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Development of a World-wide Worldwide harmonised Light duty driving Test Procedure (WLTP)

~ Draft Technical Report ~

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UN/ECE/WP.29/GRPE/WLTP-IG

DTP subgroup

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1 Introduction

The development of the WLTP was carried out under a program launched by the World Forum for the Harmonization of Vehicle Regulations (WP.29) of the United Nations Economic Commission for Europe (UN ECE) through the working party on pollution and energy (GRPE). The aim of this project was to develop, by 2014, a World-wide harmonised Light duty driving Test Procedure (WLTP). A roadmap for the development of a UN Global Technical Regulation (UN GTR) was first presented in August 2009.[1]

Most manufacturers produce vehicles for a global clientele or at least for several regions. Albeit vehicles are not identical worldwide since vehicle types and models tend to cater to local tastes and living conditions, the compliance with different emission standards in each region creates high burdens from an administrative and vehicle design point of view. Vehicle manufacturers therefore have a strong interest in harmonising vehicle emission test procedures and performance requirements as much as possible on a global scale. Regulators also have an interest in global harmonisation since it offers more efficient development and adaptation to technical progress, potential collaboration at market surveillance and facilitates the exchange of information between authorities.

Apart from the need for harmonisation, there was also a common understanding that the new test procedure was expected to represent typical driving characteristics around the world. Increasing evidence exists that the gap between the reported fuel consumption from type approval tests and the fuel consumption during real-world driving conditions has grown over the years. The main driver for this growing gap is the pressure put on manufacturers to reduce CO_2 emissions of the vehicles. As a result, this has led to exploiting the flexibilities available in current test procedures, as well as the introduction of fuel reduction technologies which show greater benefits during the test than on the road. Both issues are best managed by a test procedure and cycle that match the conditions encountered during real-world driving as close as possible.

Since the beginning of the WLTP process, the European Union had a strong political objective set by its own legislation (Regulations (EC) 443/2009 and 510/2011) to develop a new and more realistic test cycle by 2014. This very aspect has been a major political driving factor for setting the time frame of the phase 1 of the WLTP development.

The development of the WLTP took place taking into account that two main elements form the backbone of a procedure for vehicle emission legislation:

a) the driving cycle used for the emissions test, and

b) the test procedure which sets the test conditions, requirements, tolerances, and other parameters concerning the emission test

The development of the WLTP was structured accordingly, having two working groups in parallel.

This document is the technical report that describes the development of the test procedure, and explains the elements that are new or improved with respect to existing emission testing procedures.

The technical report on the development of the driving cycle is described in a separate document[2], which specifically focuses on the development process of the test procedure. There is also an Executive Summary, which shows the general scope and structure of the WLTP[3].

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[1] See document ECE/TRANS/WP.29/2009/131 - http://www.unece.org/fileadmin/DAM/trans/doc/2009/wp29/ECE-TRANS-WP29-2009-131e.pdf

[2] See document GRPE-68-03 http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/grpeinf68.html

[3] See document GRPE-67-05 http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/grpeinf67.html

2 Objective

This work aimed to develop a worldwide harmonised test procedure based on a world-wide harmonised light duty vehicle driving test cycle:

(a) the test procedure was intended to contain a method to determine the levels of gaseous and particulate emissions, fuel and electric energy consumption, CO_2 emissions and electric range in a repeatable and reproducible manner;

(b) the test cycle was meant to be representative of real-world vehicle operation.

The measurement resulting from the test procedure and the test cycle should form the basis for the regulation of light vehicles within regional type approval and certification procedures, as well as an objective and comparable source of information to consumers on the expected fuel/energy consumption (and electric range, if applicable).

3 Organisation, structure of the project and contributions of the different subgroups to the UN GTR

3.1 WLTP Informal Group

The development of the test procedure and the test cycle were assigned to the WLTP informal working group (WLTP-IG), established under the GRPE. The first meeting of the WLTP group took place in Geneva, on 4 June 2008. After the 4th meeting the WLTP informal group was disbanded and the steering group as shown in Figure 1 took the lead over the development process.

Three technical groups were established, each with a specific development task (Figure 1):

a) the development of the worldwide harmonised test cycle (DHC) group, to develop the Worldwide-harmonised Light-duty vehicle Test Cycle (WLTC), including validation test phase 1 to analyse the test cycle and propose amendments;
b) the development of the test procedure (DTP) group, to develop the test procedure, and to transpose this into a UN GTR;
c) the validation task force (VTF) group, to manage the validation test phase 2, and to analyse the test results and to propose amendments to the test procedure.

Figure 2 shows the road map for the development of WLTP, which started in September 2009.

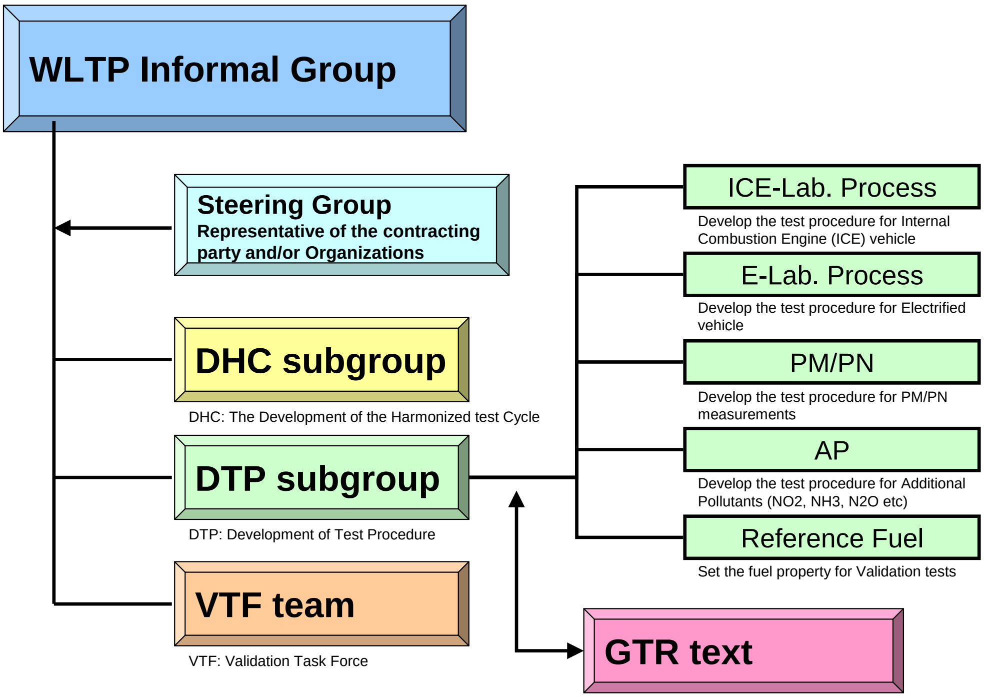

Figure 1: The structure of WLTP-IG

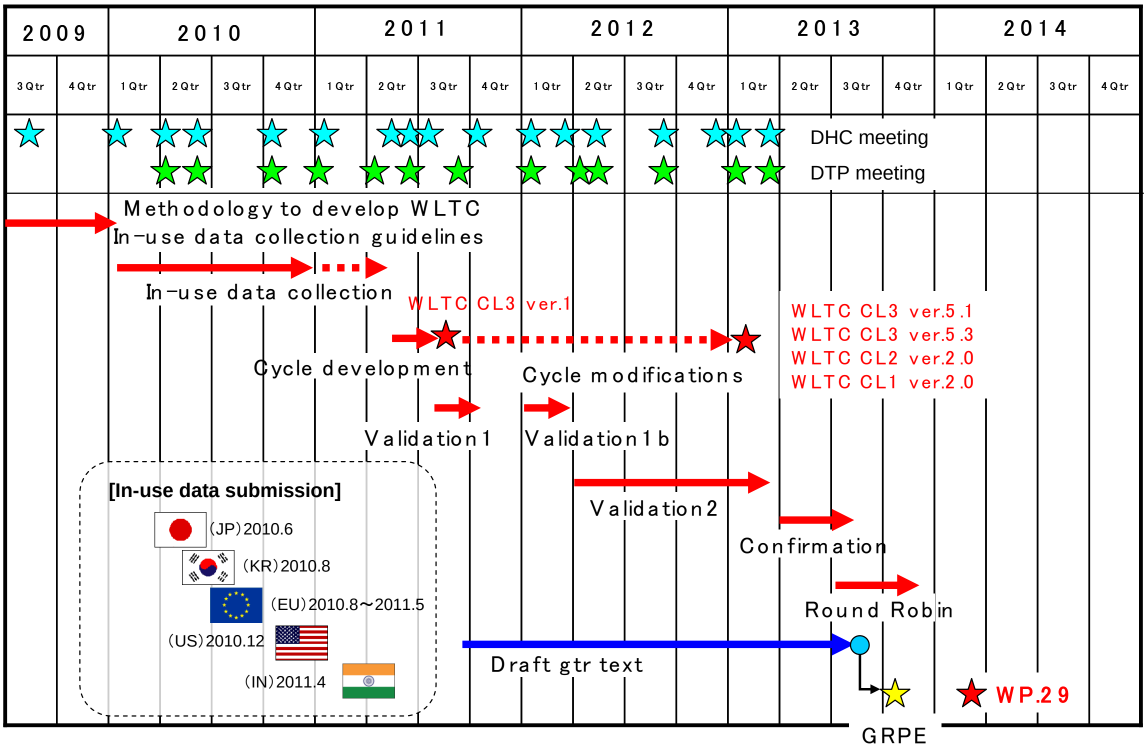

Figure 2: The time schedule for Cycle and Procedure development

3.2 DHC group

The structure and details of the DHC group are outside the scope of this report, and can be found in the Technical Report of the DHC[2] and/or in the Executive Summary[3].

3.3 DTP group and subgroups

The first meeting of the DTP subgroup took place at Ann Arbor (United States of America) from 13 to 15 April 2010. The DTP group was first chaired by Michael Olechiw (Environmental Protection Agency, United States of America). The chairmanship was later taken over by Giovanni D’Urbano (Federal Office for the Environment, Switzerland). Initially the secretary was Norbert Krause (International Organisation of Motor Vehicle Manufacturers (OICA)), later followed-up by Jakob Seiler (German Association of the Automotive Industry (VDA)).

Table 2
DTP Chairs and secretaries

Chair	*Secretary*
Michael Olechiw (Environmental Protection Agency, United States of America) Giovanni D’Urbano, Federal Office for the Environment (Switzerland)	Norbert Krause (OICA) Jakob Seiler, German Association of the Automotive Industry (VDA)

As indicated in Figures 1 and 2, there were five working groups established within the DTP group to promote an efficient development process by dealing with specific subjects of the test procedure:

a) laboratory procedures for internal combustion engine vehicles (LabProcICE) to work on the road-load determination and test procedures in the testing laboratory for conventional vehicles;

b) laboratory procedures for electrified vehicles (LabProcEV) to work on all test procedures that specifically address electrified vehicles;

c) particulate mass/particle number (PM/PN) to work on test procedures for the determination of particulate mass and particulate numbers in the exhaust gas;

d) alternative pollutants (AP) to work on test procedures for gaseous emission compounds other than CO_2, NO_x, CO and HC;

e) reference fuel (RF) to work on specifications for reference fuels used in emission testing.

The subgroup leaders were appointed at the second DTP meeting which was held in Geneva in June 2010[4] (see WLTP-DTP-02-03). After this meeting, the subgroups started their work and the following DTP meetings (14 in total until mid of 2013) were dedicated to discussions about the reports from the subgroups. The structure of the work distribution and the allocation of tasks are illustrated in Figure 4.

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[4] See document WLTP-DTP-02-03
http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/wltp_dtp02.html

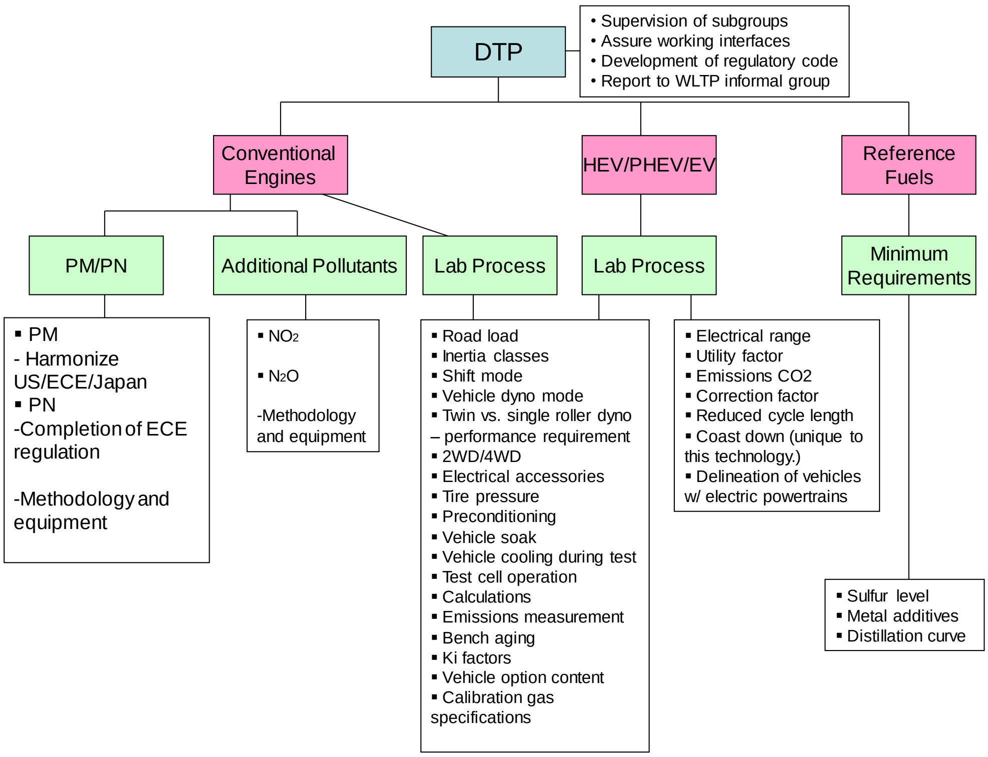

Figure 3: Structure of the DTP and its subgroups[5]

The structure of the work distribution and the allocation of tasks are illustrated in Figure 3. A more detailed overview for the scope of activities of these subgroups is presented in the next paragraphs.

3.3.1 Terms of Reference (ToR)

The terms of reference were the same for all subgroups and are listed below:

1. The working language of the subgroup will be English.
2. All documents and/or proposals shall be submitted to the Chair (in a suitable electronic format) in advance of scheduled meetings/web-conferences. Participants should aim to submit documents 5 working days in advance of meetings/web-conferences.
3. An agenda and related documents will be circulated to all subgroup participants in advance of all scheduled meetings/web-conferences.
4. Documents will also be uploaded by the Chair to the European Commission’s website and a link provided from the UN-ECE website.
5. The progress of the subgroup will be reported to DTP group meetings by the Chair (or other nominated person). Reporting will include a list of “Open Issues” on which agreement has yet to be reached within the subgroup, which will be updated by the Co-chair.

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[5] See document WLTP-DTP-01-14
http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/wltp_dtp01.html

6. Following each meeting/web conference the Chair (or other nominated person) will circulate a short status report, along with the list of “Open Issues” to chairs and co-chairs of DHC, DTP and other DTP subgroups.

Another point which is common to all subgroups is the development approach. The development of the measurement procedures was based on a review and comparison of already existing regional regulations in the Contracting Parties of the 1998 Agreement.

The scope of activity was dedicated to the issues covered by the tasks of the different subgroups and is further detailed in the following paragraphs.

3.3.2 Laboratory procedures for internal combustion engine vehicles (LabProcICE)

Chair	*Secretary*
Stephan Redmann, Ministry of Transport (Germany)	Dr. Werner Kummer, OICA
Béatrice Lopez de Rodas, UTAC (France)	Dr. Konrad Kolesa, OICA

The first meeting of this subgroup took place from 3 to 6 August 2010 in Ingolstadt, Germany. The LabProcICE subgroup had to develop a test procedure including vehicle preparation, vehicle configuration, vehicle operation, measurement equipment and formulae for the measurement of criteria pollutants, CO_2, and fuel consumption for internal combustion engine light duty vehicles. In addition, the LabProcICE subgroup was responsible for the development of the testing specifications that are in common with electrified vehicles.

The scope of activity for this subgroup covered[6]:

a) the identification of the content of Contracting Party legislation relevant to laboratory procedures for conventionally fuelled light duty vehicles excluding PM/PN and additional pollutants measurement procedures (see Annex 1 for an overview);

b) the comparison of the relevant content of Contracting Party legislation (United States of America, Japan, UN ECE);

c) deciding upon which content to use for WLTP or, where appropriate, to specify alternative requirements for WLTP;

d) if necessary, conducting improvements on the basis of the following principles:

    (i) narrow tolerances/flexibilities to improve reproducibility;

    (ii) cost effectiveness;

    (iii) physically reasonable results;

    (iv) adapted to new cycle;

    (v) adapted to technical progress of measurement equipment;

e) drafting laboratory procedures for internal combustion engine light duty vehicles and specification text.

In LabProcICE the work was further structured into the following three subjects:

a) Road load determination,

b) Test procedure,

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[6] See document WLTP-DTP-LabProcICE-002-ToR-V3, available at CIRCABC under WLTP-DTP section

c) Emission measurement/calculations.

The different sections of a first draft GTR proposal, based on GTR's 2 and 4, were marked according to agreements, proposals and open issues. Not surprisingly, the majority of points was marked as "open issues" at the beginning of the work

The LabProcICE subgroup was responsible for the following annexes of the UN GTR:

a) Annex 4 - Road and dynamometer load. This Annex describes the determination of the road load of a test vehicle and the transfer of that road load to a chassis dynamometer. Annex 4 has the following appendices:
   (i) Appendix 1 - Calculation of road load for the dynamometer test;
   (ii) Appendix 2 - Adjustment of chassis dynamometer load setting;

b) Annex 5 - Test equipment and calibrations;

c) Annex 6 - Type 1 test procedure and test conditions. This test verifies the emissions of gaseous compounds, particulate matter, particle number, CO_2 emissions, and fuel consumption, in a representative driving cycle. Annex 6 has the following appendices:
   (i) Appendix 1 - Emissions test procedure for all vehicles equipped with periodically regenerating systems,
   (ii) Appendix 2 - Test procedure for electric power supply system monitoring.

d) Annex 7 – Calculations. All the necessary steps are included to work out the mass emissions, particle numbers and cycle energy demand, based on the test results. CO_2 and fuel consumption are calculated for each individual vehicle within the CO_2 vehicle family.

Those parts of Annexes 5 and 6 that are dealing with particles and additional pollutants were developed by the corresponding (PM/PN and AP) subgroups.

3.3.3 Laboratory procedures for electrified vehicles (LabProcEV)

Chair	*Secretary*
Per Öhlund – Swedish Transport Agency (Sweden) Kazuki Kobayashi - NTSEL (Japan)	Yatuka Sawada, OICA

The first meeting of this subgroup took place at 21.09.2010. The LabProcEV subgroup was tasked with developing a test procedure which includes vehicle preparation, vehicle configuration, vehicle operation, measurement equipment and formulae for the measurement of criteria pollutants, CO_2, fuel consumption and electric energy consumption for electrified vehicles.

The scope of activity was described as follows[7]:

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[7] See document WLTP-DTP-E-LabProc-001-ToR._V2, available at CIRCABC under WLTP-DTP section

a) identify content of Contracting Party legislation relevant to laboratory procedures for Electrified vehicles excluding PM/PN and additional pollutants measurement procedures;

b) compare relevant content of Contracting Party legislation (US, UN ECE, Japanese);

c) decide upon which content to use for WLTP or, where appropriate, to specify alternative requirements for WLTP;

d) identify additional performance metrics associated with electrified vehicles that may not be covered by existing regulations. (i.e. battery charging times). Create harmonised test procedures for the new performance metrics;

e) if necessary, conduct improvements on the basis of the following principles:

    (i) narrow tolerances / flexibilities to improve reproducibility;

    (ii) cost effectiveness;

    (iii) physically reasonable results;

    (iv) adapted to new cycle.

f) draft laboratory procedures for electrified light duty vehicles and specification text.

The LabProcEV subgroup was responsible for Annex 8 (pure and hybrid electric vehicles) of the UN GTR. This is where measurement procedures and equipment dedicated to electric vehicles (and deviating from Annexes 5 and 6) are defined.

3.3.4 Particulate mass/Particulate number (PM/PN)

Chair	*Secretary*
Chris Parkin, Department for Transport (United Kingdom)	Caroline Hosier, OICA (after Chris Parkin left WLTP she chaired this subgroup)

The PM/PN subgroup started its work by a web/phone conference at 07.07.2010. The scope of activity included the following tasks[8]:

a) identify content of Contracting Party legislation relevant to PM and PN measurement procedures;

b) compare relevant content of Contracting Party legislation (US, UN ECE, Japanese);

c) decide upon which content to use for WLTP or, where appropriate, to specify alternative requirements for WLTP;

d) draft PM and PN measurement procedure and specification text.

The approach taken by the PM/PN group was to start from a detailed comparison of the regulations from European Union, Japan and the United States of America. PM/PN established a number of small expert teams to review and make recommendations back to the wider team on measurement equipment specifications, particulate mass sampling, weighing and all aspects of particle number measurement.

PM measurement is made by collecting the particulate on a filter membrane which is weighted pre and post-test in highly controlled conditions. It was decided to update the requirements as far as possible for technical progress and harmonisation, in such a way that

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[8] See document WLTP-DTP-PMPN-01-02 Rev.2, available at CIRCABC under WLTP-DTP section

it would not require to replace the majority of existing particle mass measurement systems. A major aspect of this decision is that particle number is also measured.

Regarding PN, only the UN Regulation No. 83 contains particle number measurement requirements. Particle number measurement is an on-line measurement process to count solid particles in the legislated size range in real time, where the total number of particles per kilometre is reported for the test. The experts on particle number measurement reviewed the procedure in detail to identify opportunities for tightening the tolerances to improve repeatability / reproducibility as well as improvements to the process and calibration material specifications to adapt this method to recent technical progress.

The work of the PM/PN subgroup was incorporated in relevant parts of Annex 5, 6 and 7 of the UN GTR.

3.3.5 Additional pollutants (AP)

Chair	*Secretary*
Oliver Mörsch – OICA	Covadonga Astorga, Joint Research Centre (European Commission)

The first web/phone meeting of the AP subgroup took place at 20.07.2010.

The scope of activity for the AP subgroup (see WLTP-DTP-AP-01-01) included the following tasks, building on procedures in existing legislation and expert knowledge within the group:

a) agree on additional pollutants to be addressed;

b) identify appropriate measurement methods for each of the pollutants;

c) describe measurement and calibration procedures and calculations based on existing legislation and on output from lab procedure subgroup;

d) draft legislation text.

The following guidelines have been applied for the development of measurement methods for the additional pollutants:

a) use or modify existing methods where ever reliable, cost effective and easy to apply technologies are available;

b) reflect state of the art;

c) stipulate development of new measurement technologies;

d) replace cumbersome offline methods by online methods.

The work of the AP subgroup was incorporated in relevant parts of Annex 5, 6 and 7 of the UN GTR.

3.3.6 Reference fuel (RF)

Chair	*Secretary*
William (Bill) Coleman – OICA	

No separate meetings were held for the RF subgroup. The scope of activity for the RF subgroup was described as follows:

a) defining a set of validation fuels to support the development stages of the WLTP project (stage 1), and;

b) defining a framework for reference fuels to be used by Contracting Parties when applying the WLTP UN GTR (stage 2).

The scope of activity is related to stage 1. The subgroup had to undertake the following tasks on the basis of a comparison of reference fuels in existing legislation and expert knowledge within the group:

a) agree a limited number of fuel types and/or blends for which reference fuels are expected to be required in the time frame of implementation of the WLTP project;

b) identify a list of fuel properties that will be significant to the validation of a future drive cycle and/or test procedure for emissions and/or fuel consumption;

c) propose limits for the variation of these critical properties in order to specify a limited number of candidate validation fuels to assess potential impact of the future drive cycle on emissions and/or fuel consumption;

d) obtain approval from the WLTP project for the technical scope of the validation fuels described in (c);

e) upon approval of the above mentioned parameter list, develop specifications for candidate validation fuels to be used in the validation of the proposed drive cycles and test procedures. These fuels should be limited in number, available at reasonable cost and are not intended to restrict the decisions regarding reference fuels for the final implementation of WLTP (Stage 2);

f) provide a forum of reference fuel experts who can at relatively short notice provide coordinated advice and support on fuel related project issues to members of other sub-groups of the WLTP Project.

These tasks required a fruitful cooperation with experts from the fuel production industry. Since this cooperation could not be established, points (a) to (d) and (f) could not be fulfilled. Already defined regional reference fuels were used for the validation tests of the proposed drive cycles and test procedures.

As a consequence, Annex 3 of the UN GTR dedicated to reference fuels consists only of the two paragraphs, requiring the recognition of regionally different reference fuels, proposing examples of reference fuels for the calculation of hydrocarbon emissions and fuel consumption, and recommending that Contracting Parties select their reference fuels from the Annex. The text recommends to bring regionally agreed amendments or alternatives into the UN GTR by amendments, without limiting the right of Contracting Parties to define individual reference fuels to reflect local market fuel specifications.

In addition to that, tables with specifications for the following fuel types are included in the UN GTR:

a) liquid fuels for positive ignition engines:

    (i) gasoline/petrol (nominal 90 RON, E0);

    (ii) gasoline/petrol (nominal 91 RON, E0);

- (iii) gasoline/petrol (nominal 100 RON, E0);
- (iv) gasoline/petrol (nominal 94 RON, E0);
- (v) gasoline/petrol (nominal 95 RON, E5);
- (vi) gasoline/petrol (nominal 95 RON, E10)
- (vii) ethanol (nominal 95 RON, E85);

b) gaseous fuels for positive ignition engines:

- (i) LPG (A and B);
- (ii) natural gas (NG)/biomethane:
  - a. "G20" "High Gas" (nominal 100 % methane);
  - b. "K-Gas" (nominal 88 % methane);
  - c. "G25" "Low Gas" (nominal 86 % methane);
  - d. "J-Gas" (nominal 85 % methane)

c) liquid fuels for compression ignition engines:

- (i) J-Diesel (nominal 53 Cetane, B0);
- (ii) E-Diesel (nominal 52 Cetane, B5);
- (iii) K-Diesel (nominal 52 Cetane, B5);
- (iv) E-Diesel (nominal 52 Cetane, B7).

4 Test procedure development

4.1 General Purpose and Requirements

Increasing evidence exists that the gap between the reported fuel consumption from type approval tests and fuel consumption during real-world driving has increased over the years. The main driver for this growing gap is linked to the flexibilities available in current test procedures, as well as the introduction of fuel reduction technologies which show greater benefits during the existing cycle than on the road. Both issues are best managed by a test procedure representing the conditions encountered during real-world driving. As explained in the introduction, this is the main objective for developing the WLTP. By bringing the test conditions and driving characteristics of the test as close as possible to how vehicles are used in practice, the fuel consumption levels of test and reality are most likely to correspond. The results from such a representative test would then implicitly serve as an objective and comparable source of information to legislators and consumers.

At the same time, striving for the most representative test conditions might conflict with other important test attributes. There are a number of constraints that need to be observed for the development of the test procedure, such as:

a) Repeatability
If the test is repeated in the same conditions and in the same laboratory, the test result should be similar (within a certain tolerance for accuracy). This means that e.g. all conditions at the start of the test (such as the battery state-of-charge) should be well-defined. If it is difficult to control or measure a vehicle parameter, it will be necessary to fix the start condition at a worst- or best-case value while in representative driving conditions this parameter may always be somewhere in between. Some of the ‘representativeness’ of the test is then sacrificed to obtain repeatability.

b) Reproducibility
If the test is repeated in the same conditions in a *different* laboratory, the test result should be similar (within a certain tolerance for accuracy). If results from all labs over the world have to be the comparable, this sets restrictions to the test conditions and the use of cutting-edge measurement instruments. For instance, the test temperature level cannot be chosen too low, since there are also many laboratories in areas with high ambient temperatures.

c) Cost-efficiency
Covering all the effects that test conditions and driving characteristics have on the fuel consumption and emissions would require a lot of different tests. The costs for this high test burden will eventually be charged to the consumers, so there needs to be a balance between test effort and results. Additional testing can only be justified if variations in conditions have a significant effect on the result. Therefore, some of the 'representativeness' of the test is compromised to reduce the test burden. For example, the length of the test cycle is only 30 minutes, which is a challenging timeframe to contain all of the world's driving characteristics.

d) Practicability
A test procedure needs to be executable in a practical way, without asking unrealistic efforts from the testing personnel and/or the test equipment. That would be the case, for instance, if tyres were required to be run-in at a test track by a test driver until they have worn down to a certain level. Normally, such requirements will also have issues relating to the other constraints such as the cost-efficiency. There may also be practical restrictions to the test vehicle itself, e.g. monitoring the temperature in the catalyst, or monitoring the battery state-of-charge with current transducer clamps in the engine bay.

The general purpose for the DTP was therefore to primarily aim at the testing procedure that is most representative for real-world conditions, but within the boundaries of it being repeatable, reproducible, cost-effective and practicable. During the discussions in the development process, this often led to conflicts in choosing which method to apply.

4.2 Approach

For the development of the test procedures, the DTP sub-group took first into account existing emissions and energy consumption legislation, in particular those of the UN ECE 1958 and 1998 Agreements, those of Japan and the US Environmental Protection Agency Standard Part 1066. A detailed overview of the regional emission legislations that were studied for the UN GTR is included in Annex 1. These test procedures were critically reviewed and compared to each other to find the best starting point for the draft text of the UN GTR. The development process focused in particular on:

a) updated specifications for measurement equipment towards the current state-of-art in measurement technology;

b) increased representativeness of the test and vehicle conditions, in order to achieve the best guarantee for similar fuel efficiency on the road as under laboratory conditions;

c) ensure the capacity to deal with current and expected technical progress in vehicle and engine technology in an appropriate and representative way. This particularly involves the section on electrified vehicles.

As such, the GTR text was updated and complemented by new elements where necessary. For this technical report it would be too comprehensive to list all the modifications that were introduced. General updating activities -such as bringing the accuracy requirements of the instrumentation to the current state of the art- need no further clarification and fall outside of the scope. Instead, the important changes that have contributed the most in achieving an improved and representative test procedure will be identified and explained.

Paragraph 4.3 generally outlines the main improvements in the GTR. The modifications that need some more clarification or justification will be detailed in Paragraph 4.4.

4.3 Improvements in the GTR

As a result of extensive analyses and discussions among the stakeholders, the WLTP GTR has managed to improve on many aspects of the existing emissions testing procedures. These include:

a) The use of state-of-the-art measurement equipment with tightened tolerances and calibration techniques to take advantage of advancements in measurement technology (including NO_2 and N_2O emissions);
b) More stringent requirements imposed on the test vehicle and test track used in determining the representative road load;
c) New procedures to measure fuel/energy consumption and emissions of electric vehicles and hybrids, as well as to determine the effect of other anticipated future drive train technologies;
d) Improved methods to correct measurement results for parameters related to fuel consumption and CO_2 emissions (e.g. test temperature, vehicle mass, battery state of charge).

On a more detailed level, the following list shows the improvements on specific aspects of the testing methodology which have contributed to increase the representativeness of the test results:

- Instead of declaring one CO_2 value for an entire family of vehicles (as currently required by EU legislation) each individual vehicle within a vehicle family will receive a CO_2 value based on its individual mass, rolling resistance and aerodynamic drag, as determined by its standard and optional equipment. In WLTP, this was called the ‘combined approach’, but in the GTR it is referred to as the ‘CO_2 interpolation method’. It considers the combined CO_2 influences of mass, rolling resistance and aerodynamic performance characteristics.

- The test-mass of the vehicle is raised to a more representative level, and is made dependent on the payload. Also, instead of using discrete inertia steps, the simulated inertia corresponds exactly to the test mass.

- The difference in battery state-of-charge over the cycle is monitored and the fuel consumption corrected as needed based upon changes in battery state-of-charge over the cycle. Battery state-of-charge at the start of the test is changed from fully charged (NEDC) to a representative start value (the fully charged battery will be partially depleted by first driving a WLTC as preconditioning cycle).

- The test temperature in the laboratory is modified from a range of 20 to 30°C (NEDC) to a set point of 23 °C.

- Requirements and tolerances with respect to the road load determination procedure are strengthened and improved:

    - The test vehicle and tyre specifications must be similar to those of the vehicle that will be produced;

    - Test tyre preconditioning are more stringent (tread depth, tyre pressure, run-in, shape, no heat treatment allowed, etc.) to more closely match the tyre conditions on production vehicles;

  - Use of on-board anemometry will be permitted, and the correction method applied for wind during the coast-down method is improved (both for stationary wind measurement as for on-board anemometry);
  - Special brake preparation to avoid parasitic losses from brake pads touching the brake discs will be prevented;
  - Test track characteristics (e.g. road inclination) will be more stringent to reduce positive influences on the road load determination.
- Instead of the ‘table of running resistances’ (the ‘cookbook’ of road load values that can be used if the road load for a vehicle has not been determined by track tests), a formula for calculating road load is provided, based on related vehicle characteristics. This methodology will be validated and completed in phase 1b.
- The GTR text was made more robust on various testing details (e.g. the torque-meter method for road load determination)
- Definitions in the GTR, e.g. on mass, reference speeds, etc. have been improved.
- NO_2 and N_2O were added as additional emissions to be measured, with the according measurement procedures.
- Electric and hybrid vehicles are separated from conventional vehicles with only an internal combustion engine, and dedicated test procedures have been developed for these vehicle types. Range, fuel/energy consumption, and emissions of electrified vehicles are defined in all-electric, charge-sustaining, and charge-depleting mode, and weighted by utility factors (if applicable).
- For pure electric vehicles (PEV) and hybrid electric vehicles (HEV) the provisions for test preparation and preconditioning as well as for the tests were modified with respect to existing regulations on the following aspects:
  - REESS preparation,
  - Test procedure, separately for
    - OVC-HEV, with and without driver-selectable operating modes,
    - NOVC-HEV, with and without driver-selectable operating modes,
    - PEV, with and without driver-selectable operating mode.
  - Calculations concerning
    - Emission compound calculations,
    - CO2 and Fuel Consumption Calculations,
    - Electric Energy Consumption Calculations,
    - Electric Range.
- Test equipment and calibration procedures were improved and/or supplemented in order to better reflect the technical progress and current state of the art, particularly on the following items:
  - Cooling fan specifications (increased dimensions, decreased tolerances of the velocity of the air of the blower),
  - Chassis dynamometer (provisions for 4WD were added, the general requirements were aligned with US 1066),
  - Exhaust gas dilution system (subsonic venturi (SSV) or an ultrasonic flow meter (USM) were added),
  - Emission measurement equipment (N_2O measurement systems were added),

- Calibration intervals and procedures (calibration and recheck before and after each test instead of each bag analysis),
- Reference gases (tolerances reduced from 2% to 1%).

4.4 New concepts of the GTR

The main improvements introduced by the GTR have been identified in the previous paragraph. In some cases it was sufficient to tighten a tolerance, or add a simple requirement. For other improvements it was necessary to develop a whole new approach, leading to a new concept in the GTR. To give a more detailed explanation on the background and the working principles, this paragraph will outline the main new concepts introduced by the GTR.

4.4.1 CO_2 interpolation method

One of the key requirements of WLTP, as specified in par. 4.2, is to develop the test cycle and test procedure in such a way that the resulting CO_2 emission and fuel consumption is representative for real-life vehicle usage. The DTP group recognised early in the development process as a barrier to achieve that goal the fact that tests are executed on single vehicles, while the results of these tests are used to type-approve a whole family of vehicles. The vehicles in one family would mainly differ from each other in terms of options selected by the customer that lead to differences in mass, tire/wheel rim combinations and vehicle body trim and/or shape. It was considered valuable to find a method that would attribute CO_2 to individual vehicles within the family in an appropriate way.

First of all, it was recognised that testing only one vehicle does not provide sufficient information. At least two different vehicles within the family have to be tested to determine a difference in CO_2 that can be attributed to vehicle characteristics, a ‘worst-case’ vehicle and preferably a ‘best-case’ to allow good coverage of all vehicles in the family. Within the GTR these test vehicles are referred to as vehicle H and vehicle L respectively. It was also agreed that pollutant emission standards should be met by all vehicles of the family.

The next challenge was to attribute the difference found in CO_2 between vehicle H and L to vehicles in between. There is not a parameter available that single-handed correlates well to the increased CO_2 as a result of differences in mass, aerodynamic drag and rolling resistance. As a first candidate, the mass of the vehicle was proposed as a parameter for interpolation between vehicle H and L. Analysis of such an interpolation method lead to unacceptable errors. This is easily understandable by considering that some options only add mass, while others (e.g. spoilers, wider tires) only have a marginal effect on mass but add considerable aerodynamic drag and/or rolling resistance.

The final breakthrough in this discussion arrived with the insight that it is the energy needed at the wheels to follow the cycle which has a more or less direct effect on the CO_2 of the test vehicle, under the assumption of a relatively constant engine efficiency for vehicle L and H. The cycle energy is the sum of the energy to overcome the total resistance of the vehicle, and the kinetic energy from acceleration:

$E_{cycle} = E_{resistance} + E_{kinetic}$

With:

$E_{resistance}$ = road load force F(v) multiplied by distance.

$E_{kinetic}$ = vehicle test mass TM multiplied by acceleration and distance

These energy components are summed for each second of the cycle to form the total cycle energy demand. Please note that if E_{cycle} is negative, it is calculated as zero.

The total resistance force F(v) follows from the road load determination procedure, as outlined in Annex 4, and is expressed as a second order polynomial with the vehicle speed:

$F(v) = f_0 + f_1.v + f_2.v^2$

With:

f_0, f_1 and f_2 being the road load coefficients which are found by regression of the polynomial to the road load determination results.

The key elements for success of this method are that:

a) the difference ΔCO_2 between vehicle L and H correlates well to the difference in cycle energy ΔE_{cycle}, and

b) differences in mass, rolling resistance and aerodynamic drag due to vehicle options can be translated into independent effects on f_0, f_1 and f_2 and consequently into ΔE_{cycle}.

This last statement can be assumed fulfilled by considering the following arguments:

- The kinetic energy responds linearly to the mass of the vehicle.
- f_0 responds linearly to the tyre rolling resistance and the mass of the vehicle.
- f_1 has nearly no correlation to the mass, rolling resistance and/or aerodynamic drag and can be considered identical for vehicles L and H.
- f_2 responds linear to the product of aerodynamic drag coefficient C_d and vehicle frontal area A_f.

Consequently, if the values for mass, rolling resistance and aerodynamic drag are known for vehicles L, vehicle H and individual vehicle, the difference in cycle energy ΔE_{cycle} can be calculated with respect to vehicle L, and from the interpolation curve the ΔCO_2 is derived . This so-called CO_2 interpolation method is illustrated in the figure below for an individual vehicle with a ΔE_{cycle} which is 40% of the difference in cycle energy between vehicle L and H.

The general principle of this CO_2 interpolation method is described in par. 1.2.3.1 of Annex 6. The mathematical representation is found in the formulas of par. 3.2.2 and section 5 of Annex 7. Please note that the method is applied for each cycle phase separately (Low, Medium, High and Extra-High).

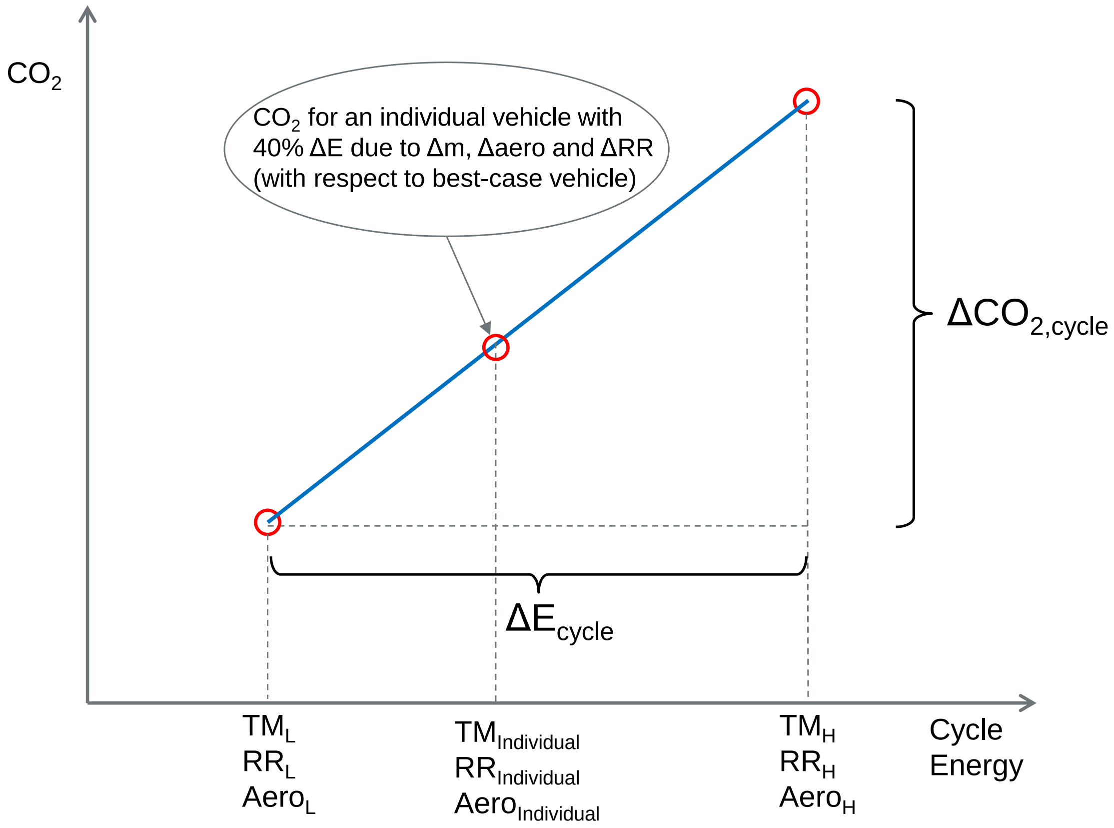

Figure 4: Example of the CO_2 interpolation method applied for road load relevant vehicle characteristics.

4.4.2 Vehicle selection

In a first attempt to specify test vehicle H for the CO_2 vehicle family, the vehicle with the highest mass, the highest rolling resistance tyres and the highest aerodynamic drag was proposed. This seemed a sensible approach to describe a worst-case vehicle until it was recognised that the vehicle with the highest mass may not be fitted with the worst-case tyres and vice versa. Specifying such a worst-case vehicle could then lead to a non-existing vehicle. The definition for vehicle selection in par. 4.2.1 of Annex 4 was therefore chosen to be described in a more functional way: “A test vehicle (vehicle H) shall be selected from the CO_2 vehicle family … with the combination of road load relevant characteristics (i.e. mass, aerodynamic drag and tyre rolling resistance) producing the highest energy demand.” If in the example above the influence of tyre rolling resistance on the energy demand is higher than that of the mass and aerodynamics, the vehicle with the worst-case tyres is selected as vehicle H. Consequently, the paragraphs dealing with the test mass (in 4.2.1.3.1), tyres (in 4.2.2) and aerodynamics (in 4.2.1.1) do not explicitly specify what to select for test vehicle H, since that is implicitly stated in paragraph 4.2.1.

Of course, a similar approach is followed for the selection of the best-case test vehicle L.

4.4.3 Interpolation/extrapolation range

The accuracy of the CO_2 interpolation method has been validated by 2 vehicle manufacturers using their detailed in-house simulation models. The CO_2 and E_{cycle} for vehicles L and H were determined, and used to interpolate the CO_2 of vehicles in between. Comparing the interpolation results with the simulation results for intermediate vehicles of the family demonstrated that the combined approach is accurate well within 1 g/km of CO_2 up to a ΔCO_2 of more than 30 g/km[9]. On the basis of these results the methodology was accepted and the allowed interpolation range was set at 30 g/km or 20% of the CO_2 for vehicle H, whichever is the lower value. The latter was needed to prevent that low CO_2 emitting vehicles would receive a relatively large interpolation range. Also a lower range limit of 5 g/km between vehicle L and H was set to prevent that measurement inaccuracies have a large influence on the course of the interpolation line. Finally it was also agreed that the interpolation line may be extrapolated to both ends by a maximum of 3 g/km, e.g. to include future vehicle modifications within the same type approval. However, the absolute interpolation range boundaries of 5 and 30 g/km may not be exceeded.

The allowed interpolation/extrapolation range is specified in 1.2.3.2 of Annex 6.

4.4.4 Vehicle test mass

The mass of the test vehicle in UN-ECE Regulation 83 was found to be lower than in real-life conditions. It is based on the so-called mass in running order (MRO), which is the sum of the mass of the empty vehicle, the standard equipment (including spare wheel), at least 90% of the fuel tank filled, and a mass of 75 kg to represent the weight of the driver. Any additional mass due to the optional equipment and/or the carrying of passengers and luggage is not taken into account. This definition can be found in the Special Resolution on Consolidated Resolution on the Construction of Vehicles (R.E.3)[10]

For WLTP it was decided that the test mass of the vehicle should also include a representative share of these missing elements. Based on some elementary studies and calculations, the agreed compromise was that the test mass (TM) would be determined by the sum of the following mass contributions[11]:

a) The empty mass of the vehicle (to make use of the definition in the Special Resolution, this is defined as the MRO minus 75 kg),

b) The mass of the driver (75 kg),

c) An additional constant mass of 25 kg, related to after-sales equipment and luggage,

d) The mass of optional equipment (factory installed equipment that is selected by the customer),

e) A variable mass that depends on the carrying capacity (payload) of the vehicle. Depending on their category and/or anticipated usage (decided at regional level) the payload factor will be 15 or 28% of the difference between the technical permissible maximum laden mass and the sum of the mass contributions of a) to d).

The difference between the test mass of vehicle H (TM_H) and vehicle L (TM_L) corresponds to the mass difference due to the installed optional equipment on these vehicles.

The mass of the test vehicle is checked before the road load determination is started, and needs to be equal or higher than the target test mass. During the test phase this mass may change, e.g. due to the fuel consumed. After the procedure has been completed the vehicle's

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[9] See document WLTP-DTP-LabProc-238

[10] See document ECE/TRANS/WP.29/78/Rev.2 http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29classification.html

[11] See document WLTP-DTP-08-02e http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/wltp_dtp08.html

mass is measured again, and the average of these measurements will be used as input for the calculations ($TM_{H,actual}$ respectively $TM_{L,actual}$).

The vehicle test mass is defined in paragraph 4.2.1.3.1 of Annex 4.

4.4.5 Vehicle coastdown mode and dynamometer operation mode

There are two special modes the vehicle can be equipped with, that are specifically developed for the purpose of being able to test the vehicle:

a) Vehicle coastdown mode: This mode is needed when the road load determination procedure uses the coastdown principle, while the verification criteria cannot be met due to non-reproducible forces in the driveline (e.g. parasitic losses in electric engines for propulsion). By activating the vehicle coastdown mode, the driveline components that generate these non-reproducible forces should be mechanically and/or electrically decoupled. The vehicle coastdown mode has to be activated both during the road load determination procedure as on the chassis dynamometer.

b) Vehicle dynamometer operation mode: This mode is used to be able to drive the vehicle normally on a single-axis chassis dynamometer. If the vehicle is front wheel driven, the rear wheels are not rotating during the test. This might trigger the electronic stability program (ESP) system of the vehicle, which response would render the test result incorrect. The vehicle dynamometer mode is only used when the vehicle is tested on the chassis dynamometer.

Both these special modes are not intended to be used by the customer and should therefore be ‘hidden’. They could be activated by a special routine e.g. using vehicle steering wheel buttons in a special sequence pressing order, using the manufacturer’s workshop tester, or by removing a fuse.

The requirements for vehicle coastdown mode can be found in paragraph 4.2.1.5.5 of Annex 4, and for the dynamometer operation mode in paragraph 1.2.4.2 of Annex 6.

4.4.6 Tyres

The rolling resistance coefficient (RRC) of a tyre has to be measured according to Regulation No. 117-02, or a similar internationally-accepted equivalent, and aligned according to the respective regional procedures (e.g. EU 1235/2011). The UN GTR also introduced a classification scheme, identical to EU Tyre Labelling Regulation 1222/2009. There are two reasons for having a classification table:

a) The rolling resistance coefficient determination procedure is complicated, and known to have inaccuracies. By introducing classes with a range of RRC’s which all receive the same class value, the inaccuracy of this determination procedure takes no effect.

b) Since the GTR has introduced the CO_2 interpolation method, every individual vehicle will receive its own CO_2 value. During the production, manufacturers could switch from one tyre supplier to another. If the other tyres have a slightly different RRC, a situation could occur that two completely identical vehicles (except for the brand of the tyres fitted) would receive a different CO_2 rating value. With the classification this situation is prevented, as long as the different tyres fall into the same class.

The influence of the class width on the CO_2 emissions was investigated. The difference in measured CO_2 between the actual RRC and the RRC class value was found to be smaller than 1.2 g/km per ton of vehicle mass[12].

There are 3 different tyre categories (C1, C2 and C3) that may be fitted to the vehicles. In case that tyres from different categories are used in one vehicle family, the class value determines which tyre should be selected.

For the calculation procedure that establishes the 'slope' of the CO_2 interpolation line, the actual RRC values are used as an input, not the class values. Later on in the procedure, when the individual CO_2 values are calculated for vehicles in the family, the RRC class values are used.

The tyre selection and the accompanying classification table can be found in paragraph 4.4.2 of Annex 4.

4.4.7 Default road load factors

In case of small production series or if there are many variants in one vehicle family, it may not be cost-effective to do all the necessary road-load determination work by measurements. Instead, a manufacturer may elect to use a default road-load factors. In UNECE Regulation 83 a table with road load coefficients is included ('table values'), which are only related to the reference mass of the vehicle, regardless of the vehicle size. It was agreed to develop a new proposal for this table, with the following improvements[13]:

a) The table should be based on existing road load data, and should be oriented towards the "worst" case, e.g. it might represent the 5% vehicles with the highest running resistances, rather than an "average" case, in order not to create an incentive to apply the default values to poorly performing vehicles.

b) The table should use vehicle parameters as input which have a relation to the road load of the vehicles

c) The specified load parameters will be used as *target* coefficients for the chassis dynamometer setting, in contrast to Regulation 83 where the table values are intended as *set* coefficients

A detailed study and a statistical analysis was performed by TNO on a dataset of road-load factors which led to a formula for the road load factors, rather than a table[14]. The formula is based on the vehicle's test mass, and the product of vehicle width and height as an indicator for the size of the vehicle. The formula can be found in paragraph 5.2 of Annex 4.

4.4.8 RCB correction

In Regulation 83, the vehicle battery is a fully charged at the start of the test. The state of charge upon completion of the test will always be lower than 100%, which means that effectively the energy drawn from the battery has been consumed over the test cycle. Or, more scientifically correct, the engine did not have to restore the charging energy though providing mechanical energy to the alternator. Early in the WLTP process, this was

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[12] See document WLTP-DTP-LabProcICE-140

[13] See document WLTP-DTP-13-05 https://www2.unece.org/wiki/display/trans/DTP+13th+Session

[14] See document WLTP-DTP-14-07 https://www2.unece.org/wiki/display/trans/DTP+14th+Session

recognized as issue which has an unrealistic effect on the fuel consumption at type approval, and which influence is too high to be ignored[15].

As a first step towards a representative test procedure, the battery state-of-charge at the start of the test was changed from fully charged (NEDC) to a representative start value. This is achieved by driving a preconditioning WLTC with a fully charged battery at the beginning.

Then, a pragmatic approach was prepared to monitor and correct a significant difference in battery charge over the cycle. The idea is to correct the fuel consumption and CO_2 emissions towards a zero charge balance, i.e. no net energy drawn from or supplied to the battery. Please note that the term used for battery in the GTR is 'REESS' – Rechargeable Electric Energy Storage System, and the 'REESS Charge Balance is abbreviated to RCB. The difference in energy level of the battery over the cycle is expressed as ΔE_{REESS}.

During the test, the battery current is monitored by a clamp-on or closed type current transducer. This signal is integrated over the whole duration of the cycle to deliver the RCB. If this RCB is negative (charge is reduced) and exceeds a specified threshold, the fuel consumption will be corrected. This threshold is laid down in the RCB correction criteria table, and is based on the ΔE_{REESS} divided by the equivalent energy of the consumed fuel. In case this is lower than the specified criteria (0.5% for the complete WLTC cycle including the Extra-High phase), no correction needs to be applied.

The correction of the fuel consumed will be applied for every cycle phase independently (Low, Medium, High and Extra-High). It is calculated by considering the ΔE_{REESS} per cycle phase, an assumed alternator efficiency of 0.67, and the combustion process specific Willans factor. The Willans factors are expressing the engine's efficiency in terms of the positive work of the engine against the liters of consumed fuel. Under the driving conditions of the WLTC, the Willans factors will remain relatively constant for small variations in cycle or load, and therefore provide a good basis for correction. The corrected fuel consumption is expected to correspond to a WLTC with zero charge balance. A similar approach is followed to correct the CO_2 emission.

The correction method for the RCB is outlined in Appendix 2 of Annex 6. Please note that this correction method only applies to batteries of conventional ICE vehicles. The RCB correction for hybrid electrical vehicles which are tested according to Annex 8 have a different battery correction principle because they have more than one battery while the energy content is much higher. In this case a fuel consumption correction factor K_{fuel} is determined by doing a number of consecutive measurements with positive and negative charge balance. This procedure is outlined in Appendix 2 of Annex 8.

4.4.9 Electrified Vehicles

In the GTR a separate annex is dedicated to electrified vehicles (Annex 8). The electrified vehicles are separated into the following groups according to their propulsion concepts:

- Pure electric vehicles (PEV)
- Hybrid electric vehicles, further subdivided into:
    - Not off vehicle charging hybrid electric vehicles (NOVC-HEV),
    - Off vehicle charging hybrid electric vehicles (OVC-HEV)

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[15] See the report by Helge Schmidt and Ralf Johannsen: Future Development of the EU Directive for Measuring the CO_2 Emissions of Passenger Cars - Investigation of the Influence of Different Parameters and the Improvement of Measurement Accuracy" - Final Report, 14 December 2010 (listed as document WLTP-DTP-LabProcICE-038)

Since it was not possible to determine appropriate parameters for the calculation of a rated power value, the electrified vehicles could not be classified according to the method applied to ICE vehicles. Consequently, different specifications for the cycle versions and the provisions for vehicles that cannot follow the trace had to be elaborated.

The test procedure for monitoring the electric power supply system, defining the specific provisions regarding the correction of test results for fuel consumption (l/100 km) and CO_2 emissions (g/km) as a function of the energy balance ΔE_{REESS} for the vehicle batteries, is different from that for ICE vehicles (REESS = Rechargeable Electric Energy Storage System). This procedure is referred to as the REESS charge balance (RCB) correction method. All installed REESS are considered for the RCB correction of CO_2 and fuel consumption values. The sum of ΔE_{REESS} is the sum of each REESS's RCB, multiplied by the respective nominal voltage.

New range tests for OVC-HEVs and PEVs are specified. Vehicles with manual transmission shall be driven according to the manufacturer's instructions, as incorporated in the manufacturer's handbook of production vehicles and indicated by a technical gear shift instrument.

The vehicles shall drive the applicable WLTC and WLTC city phases (low and medium only) in both charge-sustaining and in charge-depleting mode. This means that electrical range as well as fuel consumption and CO_2 emissions are determined for the whole cycle and the low and medium speed phase cycle separately.

Concerning the electric range of OVC-HEVs and PEVs the GTR contains completely new requirements with respect to existing regulations. The break off criteria for the electric range tests were modified on the basis of the results from the validation 2 phase of the WLTP development.

For NOVC-HEV with and without driver-selectable operating modes the RCB correction for CO_2 and fuel consumption measurement values are required. The RCB correction is not required for the determination of emissions compounds.

Also the determination of weighted CO_2 and FC emissions for OVC-HEVs based on utility factors is required.

4.5 GTR structure

The GTR covers every aspect on emission testing to the last detail and consequently it has become a large document. For someone who is not familiar with it, the amount of information contained in the GTR can be overwhelming. Even though a clear structure was used, not all of the test requirements are always found at the place where they would intuitively be expected. As an introductory guide for those that are relatively new to the GTR, this paragraph summarizes the contents of the Annexes which are related to the test procedure. Annex 1 and 2 are missing in this overview since they are covered by the technical report on the DHC[2].

4.5.1 Annex 3 – Reference fuels

The structure of annex 3 has to be seen as temporary. In phase 1 of the GTR development it is merely a re-formatted list of the specifications of reference fuels that are in current usage in the Contracting Parties. This serves two purposes, one is to provide technical specification values to reference in the calculation formulae throughout the GTR and the second is to offer specifications to Contracting Parties in the future in an attempt to prevent further disharmonisation.

The structure can and probably will change with any attempt to harmonise reference fuels in future phases of GTR development.

4.5.2 Annex 4 - Road and dynamometer load

This Annex describes the determination of the road load of a test vehicle and the transfer of that road load to a chassis dynamometer. The procedure is briefly outlined and explained in this paragraph.

General requirements

Road load can be determined using coast down or torque meter methods, at a later stage the wind tunnel method may be added as an alternative (to be decided in Phase 1b). Yet, at the beginning of Annex 4 the wind tunnel criteria are specified. These are related only to the determination of *difference* in aerodynamic drag between individual vehicles within the vehicle family, not to the determination of total road load for a vehicle.

To compensate the effects of wind on the road load determination procedure, the wind conditions need to be measured. Two methods are possible: using stationary anemometry alongside the test track (in both driving directions if the track has an oval shape), or by using on-board anemometry. The latter method has more relaxed limitations towards the maximum wind speeds under which it is allowed to determine the road load.

The temperature window within which the road load determination tests take place is specified as 278 to 313 K (5 to 40°C), but on regional level Contracting Parties may deviate up to +/- 5 K from the upper limit, and/or lower the range to 274 K.

Vehicle selection

Vehicle H is selected for the road load determination, being the vehicle within the CO_2 vehicle family with the combination of road load relevant characteristics (i.e. mass, aerodynamic drag and tyre rolling resistance) producing the highest cycle energy demand (see also par. 4.4.2 of this report). If the manufacturer wants to apply the CO_2 interpolation method, additionally the road load is also measured on vehicle L. This is the vehicle within the CO_2 vehicle family with the combination of road load relevant characteristics (i.e. mass, aerodynamic drag and tyre rolling resistance) producing the lowest cycle energy demand.

Aerodynamic drag

Any moveable aerodynamic body parts are allowed to operate in the same way as they would do under conditions encountered in the Type 1 test (test temperature, speed, acceleration, engine load, etc.). A moveable spoiler for stability at higher speeds, as an example, may move out or retract in the same way as it would do on the road. However, this requirement is not intended to be ill-treated to determine an unrealistic low road load. If such practices are observed or suspected, appropriate requirements will have to be added at a later stage.

For the determination of aerodynamic drag differences within the vehicle family a windtunnel has to be used. However, not every windtunnel may be fitted with a moving belt, which is needed to properly establish the drag of different wheel rim/tyre combinations. In such cases, the manufacturer may alternatively propose a selection based on wheel rim/tyre attributes (see 4.2.1.2 of Annex 4). If the wheel rim/tyre selection for vehicle H is done by this alternative approach, the CO_2 regression method cannot be used for the wheels, and the worst-case wheel rim/tyre combination is applied for all vehicles within the vehicle family.

Vehicle preparation

The test mass of the vehicle is measured before the road load determination procedure starts, and is verified to be equal or higher than the specified test mass. After the road load determination procedure is finished, the mass of the vehicle is measured again. The average of the mass before and after testing is used as input for the calculation of the road load curve (see also paragraph 4.4.4 of this report).

The selected vehicle needs to conform in all its components and settings (e.g. tyre selection, tyre pressures, wheel alignment, ground clearance, vehicle height, drivetrain and wheel bearing lubricants) to the corresponding production vehicle. It is allowed to be run-in for 10,000 to 80,000 km, but at the request of the manufacturer a minimum of 3,000 km may be used.

If the vehicle is equipped with a vehicle coastdown mode (see paragragph 4.4.5 of this report), it needs to be activated both during the road load determination procedure as during tests on the chassis dynamometer.

The tyre tread depth needs to be at least 80% of the original tread depth over the full width of the tyre, meaning that the outer shape of the worn tyre is similar to that of a new tyre. This requirement needs to be checked before starting the road load determination procedure. To prevent that the tread depth is further reduced by all of the testing activities, this measurement is only valid for a maximum of 500 kilometres. After this 500 kilometres, or if the same set of tyres is used for another vehicle, the tread depth has to be checked again.

Tyre pressure is set to the lower limit of the tyre pressure range specified by the manufacturer for the specific tyre, and is corrected if the difference between ambient and soak temperature is more than 5 K.

Vehicle warm-up

The vehicle is warmed up by driving the vehicle on the road or track at 90 % of the maximum speed for the applicable WLTC (or 90 % of the next higher phase if this is added to the applicable cycle). Before the warm-up it will be decelerated by moderate braking from 80 to 20 km/h within 5 to 10 seconds. This procedure prevents any practices to reduce parasitic losses from brake pads touching the brake discs.

Measurement procedure options

There are three different methods that can be used to determine the road-load of the vehicle:

a) Coastdown method: A vehicle is accelerated to a speed above the highest reference speed, and is decelerated by coasting down with the transmission in neutral. (paragraph 4.3 of Annex 4)

b) Torque-meter method: Torque meters are installed at the wheels of the vehicle, and the torque is measured while the vehicle travels at constant reference speeds. (paragraph 4.4 of Annex 4)

c) Default road load: Instead of measuring the road load, the manufacturer may choose to use a 'default road load' which is based on vehicle parameters (paragraph 5 of Annex 4)

Measuring the road load in a wind tunnel was identified as a fourth method, but this is not yet considered sufficiently robust to be added to the test procedure (possibly this will be done in phase 1b of the GTR).

Measurement procedure – Coastdown method

The coastdown method itself can also be conducted in two different ways:

a) Multi-segment method with stationary anemometry (paragraph 4.3.1 of Annex 4)

b) On-board anemometer-based coastdown method (paragraph 4.3.2 of Annex 4)

Ad a): At least 6 reference speeds are selected over the speed range of the applicable cycle, with a maximum separation of 20 km/h. The vehicle is coasted down from at least 5 km/h above the highest reference speed to at least 5 km/h below the lowest reference speed. Though it is recommended that coastdown runs are performed without interruption over the whole speed range, it is allowed to split the runs (e.g. if there is not sufficient length on the test track) while taking care that vehicle conditions remain constant. Coastdown runs are repeatedly performed in opposite driving directions until the statistical accuracy is satisfied. The coastdown time at each reference speed is determined by calculating the harmonised time averages of runs (separately for opposite directions). By taking the vehicle inertia into account, the deceleration curve can be used to calculate the road load force for each reference speed. Vehicle inertia is calculated by taking the average of the vehicle mass before and after the road-load determination procedure, increased by the equivalent effective mass m_r of wheels and other rotating components. The sets of reference speeds and corresponding road load force are used to fit a second-order polynomial regression curve with the road load factors f_0, f_1 and f_2. This procedure is done for both driving directions separately, and the average of the road load factors is calculated from it. As a final step, the road load factors are corrected for the average wind speed, actual test mass, temperature effect on rolling resistance and deviations from standard temperature and pressure affecting the aerodynamic drag.

Ad b): The vehicle will be equipped with on-board anemometry to accurately determine the wind speed and direction. This is either a boom approximately 2 meters in front of the vehicle or a roof-mounted device at the vehicle centreline. The test procedure is similar as for a), but at least 5 coastdown runs are performed in each direction. The results from the coastdown curves and the anemometry data are combined in an 'equation of motion'. In a complex calculation procedure the parameters that define the road load curve are derived. The correction for wind is implicitly included in this process, while the equation of motion is afterwards corrected to reference conditions. The test procedure for on-board anemometry is largely based on ISO 10521 Annex A, but was reviewed and improved for the GTR.

Measurement procedure – Torque-meter method

The alternative for coastdown testing method is the torque-metering method (see paragraph 4.4 of Annex 4), which has the following fundamental differences:

a) Instead of calculating the road load indirectly from the deceleration curve, the torque is measured directly at the wheels (which can be translated into a resistance force with the dynamic radius of the tyre). Therefore, this method can be applied with the vehicle at constant speed. If a vehicle has non-reproducible forces in the driveline which cannot be prevented by the coastdown mode, the torque meter method is the only method available for road load determination.

b) Since the torque meter is usually installed between the wheel hub and tyre rim, all of the resistances upstream in the driveline of the vehicle are not measured. The torque-meter method therefore finds a lower resistance force than the coastdown method. To avoid mixing up these forces, the coastdown method is said to determine the 'total resistance', while the torque-meter method determines the 'running resistance'. To obtain a proper setting of the chassis dynamometer, the vehicle with torque-meters installed will be put on the dyno, and the running resistances found on the track are reproduced. Once the chassis dynamometer is set, a coastdown will be executed, from which the road load factors can be derived for any subsequent testing purposes. Of course, if the vehicle has non-reproducible forces in its driveline, the chassis dynamometer can only be set with torque-meters installed.

The test procedure for the torque-meter method also involves the selection of at least 6 reference speeds over the speed range of the applicable cycle, with a maximum separation of 20 km/h. The vehicle is driven at each reference speed for a minimum of 5 seconds, while the speed is kept constant within a small tolerance band. Measurements are repeated in opposite driving directions and compensated for speed drift, until the statistical accuracy is satisfied. The sets of reference speeds and corresponding resistance torques are used to fit a second-order polynomial regression curve with the running resistance factors c_0, c_1 and c_2, which describe the wheel torque as a function of vehicle speed. This procedure is done for both driving directions separately, and the average of the running resistance factors is calculated from it. As a final step, the running resistance factors are corrected for the average wind speed, actual test mass, temperature effect on rolling resistance and deviations from standard temperature and pressure affecting the aerodynamic drag.

Default road load

The third option for road load determination is to abstain from measurements on a track, by using default values for the road load factors (see paragraph 4.4.7 of this report). This may be a cost-effective alternative, especially in case of small production series or if there are many variants in one vehicle family. The default road load values are based on the test mass of the vehicle as an indicator for rolling resistance, and the product of vehicle width and height as an indicator for aerodynamic drag. To prevent that these default values would create an advantage over measured road load, they have been developed to go towards a worst-case.

Preparation for the chassis dynamometer test

The first step in the chassis dynamometer test is to set the equivalent inertia mass. This mass is the same as the average mass of the vehicle during the road load determination procedure. In contrast to Regulation 83 there are no inertia steps, so the setting has to meet the test mass exactly, or – if that is not possible – the next higher available setting. In case a single-axis dynamometer is used, one pair of wheels is not rotating. To compensate for this, the inertia mass is increased by the equivalent effective mass m_r of the non-rotating wheels (if that information is not available, this may be estimated at 1.5 per cent of the unladen mass).

In the next step, both vehicle and chassis dynamometer are warmed up as indicated in the GTR. The warm-up procedure for the vehicle depends on the applicable test cycle. Alternatively, the manufacturer may use a shorter warm-up cycle for a group of vehicles, but only at the approval of the responsible authority after demonstrating equivalency.

Chassis dynamometer load setting

The purpose of the chassis dynamometer setting is to reproduce the load that was found in the road load determination process as close as possible. Since the resistance of a vehicle on a chassis dynamometer is much different from being on the road, the aim is to let these differences be compensated by the dynamometer setting. There are two sets of road load coefficients specified (these are the coefficients that describe the second order polynomial curve):

a) Target coefficients: road load that was determined on the road

b) Set coefficients: load that is set on the chassis dynamometer

The difference between these two loads is mainly caused by internal friction in the chassis dynamometer, the different contact of wheels on rollers, and the absence of aerodynamic drag.

If the road load determination was done by the coastdown method, this setting of the chassis dynamometer is also done by using a coastdown method. There are 2 possible options:

a) The fixed run method: in an automated process the software of the chassis dynamometer performs 3 consecutive coastdowns, and calculates the appropriate setting by subtracting from the target coefficients. a 2-run average of the set coefficients

b) The iterative method: coastdowns are adjusted and repeated until 2 consecutive runs (after regression) fulfil a maximum tolerance of ± 10 N.

If the road load determination was done by the torque meter method, identical torque meters will be installed on the vehicle, and the settings are iteratively adjusted until the difference between simulated and measured load satisfy the specified error criteria.

Finally, there are 2 appendices to Annex 4:

Appendix 1: the process of a performing a coastdown on the chassis dynamometer, and how to convert the measured road load forces at reference speeds into a simulated road load curve (constants for the second order polynomial).

Appendix 2: the process of adjusting the chassis dynamometer load setting to match the simulated road load to the target road load, separately for the coastdown method and the torque-meter method (determination of the proper ‘set coefficients’).

4.5.3 Annex 5 – Test equipment and calibrations

In this annex the requirements for the test equipment, the measurement and analysis equipment, calibration intervals and procedures, reference gases and additional sampling and analysis methods are specified.

The test equipment requirements cover the cooling fan and the chassis dynamometer. The cooling fan requirements specify performance, dimensions and number and location of measurement points for the check of the performance. The position of the fan with respect to the front of the vehicle is made more robust. The chassis dynamometer requirements are based on existing regulations but are supplemented by requirements for vehicles to be tested in four wheel drive (4WD) mode. The chassis dynamometer calibration concerns the force measurement system, parasitic losses and the verification of road load simulation.

The measurement and analysis equipment requirements cover the exhaust gas dilution system, the emissions measurement equipment and the necessary calibration intervals and procedures.

A full-flow exhaust dilution system is required for emission testing. This requires that the total vehicle exhaust be continuously diluted with ambient air under controlled conditions using a constant volume sampler. A critical flow venturi (CFV) or multiple critical flow venturis arranged in parallel, a positive displacement pump (PDP), a subsonic venturi (SSV), or an ultrasonic flow meter (USM) may be used. The exhaust dilution system consists of a connecting tube, a mixing chamber and dilution tunnel, dilution air conditioning, a suction device and a flow measurement device.

Specific requirements are given for the connection to the vehicle exhaust, the dilution air conditioning, the dilution tunnel, the suction device and the volume measurement in the primary dilution system. Recommended systems are exemplarily described.

These requirements are followed by the specifications of the CVS calibration and the system verification procedures.

The requirements for the emission measurement equipment include gaseous emission measurement equipment, particulate mass and particulate number emission measurement equipment. They start with system overviews and end with descriptions of recommended systems.

The calibration intervals and procedures cover instrument calibration intervals as well as environmental data calibration intervals and analyser calibration procedures.

The requirements for the additional sampling and analysis methods cover fourier transform infrared (FTIR) analyser and sampling and analysis methods for N_2O.

4.5.4 Annex 6 – Type 1 test procedure and test conditions

This Annex describes the execution of the testing activities to verify emissions of gaseous compounds, particulate matter, particle number, CO_2 emissions, and fuel consumption over the WLTC applicable to the vehicle family.

General requirements

Testing is done in a conditioned environment on a chassis dynamometer, while a proportional part of the diluted exhaust emissions is collected for analysis by a constant volume sampler (CVS). Background concentrations in dilution air are measured simultaneously for all emission compounds as well as particulate mass and number to correct the measurement results.

The temperature in the test cell has a setpoint of 296K with a tolerance of ±5 K during testing, at the start of the test it should be within ±3 K. The setpoint for the soak area is the same with a tolerance of ±3 K. In all cases, the temperature may not show a systematic deviation from the setpoint.

Test vehicle

For the emission test (‘Type 1’) at the chassis dynamometer the road load which was determined at test vehicle H has to be applied. If at the request of the manufacturer the CO_2 interpolation method is used (see paragraph 4.4.1 of this report), an additional measurement of emissions is performed with the road load as determined at test vehicle L. However, the CO_2 interpolation method may only be applied on those road load relevant characteristics that were chosen to be different between test vehicle L and test vehicle H. For example, if both test vehicle L and H are fitted with the same tyres, no interpolation is allowed for the rolling resistance coefficient. Refer to paragraph 4.4.3 of this report for the allowed interpolation/extrapolation range.

Please note that this interpolation method only applies to the group of vehicles that fall into the same ‘CO_2 vehicle family’, whose criteria are specified by par. 5.6 in part II of the UN-GTR.

The vehicle is placed on the chassis dynamometer, and if it is equipped with a ‘dynamometer operation mode’ and/or a ‘vehicle coastdown mode’, these modes have to be activated (refer to paragraph 4.4.5 of this report). Auxiliaries are switched off during the test.

The tyres fitted on the test vehicle should be of a type specified as original equipment by the manufacturer, but it is allowed to increase the tyre pressure by a maximum of 50 per cent above the specified tyre pressure. Since any differences in rolling resistance are implicitly corrected by the chassis dynamometer setting, this will not affect the accuracy of the road load, as long as the same pressure is used throughout the tests.

Vehicle preconditioning

The chassis dynamometer is set in accordance with the procedure described in Annex 4. For reasons of reproducibility, the battery will be fully charged. To precondition the vehicle and the battery, the applicable WLTC will be driven (preconditioning cycle). Additional preconditioning cycles may be driven at the request of the responsible authority or the manufacturer, to bring the vehicle and its control systems to a stabilized condition. For example, if the vehicle is equipped with an automatic gearbox that slowly adapts to the driving behavior, multiple preconditioning cycles could be needed to let the algorithm of the shifting strategy adapt to the WLTC. After preconditioning and before testing, the vehicle is soaked for a minimum of 6 hours to a maximum of 36 hours in a conditioned environment (soak area setpoint of 296 K ± 3 K) until the engine oil temperature and coolant temperature are within ± 2 K of the setpoint.

Transmissions

For manual transmissions, the gear shift prescriptions according to Annex 2 have to be fulfilled within a tolerance on the point of shifting of ± 1 second. If the vehicle is unable to follow the speed trace it has to be operated with the accelerator control fully activated.

Vehicles with an automatic-shift or multi-mode gearbox have to be tested in the ‘predominant mode’, but only if such a predominant mode is present and is agreed by the responsible authority to fulfil the requirements of 3.5.10 in part II of the GTR. The results in predominant mode are used to determine fuel consumption and CO_2 emissions.

It should be avoided that the vehicle would automatically shift itself to another mode as the predominant mode, as this could open the way for misuse. Therefore a requirement was added to state that ‘the switch of the predominant mode to another available mode after the vehicle has been started shall only be possible by an intentional action of the driver having no impact on any other functionality of the vehicle’.

If the vehicle has no predominant mode or the requested predominant mode is not agreed by the responsible authority as a predominant mode, the vehicle shall be tested in the best case mode and worst case mode for criteria emissions, CO_2 emissions, and fuel consumption. The results of best- and worst-case mode are averaged to determine fuel consumption and CO_2 emissions.

Even if there is a predominant mode available, the vehicle still has to fulfil the limits of criteria emissions in all forward driving modes, except for modes that are used for special limited purposes (e.g. maintenance mode, crawler mode).

Type 1 test

The testing can start after the vehicle has been properly soaked (see ‘vehicle preconditioning’). The vehicle is moved from the soak area to the test room, and placed on the chassis dynamometer. All the necessary equipment for emission measurement, particulate filter and particle sampling is prepared and/or calibrated prior to the test. The vehicle is started, and the applicable WLTC is driven while staying within the indicated speed trace tolerances - refer to paragraph 1.2.6.6 of Annex 6 for detailed speed trace tolerances. Except for particulate filter sampling, all measurements of compounds have to be available for each of the individual cycle phases (Low, Medium, High and Extra-High), in order to accommodate regional weighting by the Contracting Parties. Particulate sampling is done on one filter for the whole cycle or –again for regional weighting purposes – on one filter over the first three phases, and one separate filter for the fourth phase.

Post-test procedures

Just prior to the analysis, the zero and range of the analyzers will be calibrated as prescribed. On completion of the cycle phases, the bags containing the diluted exhaust gases will be analyzed as soon as possible, in any event not later than 30 minutes after the end of the cycle phase. The particulate filter is transferred to the weighing room within one hour after completing the test.

Annex 6 has two appendices:

Appendix 1: Emissions test procedure for vehicles equipped with periodically regenerating systems.

If the emission limits applied by the Contracting Party are exceeded during a cycle by the regeneration of periodically regenerating emission reduction system(s), these emissions may be calculated into a weighted average. This is done by the K_i factor, which defines how the elevated levels of emission compounds during cycles where regeneration occurs are attributed to the emission performance on cycles without regeneration. Basically, the procedure for K_i determination takes into account the number of cycles without regeneration and the emission performance on those cycles, and compares this to the one (or several) cycles where regeneration occurs with the corresponding elevated emission levels. The K_i can be applied as a multiplicative or an additive factor. The procedure also provides a K_i calculation method for vehicles with more than one regenerating emission reduction system.

Appendix 2: Test procedure for electric power supply monitoring system

The monitoring of the charge/discharge energy of the battery in conventional ICE vehicles is described, and the procedure to correct the fuel consumption and CO_2 emissions.

This procedure is already explained in detail in paragraph 4.4.8 of this report.

4.5.5 Annex 7 – Calculations

In this annex the procedures are described to calculate the results from all the data collected from the Type 1 tests, and to make the necessary corrections. The calculations that are specifically related to electrified vehicles are not included in here; these can be found in Annex 8.

First the diluted exhaust gas volume is determined and corrected towards standard conditions. In the next step the mass emissions of all the monitored gaseous compounds are calculated from the measured concentrations in the bags. These are corrected by the concentrations already present in the dilution air. The final result is presented as mass emissions in g/km for each of the cycle phases (Low, Medium, High and Extra-High).

The calculation procedure of the CO_2 interpolation method to determine vehicle specific CO_2 emissions and fuel consumption for individual vehicles within the CO_2 vehicle family is also included in Annex 7. A detailed overview of this calculation procedure is given in paragraph 4.4.1 of this report. As the CO_2 interpolation method uses the energy demand over the cycle as an input, a separate calculation method is included for this in paragraph 5 of Annex 7.

The remaining procedures in Annex 7 describe the calculation process to derive the mass emission in mg/km of particulates from the collected mass on the filter, and the particle number emissions in particles per km.

Based on the calculated emissions for CO_2, HC and CO and test fuel density, the fuel consumption is calculated for each of the cycle phases.

4.5.6 Annex 8 - Pure and hybrid electric vehicles

This annex is dedicated to pure and hybrid electric vehicles and is structured into the following paragraphs:

1. General requirements

   Here is stated that the test procedure for electric power supply system monitoring defining the specific provisions regarding the correction of test results for fuel consumption (l/100 km) and CO_2 emissions (g/km) as a function of the energy balance ΔE_{REESS} for the vehicle batteries is different from that for ICE vehicles (see appendix 3 of Annex 8).

   Furthermore the general requirements are dedicated to the following issues

   1. Energy balance,
   2. Electric energy consumption and range testing,
   3. Emission and fuel consumption testing,
   4. Measurement units and presentation of results,
   5. Type 1 test cycles to be driven,
   6. Range tests for OVC-HEVs and PEVs,
2. REESS Preparation
3. Test procedure

This paragraph is subdivided into the following issues:

- General requirements

  Vehicles shall be conditioned, soaked and tested according to the test procedures applicable to vehicles powered solely by a combustion engine described of Annex 6 to this GTR unless modified by this Annex.

  Class 3a and 3b vehicles shall drive the applicable WLTC and WLTC city phases in both charge-sustaining and in charge-depleting mode.

  If the vehicles cannot follow the trace, the acceleration control shall be fully activated until the required speed trace is reached again. Power to mass calculation and classification methods shall not apply to these vehicle types.

- OVC-HEV, with and without driver-selectable operating modes

  Vehicles shall be tested under charge-depleting (CD) and charge-sustaining (CS) conditions. Three options for test sequences are offered in annex 8 (CD + CS, CS + CD, CD and CS separately) The requirements for these options are described in detail.

  The cycle energy demand of the test vehicle shall be calculated according to Annex 7, section 5.

  CS tests shall be carried out with the vehicle operated in charge-sustaining operation condition in which the energy stored in the REESS may fluctuate but, on average, is maintained at a charging neutral balance level while the vehicle is driven. In case the requirements of the charging balance window are not fulfilled, the CS test CO_2 and fuel consumption values shall be corrected according to Appendix 2 to Annex 8. The profile of the state of charge of the REESS during different stages of the Type 1 test is given in Appendices 1a and 1b. Upon request of the manufacturer and with approval of the responsible authority, the manufacturer may set the start state of charge of the traction REESS for the charge-sustaining test.

  The electric range of OVC-HEVs and PEVs is determined for the whole WLTC as well as for the city cycle consisting of the low and medium phases only.

- NOVC-HEV, with and without driver-selectable operating modes

  These vehicles shall be tested according to annex 6, unless modified by annex 8.

- PEV, with and without driver-selectable operating mode

  If the vehicle is equipped with a driver-selectable operating mode, the charge-depleting test shall be performed in the highest electric energy consumption mode that best matches the speed trace.

  The measurement of all-electric range AER and electric energy consumption shall be performed during the same test.

  The test method shall include the following steps:

  (a) initial charging of the traction REESS;

  (b) driving consecutive WLTCs until the break-off criteria is reached and measuring AER;

  (c) recharging the traction REESS and measuring electric energy consumption.

4. Calculations

This paragraph is subdivided into the following issues:

- Emission compound calculations

  For NOVC-HEV with and without driver-selectable operating modes exhaust emissions shall be calculated as required for conventional vehicles according to Annex 7. The charging balance correction (RCB) calculation is not required for the determination of emissions compounds.

- CO_2 and Fuel Consumption Calculations

  For OVC-HEV with and without an operating mode switch the calculation procedure is analogous to that for the emissions compound except for the test result correction as a function of REESS charging balance for charge sustaining tests. For this case Annex 8 describes the conditions where corrections are not necessary or have to be applied.

  Where RCB corrections of CO_2 and fuel consumption measurement values are required, the procedure described in Appendix 2 to Annex 8 shall be used.

  Also the determination of weighted CO_2 and FC emissions is analogous to that for the emissions compound.

  For NOVC-HEV with and without driver-selectable operating modes exhaust gases shall be analysed according to Annex 6. Charge-sustaining fuel consumption and CO_2 emissions shall be calculated according to the procedures specified for OVC-HEV. Test result correction have to be applied as a function of REESS charging balance.

  The corrected values $CO_{2,CS,corrected}$ and $FC_{,CS,corrected}$ shall correspond to a zero energy balance (RCB=0), and shall be determined according to Appendix 2 to this Annex.

  All installed REESS shall be considered for RCB correction of CO_2 and fuel consumption values. The sum of ΔE_{REESS} shall be the sum of RCB(i) multiplied by respective nominal voltage (i) of all REESSs.

  The electricity balance, measured using the procedure specified in Appendix 3 to Annex 8, is used as a measure of the difference in the vehicle REESS's energy content at the end of the cycle compared to the beginning of the cycle. The electricity balance is to be determined for the WLTC driven.

  Where RCB corrections of CO_2 and fuel consumption measurement values are required, the procedure described in Appendix 2 to Annex 8 shall be used.

- Electric Energy Consumption Calculations

  For OVC-HEV three complementary electric energy consumption values are calculated based on the measured recharged electric energy from the mains (E_{AC}), so that the charging losses are included.

  For PEV the electric energy consumption in Wh/km is calculated by the recharged electric energy from the mains divided by the all electric range.

- Electric Range

  The calculations have to be performed separately for the WLTC and the WLTC city cycle tests.

  In the case of an off-vehicle charging hybrid electric vehicle (OVC-HEV) four complementary electric range values are calculated.

All-electric range (AER) in the case of a pure electric vehicle (PEV) means the total distance travelled from the beginning of the charge-depleting test over a number of WLTCs until the break-off criteria is reached.

The electric range results have to be rounded to the nearest whole number.

Annex 8 has the following appendices:

Appendix 1a - RCB profile OVC-HEV, charge-depleting and charge-sustaining tests

This appendix contains figures showing exemplarily the RCB profile for a charge depleting test followed by a charge sustaining test.

Appendix 1b - RCB profile, OVC-HEV, charge-sustaining test

This appendix contains a figure showing exemplarily the RCB profile for a charge sustaining test.

Appendix 1c - RCB profile, PEV, electric range and electric energy consumption test

This appendix contains a figure showing exemplarily the RCB profile for an electric range and electric energy consumption test for PEVs.

Appendix 2 - REESS charge balance (RCB) compensation,

This Appendix describes the test procedure for RCB compensation of CO2 and fuel consumption measurement results when testing NOVC-HEV and OVC-HEV vehicles.

Appendix 3 - Measuring the electricity balance of NOVC-HEV and OVC-HEV batteries

This Appendix defines the method and required instrumentation to measure the electricity balance of OVC-HEVs and NOVC-HEVs.

Appendix 4 - Preconditioning of PEVs and OVC-HEVs

This Appendix describes the test procedure for REESS and combustion engine preconditioning in preparation for:

- electric range, charge-depleting and charge-sustaining measurements when testing OVC-HEV; and
- electric range measurements as well as electric energy consumption measurements when testing PEV vehicles.

Appendix 5 - Utility factor (UF) for OVC-HEVs,

Utility Factor (UF) are ratios based on driver statistics and the ranges achieved in charge-depleting mode and charge-sustaining modes for OVC-HEVs and are used for weighting CO2 emissions and fuel consumptions.

Each Contracting Party may develop its own UFs.

Appendix 6 - Determining the range of PEV's on a per phase basis

This annex is reserved for further development or amendment but does not yet contain any requirements.

5 Validation of the test procedure

Within the WLTP development programme two validation steps were executed. The first validation phase aimed at the assessment of the driveability of the WLTP cycles, these results are included in the Technical Report on the development of the harmonised driving cycle (DHC)[16]. This chapter will give an overview of the activities that were done in the Validation phase 2, which was dedicated to test and validate the new elements in the test procedure.

5.1 Tests

5.1.1 Participants and vehicles, measured parameter

Validation phase 2 was executed between April 2012 and December 2012. All necessary information concerning:

- Test plan,
- Parameter list and test procedure,
- Test sequences,
- Driving cycle schedules,
- Gearshift prescriptions for manual transmission vehicles,
- Data collection and delivery

were made available to the participants via JRC's FTP-server.

For class 1 and class 2 vehicles the cycle version 1.4 was used, for class 3 vehicles the cycle version 5 was applied. At the beginning of the validation 2 phase the gearshift calculation tool version from 16.04.2012 was used.

Some modifications on procedural issues needed to be performed during the validation 2 phase, based on the analysis of the results obtained so far. The following table gives an overview of these modifications.

The most important modifications were made by the VP2 information package from 25. July 2012. For class 1 and class 2 vehicles the cycle versions 1.4 were replaced by cycle versions 2 and the gearshift calculation tool from 16.04.2012 was replaced by the version from 09.07.2012.

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[16] See document GRPE-68-03 http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/grpeinf68.html

No.	Date	Filename	Modification
1	19 April 2012	File_2 - Parameter_List_for_Validation_2_v7_DTP_19-April-2012.xlsx	Item 21: Proportional fan
2	23 April 2012	File_1 - Validation2 Test Plan_23-April-2012.xls	Addition of TNO as Participating Lab (in box L5 and in Evaluation Item "ICE Vehicle weight")
3	23 April 2012	File_8 - WLTP_VP2_Participating Labs_list_23-April-2012.docx	Update of the List of Participating Labs (TNO – The Netherlands)
4	26 April 2012	File_6 - Data_collection_template_26-April-2012.xls	Addition of columns (related to adopted Gear Shift strategy) to the "bag results test i *" pages
5	15 May 2012	File_DHC_B_ANNEX_15-May-2012.doc	New file - Addition of a ".doc" file with detailed instructions on how to use the Gear Shift Evaluation Tool
6	15 May 2012	File_3 - LabProc-EV-TestMatrix_from ACEA_15-May-2012.xlsx	New file - Addition of the Test Matrix for EV/HEV
7	15 May 2012	File_0 - Read me_15-May-2012.docx	"Read me" file updated
8	09 July 2012	File_DHC_A - Driving Cycles_09-July-2012.xlsx	New version of Class 1 and Class 2 driving cycles
9	09 July 2012	File_DHC_B_gearshift_calculation_tool_09-July-2012.mdb	Gear Shift calculation tool updated and streamlined
10	09 July 2012	File_DHC_B_ANNEX_09-July-2012.doc	Revised explanatory note on how to use the Gear Shift calculation tool
11	23 July 2012	File_8 - WLTP_VP2_Participating Labs_list_23-July-2012.docx	File updated
12	23 July 2012	File_9 - JRC_ftp_server_Owners_23-July-2012.xlsx	File updated
13	25 July 2012	File_6.1 - Data_collection_template_lab_and_vehicle_info_25-July-2012.xls	New version of the excel template to report test results. The original file has been split in two files, now including also EV/HEV and PM/PN features
		File_6.2 - Data_collection_template_test_results_25-July-2012.xls	
14	25 July 2012	File_0 - Read me_25-July-2012.docx	File updated

Table 1: Procedural modifications during the validation 2 phase

In total, 34 different laboratories, institutions and manufacturers participated in the validation phase 2.

The results were delivered to the JRC server and then collected in an Access database. A total number of 109 vehicles were tested in the validation phase 2. These can be categorised into subgroups as shown in Table 2.

Vehicle subcategory	number
Battery electric vehicle	6
Hybrid electric vehicle with Petrol ICE	3
Hybrid electric vehicle with Diesel ICE	1
Plug in hybrid electric vehicle with Petrol ICE	2
M1, class 1, Diesel	2
M1, class 1, NG	1
N1, class 1, Diesel	5
M1, class 2, Diesel	1
M1, class 2, Petrol	2
M1, class 3, Diesel	33
M1, class 3, NG/LPG	6
M1, class 3, Petrol	40
N1, class 3, Diesel	4
N1, class 3, Petrol	2
N1, class 3, NG	1

Table 2: Overview of the validation 2 vehicle sample

Information about the chassis dynamometers was delivered by 33 of the 34 participating laboratories. For 19 laboratories it was possible to measure all 4 phases of the WLTC in one test, because their test benches had 4 bag measuring devices. The other laboratories had only 3 bag measuring devices. Most of them measured the first 3 phases (L&M&H) with a cold start and then phases L, M and exH in hot condition in a second test. Some participants measured different phase combinations in addition to the base test.

For the major part of the vehicles only the basic tests were performed. The base test was the WLTP test with a cold start at the test mass high (TMH). For 92% of the ICE vehicles additional hot start test were performed. It was foreseen to repeat all tests at least twice, so that three results could be used to assess the repeatability. Some participants did additional tests with parameter variations.

The following parameter variations were performed:

- Four filter (one per cycle phase) and one filter tests (for all phases) for particulate mass (vehicles 1 and 3),
- Gearshifts according to GSI and calculation tool (vehicles 4, 5, 8, 10 and 102),
- Test mass and/or road load variations (16 vehicles, from 2 variants up to 4 variants),
- Different preconditioning tests (vehicles 19 and 43),
- Overnight soak with forced cooling (vehicles 43, 44, 53, 61, 67, 68, 69 and 70)

For the pure electric vehicles charge depleting tests were performed, in some cases with different cycles or phase combinations.

An overview of the different cycle combinations and number of tests performed is given in the following tables.

Table 3 shows the cycle allocation for PEV’s and hybrids. All hybrids and 4 of the 6 PEV’s were tested with the class 3 cycles. Although its maximum speed was 145 km/h, vehicle 58 was classified as class 2 vehicle because the power to mass ratio was below 34 kW/t, if one uses the 30 minutes power as rated power. Consequently this vehicle was tested with the class 2 cycles.

Vehicle 84 had a 30 minutes power of 28 kW. Using this value the vehicle was classified as class 1 vehicle, although the maximum speed was 130 km/h. Consequently this vehicle was tested first with the class 1 cycles. But since the discussions about the classification of PEV's was already ongoing at that time, additional tests were performed with the class 2 and class 3 cycles.

The EV subgroup finally decided that a power to mass ratio determination is not yet possible for PEV's and that therefore all PEV's should be tested with the class 3 cycles.

All class 1 and class 2 vehicles with ICE are from India. Table 4 shows that 5 of the 8 class 1 vehicles were tested with both cycle phases (low and medium), the remaining 3 were tested with the low phase only, because the maximum speed was below 70 km/h.

All class 2 vehicles were tested with the class 2 cycle but without the extra high speed phase (see Table 5).

All M1 class 3 vehicles were tested with all 4 cycle phases (see Table 6 and Table 7), while 1 of the 7 N1 class 3 vehicles was tested without the extra high speed phase (see Table 8).

			Number of tests								
Veh_Cat	engine_type	IDveh	WLTC, C 1, V 2, L&M	WLTC, C 1, V 2, L&M&L	WLTC, C 2, V 1_4, L&M	WLTC, C 2, V 1_4, L&M&H	WLTC, C 2, V 2, L&M&H&exH	WLTC, C 3, V 5, L&M	WLTC, C 3, V 5, L&M&H	WLTC, C 3, V 5, L&M&H&exH	WLTC, C 3, V 5, L&M&H&L
BEV	EM	58			70	36					
BEV	EM	59						48		12	30
BEV	EM	77								5	
BEV	EM	80								8	12
BEV	EM	84	50	37			6		10		
BEV	EM	108						43		12	
PHEV	Petrol OVC	60						22		35	
PHEV	Petrol OVC	65								4	
HEV, class 3	Diesel, NOVC	104								3	
HEV, class 3	Petrol NOVC	9								13	
HEV, class 3	Petrol NOVC	78						2		2	
HEV, class 3	Petrol NOVC	85								9	

Table 3: Overview of tests for pure electric and hybrid electric vehicles

Veh_Cat	engine_type	IDveh	WLTC, C 1, V 2, L&L&L	WLTC, C 1, V 2, L&M&L
M1, class 1	DIESEL	87		6
M1, class 1	Diesel	101	6	
M1, class 1	NG	86		6
N1, class 1	Diesel	89	6	
N1, class 1	Diesel	90		6
N1, class 1	Diesel	91		6
N1, class 1	Diesel	92		6
N1, class 1	Diesel	93	6	

Table 4: Overview of tests for class 1 vehicles with ICE

Veh_Cat	engine_type	IDveh	WLTC, C 2, V 2, L&M&H	WLTC, C 3, V 5, L&M&H&exH
M1, class 2	DIESEL	88	6	
M1, class 2	Petrol	35	6	
N1, class 2	NG	2		12

Table 5: Overview of tests for class 2 vehicles with ICE

Veh_Cat	engine_type	IDveh	WLTC, C 3, V 5, L	WLTC, C 3, V 5, L&L	WLTC, C 3, V 5, L&M	WLTC, C 3, V 5, L&M&exH	WLTC, C 3, V 5, L&M&H	WLTC, C 3, V 5, L&M&H&exH	WLTC, C 3, V 5_1, L&M&H&exH
M1, class 3	Diesel	81						18	
M1, class 3	Diesel	82	2	4	17			27	
M1, class 3	Diesel	83		4	10			16	
M1, Class 3	DIESEL	94				3	3		
M1, class 3	Diesel	96						3	
M1, class 3	Diesel	102		2	12			14	
M1, class 3	Diesel	109						30	
M1, class 3	Diesel	3						12	
M1, class 3	Diesel	4						12	
M1, class 3	Diesel	5						12	
M1, class 3	Diesel	14			3				3
M1, class 3	Diesel	19						6	
M1, class 3	Diesel	21				4	4		
M1, class 3	DIESEL	30				3	3		
M1, class 3	DIESEL	31				3	3		
M1, class 3	Diesel	39						30	
M1, class 3	Diesel	40				3	3		
M1, class 3	Diesel	41						4	
M1, class 3	diesel	42						12	
M1, class 3	Diesel	44						21	
M1, class 3	Diesel	45			4			8	
M1, class 3	Diesel	46			4			6	
M1, class 3	Diesel	47						18	
M1, class 3	Diesel	48			3			3	
M1, class 3	Diesel	51						18	
M1, class 3	Diesel	52						6	
M1, class 3	Diesel	56				3	3		
M1, class 3	diesel	61						18	
M1, class 3	Diesel	64						50	
M1, class 3	Diesel	66				3	3		
M1, class 3	Diesel	68				3	4		
M1, class 3	Diesel	76						18	
M1, class 3	Diesel	79			3			3	

Table 6: Overview of tests for class 3 M1 vehicles with Diesel ICE

Veh_Cat	engine_type	IDveh	WLTC, C 2, V 2, L&M&H	WLTC, C 3, V 5, L&M	WLTC, C 3, V 5, L&M&exH	WLTC, C 3, V 5, L&M&H	WLTC, C 3, V 5, L&M&H&exH	WLTC, C 3, V 5_1, L&M&H&exH
M1, class 3	LPG	55			3	3		
M1, class 3	NG	25			3	3		
M1, class 3	NG	36			3	3		
M1, class 3	NG	37			3	3		
M1, class 3	NG	7					6	
M1, class 3	NG	50					6	
M1, class 3	Petrol	95					3	
M1, class 3	Petrol	97			1	1		
M1, class 3	Petrol	98			5	5		
M1, Class 3	Petrol	99					3	
M1, class 3	Petrol	105		2			2	
M1, class 3	Petrol	106		1			2	
M1, class 3	Petrol	107		1			1	
M1, class 3	Petrol	1					12	
M1, class 3	Petrol	8					42	
M1, class 3	Petrol	10					16	
M1, class 3	Petrol	11					8	
M1, class 3	Petrol	12					32	
M1, class 3	Petrol	13					16	
M1, class 3	Petrol	15		3				3
M1, class 3	Petrol	16		3			3	
M1, class 3	Petrol	17			6	6		
M1, class 3	Petrol	20					6	
M1, class 3	Petrol	22			3	3		
M1, class 3	Petrol	23			3	3		
M1, class 3	Petrol	24			3	3		
M1, class 3	Petrol	26			3	3		
M1, class 3	Petrol	27					6	
M1, class 3	Petrol	28			3	3		
M1, class 3	Petrol	32			3	3		
M1, class 3	Petrol	33			3	3		
M1, class 3	Petrol	34			3	3		
M1, class 3	Petrol	38					6	
M1, class 3	Petrol	43					23	
M1, class 3	Petrol	49		3			3	
M1, class 3	Petrol	53					6	
M1, class 3	Petrol	54					2	
M1, class 3	Petrol	57			3	3		
M1, class 3	Petrol	62					4	
M1, class 3	Petrol	63					4	
M1, class 3	Petrol	67			4	5		
M1, class 3	Petrol	71					6	
M1, class 3	Petrol	72					6	
M1, class 3	Petrol	73					6	
M1, class 3	Petrol	74					23	
M1, class 3	Petrol	75					10	
M1, class 3	Petrol	100	3					

Table 7: Overview of tests for class 3 M1 vehicles with NG or Petrol ICE

Veh_Cat	engine_type	IDveh	WLTC, C 3, V 5, L&M	WLTC, C 3, V 5, L&M&exH	WLTC, C 3, V 5, L&M&H	WLTC, C 3, V 5, L&M&H&exH	WLTC, C 3, V 5, L&M&L
N1, class 3	Diesel	103	2			2	
N1, class 3	Diesel	6				6	
N1, class 3	Diesel	18		3	3		
N1, class 3	Diesel	29			3		3
N1, class 3	Petrol	69		3	4		
N1, class 3	Petrol	70		4	5		

Table 8: Overview of tests for class 3 N1 vehicles

5.1.2 Evaluation issues

The following evaluation issues were discussed in the DTP subgroups:

- Soak Temperature Tolerances
- Soak with forced Cooling down
- Test Cell Temperatures
- Tolerances of Humidity during Test Cycle
- Tolerances of Emission Measurement System
- Preconditioning Cycle
- Preconditioning for Dilution Tunnel
- Speed Trace Tolerances
- Gearshift tolerances for manual transmission vehicles
- Monitoring of RCB of all Batteries
- Cycle Mode Construction
- Required Time for Bag Analysis
- Dilution Factor
- Dyno Operation Mode

Out of these the following issues will be discussed in this report based on the validation phase 2 results:

- Overnight soak temperature,
- Test cell temperature and humidity,
- Speed trace violations,
- Charge depleting tests for PEV and OVC HEV

Other issues are not mentioned in detail here, such as the test mass influence, because the tests results did not provide evidence that there was a need to modify the GTR on those issues. The differences between the results for manual transmission vehicles with gearshifts according to the on board GSI and the WLTP calculation tool were rather small and did not show any trends.

5.2 Results

5.2.1 Overnight soak temperatures

The validation 2 results database contains temperature monitoring for 274 different overnight soaks without and 15 soaks with accelerated cooling. Figure 5 shows an example for coolant and air temperature monitoring of 7 different tests with the same vehicle.

An extensive evaluation of the results led to the following specifications in the GTR:

- The soak area shall have a temperature set point of 296 K and the tolerance of the actual value shall be within ± 3 K on a 5 minute running average and shall not show a systematic deviation from the set point. The temperature shall be measured continuously at a minimum of 1 Hz.

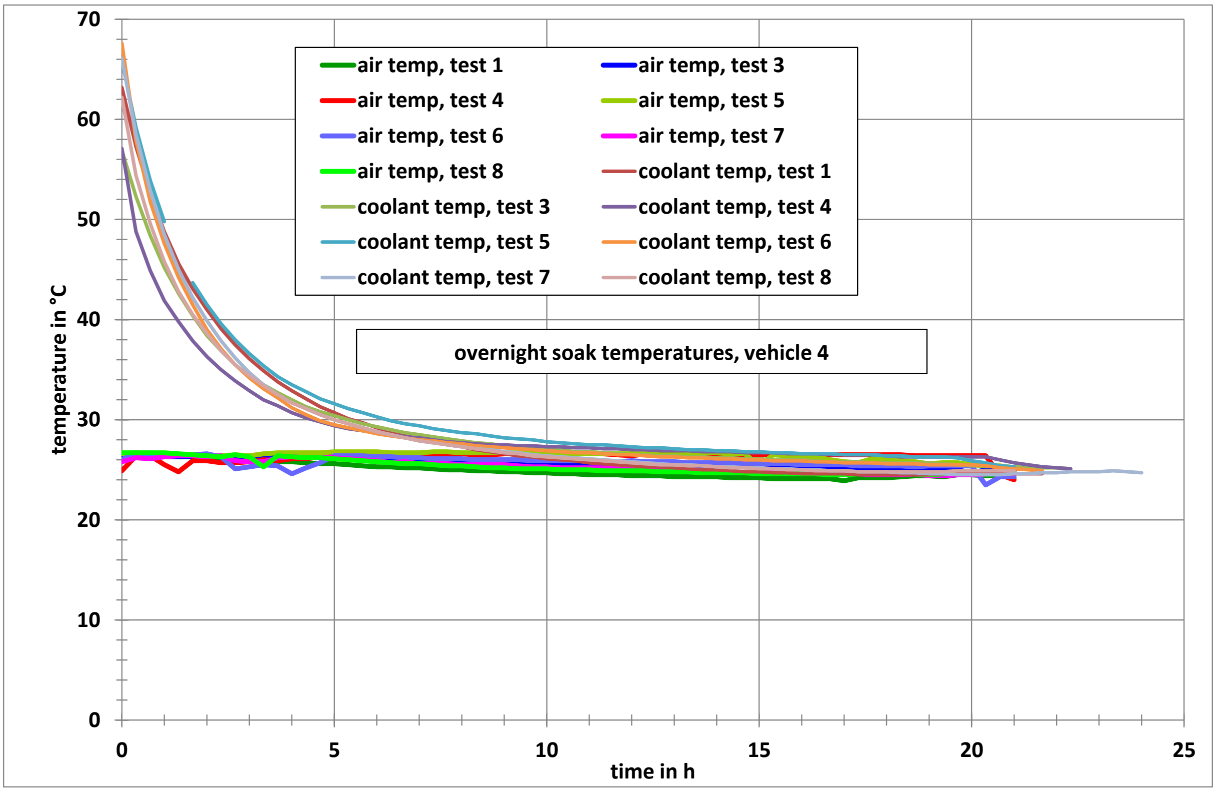

Figure 5: Example of overnight soak temperature monitoring

5.2.2 Test cell temperatures

A further validation point was the variation of the test cell temperature during the tests. The class 3 cycle was used for the evaluation. Figure 6 shows the time history of the test cell temperature with the lowest variation, Figure 7 shows the case with the highest variation.

The variation ranges for all tests are shown in Figure 8.

Based on these results the following requirements were drafted for the GTR:

- The test cell shall have a temperature set point of 296 K. The tolerance of the actual value shall be within ± 5 K. The air temperature and humidity shall be measured at the vehicle cooling fan outlet at a rate of 1 Hz.

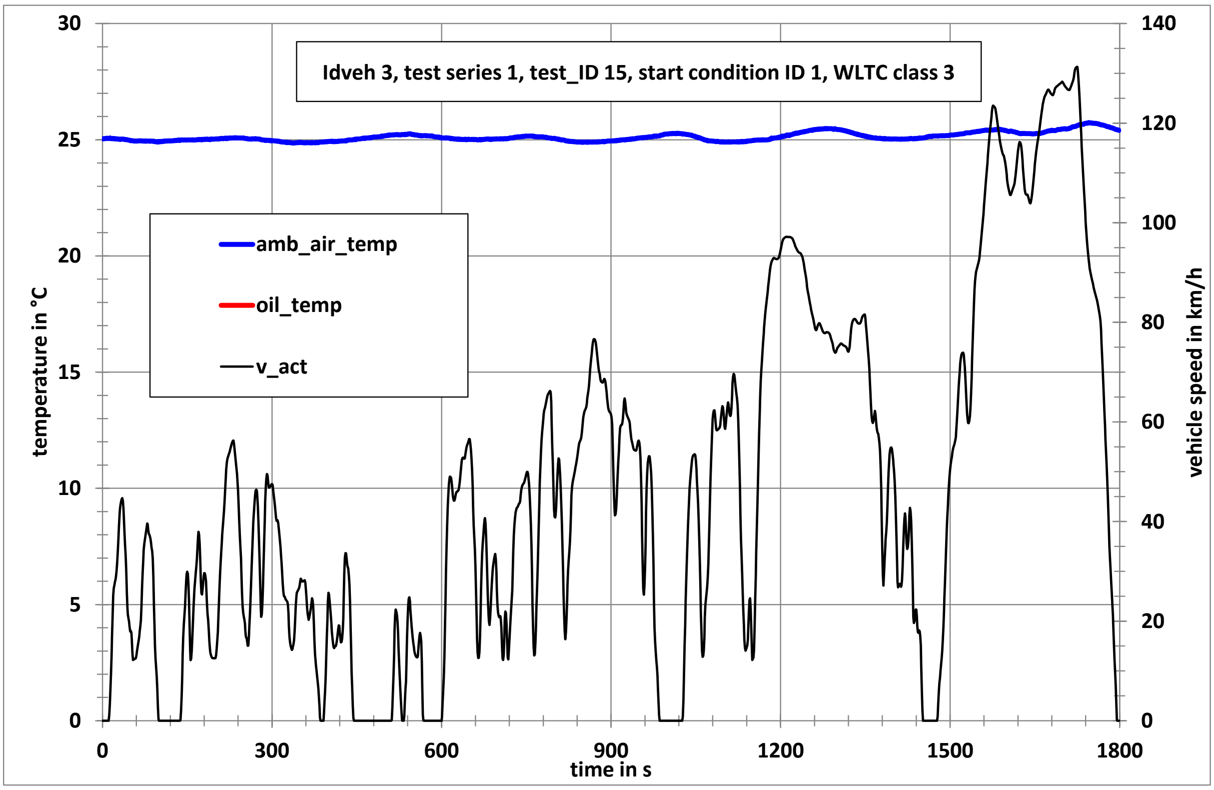

Figure 6: Best case of test cell temperature over all 4 phases of the class 3 WLTC

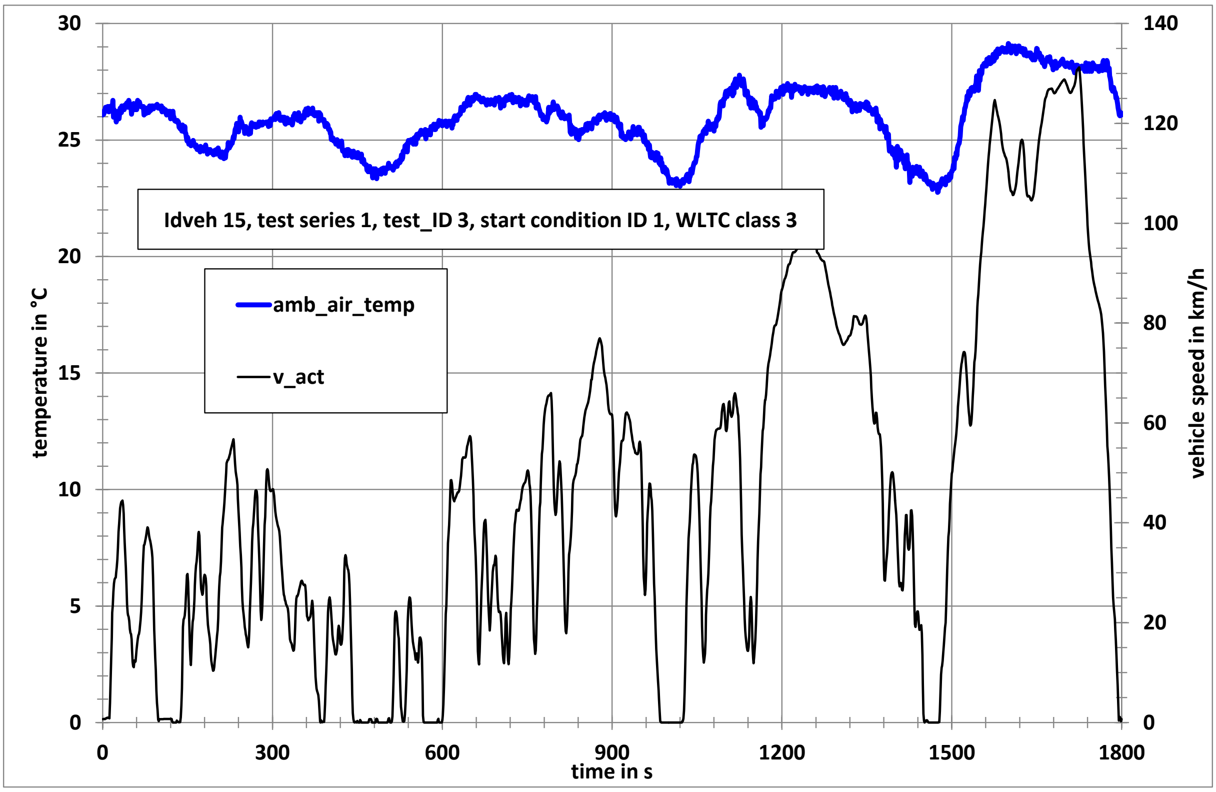

Figure 7: Worst case of test cell temperature over all 4 phases of the class 3 WLTC

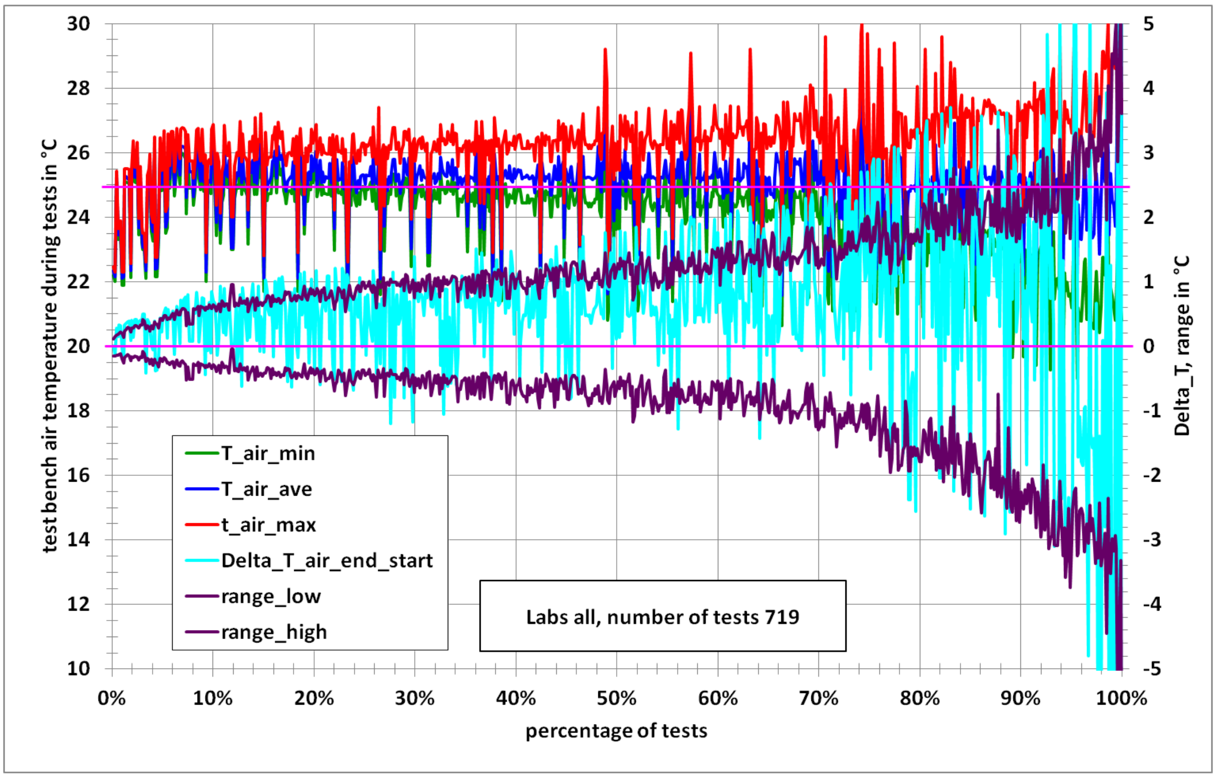

Figure 8: Test cell temperature variation range during class 3 WLTC, all tests

5.2.3 Test cell humidity

Examples for the time history and the variances of test cell humidity are shown in the following figures (Figure 9 to Figure 11).

Based on these results the following requirements were drafted for the GTR:

- The absolute humidity (H_a) of either the air in the test cell or the intake air of the engine shall be such that: $5.5 \leq H_a \leq 12.2$ (g H_2O/kg dry air),
- Humidity shall be measured continuously at a minimum of 1 Hz.
- Absolute humidity (H_a) shall be measurable to within ±1 g H_2O/kg dry air.

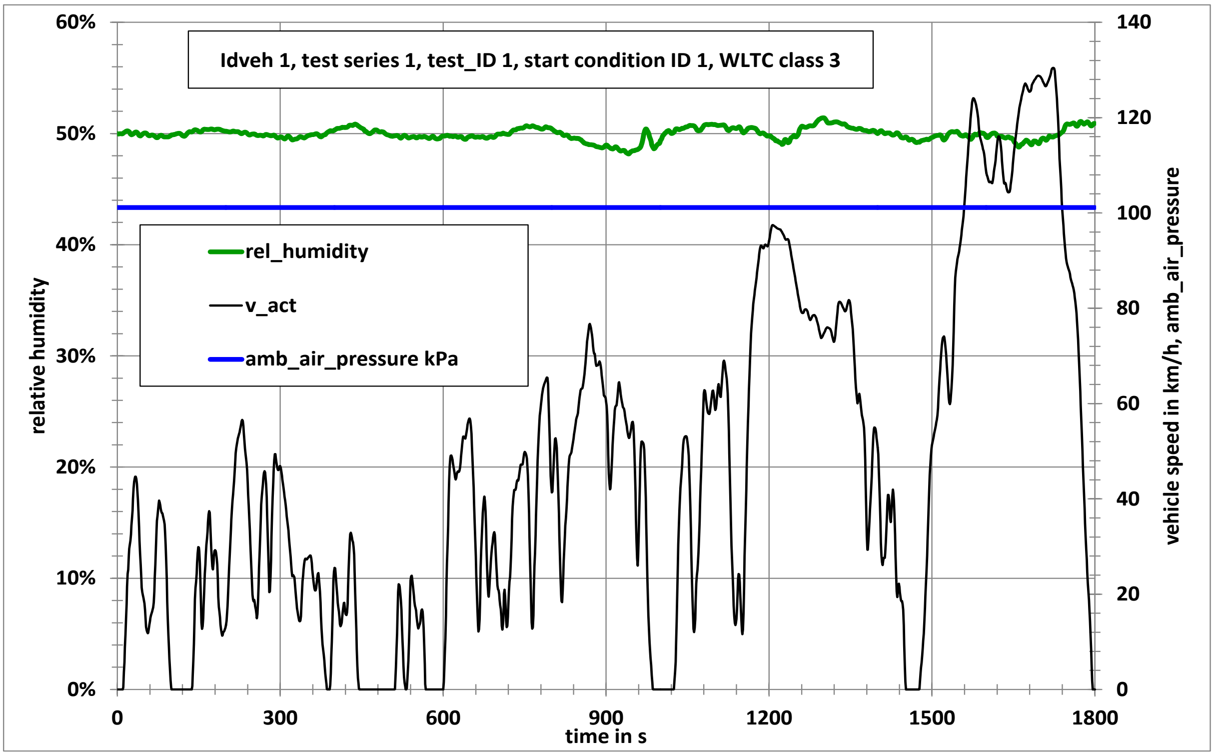

Figure 9: Example for the time history of the test cell humidity over the class 3 WLTC

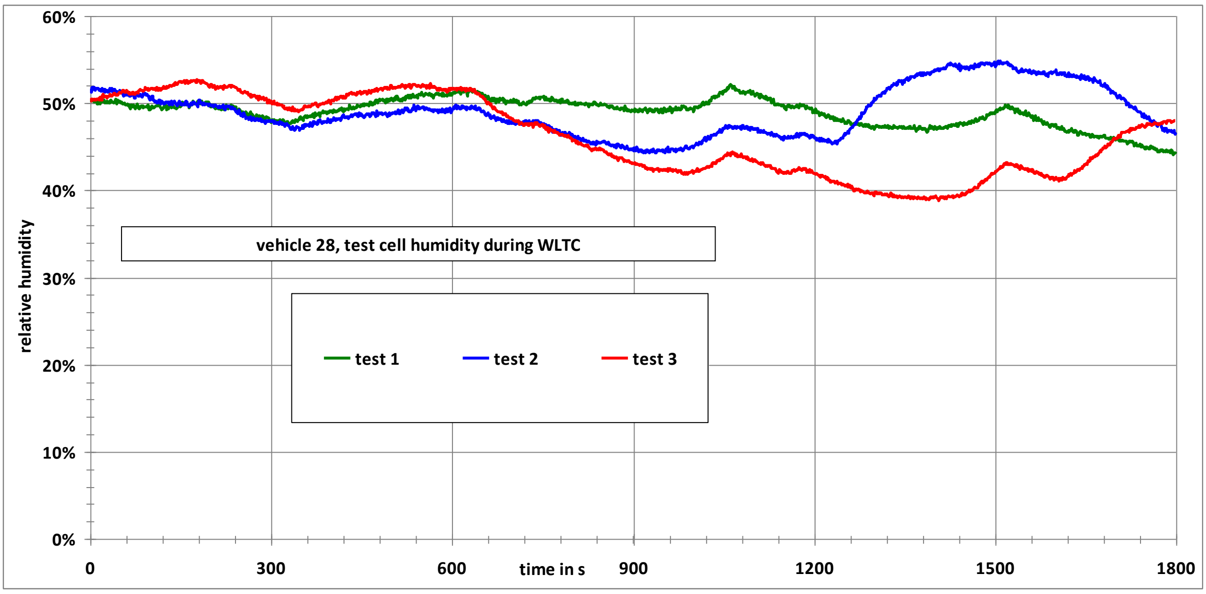

Figure 10: Examples for the time history of the test cell humidity over the class 3 WLTC

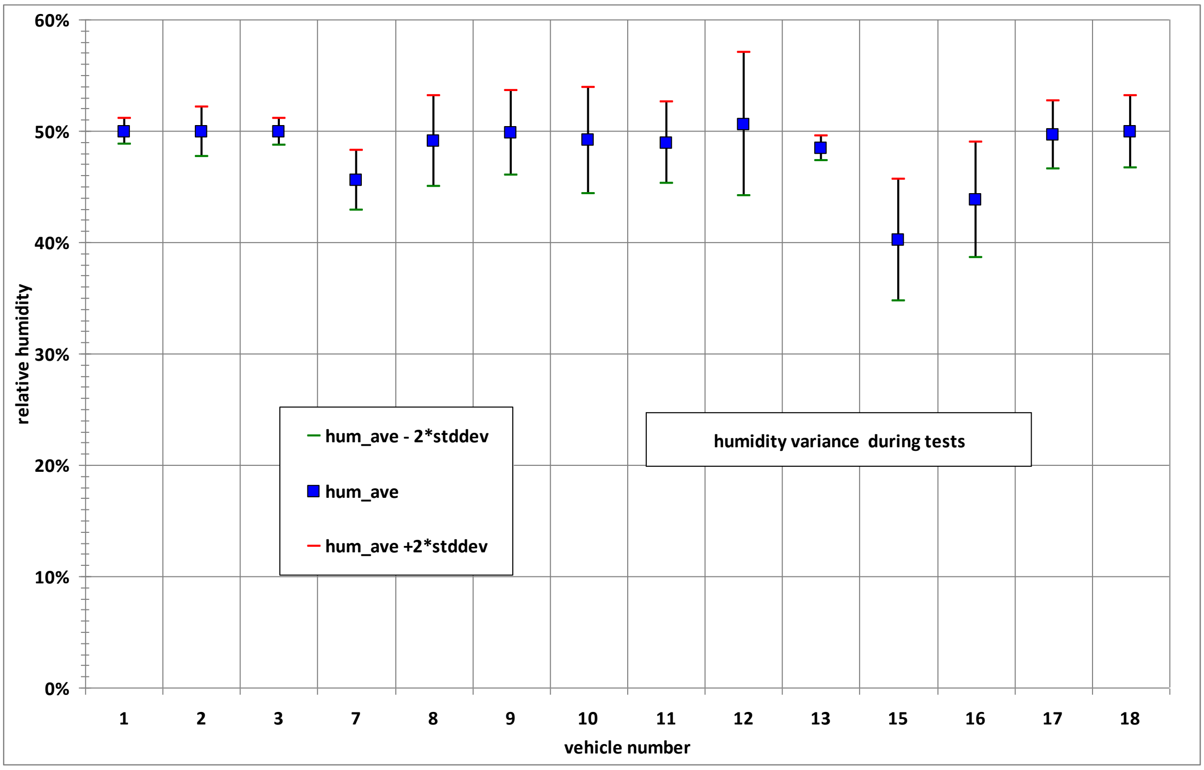

Figure 11: Test cell humidity variances during the tests

5.2.4 Speed trace violations

The participants of the validation 2 phase delivered the time sequences of the measured vehicle speed signal together with the set speed with 1 Hz resolution. The deviations of the measured speed from the set speed were then calculated for all tests and compliances/violations were calculated for the following tolerance bands:

- ± 3 km/h, ± 1 s,
- ± 2 km/h, ± 1 s,
- Figure 12 shows examples of the first 300 s of the speed traces of 6 tests for a subcompact car with a power to mass ratio of 43,6 kW/t together with the set speed and the tighter of the above listed tolerance bands (± 2 km/h, ± 1 s) .

In most cases the drivers did not have problems to keep the actual speed within this tolerance band. In some cases tolerance violations occurred due to lack of power (see Figure 13 and Figure 14).

Figure 13 shows the speed trace of the extra high speed part for a N1 vehicle with a Petrol engine retrofitted for CNG bi-fuel operation. Running on Petrol, the rated power is 85 kW. With a kerb mass of 2003 kg this leads to a power to mass ratio (pmr) of 42,4 kW/t, so that this vehicle would be a class 3 vehicle, since the borderline between class 2 and class 3 is 34 kW/t.

This vehicle was also tested with natural gas, which reduced the rated power to 68 kW, resulting in a pmr value just below the borderline. The tolerance violations shown in Figure 13 would not occur, if the vehicle would have been tested on the class 2 cycle, since this cycle has less demanding accelerations and a lower top speed.

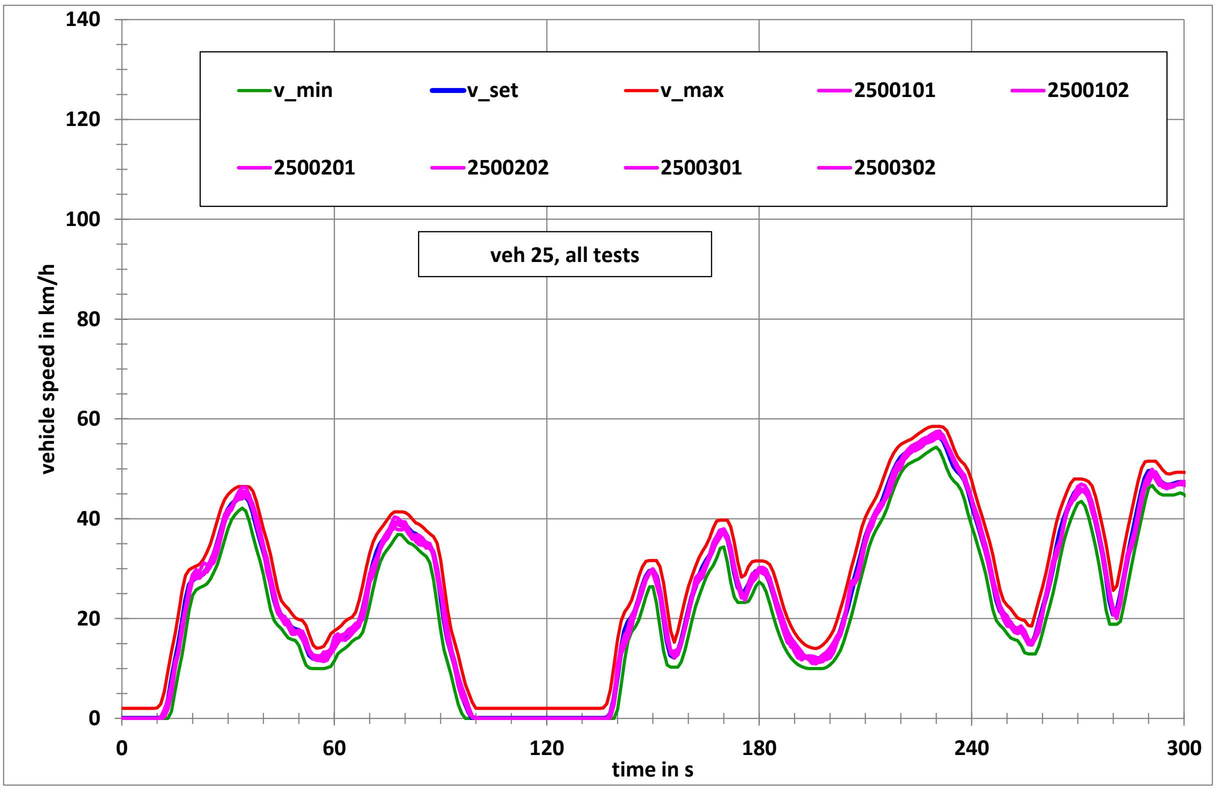

Figure 12: Example for speed trace and tolerance band for the class 3 WLTC

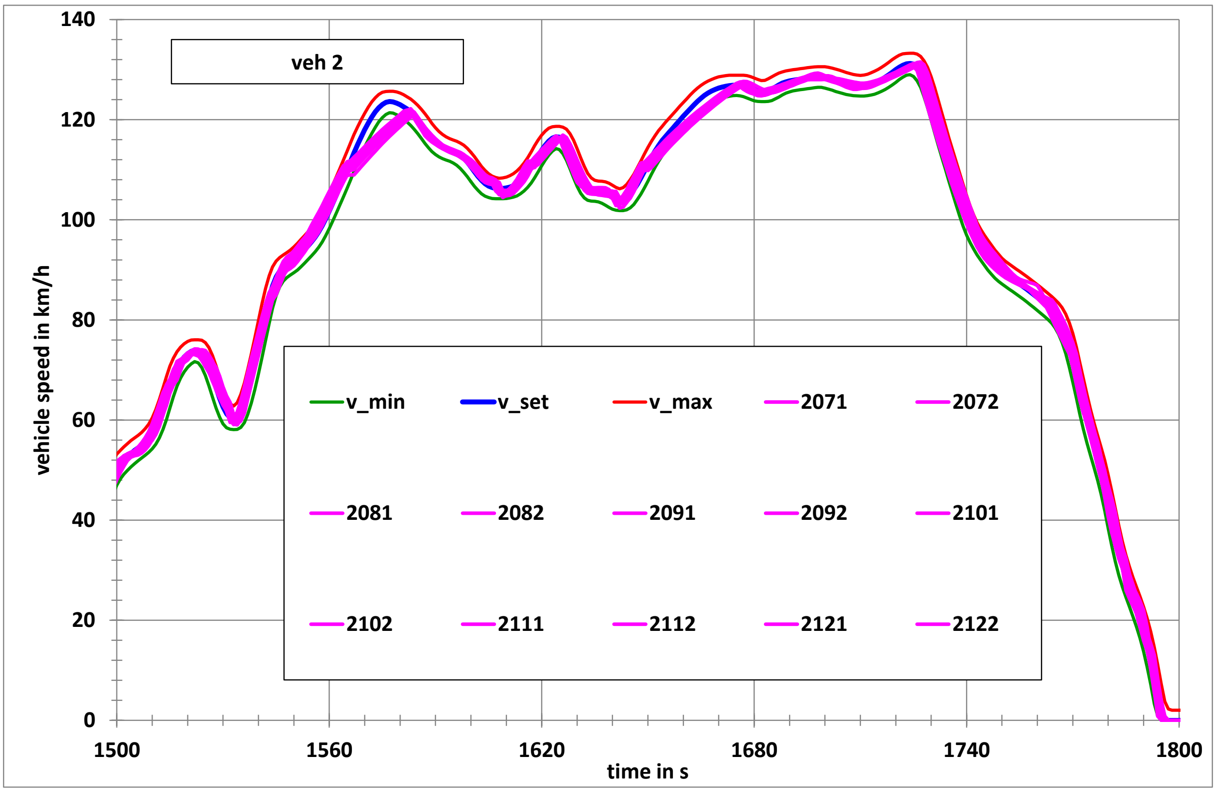

Figure 13: Example for tolerance band violations for the extra high speed phase of the class 3 WLTC

A more severe example is shown in Figure 14. This vehicle from India was tested with natural gas, which obviously reduced the maximum power compared to the operation with Petrol and would qualify the vehicle as class 2 vehicle. And even in this case it would not be able to reach the top speed of the extra high speed phase of the class 2 cycle (123 km/h).

In addition to that, Figure 14 clearly shows that the driveability problems are not only related to the top speed sections but occur already around the cycle time of 1550 to 1560 s at a vehicle speed of 80 km/h.

A more detailed analysis of such driveability problems led to the downscaling method for low powered vehicles, which is described in detail in the DHC part of the report.

Based on the results of the speed compliance/violation analysis the ± 2 km/h, ± 1 s tolerance was concluded to be feasible, and was therefore implemented into the GTR.

Gearshifts did not cause driveability problems for manual transmission vehicles.

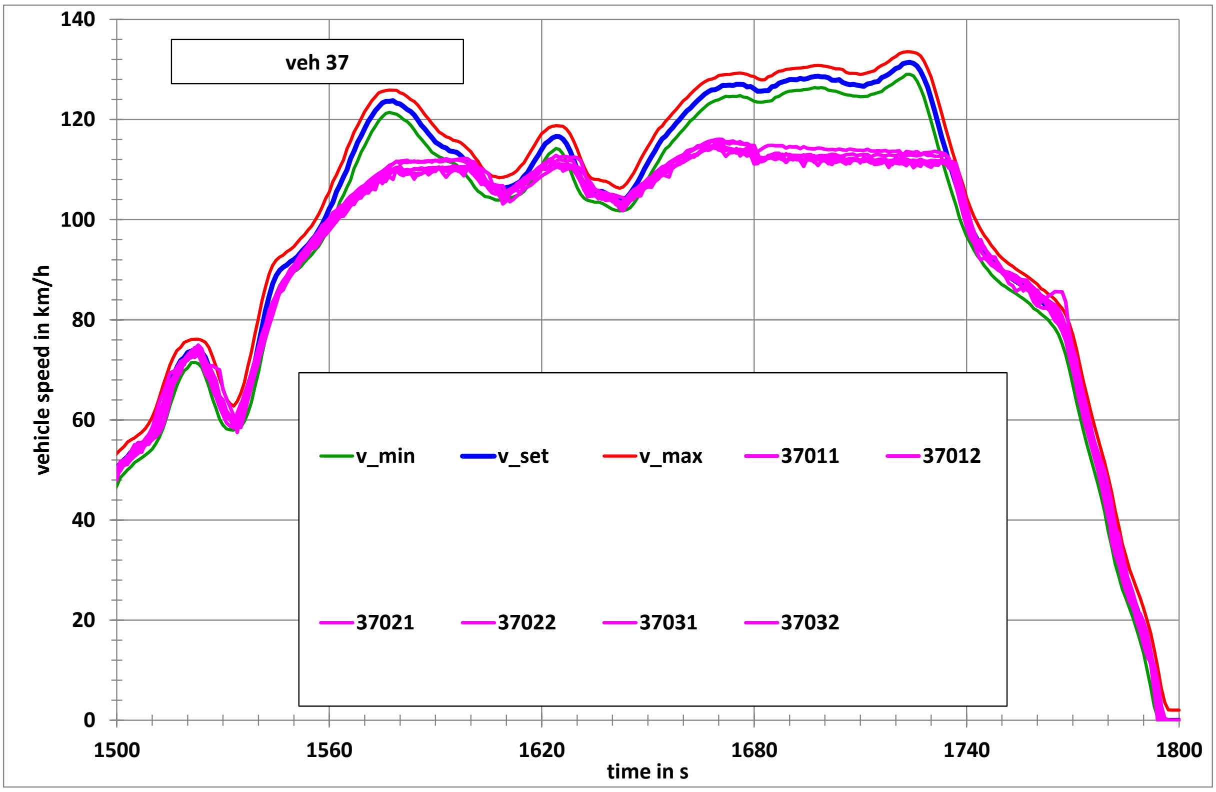

Figure 14: Example for tolerance band violations for the extra high speed phase of the class 3 WLTC

5.2.5 Charge depleting tests for PEV and OVC HEV

As already mentioned, charge depleting tests were performed for 6 pure electric vehicles (PEV) in the validation 2 exercise. Since it was not quite clear, how to classify PEV with respect to vehicle classes, the cycle version allocation was done differently by different participants. One participant used the 30 minutes maximum power of the electrical motor and classified the vehicles by calculating the power to (kerb) mass ratio based on the 30 minutes maximum power.

This led to the situation that vehicle 58 with a peak power of 120 kW, but a 30 minutes power of only 60 kW, and a kerb mass of 1860 kg was classified as class 2 vehicle, although its maximum speed was 145 km/h. This vehicle could have easily driven the class 3 cycle, but was only tested on the class 2 cycle in the version 1.4, that did not contain an extra high speed part. With the 3 phases low, medium and high of the class 2 version 1.4 cycle the vehicle could drive more than 250 km or more than 17 cycles before the batteries were discharged.

Two CD tests on this cycle were performed with vehicle 58. The cumulative discharge curves are shown in Figure 15 and Figure 16. At the first glance there seems to be a wide spread of the energy consumption per cycle within a charge depleting test. For both tests the difference between maximum and minimum discharge energy over one cycle is 0,6 Ah which corresponds to 14% of the average (-6% to +8%) which is reasonably good.

However the break off point (end of charge depleting test) is significantly different in both tests (see Figure 17, Figure 18 and Figure 19), which results in a difference in the driven distance of about 9 km (253,5 km to 263,2 km/h) or +/- 3,5% in relation to the average range.

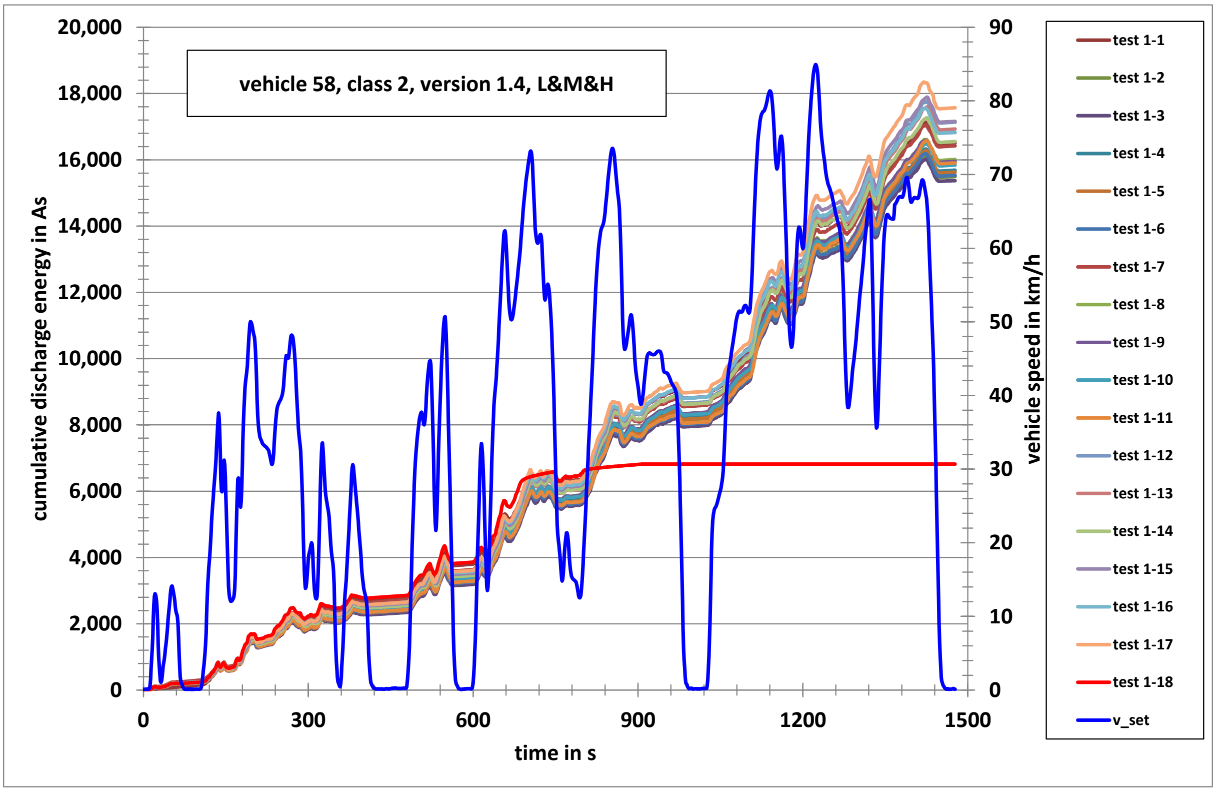

Figure 15: Cumulative discharge energy for CD test 1 for vehicle 58 on the class 2, version 1.4 cycle

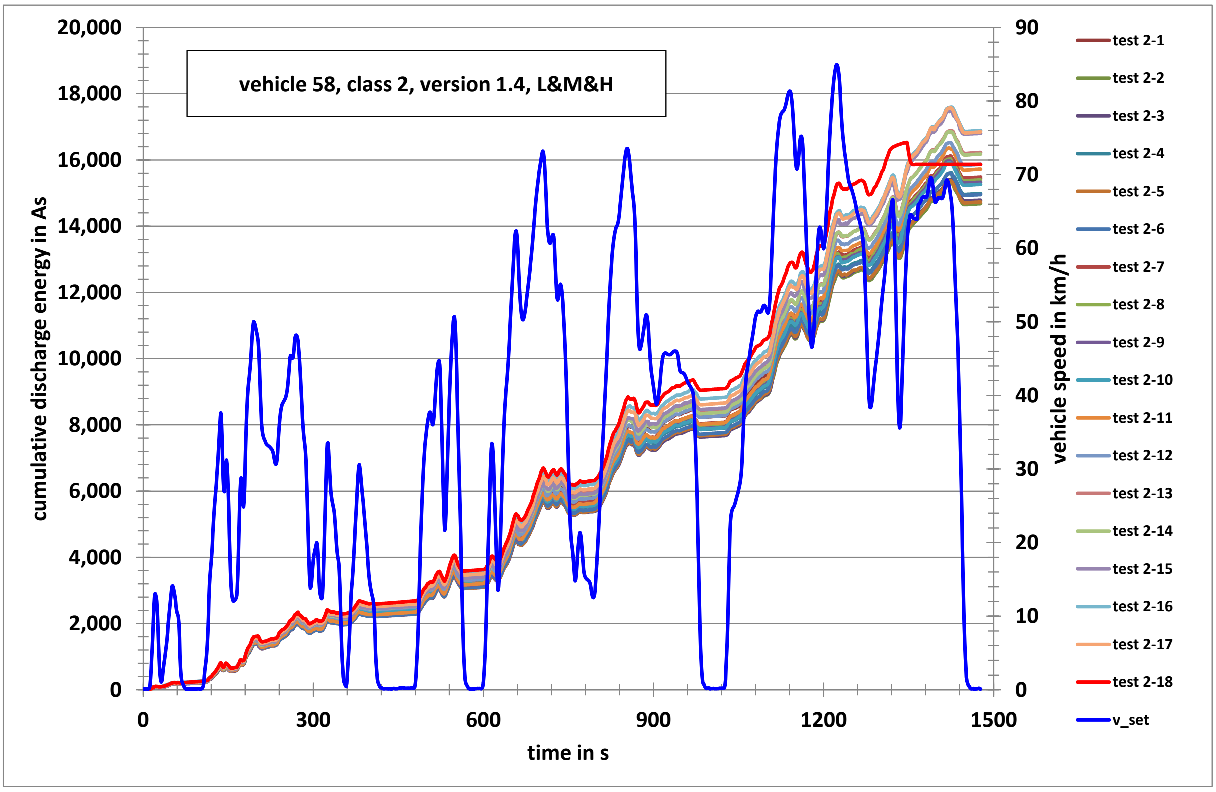

Figure 16: Cumulative discharge energy for CD test 2 for vehicle 58

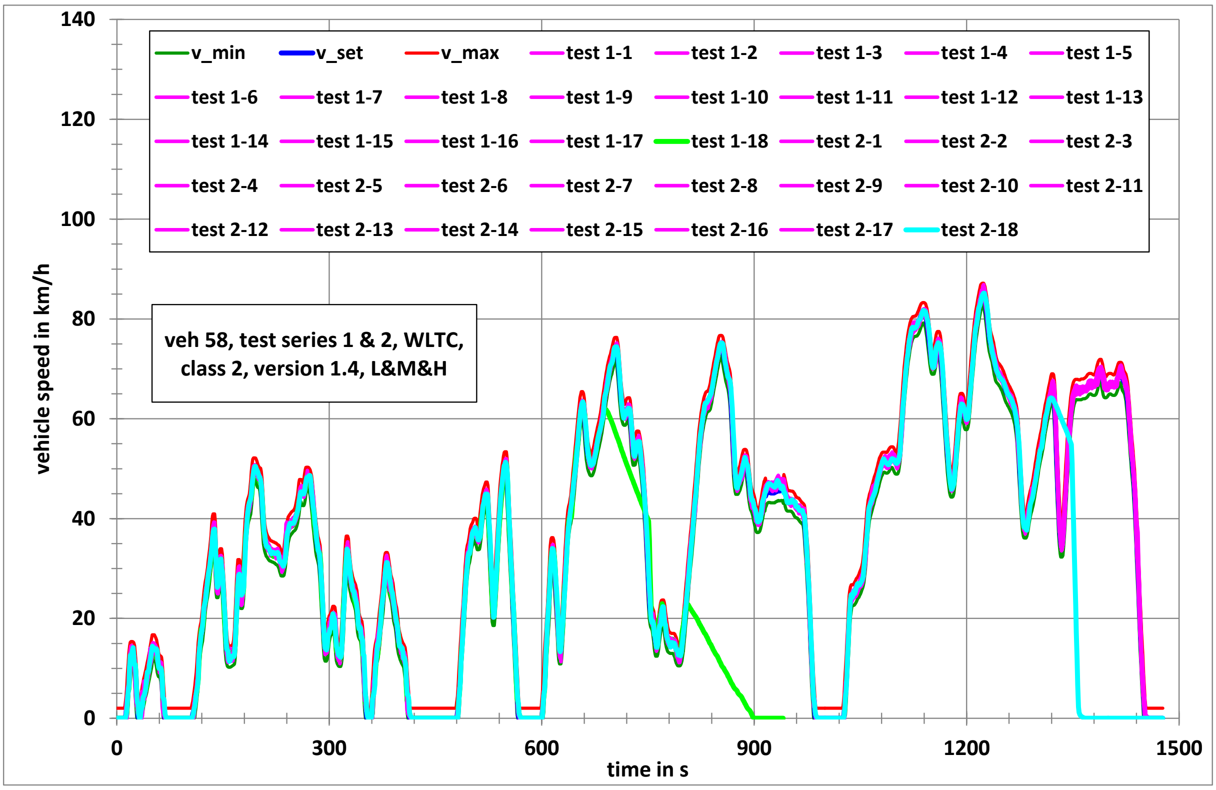

Figure 17: Time series of the vehicle speed for CD tests 1 and 2 for vehicle 58

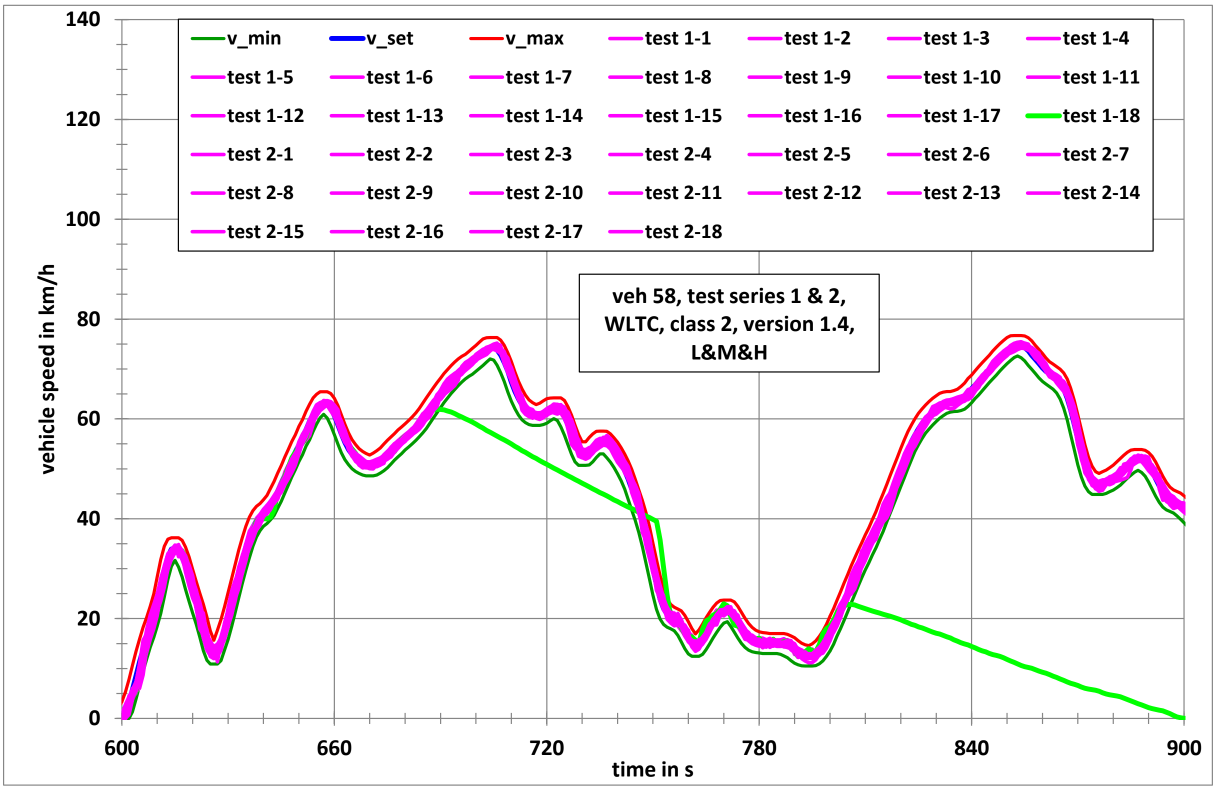

Figure 18: Time series of the vehicle speed for CD test 1 for vehicle 58 at break off point

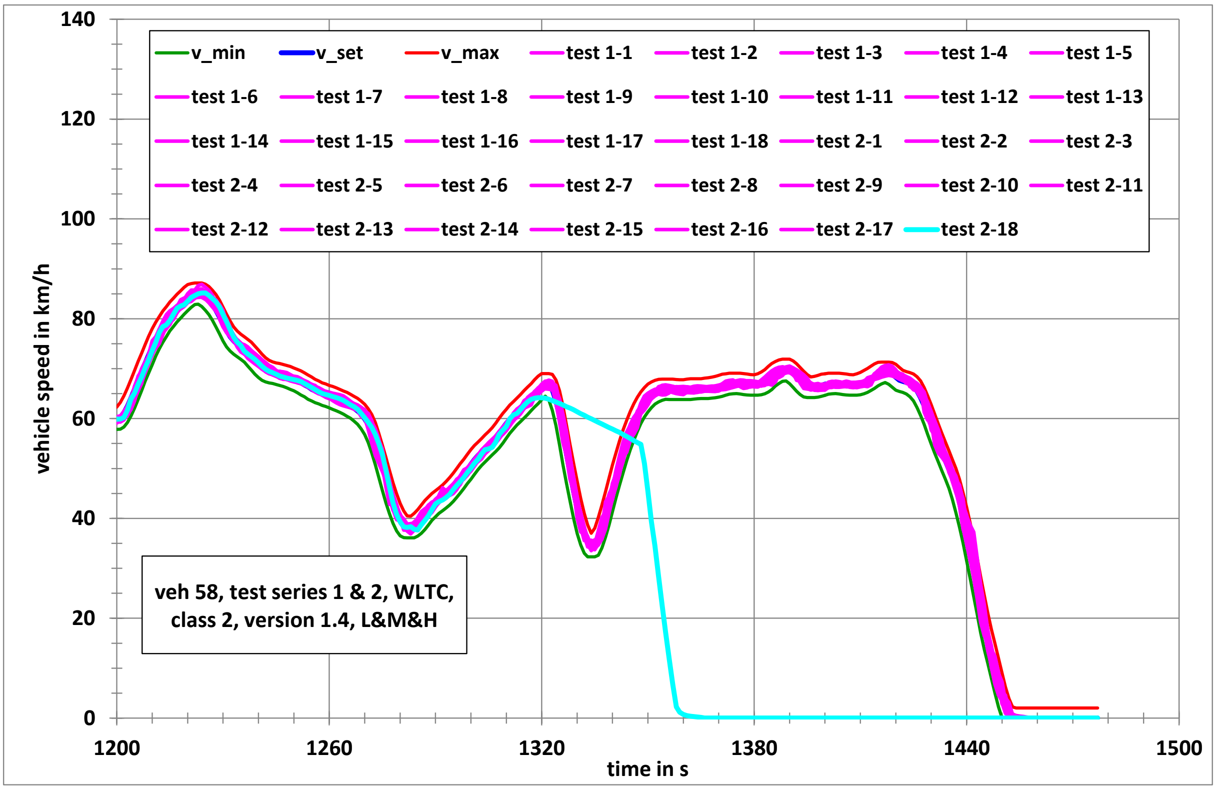

Figure 19: Time series of the vehicle speed for CD test 2 for vehicle 58 at break off point

The driver instruction for the end of a charge depleting test was as follows: If the vehicle speed falls below the tolerance for 4 s or more, the vehicle should be brought to standstill within the following 15 s. As can be seen in Figure 18 and Figure 19, this instruction was not followed. And this was also the case for the other vehicles. On the contrary, Figure 19 shows that the driver was aware that the batteries became fully discharged but tried to still drive as long as possible with full power so that the actual speed trace was significantly above the tolerance within a deceleration phase.

So, generally, the charge depleting tests especially at the break off sections were very helpful for the definition of break off criteria for the GTR.

Vehicle 59 was also tested by the same participant. But since this vehicle had a 30 minutes maximum power of 35 kW (55 kW peak power) and a kerb mass of 940 kg, it was classified as class 3 vehicle (pmr > 34 kW/t) and consequently tested on the class 3 cycle, although the maximum speed was only 124 km/h, which is 6 km/h below the maximum speed of the cycle.

Another PEV, that was tested by this participant, is vehicle 84. This vehicle had a kerb mass of 1290 kg, a peak power of 56 kW and a 30 minutes power of 28 kW. The vehicle was originally tested on the class 1 version 2 cycle because the power to mass ratio is below 22 kW/t, if the 30 minutes power is used as rated power. But since the vehicle had a maximum speed of 130 km/h, it was also tested on all 4 phases of the class 2 version 2 cycle and on the first 3 phases (L&M&H) of the class 3 cycle. The 4th phase of the class 3 cycle was skipped, because the vehicle could even not reach the maximum speed of the extra high speed phase of the class 2 cycle (see Figure 20). Figure 21 shows the break off section for the class 3 cycle.

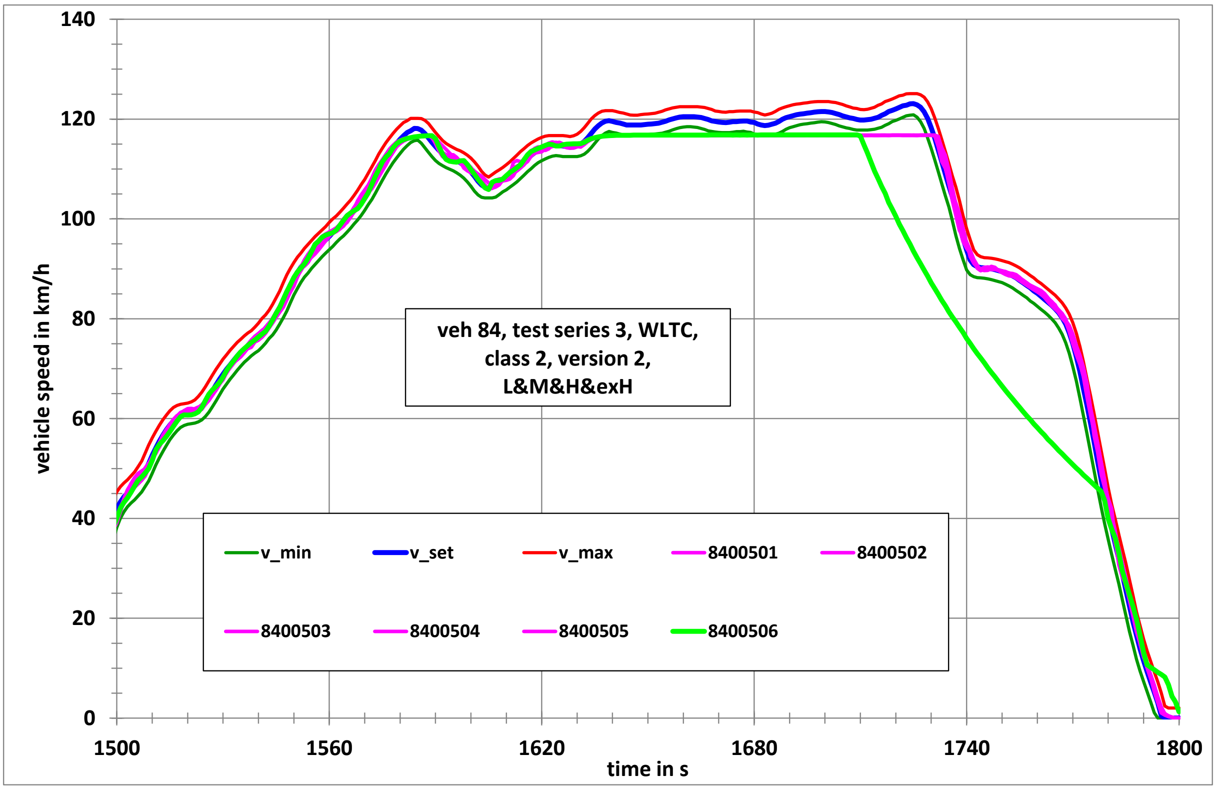

Figure 20: Time series of the vehicle speed for CD test 3 for vehicle 84 at break off section

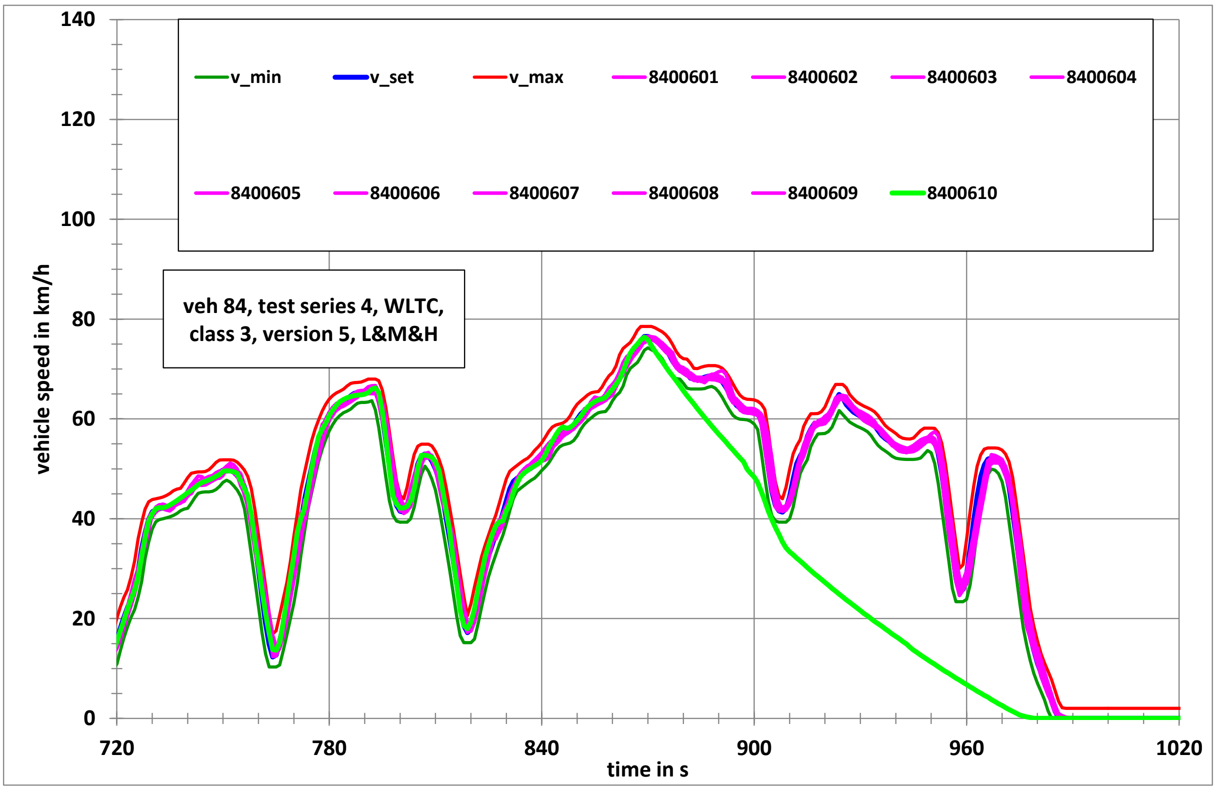

Figure 21: Time series of the vehicle speed for CD test 4 for vehicle 84 at break off section

All other PEV's were tested on the class 3 cycle.

Vehicle 77 had no problems to drive the extra high phase of the class 3 cycle. The break off section of this vehicle is unambiguous (see Figure 22).

Vehicle 80 had a kerb mass of 1590 kg and a 30 minutes power of 50 kW and would have been classified as class 2 vehicle with these values. But it was tested on the class 3 cycle, once over the whole cycle and once with a second low phase instead of the extra high speed phase.

For vehicle 108 the break off point was reached at a vehicle speed above 110 km/h, which makes it really tough, to bring the vehicle to a stop within 15 seconds. Consequently this time period was extended to 60 s in the GTR draft.

The results of all CD tests for the PEV's are summarised in Table 9. There is a dependency of the CD test range and the average speed of the driven cycle but there are of course also significant differences between the vehicles for a given average speed or a given cycle (see Figure 23).

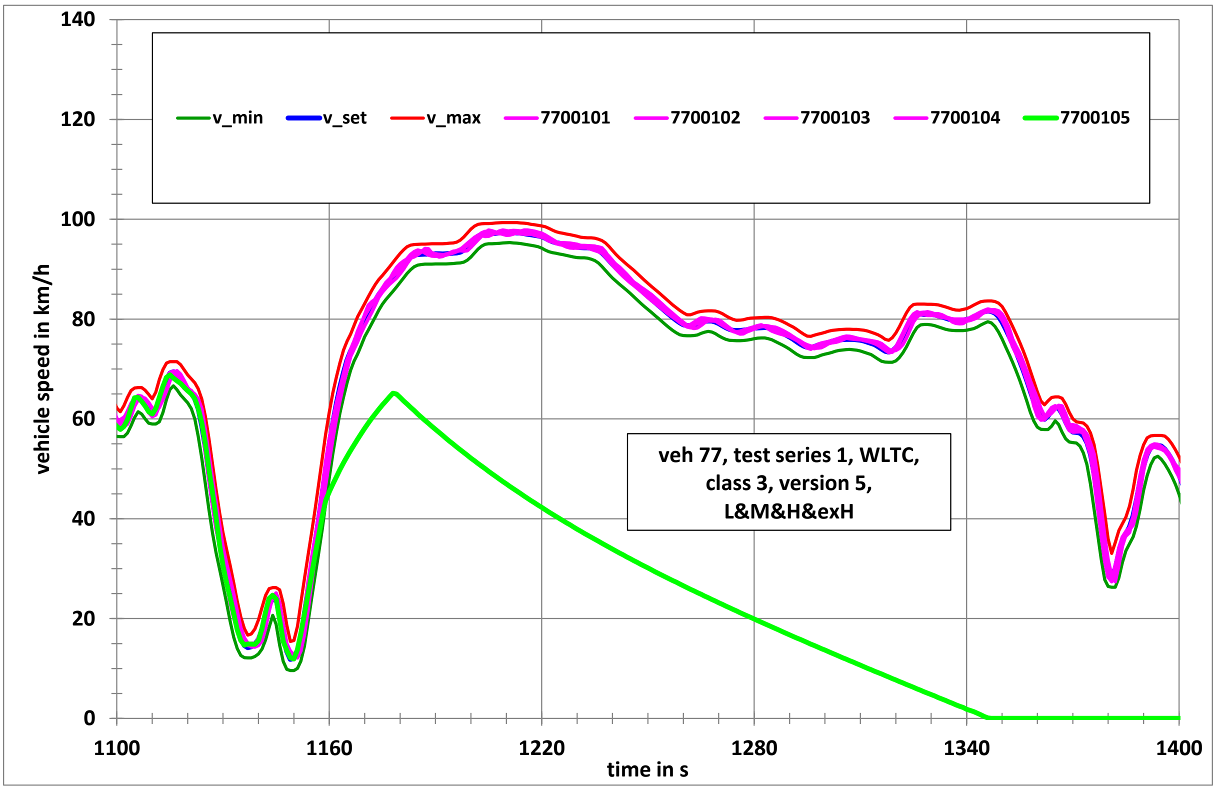

Figure 22: Time series of the vehicle speed for the CD test for vehicle 77 at break off section

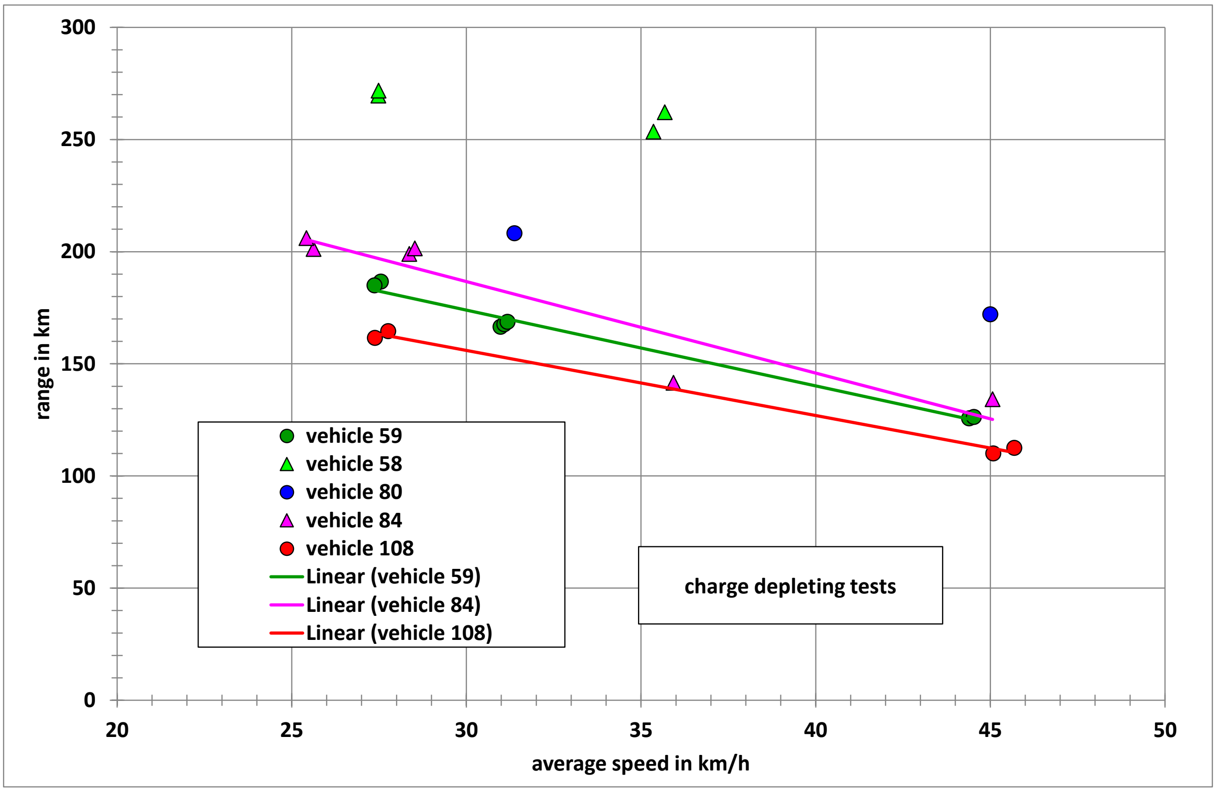

Figure 23: Range of the CD tests for the PEVs versus average speed of the cycles

IDveh	Test series ID	Test ID	cycle ID	description	duration in h	average in h	distance in km	number of cycles	average in km	vehicle speed at end of test in km/h	deceleration last 15 s in m/s²	distance till end of test in m	distance to stop last 15 s in m
58	1	1	20	WLTC, class 2, version 1.4, L&M&H	7.2	**7.3**	253.5	17.3	**257.8**	61.91	-1.15	253,401	129.0
58	1	2	20	WLTC, class 2, version 1.4, L&M&H	7.3		262.2	17.9		62.74	-1.16	262,025	130.7
58	2	3	26	WLTC, class 2, version 1.4, L&M	9.8	**9.8**	269.6	34.4	**270.7**	34.39	-0.64	269,515	71.6
58	2	4	26	WLTC, class 2, version 1.4, L&M	9.9		271.8	34.7		45.63	-0.85	271,725	95.1
59	1	1	14	WLTC, class 3, version 5, L&M&H&L	5.4	**5.4**	166.4	9.2	**167.6**	33.88	-0.63	166,362	70.6
59	1	2	14	WLTC, class 3, version 5, L&M&H&L	5.4		167.7	9.3		41.08	-0.76	167,580	85.6
59	1	3	14	WLTC, class 3, version 5, L&M&H&L	5.4		168.7	9.3		71.62	-1.33	168,571	149.2
59	2	4	11	WLTC, class 3, version 5, L&M	6.8	**6.8**	186.6	23.8	**185.8**	59.03	-1.09	186,521	123.0
59	2	5	11	WLTC, class 3, version 5, L&M	6.8		184.9	23.6		61.06	-1.13	184,776	127.2
59	3	6	1	WLTC, class 3, version 5, L&M&H&exH	2.8	**2.8**	125.7	5.4	**126.0**	89.63	-1.66	125,481	186.7
59	3	7	1	WLTC, class 3, version 5, L&M&H&exH	2.8		126.3	5.4		91.61	-1.70	126,080	190.9
77	1	1	1	WLTC, class 3, version 5, L&M&H&exH	2.3		102.5	4.4		40.38	-0.75	102,433	84.1
80	1	1	14	WLTC, class 3, version 5, L&M&H&L	6.6		208.2	11.5		39.76	-0.74	208,114	82.8
80	2	2	1	WLTC, class 3, version 5, L&M&H&exH	3.8		172.0	7.4		42.64	-0.79	171,918	88.8
84	1	1	31	WLTC, class 1, version 2, L&M&L	7.9	**8.0**	201.2	17.6	**203.6**	59.30	-1.10	201,101	123.5
84	1	2	31	WLTC, class 1, version 2, L&M&L	8.1		206.0	18.0		35.20	-0.65	205,947	73.3
84	2	3	3	WLTC, class 1, version 2, L&M	7.0	**7.0**	199.0	24.6	**200.2**	52.26	-0.97	198,856	108.9
84	2	4	3	WLTC, class 1, version 2, L&M	7.1		201.5	24.9		50.62	-0.94	201,345	105.5
84	3	5	2	WLTC, class 2, version 2, L&M&H&exH	3.0		134.2	5.9		108.08	-2.00	133,980	225.2
84	4	6	12	WLTC, class 3, version 5, L&M&H	3.9		141.5	9.4		69.48	-1.29	141,369	144.8
108	1	1	11	WLTC, class 3, version 5, L&M, 1250 kg	5.9		164.5	21.0		40.89	-0.76	164,402	85.2
108	2	2	11	WLTC, class 3, version 5, L&M, 1350 kg	5.9		161.5	20.6		50.45	-0.93	161,441	105.1
108	3	3	1	WLTC, class 3, version 5, L&M&H&exH, 1250 kg	2.5		112.5	4.8		112.16	-2.08	112,290	233.7
108	4	4	1	WLTC, class 3, version 5, L&M&H&exH, 1350 kg	2.4		110.0	4.7		117.28	-2.17	109,760	244.3

Table 9: Results of charge depleting tests for the 6 pure electric vehicles

In addition to the PEVs 2 OVC HEVs were tested on the class 3 cycle (vehicles 60 and 65). Vehicle 60 had a kerb mass of 1730 kg, a 1,4 l Petrol engine with a rated power of 63 kW and an electric motor with a peak power of 111 kW. Vehicle 65 had a kerb mass of 1425 kW, a 1,8 l Petrol engine with a rated power of 73 kW and an electric motor with 60 kW power, which is most probably the peak power. Both vehicles would be classified as class 3 vehicles when considering the rated power of the ICE only. The difference in kerb mass reflects the fact that vehicle 60 had a much higher traction battery capacity than vehicle 65.

This resulted in a much higher electrical range for vehicle 60 compared to vehicle 65 (see Figure 24 to Figure 27). Vehicle 60 could drive almost 3 full class 3 cycles (all 4 phases) without assistance of the ICE, while vehicle 60 could only drive the low, medium and high speed part of one class 3 cycle in electrical mode (see Figure 24 and Figure 26).

Another difference was, that the traction battery was recharged to a certain extent during following CS tests, which was not the case for vehicle 65 (see Figure 25 and Figure 27).

These results built the basis for the prescriptions for charge depleting and charge sustaining tests in the GTR, especially for the break off criteria (CD tests) and the determination of the electric range for PEVs and OVC-HEVs.

But the results show also quite clearly, that the current vehicle classification for PEV and OVC-HEV in the GTR is not satisfactory. For that reason a better classification is one of the open issues to be solved within phase 1b of the WLTP development.

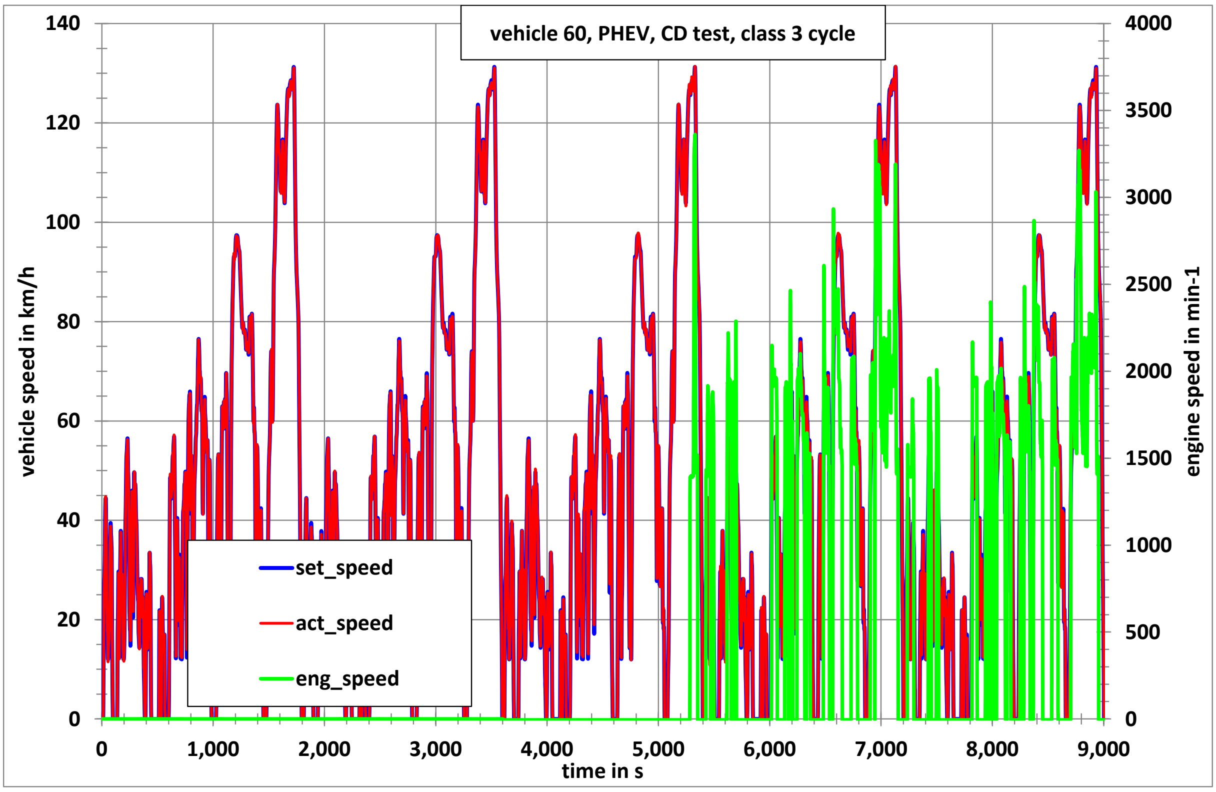

Figure 24: Charge depleting test for OVC HEV vehicle 60, vehicle speed and engine speed

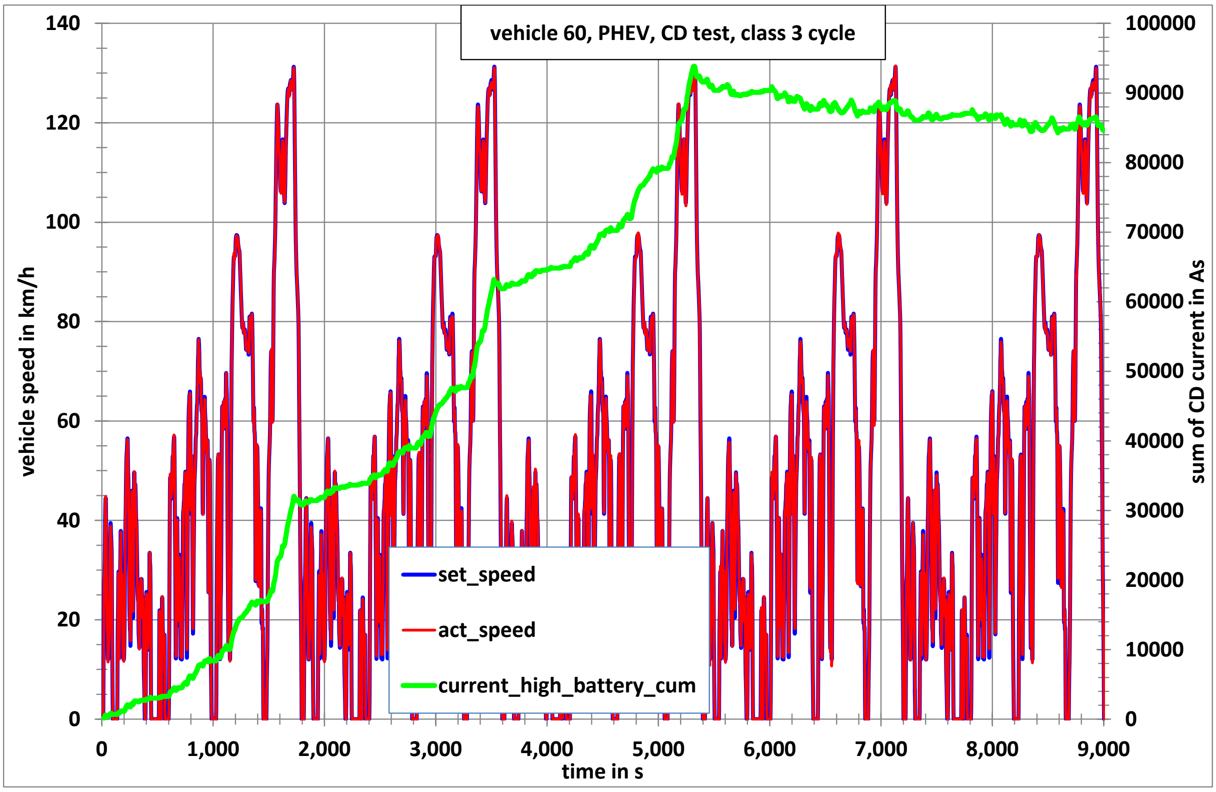

Figure 25: Charge depleting test for OVC HEV vehicle 60, vehicle speed and current

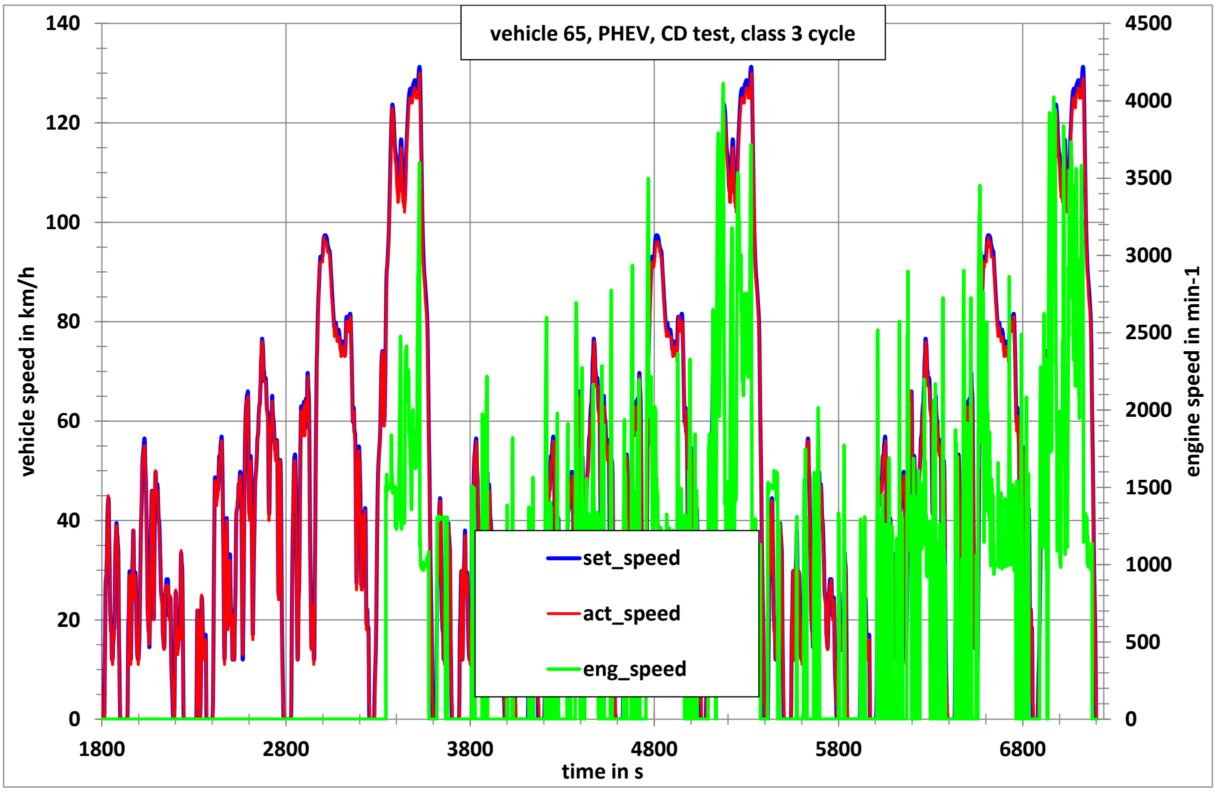

Figure 26: Charge depleting test for OVC HEV vehicle 65, vehicle speed and engine speed

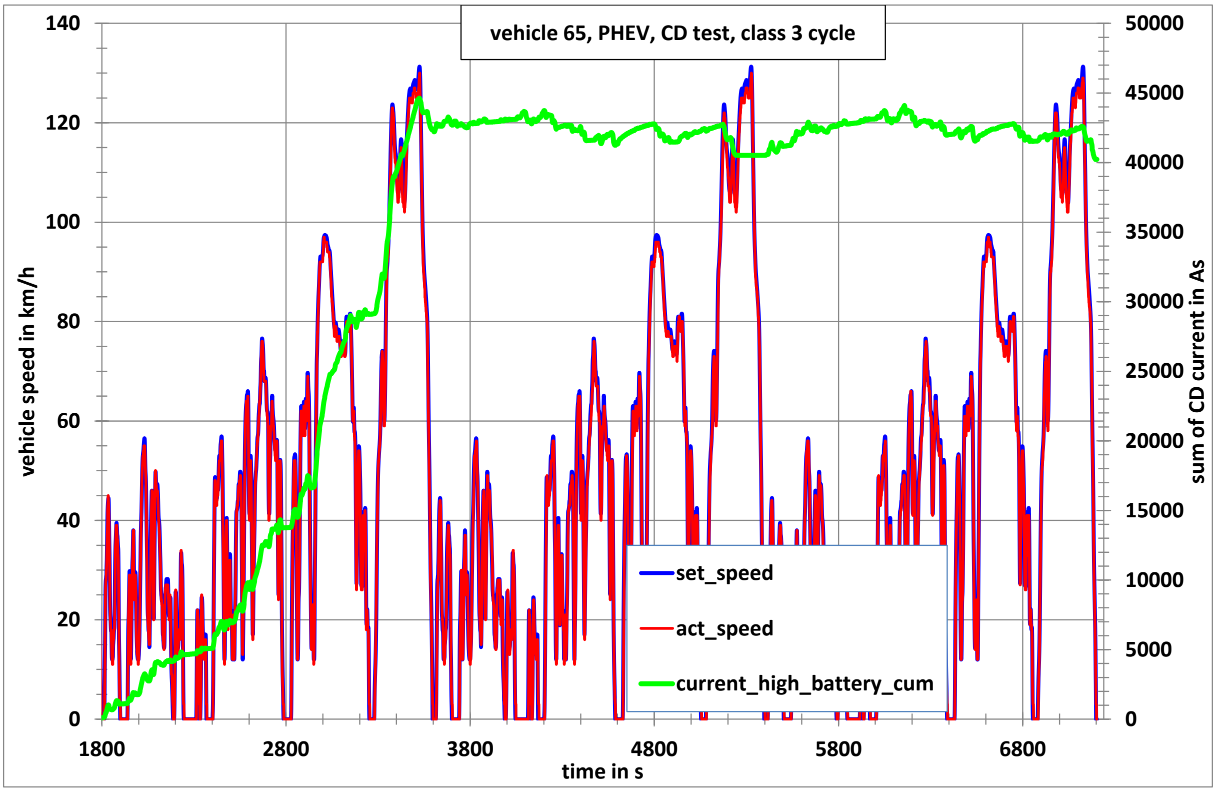

Figure 27: Charge depleting test for OVC HEV vehicle 65, vehicle speed and current

Annex 1 - Emission legislation:

The following emission and fuel consumption legislation was reviewed as a basis for the GTR:

US-Regulations (EPA and ARB)

CFR-2009-title40-part86-Volume18

CFR-2009-title40-part86-Volume19

CFR-2009-titel40-part1065-Volume32

CFR-2010-title40-part86-Volume18

CFR-2010-title40-part86-Volume19

CFR-2010-titel40-part1065-Volume32

CFR-2010-titel40-part600

California non-methane organic gas test procedures

Compliance guidance letters

Advisory Circulars

US CARB[17]

UNECE (comparable to EC 715/2007, EC 692 /2008)

ECE-R 83

ECE-R 101

ECE-R 24

ISO 10521-1

ISO 10521-2

GTR no.2 (Two-wheeled motorcycles)

GTR no.4 (Heavy duty vehicles)

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[17] ***Formaldehyde*** *emissions from light-duty are measured with a methodology based on Federal Test Procedure as set forth in* ***subpart B, 40 CFR*** *Part Subpart B, 40 CFR Part 86, and modifications located in "CALIFORNIA EXHAUST EMISSION STANDARDS AND TEST PROCEDURES FOR 2001 AND SUBSEQUENT MODEL PASSENGER CARS, LIGHT-DUTY TRUCKS, AND MEDIUM-DUTY VEHICLES" page II-1 and II-16 respectively.*

The Formaldehyde test method used in CALIFORNIA EXHAUST EMISSION STANDARDS AND TEST PROCEDURES FOR 2001 AND SUBSEQUENT MODEL PASSENGER CARS, LIGHT-DUTY TRUCKS, AND MEDIUM-DUTY VEHICLES is the DNPH impinger method or DNPH cartridge. After collecting Formaldehyde using DNPH impinger or DNPH cartridge, the sample is send to the Lab to do analysis, such as HPLC.

Japan

Automobile Type Approval Handbook for Japanese Certification

Brazil

ABNT NBR 15598 (Brazilian Standard for Ethanol)

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- Oliver Eberhardt, Ministry of Environment
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