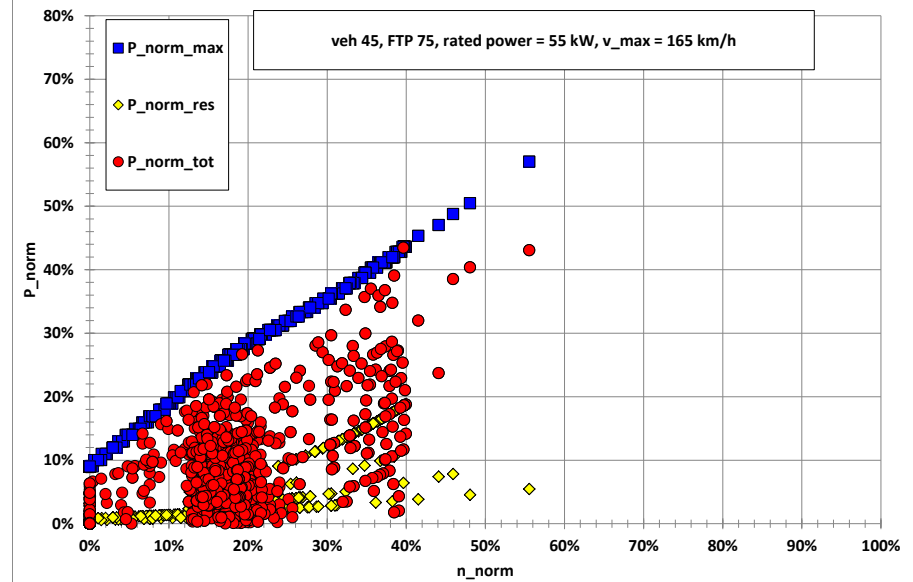
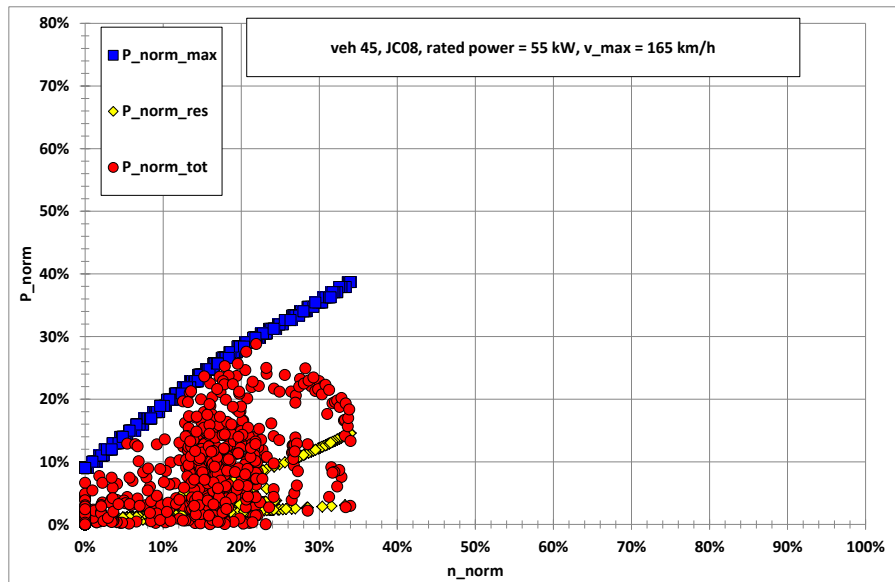
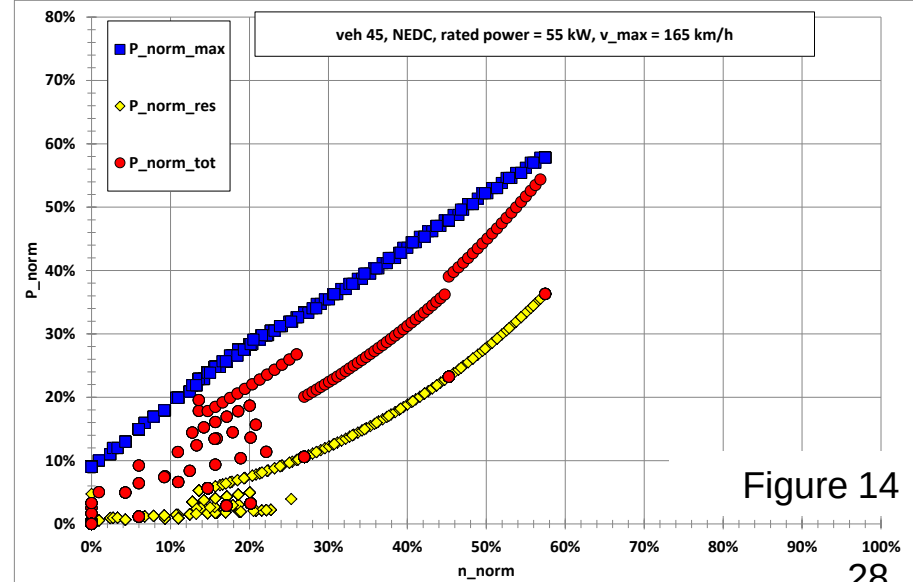


Figure 14

Engine map comparison, medium Diesel car

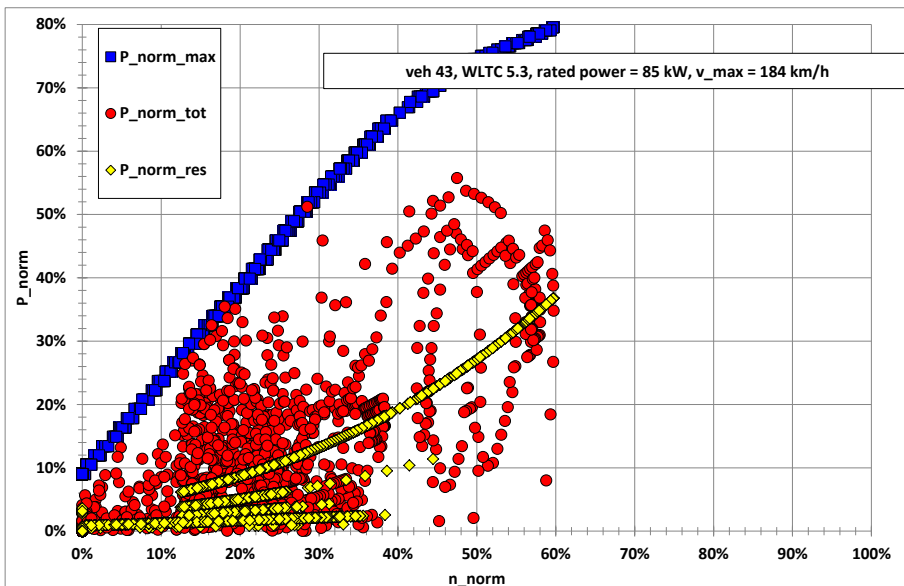
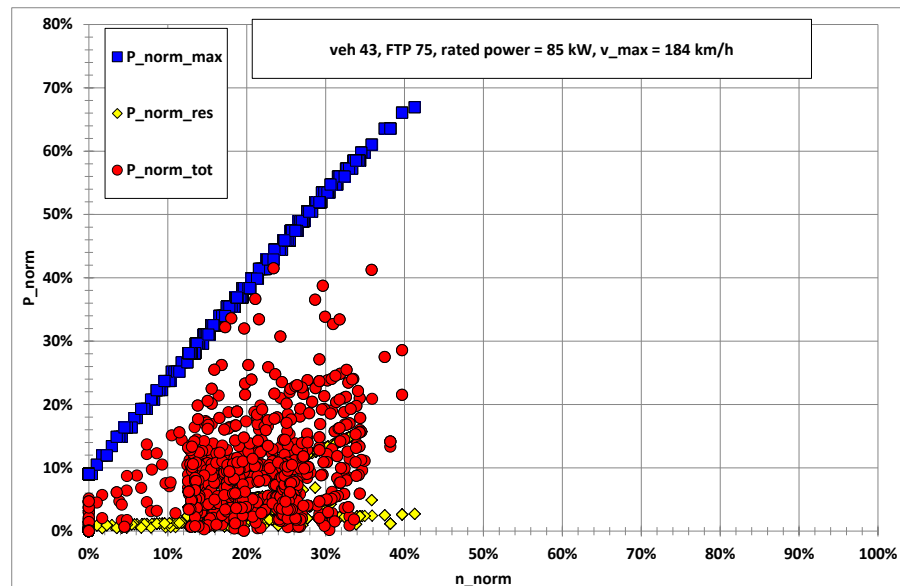
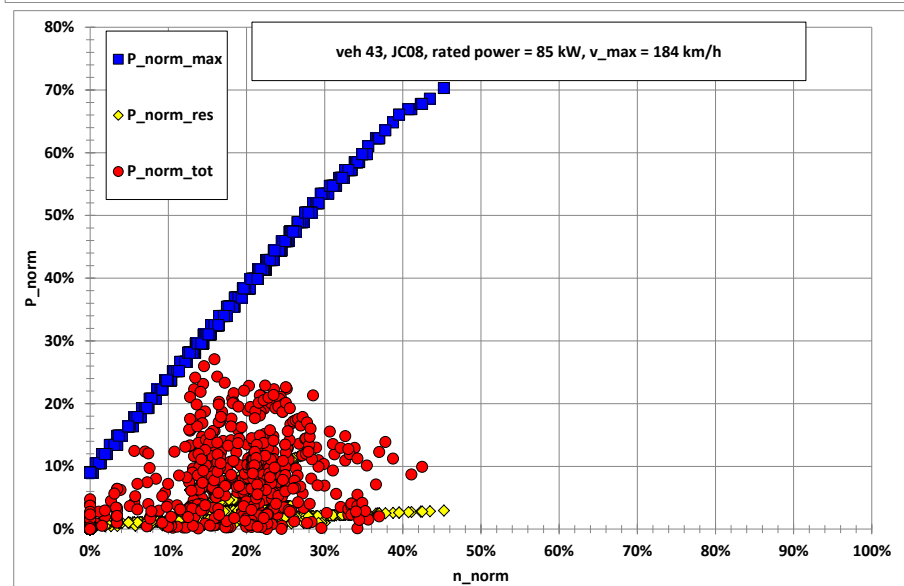
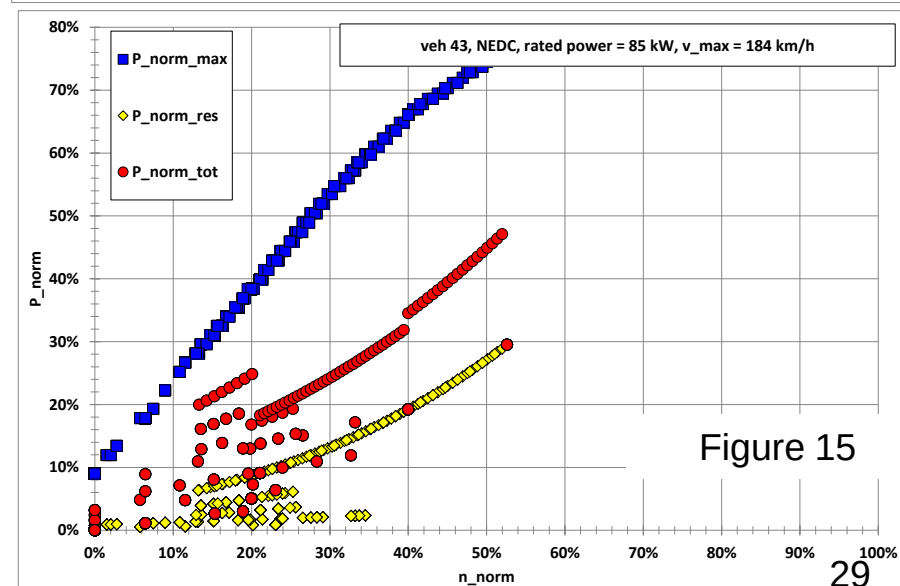


Figure 15

Comparison with NEDC, FTP 75 and JC08



- First emission tests during the validation phases showed that the CO₂ emissions of the WLTC are close to those of the NEDC, at least if the same side conditions in terms of test mass and road load settings are used and although the WLTC is much more dynamic than the NEDC.
- An explanation is given in figure 16, where the CO₂ emissions in g/km are displayed as function of average speed and the dynamic parameter $v \cdot a$. The solid curve ($v \cdot a = 0$) represents constant speed driving.
- The dotted curves represent deceleration and acceleration.
- The CO₂ emissions for the discussed cycles are also shown.
- The WLTC emissions are further away from the constant speed curve than the values for the other cycles, but the average speed is closer to the area of minimum CO₂ emissions (between 60 km/h and 80 km/h).

CO2 emission

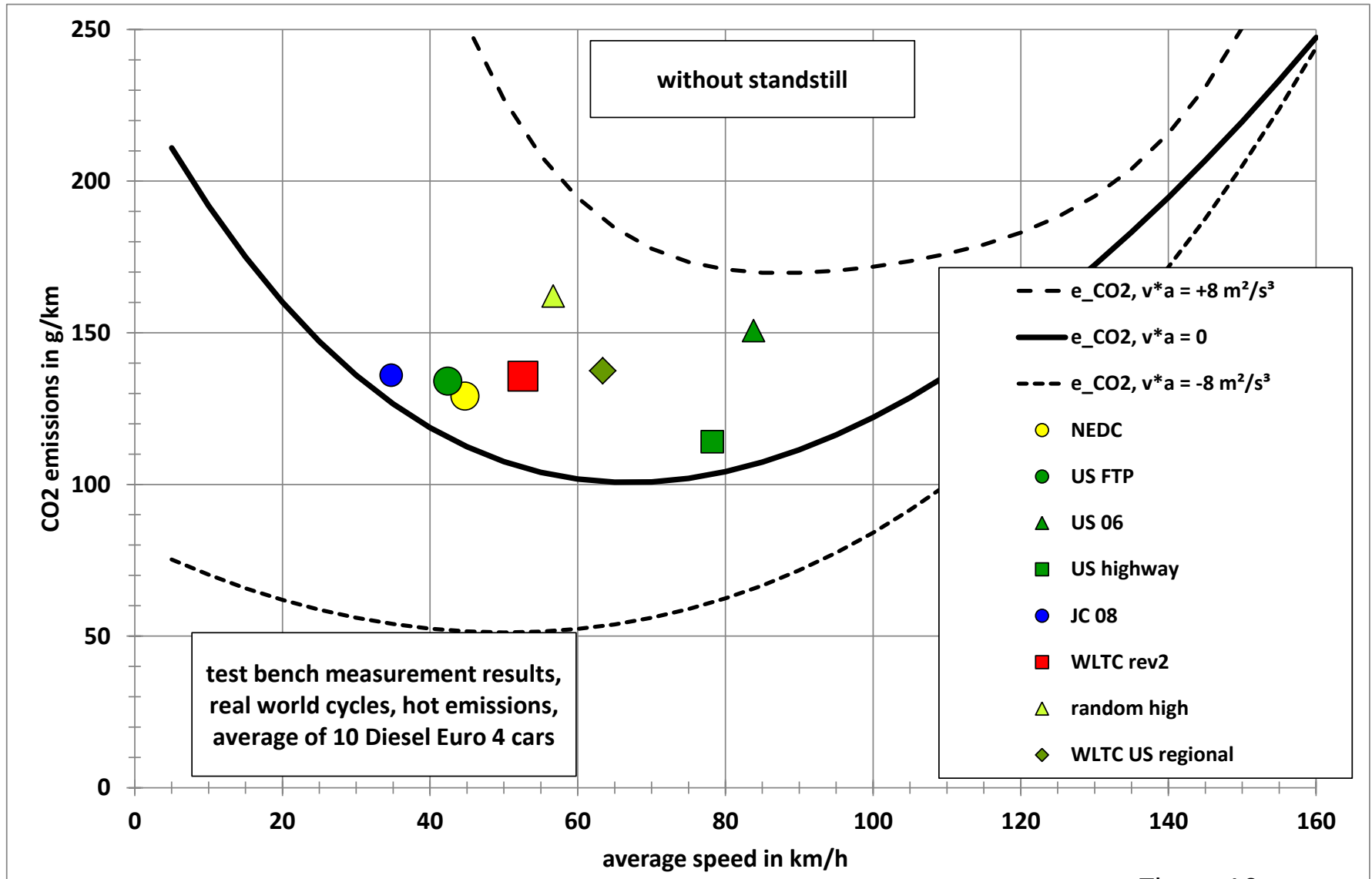


Figure 16

Status of the WLTP



- The current status of the WLTP can be summarised as follows:
- The cycle development phase is completed.
- The current discussions in the DHC subgroup (cycle development group) focus on the remaining issue, how to proceed with vehicles that cannot follow the cycle trace within the tolerances.
- For class 2 and class 3 vehicles this problem is exclusively related to the extra high speed phase.
- The author has proposed to solve this problem by downscaling of those extra high speed sections that cause high power demand (see figure 17).

Downscaling example

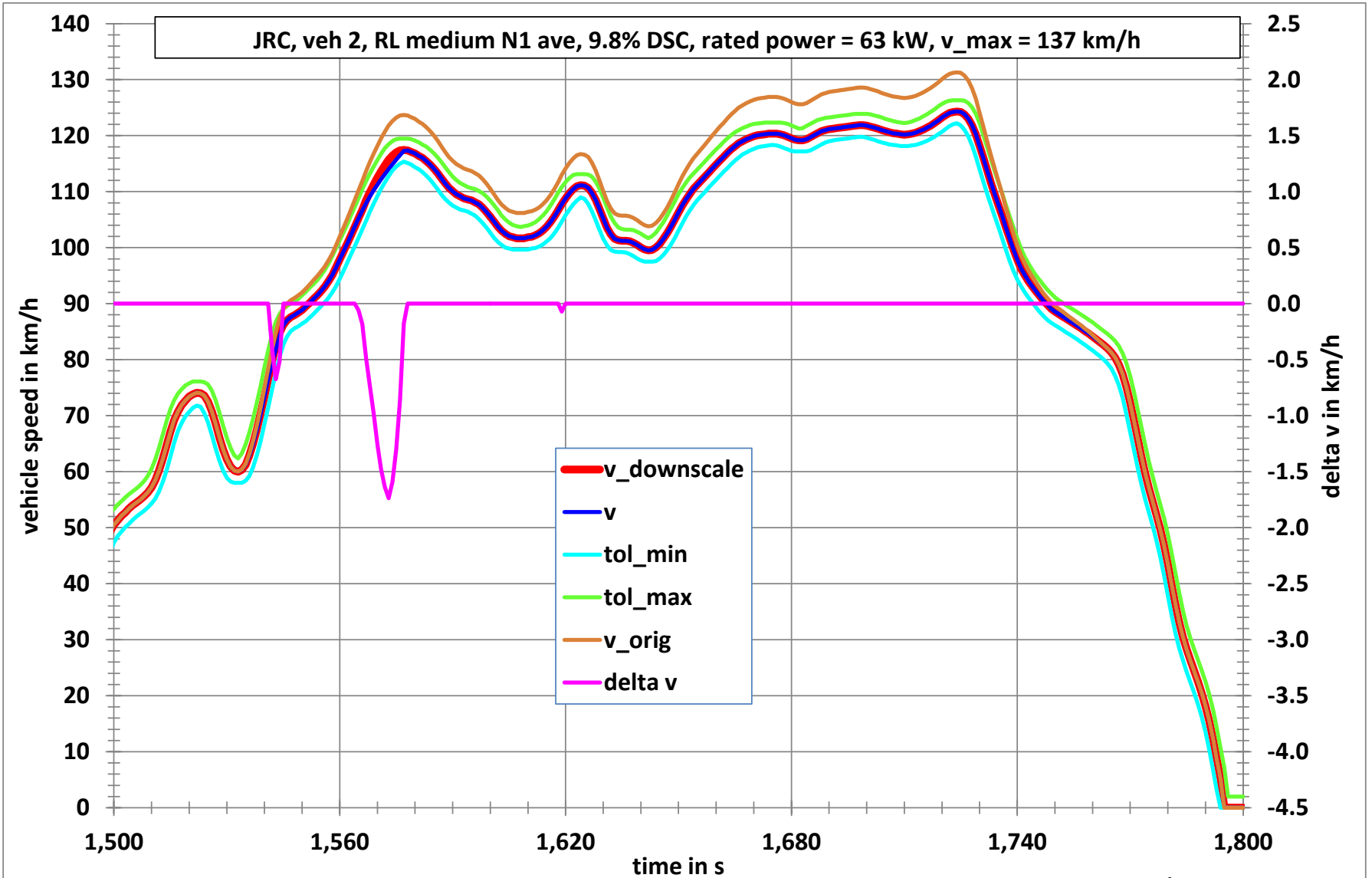


Figure 17

Status of the WLTP



- The DTP subgroup (test procedure development group) has already reached agreements about the test mass and the road load settings in principle, but some details still need to be resolved.
- The modifications will lead to higher test mass and driving resistances so that the CO₂ emissions will be higher compared to the current test conditions.

End



- Thank you for your attention!