Submitted by the Chair of the IWG on WLTP

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agenda item 3(b)

Technical Report on the development of a World-wide Worldwide harmonised Light duty driving Test Procedure (WLTP)

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

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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, namely:

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.

Within the roadmap of WLTP there are 3 phases distinguished, and the first phase is further subdivided in a phase 1a and 1b (see paragraph 3.1).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. This report was published at the time that phase 1b was completed.

The technical report on the development process of the driving cycle is described in a separate document[2], which was published at the point where WLTP phase 1a had finished.

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

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

2 Objective of WLTP

The primary objective of the global technical regulation (GTR) developed in the WLTP process is to form the basis for the emission regulation of light-duty 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. Each of the Contracting Parties to the 1998 Agreement could then transpose this new standard into their own legislative framework.

As a result of this overarching objective, the work on WLTP aimed to develop a test procedure that would fulfil the following basic demands:

a) The test procedure should be globally harmonised and applicable, and
b) The results should be representative for average real-world vehicle performance in terms of emissions, fuel and/or energy consumption.

The work on the WLTP was chosen to be structured in such a way that the two main elements that form the backbone of the procedure for vehicle emission legislation were separately developed. These two elements are:

a) the test cycle, which should be representative for average real-world vehicle operation, and
b) the test procedure, which should comprise a method to determine the levels of gaseous and particulate emissions, fuel and/or electric energy consumption, CO_2 emissions and electric range –if applicable- in a repeatable and reproducible manner.

The underlying report highlights the work that took place during the course of the development of the test procedure. The technical report on the development process of the driving cycle is described in a separate document[2].

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

3.1 WLTP Informal Group (WLTP-IG)

In its November 2007 session, WP.29 decided to set up an informal WLTP group under GRPE to prepare a road map for the development of the WLTP[3]. After various meetings and intense discussions, WLTP informal group presented a first road map in June 2009 consisting of 3 phases. This initial roadmap was subsequently revised a number of times, and consists of the following main tasks:

a) Phase 1 (2009 - 2014): development of the worldwide harmonised light duty driving cycle and associated test procedure for the common measurement of criteria compounds, CO_2, fuel and energy consumption;

b) Phase 2 (2014 - 2018): low temperature/high altitude test procedure, durability, in-service conformity, technical requirements for on-board diagnostics (OBD), mobile air-conditioning (MAC) system energy efficiency, off-cycle/real driving emissions;

c) Phase 3 (2018 - …): emission limit values and OBD threshold limits, definition of reference fuels, comparison with regional requirements.

The first meeting of the WLTP IG group took place in Geneva, on 4 June 2008. After the 4th meeting the WLTP-IG was disbanded and the steering group as shown in Figure 1 took the lead over the development process.

Three technical working groups were established under WLTP, each with a specific development task (see 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 the validation test phase 1, i.e. to analyse the test cycle and propose amendments where necessary;

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, i.e. to analyse the test results and to propose amendments to the test procedure where necessary.

Within the DTP subgroup, the following working groups were established that would deal with specific technical areas of the test procedure:

- ICE-Laboratory Procedures (LabprocICE) for the development of the road load determination methods and laboratory test procedures for conventional vehicles with an internal combustion engine (ICE)
- E-Laboratory Processes (LabprocEV) for the development of all laboratory test procedures related to electrified vehicles, including hybrids
- PM/PN for the development of a test procedure for the determination of Particulate Matter and the Particle Number in the exhaust gas.

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[3] The UNECE World Forum for Harmonization of Vehicle Regulations (WP.29) is a worldwide regulatory forum within the institutional framework of the UNECE Inland Transport Committee. For more information refer to the UNECE website: http://www.unece.org/trans/main/wp29/introduction.html

- Additional Pollutants (AP) for the test procedure of currently non-regulated gaseous emission components (NO_2, N_2O, NH_3, EtOH, aldehydes, etc.)
- Reference Fuel (RF) to define the specifications for reference fuels used in emission testing.

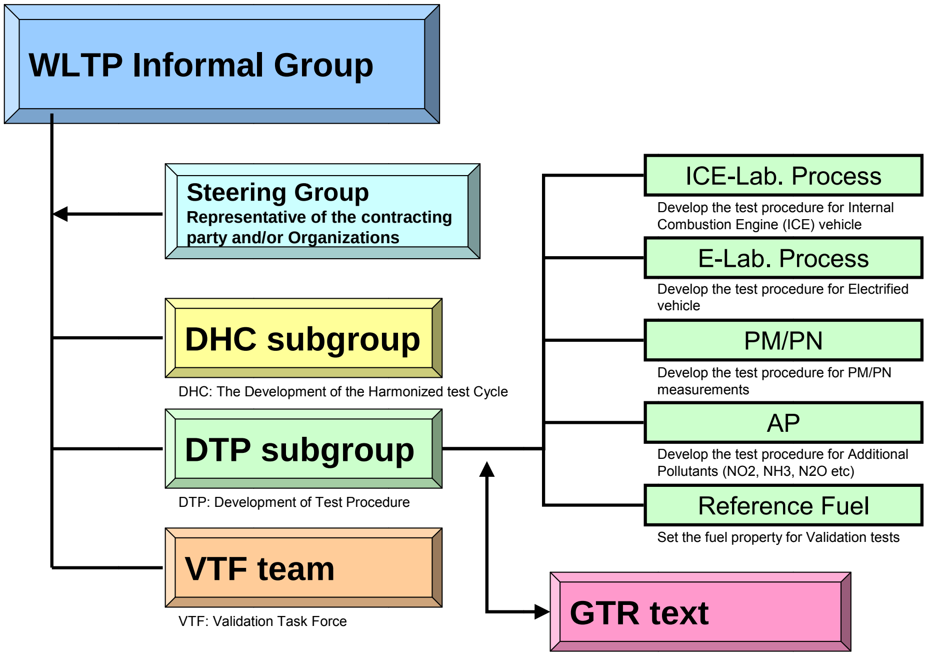

Figure 1: Original structure of WLTP-IG

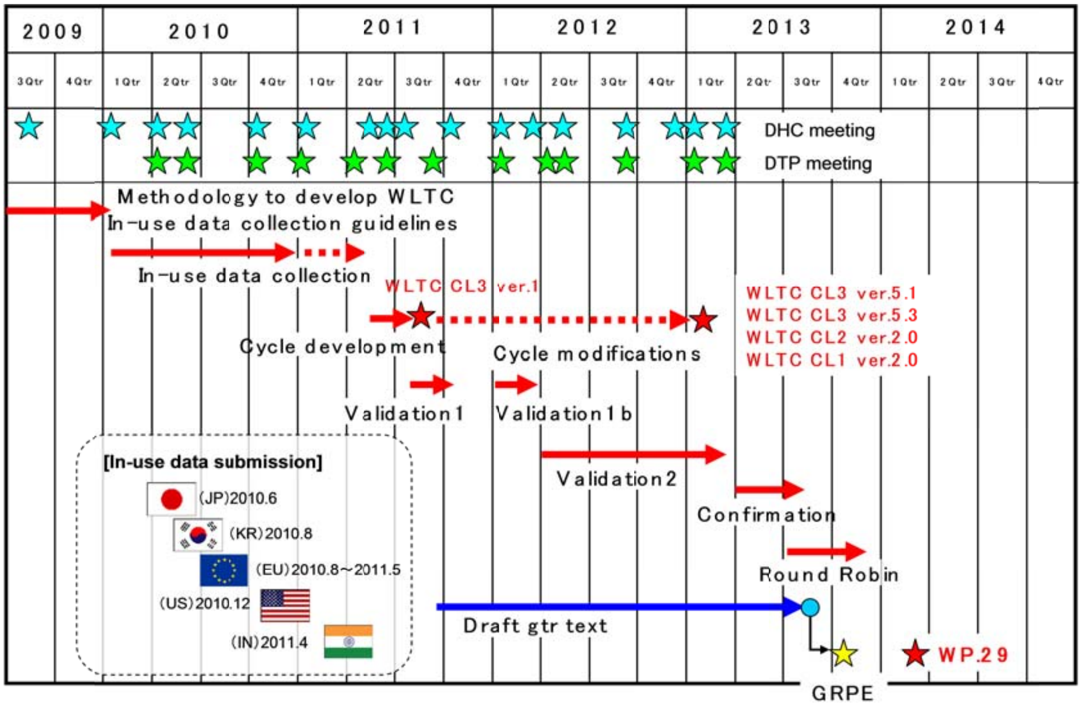

Figure 2: Original time schedule set by WLTP-IG for Cycle and Procedure development

Figure 2 shows the original road map for the development of WLTP. The development work started in September 2009.

Since the beginning of the WLTP development process, the European Union had a major political objective set by its own legislation to implement a new and more realistic test cycle by 2014[4]. This was a strong political driving factor for setting the time frame of phase 1. However, during the work of the DTP group it became clear that a number of issues, in particular but not only in relation to electric and hybrid-electric vehicles, could not be resolved in time for an adoption of the first version of the WLTP GTR by WP.29 in March 2014. Therefore it was agreed that the work of Phase 1 would be divided into 2 sub-phases:

a) Phase 1a (2009 - 2013): development of the worldwide harmonized light duty driving cycle and the basic test procedure. This led to the first version of this GTR, which was published as official working document ECE/TRANS/WP.29/GRPE/2013/13 and a series of amendments published as informal document GRPE-67-04-Rev.1;

b) Phase 1b (2013-2016): further development and refinement of the test procedure, while including additional items into the GTR.

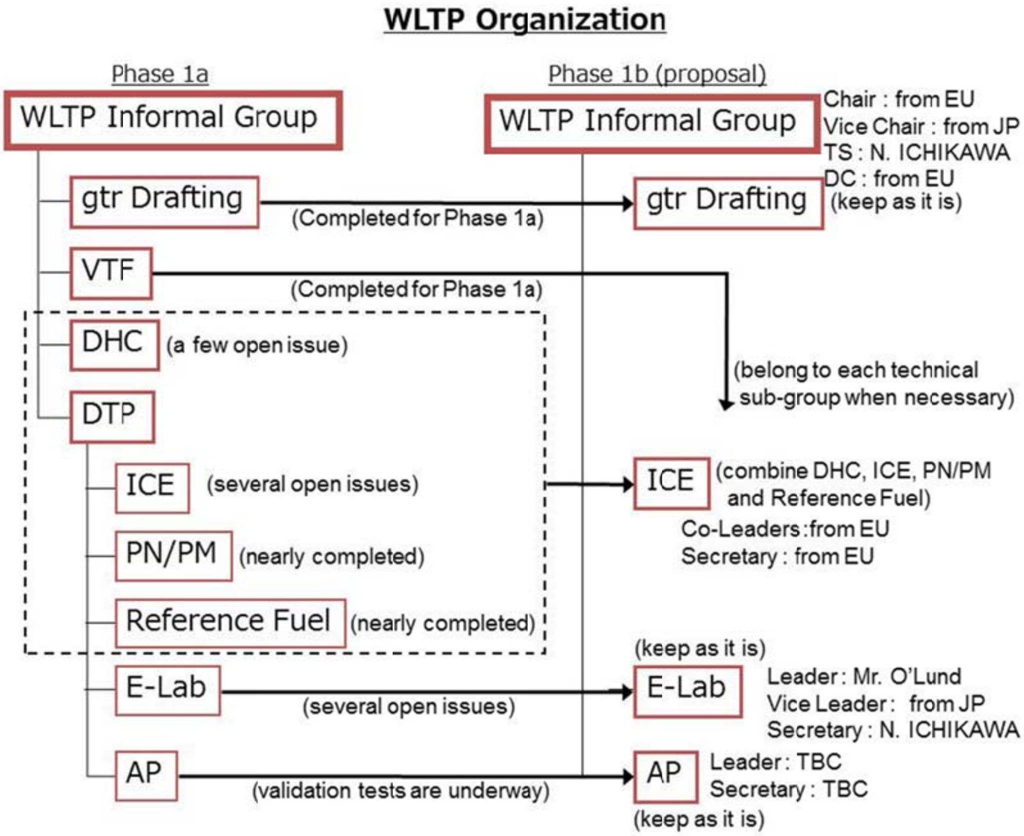

Figure 3: Proposed structure for WLTP phase 1b

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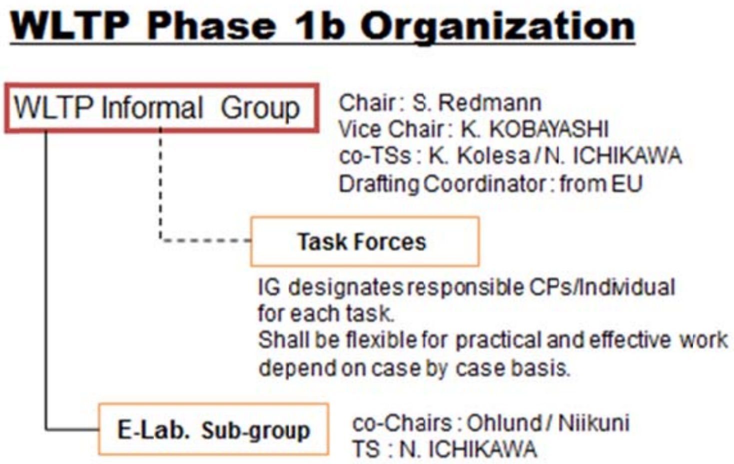
[4] Refer to Regulations (EC) 443/2009 and 510/2011



WLTP Phase 1b Organization

WLTP Informal Group

Chair: S. Redmann
Vice Chair: K. KOBAYASHI
co-TSs: K. Kolesa / N. ICHIKAWA
Drafting Coordinator: from EU

Task Forces

IG designates responsible CPs/Individual for each task.
Shall be flexible for practical and effective work depend on case by case basis.

E-Lab. Sub-group

co-Chairs: Ohlund / Niikuni
TS: N. ICHIKAWA

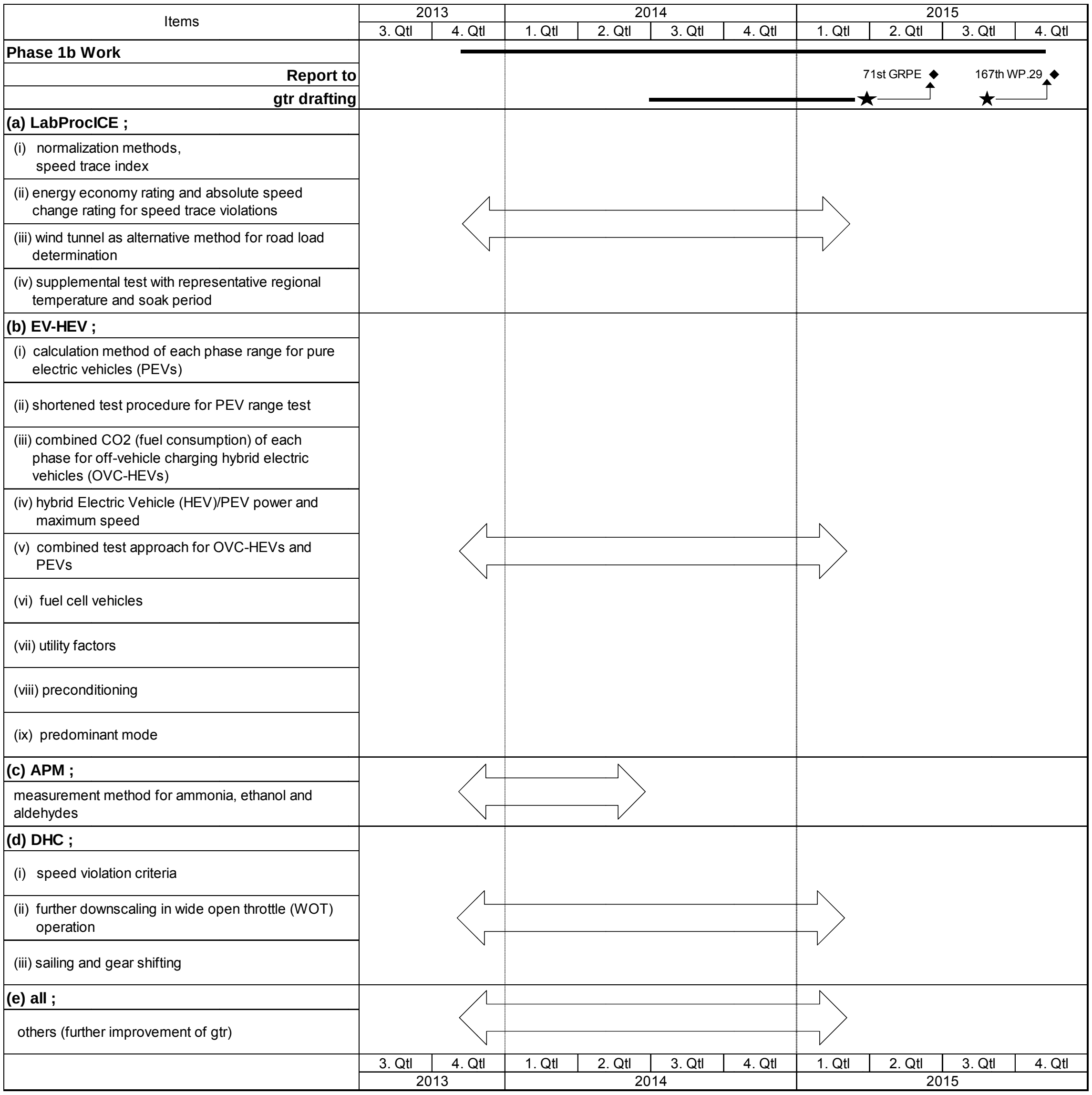


Figure 4: Changeover of the WLTP organization from phase 1a to phase 1b, and planning of phase 1b

The work for phase 1b was structured and organised according to the following expert groups under WLTP informal working group (see Figure 4 and 4):

- GTR drafting: coordination over all groups, to ensure that the GTR is robust, coherent, and consistent. This is a continuation of the GTR drafting work under phase 1a;
- E-lab: specific test conditions and measurement procedures for electric and hybrid-electric vehicles. This is a continuation of the EV-HEV group under phase 1a;
- Additional Pollutants (AP) for the test procedure of currently non-regulated emission components (NO_2, N_2O, NH_3, EtOH, aldehydes, etc.). This is a continuation of the AP group under phase 1a;
- Taskforces: for each specific topic that had to be amended or be added in phase 1b, the informal working group would designate a taskforce leader, who would work in a group with interested stakeholders on developing a testing methodology and a GTR text proposal. This could be any issue related to the former DHC, LabProcICE, PM/PN or RF working groups;
- Round Robin testing, i.e. to analyse the test results and to propose amendments to the test procedure where necessary.
- Drafting: a subgroup has been established under the lead of the drafting coordinator and with members from WLTP leading team, Annex coordinators, Contracting Parties and NGO experts. The main tasks were a „peer review“ of the GTR, check for inconsistencies, editorial review of IWG and expert proposals.

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].

3.3 DTP group and subgroups in phase 1a

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)).

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 Figure 1, 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) additional 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[5] (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 5.

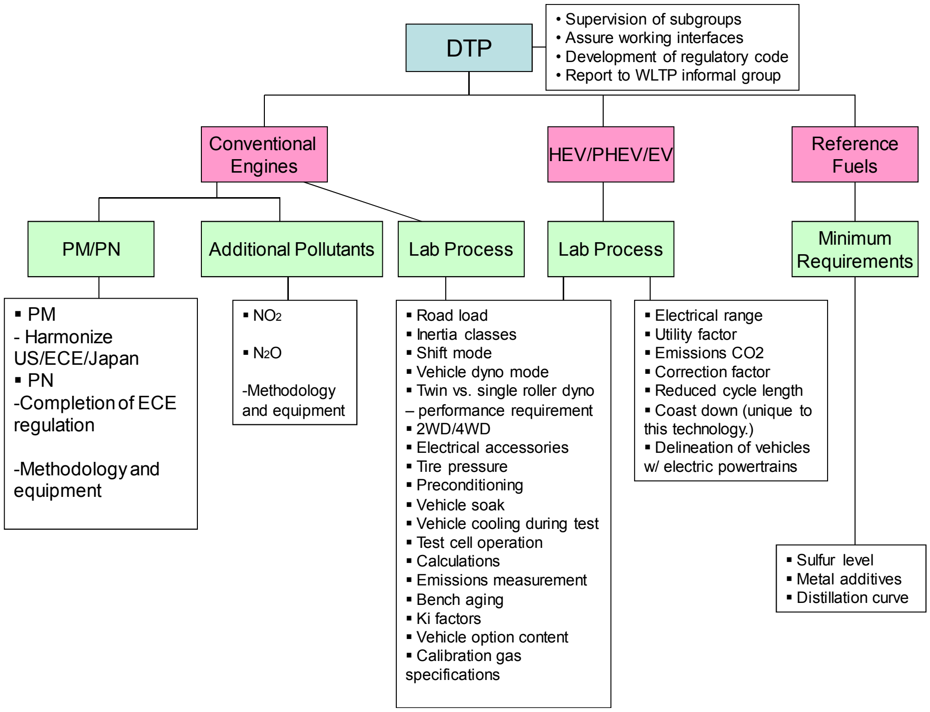


Figure 5: Structure of the DTP and its subgroups[6]

A more detailed overview for the scope of activities of these subgroups is presented in the next paragraphs.

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

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

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 at least 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.
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 was 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.

3.3.1 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]:

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;

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

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 electrified vehicles (and deviating from Annexes 5 and 6) are defined.

3.3.2 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 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

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

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.

3.3.3 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 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.

3.3.4 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 in phase 1a is restricted 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).

3.4 WLTP phase 1b

At the time that phase 1a was concluded, the main development on the test cycle and the test procedure had finished. This resulted in the first version of the GTR, which was published as official working document ECE/TRANS/WP.29/GRPE/2013/13 and a series of amendments published as informal document GRPE-67-04-Rev.1. Even though the main body of the GTR was now in place, still quite a number of open issues were yet to be resolved. Especially on the area of electrified vehicles a considerable effort was needed to finish the work on closing the open issues.

- With the changeover from phase 1a to phase 1b of WLTP, the structure of organization was modified in such a way that the remaining open issues would be addressed by dedicated taskforces. This new structure is shown in Figure 3 and Figure 4 of paragraph 3.1.
- Drafting: a subgroup has been established under the lead of the drafting coordinator and with members from WLTP leading team, Annex coordinators, Contracting Parties and NGO experts. The main tasks were a „peer review“ of the GTR, check for inconsistencies, editorial review of IWG and expert proposals.

The former subdivision into subgroups DHC and DTP was abandoned, and only a few working groups. All activities in WLTP would from now on be managed by the WLTP-IG leading team.

WLTP-IG leading team

Chair	*Technical Secretary*
Stephan Redmann – BMVI (Germany)	Noriyuki Ichikawa – OICA/Toyota
Co-Chair	*Co-Technical Secretary*
Kazuki Kobayashi - NTSEL (Japan)	Konrad Kolesa – OICA/Audi

The meetings of WLTP-IG were held in conjunction with the GRPE meetings that take place in Geneva every January and June. They were supplemented by meetings every fall and autumn to a total of 4 meetings per year. The first meeting was on 14 January of 2014 in Geneva, the last one is on 11-12 January 2016 in Geneva. Over that period, a total of 9 WLTP-IG meetings took place. For the subgroups and taskforces the same basic terms of reference as outlined in paragraph 3.3 were also applicable to the working groups in phase 1b.

The scope of activity was dedicated to the issues covered by the tasks of the different subgroups and is further detailed in the next paragraphs. A separate activity is formed by the Round Robin tests, which were conducted during the course of phase 1b by OICA. The taskforces that were formed to deal with the open issues are listed and described in paragraph 3.4.5.

All of the open issues addressed in phase 1b regarding the test cycle, gear shifting, downscaling etc. are reported separately. At the time that this report was published the update of the DHC report[2] for phase 1b was not available. The main driving cycle related issues that were discussed and agreed during phase 1b are the following:

a) Further downscaling in Wide Open Throttle (WOT) operation: the coefficients in the calculation formulae were amended at the request of Contracting Party of India

b) Modifications to the gear shifting calculation tool: the 3s rule was replaced by 2 s rule, crawler gear prescriptions were added as well as an additional safety margin for the WOT power curve

3.4.1 Drafting GTR

Chair
Serge Dubuc – on behalf of the European Commission

The European Commission had offered to WLTP leading team to fund an expert as being the Drafting Coordinator (DC) for the GTR. The main objective of the DC would be to coordinate all drafting activities into a logically structured and technically, legislatively and grammatically robust technical regulation.

To accomplish this objective, text, tables and figures resulting from decisions reached by various technical task forces and the IG were incorporated by the DC into the GTR. Technical gaps and inconsistencies were identified and either corrected or the responsible person(s) made aware of these. The DC participated in those task force, subgroup and IG meetings necessary for the processing of his task. Furthermore, the experts were occasionally contacted directly for any necessary clarifications. To support all participants, the GTR was uploaded on a regular basis to the UN ECE server in 'tracked changes' and clean versions. The ultimate goal was to have a complete and homogeneous technical regulation.

In addition to the above, a Drafting Subgroup was founded in January 2015 to be led by the Drafting Coordinator in order to support him in developing the GTR. To achieve this, five drafting sessions were held in 2015 in the form of face-to-face meetings (Brussels in March, Stockholm in April, Brussels once again in June, and Tokyo in October) and an audio/web in September. In all of these sessions, the Drafting Coordinator prepared a collection of PowerPoint slides summarizing all open points and expert proposals which required clarification. In most cases, the open points and expert proposals were clarified during these meetings or were passed on to the IG for its consideration.

The final GTR version at the end of phase 1b was uploaded to the UN-ECE website as formal document ECE/TRANS/WP.29/GRPE/2016/3, and is referred to as GTR no.15.[9]

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[9] Document ECE/TRANS/WP.29/GRPE/2016/3 with GTR no. 15 can be downloaded here: http://www.unece.org/trans/main/wp29/wp29wgs/wp29grpe/grpedoc_2016.html

3.4.2 EV subgroup

Chair	*Secretary*
Per Öhlund – Swedish Transport Agency (Sweden) Tetsuya Niikuni - NTSEL (Japan)	Noriyuki Ichikawa, OICA-Toyota Matthias Naegeli, OICA-Volkswagen

The first meeting of the WLTP EV subgroup (also referred to as E-lab subgroup) took place at 25.03.2014. This subgroup was tasked with modifying, improving and complementing the electrified vehicles' test procedures which were developed in phase 1a of WLTP. In addition, the development of compressed hydrogen fuel cell hybrid vehicles (NOVC-FCHV) test procedure was newly added to the scope of the subgroup.

Annex 8 of the UN GTR describes the test procedures for pure electric, hybrid electric and compressed hydrogen fuel cell hybrid vehicles. The WLTP EV subgroup was responsible for the delivery of the GTR text on the test procedures in Annex 8 and the other parts in the GTR related to electrified vehicles.

The scope of activities during phase 1b was described as follows:

a) Improving and complementing the test procedures for EVs which were developed in phase 1a;
b) Developing test procedures for NOVC-FCHV;
c) Providing an additional test procedure for pure electric vehicles to allow long range vehicles to be tested with low test burden;
d) Developing a method to obtain cycle phase specific values for electrified vehicles;
e) Implementing the interpolation approach which had been developed for conventional vehicles during phase 1a of WLTP to electrified vehicles;
f) Improving the correction procedure for REESS energy imbalance, in particular considering the phase specific values and NOVC-FCHV.

3.4.3 AP Taskforce

Chair	*Technical Secretary*
Cova Astorga – EC-JRC	Les Hill- Horiba

The former DTP- AP sub-group, active during phase 1a, ended its trajectory with the validation phase (VP) for Ammonia (NH_3). When the new structure for the WLTP-IG was agreed for phase 1b (67th GRPE in November 2013), all pending commitments were undertaken by a new AP Task Force integrated in a unique WLTP working group. From that moment, the AP task force reported directly to WLTP chair.

The complete set of objectives envisaged by the AP subgroup at the beginning of Phase 1b has been fulfilled:

a) To demonstrate the feasibility to measure ammonia at the vehicle exhaust with an online measurement method;
b) To describe measurement and calibration procedures, as well as calculations, based on existing legislation and on the output from laboratory procedures led by the AP subgroup, in particular for the pollutant emissions of ethanol, formaldehyde and acetaldehyde.
c) Drafting GTR text protocols and procedures including new measurement, technologies and proposing new on-line methods.

3.4.4 Round Robin testing

Chair	
Bill Coleman, OICA – Volkswagen	European Round Robin leg
Takashi Fujiwara, OICA - Honda	Asian Round Robin leg

After the phase 1a version of the GTR 15 was published, a Round Robin testing activity was planned to check the understanding and application of this GTR version in difference labs and estimate the repeatability and reproducibility of the test procedure under type approval conditions. The aim of this Round Robin was to deliver input based on which the GTR could be improved during phase1b.

The original road map proposal for development of WLTP foresaw a concluding series of tests with an open decision whether they would be confirmation tests or round robin tests or both. At the time it was reported that traditionally the Informal Working Group would organise and sponsor Confirmation testing where necessary and OICA would do the same for Round Robin testing. The differences between Validation, Confirmation and Round Robin testing are subtle, sometimes unclear and certainly overlapping. As a second phase of Validation testing was deemed necessary it was agreed that this would also serve the purposes of Confirmation testing, leaving OICA with the decision whether to initiate a Round Robin. They considered that a Round Robin testing activity would be valuable and decided to support this.

There can be many reasons to perform Round Robin testing such as:

a) checking repeatability and/or reproducibility of the test results, and/or

b) focussing on the use of physical equipment (vehicles, labs or test equipment), and/or

c) focussing on how of procedures are interpreted and applied.

These reasons obviously affect the instructions for conducting the round robin tests, the selection of the vehicles, fuels and tests themselves, the instructions to the accompanying engineer and many other aspects. As some of these objectives and decisions are contradictory it is impossible to cover everything in the round robin, hence some questions remain unanswered.

It is difficult to plan the timing of a round robin as it generally involves a vehicle being transported between laboratories, which is a time-consuming process that cannot be easily shortened. At the same time the concept of round robin testing requires a level of stability in the subject being studied and therefore cannot start before the legislative development is very mature. Thirdly there is normally more political pressure towards the point where the legislation needs to be completed in order to be able to implement it. These contradictory constraints lead to the conclusion that the timing of the round robin is always a compromise.

The following decisions were taken towards the end of phase 1a:

- Round Robin testing is considered necessary and is desired by experts.
- A worldwide Round Robin would take so much time that the results could not be considered within the development period of WLTP.
- Therefore an Asian and a European Round Robin leg would be performed with a level of interaction between accompanying engineers and some vehicle overlap towards the end of the regional testing.
- As little or no new measurement technology is prescribed by WLTP, the focus would be on the operation of the tests (as recorded by the accompanying engineer), with aim to reveal the test requirements that might be misinterpreted or are not complete.

ACEA took the role of coordinating and sponsoring a European Round Robin for which 2 vehicles were sourced, one with a petrol engine and automatic transmission and one with a diesel engine and manual transmission. The French technical service UTAC was contracted to supply the golden engineer and Celine Vallaude was allocated to the task. Labs from both the automotive industry and from authorities participated in the testing.

	European Round Robin	**Asian Round Robin**
Objectives	• Check the understanding and the application of the GTR15 (based on phase 1a text) in different labs • Estimate the repeatability and reproducibility of the test procedure under type approval conditions	
Participants	BMW, FIAT, UTAC, PSA, Daimler, Bosmal, Horiba, DEKRA, VW, TÜV Nord, JRC,	Japan: JARI, NTSEL, TOYOTA, India: ARAI Korea: NIER, KEMCO, KATRI China: CATARC, CRAES
Test vehicles	BMW 116i 1.6L Petrol 6MT Alfa Romeo Giulietta 2.0L Diesel	Toyota WISH 1.8L CVT - Petrol Mahindra & Mahindra XUV500 2.2L 6MT -Diesel
Nr. of tests at each laboratory	3 (mostly)	3 (mostly)
Expected completion timing	January 2016 (additional testing after January may be performed at India and Europe.	January 2016 (additional testing after January may be performed at India and Europe.

Table 1: Round Robin overview (performed in two parallel and linked legs in Europe and Asia)

As neither of the Round Robin legs was completed before the final Informal Working Group meeting of phase 1 (WLTP IG meeting 12, Sept./Oct. 2015 in Tokyo), it is currently only possible to deliver interim results.

The European golden engineer (Celine Vallaude, UTAC, France) reported instances of participating laboratories where the facilities were not yet upgraded to a WLTP standard and also inconsistencies of interpretation of the GTR text between participating laboratories.

The Japanese diamond engineer (Takahiro Haniu, JASIC/JARI, Japan) reported that the Asian Round Robin tests would be completed by the January 2016 with the participation of China, India, Japan and Korea. Two test vehicles are used for the testing (see Table 1). Even though it is found that there are also several laboratories whose facilities are not yet upgraded, no other urgent issues have come up yet that would lead to a change of the current GTR text.

The following are examples of issues that were found during the European and Asian Round Robin tests so far:

- The rotating inertia mass was not used appropriately at most of laboratories. This issue has been taken care of by improving the GTR text to be more specific description.
- Because the gear shift tool was under development during the round robin testing, different versions of this tool have been used by the laboratories. The final version of the gear shift tool is expected to be released soon.
- The measurement equipment for the RCB correction was not prepared by all laboratories during the Round Robin testing and the necessity of such a stringency on the equipment requirements was questioned. The required accuracy of the equipment was reviewed and revised in the final GTR text.
- The vehicle warm-up just before the coastdown for road-load determination on the chassis dyno had not been performed at one laboratory. It was corrected to what the GTR described.

It is expected that more issues will be raised towards the completion of the Round Robin tests, and they should be taken care during WLTP phase 2.

The full analyses of both legs of testing should be combined on completion of the testing and reported during the informal working group meeting in early 2016. Recommendations should be made for improvement of the GTR text during phase 2.

3.4.5 Taskforces on open issues

The remaining open issues from phase 1a were clustered, and then assigned to dedicated taskforces. For each taskforce a suitable taskforce leader was appointed, and interested stakeholders could join the group. The assignment for each taskforce was formulated as to discuss the issues they were tasked with, work out possible solutions, and come forward with an agreed proposal to the WLTP-IG. After approval by the IG, the proposal would then be worked out into a draft text for the GTR.

For a complete overview of the open issues table (OIT) please refer to document WLTP-12-03 at the UN-ECE website.[10]

An overview of the main topics that were addressed by the taskforces in phase 1b and were added to the GTR is presented in Table 2; also a reference is included to the paragraph where this issue is further detailed. Issues which have led to the introduction of a new concept to the testprocedure of the GTR (with respect to the emission test procedures currently in use) are described under paragraph 4.4: New concepts of the GTR. The remaining issues are outlined in the following subparagraphs.

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[10] https://www2.unece.org/wiki/display/trans/WLTP+12th+session

Conventional ICE vehicles *Issue*	*Paragraph*	*Taskforce leader*
Reference Fuels	3.4.5.1	William Coleman, OICA
Definitions	3.4.5.2	William Coleman, OICA
Normalisation	3.4.5.3	Nikolaus Steininger, EC
Number of tests	3.4.5.4	Takashi Fujiwara, OICA-Honda
Review of coastdown tolerances	3.4.5.5	Rob Cuelenaere, TNO
Calculation and interpolation of fuel consumption	3.4.5.6	Konrad Kolesa, OICA-Audi
Speed trace tolerance / speed trace index	3.4.5.7	Noriyuki Ichikawa, OICA-Toyota
On-board anemometry and wind speed conditions	4.4.7	Rob Cuelenaere, TNO
Interpolation family and road load family concept	4.4.9	Rob Cuelenaere, TNO
Torque meter method	4.4.10	Rob Cuelenaere, TNO
Wind tunnel as alternative method for road load determination	4.4.11	Rob Cuelenaere, TNO
Alternative C_d.A determination	4.4.12	Rob Cuelenaere, TNO
Road load matrix family	4.4.13 Appendix 2	Rob Cuelenaere, TNO
Manufacturer responsibility on road load	4.4.14	Rob Cuelenaere, TNO
Alternative vehicle warm-up procedure	4.4.15	Rob Cuelenaere, TNO
REESS charge balance (RCB) for ICE vehicles	4.4.16	Rob Cuelenaere, TNO
WLTP post-processing	4.4.24	Christoph Lüginger, OICA - BMW

Electrified Vehicles (E-lab expert group) *Issue*		*Taskforce leader*
Utility factors	3.4.5.8 Appendix 1	Tetsuya Niikuni, NTSEL Japan
Mode selection and predominant mode	3.4.5.10	Tetsuya Niikuni, NTSEL Japan
RCB correction for OVC-HEVs, NOVC-HEVs and NOVC-FCHV's	4.4.18	Tetsuya Niikuni, NTSEL Japan
Shortened test procedure for PEV range test	4.4.19	Tetsuya Niikuni, NTSEL Japan
Phase-specific values for EVs	4.4.20	Tetsuya Niikuni, NTSEL Japan
Interpolation approach for EVs	4.4.21	Tetsuya Niikuni, NTSEL Japan
End of PEV range criteria	4.4.22	Tetsuya Niikuni, NTSEL Japan
Fuel Cell Vehicle test procedure	4.4.23	Tetsuya Niikuni, NTSEL Japan
WLTP post-processing	4.4.24	Nico Schütze, OICA - BMW
Alternative Pollutants (AP) *Issue*	*Paragraph*	*Taskforce leader*
Measurement method for ammonia, ethanol, formaldehyde and acetaldehyde	3.4.5.9	Cova Astorga, EC-JRC

Table 2: Overview of taskforces to work on open issues and the responsible taskforce leader; references to the respective paragraphs are included

The next paragraphs will describe the scope and the results of what was developed by the taskforces on the open issues. Those issues that led to the introduction of a new concept to the GTR will not be described here, but have been added as subparagraph to paragraph 4.4. See Table 2 for an overview of the reference paragraphs.

3.4.5.1 Reference Fuels

In phase 1b no activity was anticipated other than drafting for correction of errors and continuing an advisory role for the WLTP experts and the Round Robin participants

As indicated in paragraph 3.3.4 it was not possible to establish a cooperation with the fuel production industry to fulfil the scope of the RF subgroup. Therefore it was not feasible to obtain within WLTP an approval on the technical scope of the validation fuels and their relevant properties.

In practice however the list of reference fuels included in the GTR now serves as a guideline, albeit non-binding. Validation was performed on the local reference fuels of the participating regions and the current disharmonization of drive cycles within GTR combined with a foreseeable continuing disharmonization of reference fuels, particularly regarding the bio-fuel content, renders a cross regional validation of the cycles and procedures somewhat irrelevant. Thereby the RF scope of activity points (b) to (e) listed in paragraph 3.3.4 will not be pursued unless the situation changes significantly.
The fuels experts from OICA will remain available to fulfil the role described in point (f)

3.4.5.2 Definitions

It was recognised at the conclusion of phase 1a that there was need for review and revision of many of the definitions that were included in the first version of the GTR. The subject areas where such actions were deemed necessary are as follows:

a) Definitions addressed by the Informal Working Group VPSD (Vehicle Propulsion System Definitions)

b) Definitions of Masses

c) Definitions concerning the measurement of Particulate and Particles (PM/PN)

d) Definitions regarding road load

e) Definitions where the wording had light differences from those currently used in other Regulations under the responsibility of GRPE

f) Definitions where improvement was possible regarding the language or structure of the text

Finally, during the work of the IG-VPSD, advice was taken on better definitions from the UN-ECE secretariat and from the EU Commission legal services. This included keeping to defining terms without including prescriptive technical requirements, trying to keep where possible to one sentence and avoiding the use of examples unless absolutely necessary for clarity. These pieces of advice were applied to a number of definitions and the amendments were subsequently adopted.

Further detailed information on items a) through d) is provided in the following section:

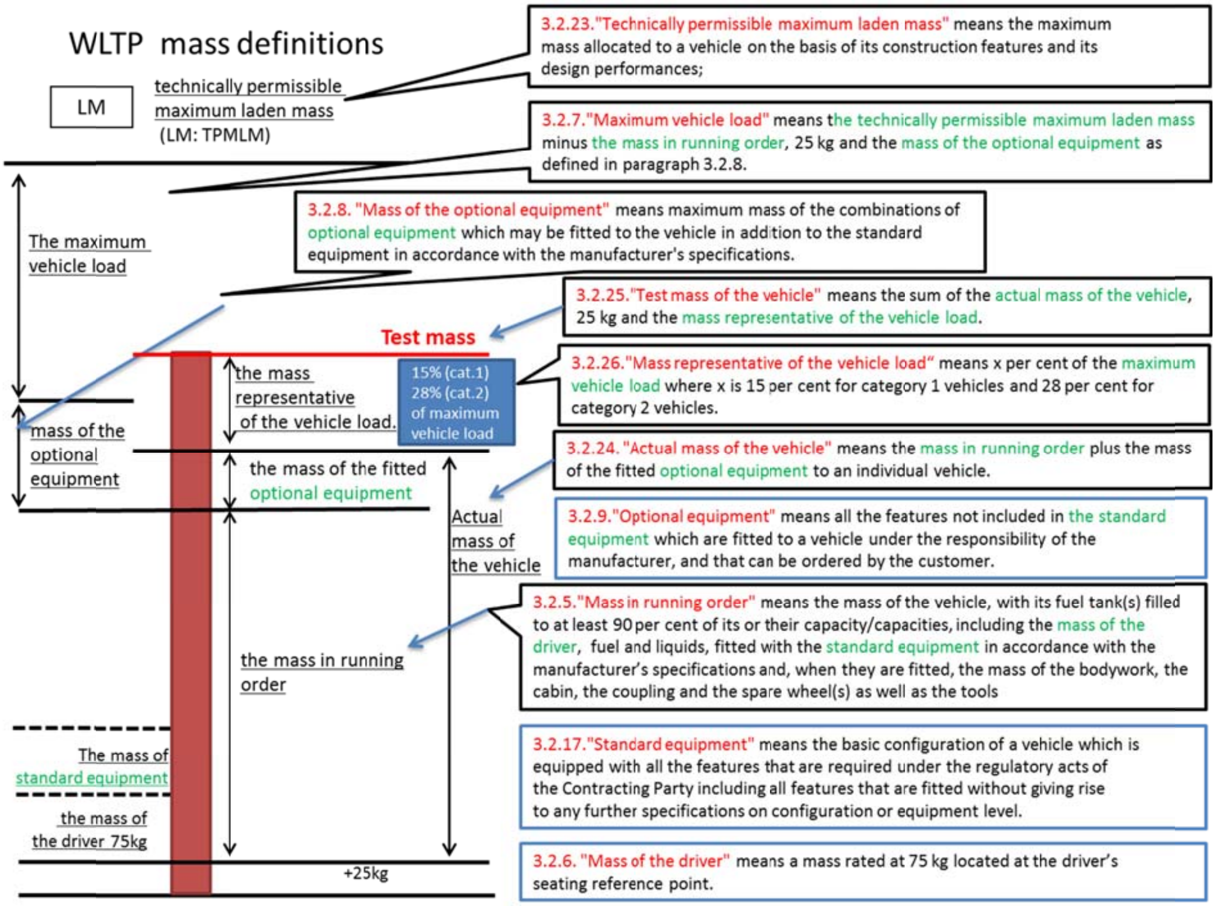
VPSD

The IG-VPSD agreed on a set of definitions which differentiate between fundamental definitions of elements (e.g. energy storage system) and those elements which are used for propulsion (e.g. propulsion energy storage system). This differentiation is justified and helpful and the VPSD definitions were therefore largely adopted into the GTR. However, IG-VPSD also agreed on some definitions that mixed the concepts of fundamental definitions and propulsion systems (e.g. "Electric machine" means a propulsion energy converter transforming between electrical and mechanical energy). The IG-WLTP found these not to be helpful rather confusing and they were not adopted.

Masses

As the concept of the combined approach to determination of CO_2 values (later renamed interpolation approach) was finalised late in the development of phase 1a, the definitions of vehicle masses did not necessarily reflect the whole concept that had been conceived. One significant contributor to this discrepancy was a concept that vehicles ‘High’ and ‘Low’ should be the absolute best and worst cases of the vehicle family. This concept contradicts the decision in phase 1a that extrapolation of CO_2 values should be allowed, within a tolerance band. A further difficulty was the decision that the mass representative of vehicle load, which contributes to the vehicle test mass, should be a single value for the family derived from the heaviest vehicle. A solution was found by adopting the current European definitions of “mass in running order”, “mass of the optional equipment” and “technically permissible maximum laden mass” as the basis for developing test mass definitions. During this discussion, inconsistencies were identified in the European definitions and the EU agreed to adopt the changes to its definition of “mass of the optional equipment” in the regional legislation in order to remove these inconsistencies. This set of definitions allowed description of the heaviest and lightest vehicles covered by an approval, while the European definition of “actual mass of the vehicle” was adopted to permit definition of the test mass of an individual vehicle.

The whole set of vehicle mass definitions and their interconnections is shown in Figure 6:



3.2.23."Technically permissible maximum laden mass" means the maximum mass allocated to a vehicle on the basis of its construction features and its design performances;

3.2.7."Maximum vehicle load" means the technically permissible maximum laden mass minus the mass in running order, 25 kg and the mass of the optional equipment as defined in paragraph 3.2.8.

3.2.8. "Mass of the optional equipment" means maximum mass of the combinations of optional equipment which may be fitted to the vehicle in addition to the standard equipment in accordance with the manufacturer's specifications.

3.2.25."Test mass of the vehicle" means the sum of the actual mass of the vehicle, 25 kg and the mass representative of the vehicle load.

3.2.26."Mass representative of the vehicle load" means x per cent of the maximum vehicle load where x is 15 per cent for category 1 vehicles and 28 per cent for category 2 vehicles.

3.2.24. "Actual mass of the vehicle" means the mass in running order plus the mass of the fitted optional equipment to an individual vehicle.

3.2.9."Optional equipment" means all the features not included in the standard equipment which are fitted to a vehicle under the responsibility of the manufacturer, and that can be ordered by the customer.

3.2.5."Mass in running order" means the mass of the vehicle, with its fuel tank(s) filled to at least 90 per cent of its or their capacity/capacities, including the mass of the driver, fuel and liquids, fitted with the standard equipment in accordance with the manufacturer’s specifications and, when they are fitted, the mass of the bodywork, the cabin, the coupling and the spare wheel(s) as well as the tools

3.2.17."Standard equipment" means the basic configuration of a vehicle which is equipped with all the features that are required under the regulatory acts of the Contracting Party including all features that are fitted without giving rise to any further specifications on configuration or equipment level.

3.2.6. "Mass of the driver" means a mass rated at 75 kg located at the driver’s seating reference point.

PM/PN

A drafting review of GTR phase 1a revealed to the non-expert reader a number of inconsistencies in the use of terminology. The assistance of the IG-PMP was necessary to solve these. This expert and non-expert review finally concluded some fundamental problems such as potential different understandings of the abbreviation PM (e.g. particulate matter or particulate mass). Potential solutions were considered such as “mass of particulate matter”, “PM-mass” and others. The identification of a second fundamental problem, that two masses were being referred to in this context, the mass collected on the sample filter (in mg) and the distance specific particulate mass emissions (in mg/km), led to the set of PM/PN definitions that were adopted as follows:

3.6.1. "Particle number emissions" (PN) means the total number of solid particles emitted from the vehicle exhaust quantified according to the dilution, sampling and measurement methods as specified in this GTR.

3.6.2. "Particulate matter emissions " (PM) means the mass of any particulate material from the vehicle exhaust quantified according to the dilution, sampling and measurement methods as specified in this GTR;

A further piece of explanatory text delivered by IG-PMP which clarifies the difference between particles and particulate was also found to be very helpful and was included in the definition section of the GTR. The following clarification is now included in paragraph 3.6 of the GTR’s definition section:

> “The term ‘particle’ is conventionally used for the matter being characterised (measured) in the airborne phase (suspended matter), and the term ‘particulate’ for the deposited matter.”

Road load

Some definitions of elements of the road load of vehicles were identified by industry experts to be physically incorrect. These were corrected by the Annex 4 task force and adopted. See also paragraph 3.4.5.5.

3.4.5.3 Normalization

Background

During phase1a, WLTP IG has already adopted many new elements to reduce testing flexibilities and tolerances, such as the soaking and test room temperature, test mass determination, the vehicle warm-up procedure, road-load calculation formula and so on. Within the framework of a test procedure it is inevitable to allow tolerances in order to get to a valid test result in a real test environment, because it is simply not possible to execute the test procedure exactly according to what is prescribed. For example, the test driver will try to follow the target speed trace as well as possible, but is unable to match this completely. However, such tolerances may lead to test-to-test variations of the quantitative test cycle results, in particular CO_2 emissions. Even worse, if the tolerances are set too wide they offer the possibility of being exploited systematically to obtain better test results. The repeatability of the test procedure would be increased if the test results are corrected for any (systematic) deviation from the target value. Correction methods for the used tolerances can therefore improve the quality of quantitative predictions of the cycle results and also render the systematic use of tolerances unattractive.

This issue was raised by the European Commission as an issue that needs to be addressed in phase 1b. The EC assigned a contractor to develop a report on such correction methods[11], and these would serve as input for the discussions within the group. The report investigates a series of corrections that could be applied to variations of test parameters within the tolerance ranges allowed by the WLTP GTR provisions. During phase 1b the concept of applying correction methods or algorithms was referred to as ‘normalization’.

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[11] See document WLTP-08-39e at https://www2.unece.org/wiki/display/trans/WLTP+8th+session

Correction algorithms

Table 3 gives an overview of the parameters for which the report has suggested correction algorithms. It also provides a suggestion by the European Commission on the priority level, and the estimated impact of the tolerance on the CO_2 emission according to the following labeling system for recommendation:

A = integrate as soon as possible into European transposition of the WLTP & propose for integration (possibly with some minor amendments) into WLTP GTR phase 1b

B = investigate further for integration in WLTP GTR phase 1b (the result of these investigations could also be that the respective correction is not applied)

C = investigate further for integration in WLTP GTR, probably within a time frame exceeding phase 1b (the result of these investigations could also be that the respective correction is not applied)

D = no further investigation since effect appears to be small and/or very complex to address

Correction type (reference in the report)	**Recommendation**	**Comment**
2.2 Deviation from target speed (including battery SOC correction)	A	The method for addressing the issue is fully developed in the report, relevant impact on CO_2 emissions of up to 5% (deviation from target speed and battery SOC correction)
2.3 Quality of reference fuel	B	Impact on CO_2 emissions still to be investigated
2.4 Inlet air temperature and humidity	B	Impact on CO_2 emissions for diesel vehicles seems to be very low, for gasoline vehicles relevant up to 2%
2.6 Temperature from preconditioning and soak	D	Very small impact on CO_2 emissions, < 0,4%
2.7 Inaccuracy of road load setting on the chassis dyno	B (withdrawn)	Several options for addressing the issue are available, relevant impact on CO_2 emissions of up to 3%
2.9 Deviation from designated gear shift points	C	There seems to be a relevant influence on CO_2 emissions, however there are no ideas yet how the issue could be addressed
4.1 Vehicle preparation for coast down, toe-in prescription	A	There is a relevant influence of the wheel alignment on road load coefficients, the requirement is easy to implement

4.2 Vehicle conditioning for coast down: tyre pressure monitoring/control	B or C	There is a relevant influence of the wheel alignment on road load coefficients, the requirements suggested are not so straightforward to implement
5.1 Ambient weather conditions at coast down: temperature, air pressure, water content of the air	B or C	There is a relevant influence of these parameters on the air drag measured at coast downs. In the current WLTP GTR there is already a correction for the air density, but this may not be sufficient.
5.2 Wind corrections at coast down	B or C	Albeit the current WLTP GTR already contains a wind correction further restrictions on side wind and gustiness may be necessary.
5.3 Road condition of coast down test track (surface roughness, gradient, undulation)	C	The road surface of the test track seems to have a significant influence on the road load parameter F0. It should therefore be envisaged to either require a minimum road "roughness" or to correct road loads measured at a given test track against a "standard" road surface. However, the investigation of relevant roughness parameters and "standard" road surface values is quite complex.
6.2 Rotational inertia correction (when evaluating the coast down test)	A	The suggested correction is very simple to implement and provides a more accurate result for CO_2 emissions.

Table 3: Correction parameters, priorities and impact on CO_2

Implementation into phase 1b GTR

It was recommended by the IG that corrections labelled with ‘A’ be implemented in the GTR in phase 1b, and that the feasibility for implementation of ‘B’ items would be investigated. All items ‘C’ were considered to be out of scope for phase 1b. For the deviation from the target speed curve (item 2.2) a separate taskforce was started by Japan, see paragraph 3.4.5.7 on Speed trace tolerance / drive trace index. However, a drive trace energy correction was postponed to phase 2.

The other ‘A’ labelled items were concluded as follows:

a) The proposal on wheel alignment was adopted for implementation in the GTR (item 4.1).

b) A correction for the rotational inertia by weighing the test tyres was rejected (item 6.2).

In response to the issue of the inaccuracy of the road load setting (item 2.7) a proposal was adopted to limit the time gap between warm-up and chassis dynamometer setting to 120 seconds, and a maximum of 60 seconds between consecutive coast-down runs for the dyno setting procedure. In addition, a separate action by Audi was initiated to assess the tolerances in the road load determination procedure, with the aim to reduce the tolerances where possible. This information is included in paragraph 3.4.5.5 (Review of coastdown tolerances).

All the other proposed correction algorithms to normalize the test results were postponed to phase 2, mainly because there was no time available to validate these methods and there was a lack of information and data on the effects on electrified vehicles. For phase 2 it has yet to be decided which of these items are taken up into the scope for further analysis.

3.4.5.4 Number of tests

During phase1a there was no consideration on the number of tests needed for the type approval process and on how to determine the final type approval value from the tests. To address these issues, a taskforce was formed which was led by Takashi Fujiwara (OICA, Honda).

The current Regulation R101 allows for a 4% CO_2 tolerance, which means that if the CO_2 test result during type approval test is within 4% of the manufacture declared value, the declared value will be accepted as the type approval value. Originally intended to reduce the testing burden in the case that a vehicle is slightly modified, this tolerance is now used as a loophole to artificially declare a lower CO_2 emission as the actual vehicle performance. Therefore it was necessary to close this loophole by tightening the type approval system on this point. At the same time this will increase the representativeness of the test result, which helps to produce reliable consumer information.

Though the taskforce had the scope to provide a technical solution, the ‘number of tests’ issue proved to have a political component as well. This political discussion was largely driven by the different way in which the type approval process takes place in Europe and Japan. While type approval testing in Europe takes largely place under responsibility of the manufacturer and is only witnessed by the type approval authority, the Japanese TAA is much more in control over the tests.

The discussions in the taskforce therefore mainly focused on the CO_2 tolerance value (referred to as ‘dCO_2‘). The European Commission proposed to introduce a ‘safety margin’ which requires manufacturers to demonstrate a better CO_2 than the manufacturer declared value at type approval. Japan initially proposed a tolerance of 1.8%, but later proposed to take the CO_2 tolerance out completely as a compromise solution. However, the European Commission could not agree to abandon their requested safety margin. There were long controversial discussions taking place in the several task force and informal working group meetings, but no agreement could be achieved on a harmonized CO_2 tolerance value. Acknowledging the differences between the regional type approval systems, it was finally decided during the last WLTP-IG meeting in Tokyo that the CO_2 tolerance value would be an option for the CP. Even though this leads to further disharmonization between the regions, it can be seen as a an acceptable solution by considering that the same stringency of the type approval process in different regions would actually require different tolerance values.

These are the main conclusions that were agreed at the end of phase 1b:

a) Remove the 4% CO_2 tolerance. The tolerance value will be determined by each Contracting Party (CP), but dCO_2 has to be within a range of -1.0% to +2.0%.
b) Electric energy consumption, all electric range and pure electric range are added for evaluation of the performance of electrified vehicles, and a 0% tolerance is allowed for any of those parameters.
c) Criteria pollutant limits should fulfilled during each of the type approval tests.

The process of the number of tests as described in paragraph 1.1.2. of Annex 6 consists of the following steps:

step 1: The manufacturer declares the required values according to Table A6/1.

step 2: Perform type approval test(s) according to Figure A6/1 (flowchart).

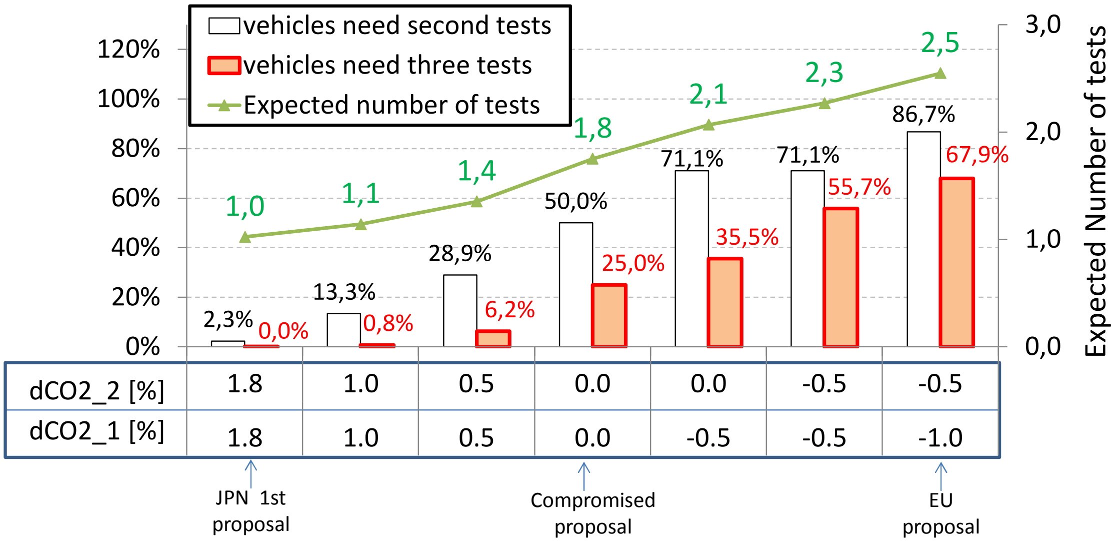
Step 3: If the criteria according to Table A6/2 are fulfilled, the declared values are accepted as type approval values for the total cycle.

step 4: The phase specific values are determined based on the test results, and are adjusted by the distance between the type approval value of the total cycle value and average of the total cycle test results.

The following statistical data were employed to derive the range of allowed CO_2 tolerance.

- The test-to-test variation (one sigma) of CO_2 emission is 0.9%. This value was confirmed by tests performed both in Europe and Japan.
- Under the assumption this test-to-test variation, the expected number of tests during type approval testing will be 2.5 on average in case of European proposal (i.e. -1.0% tolerance for the first test and -0.5% tolerance for the second test), and 1.8 on average in the case of the compromise proposal (i.e. 0.0% tolerance for all test).

The expected number of tests as a function of the chosen dCO_2 values for the first and second test are shown in Figure 7.



Assumptions for calculation;

- Average (μ) = 0
- Standard deviation (σ) = 0.9 %
- Judgment for second test is based on the average value of first and second tests. (i.e. σ for second test = 0.9/root (2) %)

Figure 7: Expected number of tests for ICE vehicles as a function of dCO_2

During phase 1b it proved not possible to incorporate criteria for NOVC-FCHV vehicles. It is foreseen to add these during WLTP phase 2, in which case they could simply be added to Table A6/1 and A6/2.

3.4.5.5 Review of coastdown tolerances

During phase 1b a need was identified to review the tolerances allowed for the different road load determination methods offered in Annex 4. The main purposes were to tighten the tolerances where possible, to make the requirements more explicit, and to align the tolerances between these methods. A proposal was prepared by BMW in July 2015, with a large number of suggested improvements. Most of these improvements were accepted without any further discussion. The remaining ones were discussed and agreed during a face to face meeting.

These are some examples of the improvements that were agreed[12]:

- Adding frequencies at which parameters should be measured (speed, torque, temperatures, pressure, wind direction, etc.)
- Deleting double tolerances, keeping the most stringent one
- Setting time windows for stationary anemometry wind speed criteria
- Specifying tyre pressure per axle
- Corrections for measurement equipment installed to the vehicle exterior
- Setting restrictions to the amount of rejected pairs of coastdown measurements.

On two issues it was not possible to reach agreement on the suggested improvement:

a) The limitation of the split run coastdown to a maximum of 3 parts and conditions to ensure a smooth connection of these parts in par. 4.3.1.3.4.

b) The limitation of the atmospheric temperature to 30°C in par. 4.1.1.2

There was one other issue introduced in phase 1b that should be mentioned here, which is closely related to this review of tolerances. This concerns the selection of reference speeds for road load determination. It was decided to set fixed reference speed points eliminating variation of the resulting road load coefficients by the choice of the reference speed points and evaluation range. Reference speed points now start at 20 km/h and go up in fixed incremental steps of 10 km/h. These increments were earlier free to choose, but limited to a maximum of 20 km/h. The highest reference speed depends on the applicable test and on the maximum vehicle speed. Since the number of reference points is increased, this means the second order polynomial road load function is more accurately defined. At the choice of the manufacturer he may also elect higher reference speeds –up to a maximum of 130 km/h- to use the same road load measurement for type-approval in different regions with a different applicable cycle.

3.4.5.6 Fuel consumption calculation

Since fuel consumption cannot be measured directly without installation of measuring devices in each tested vehicle, the fuel consumption is calculated from the measured emissions of hydrocarbons, carbon monoxide, and carbon dioxide. For each of the reference fuels listed in Annex 3, specific H/C and O/C ratios are provided in the calculation formulas.

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[12] See document WLTP-12-26e at https://www2.unece.org/wiki/display/trans/WLTP+12th+session for a complete overview.

A general equation to calculate fuel consumption for any other test fuel using the actual H/C and O/C ratios is included as well.

The calculation of fuel consumption for individual vehicles within the interpolation family follows the same interpolation method as applied for CO_2 emissions, based on the fuel consumption of vehicle H and vehicle L. Differences of HC/CO levels of vehicles within the Interpolation family were considered as of minor significance. Determination of phase specific values follows the principle of CO_2 interpolation.

The fuel consumption calculation is included in paragraph 6 of Annex 7.

3.4.5.7 Speed trace tolerance / drive trace index

One of the main purposes of WLTP is to reduce the flexibilities which are allowed as test tolerance.

During Phase1a, WLTP has already adopted many new elements to reduce the testing flexibilities, such as the soaking and test room temperature, test mass determination, the vehicle warm-up procedure, road-load calculation formula and so on. “Normalization” was also one of items for discussion and concrete normalization methods were studied to correct measurement results for any used tolerance, see paragraph 3.4.5.3.

Along the same line, the WLTP Technical Secretary(TS) has proposed during Phase1b to implement the “drive trace index” which can be applied for all type of vehicles in order to reduce the testing flexibility regarding the drive trace tolerance[13].

WLTP IG requested to establish a Task-Force(TF) on the drive trace index to work out a proposal for adoption. Its members mainly consisted of industry experts and a number of meeting were held to develop the final proposal.

The driving technique during the test (smooth or rough) within the drive trace tolerance has a significant impact on fuel consumption and CO_2.

This is illustrated in Figure 8 and Figure 9[13,15].

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[13] Refer to document WLTP-10-31e at https://www2.unece.org/wiki/display/trans/WLTP+10th+session

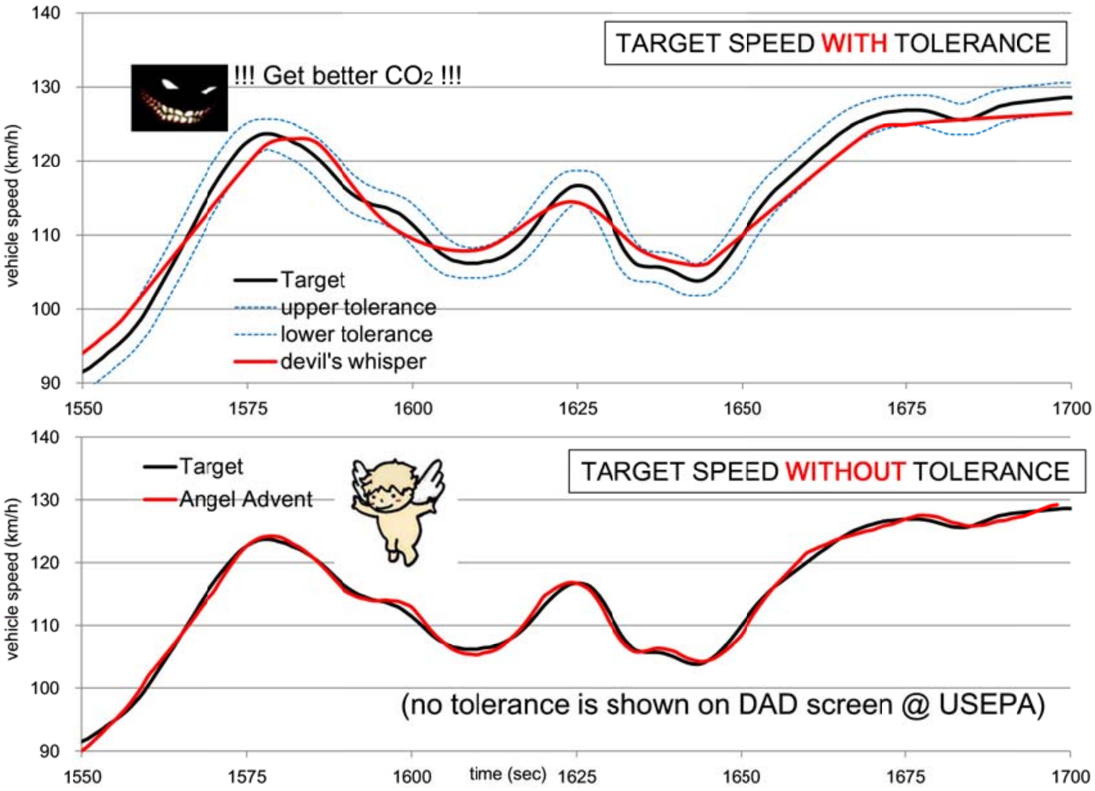

Figure 8: Examples of different driving behavior within the speed trace tolerance: a 'devil' manufacturer trying to improve CO_2 performance and an 'angel' manufacturer following the trace as well as possible

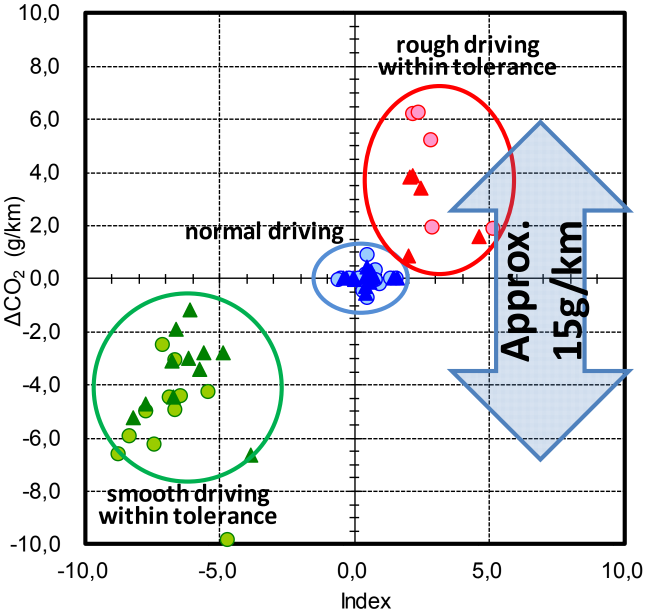

Figure 9: Effect on CO_2 of normal, 'smooth' and 'rough' driving within the speed trace tolerance

This leads to an increase of the test-to-test variation but also to unfair competition. Since the WLTC that was developed is a micro-transient type of test cycle, the current situation may become worse since there is more potential gain in smooth driving.

On the other hand, Figure 9 also indicate that test-to-test variation is negligible when the driving indexes are close to zero ('normal driving'), which means the actual drive trace is close to the prescribed cycle. Therefore, if an appropriate drive trace index(es) are chosen, it can be expected that the flexibility caused by a smooth driving technique will be reduced.

The following elements were introduced and discussed within the Taskforce:

(1) Different drive trace indexes as a reference, according to the Table 4 below. Each index is a kind of quantitative discrepancy between the actual drive trace and the prescribed trace

(2) Keep drive trace tolerance to check the test validity but not showing this tolerance on on the driver aid (the monitor that shows target and actual speed).

Index	***Name***	***Description***
ER	Energy Rating	Percentage difference between the total driven and target cycle energy
DR	Distance Rating	Percentage difference between the total driven and scheduled distance
EER	Energy Economy Rating	Percentage difference between the distance per unit cycle energy for the driven and target traces
ASCR	Absolute Speed Change Rating	percentage difference between the ASC for the driven and target traces
IWR	Inertial Work Rating	percentage difference between the inertial work for the driven and target traces
RMSSE	Root Mean Squared Error	performance indicator to meet the target speed trace throughout the test

Table 4: Evaluated drive trace indexes

The calculation of the drive trace indexes was proposed to be done according to the following procedure:

(1) Correct the actual drive trace data during homologation tests towards 10Hz (no more than 10Hz and no less than 10Hz in order to be compatible with different laboratories)

(2) Apply a linear interpolation method of the prescribed drive cycle to convert it to 10 Hz

(3) Data filtering shall be done according to SAE J2951

(4) Each index is calculated according to SAE J2951[14]

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[14] For the calculation formulas refer to slide 8-11 of document WLTP-12-27

Both ACEA and JAMA did some data evaluation studies on measured vehicles to find out if these drives speed trace indexes would qualify as good indicators of the driving behavior during the test. The results of these studies were presented in the Taskforce[15].

Since no agreement on the specific criteria for these indexes was reached, the Taskforce had to make the decision not to define specific criteria at this stage and to apply all possible index values as a reference. It was also decided that the drive trace tolerance would not be shown on the driver's aid monitor, to avoid that this tolerance would be exploited during the test.

Since drive trace indexes are now included in the GTR as a reference parameters, the following future scenario is foreseen for Phase 2:

a) Gather drive trace index data from homologation tests in a database

b) Select from the database the most suitable index(es) and accompanying index criteria to check the test validity.

c) At the same time, study "Normalization" methods for differences between target and actual speed (especially for electrified vehicles)

d) Consider which method is better from the view of eliminating flexibilities and testing practicability.

e) Implement either drive trace index(es) with the specific criteria or normalization procedures in the GTR.

3.4.5.8 Utility Factors

A conventional vehicle with an internal combustion engine (ICE) will only consume fuel, while a pure electric vehicle (PEV) will only have an electric energy consumption. But hybrid electric vehicles[16] may have a combination of electric energy and fuel consumption during the type approval test. These vehicles can be operated in two different driving modes:

a) Charge depleting mode, during which energy is drawn from the rechargeable energy storage system (REESS), and a

b) Charge sustaining mode, during which the stored energy in the REESS remains on average constant.

The extent to which a vehicle during real world operation is driven in either of these modes depends on the following factors, related to the layout of the driveline and the characteristics of the trips:

- The capacity of the electric energy storage system;
- The electric energy consumption of the vehicle while driving in charge depleting mode;
- The distance that the vehicle is able to drive in charge depleting mode (resulting from the first two factors);

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[15] Summary results of these studies can be found in document WLTP-11-21e (slide12&13) and in document WLTP-11-22e (slide 3to9) at https://www2.unece.org/wiki/display/trans/WLTP+11th+session

[16] There is a distinction between two types of hybrid electric vehicles in the GTR: off-vehicle chargeable (OVC-HEV) and the non off-vehicle chargeable hybrid electric vehicle (NOVC-HEV). The OVC-HEV is also indicated as a plug-in hybrid on the automotive market.

- The length and frequency distribution of trips made with the vehicle;
- The (off-vehicle) charging frequency for the electrical energy storage system.

The share between driving in ‘charge depleting’ and ‘charge sustaining’ mode can be calculated from these factors, and is expressed as the ‘Utility Factor’ (UF). The UF is therefore defined as the ratio between the distance driven in ‘charge depleting’ mode divided by the total driven distance. The UF can range from 0 (e.g. for a conventional vehicle or for an HEV) to 1 (for a pure electric vehicle or OVC-HEV that is driven in charge depleting mode only). It is not a constant value, but is a function of the measured range that was driven in charge depleting mode on the WLTC.

Since the fuel and energy consumption, as well as the emissions, are very different between the two driving modes, Utility Factors are needed in order to calculate weighted emissions, electric energy consumption, fuel consumption and CO_2 values. UFs are based on fleet data and driving statistics such as average daily trip length, average speed, road type distribution, etc. From these data, a Utility Factor (UF) curve can be generated which facilitates a weighting between the measured values of pollutant emissions, electric consumption, CO_2 emissions and fuel consumption for the two driving modes (‘charge-depleting’ and ‘charge-sustaining’).

During the discussions on the Utility Factors in phase 1b of WLTP, it became clear that there was no consensus on a harmonized UF curve. This is largely a result of the fact that driving statistics may differ significantly between the world regions, and they have a large effect on the UF curve. Instead of having one uniform UF curve in the GTR, each contracting party may develop its own UF curve based on the regional driving statistics. However, it was decided that at least the methodology for the determination of driving statistics and the development of regional Utility Factors should be harmonised. Appendix 5 of Annex 8 prescribes the methodology which is mainly based on SAE J2841 (Sept. 2010, Issued 2009-03, Revised 2010-09). The UF curve itself is parametrized into 10 coefficients, listed in Table A8.App5/1 of the that appendix.

Appendix 1 of this Technical Report describes the methodology that was applied to determine the UF curve for the European Union in detail, and is intended to provide a template for the UF curve determination in other regions.

3.4.5.9 Additional pollutants

The work of this taskforce was structured according to the objectives that were set for phase 1b of WLTP:

1) To demonstrate the feasibility to measure ammonia at the vehicle exhaust with an online measurement method;
2) To describe measurement and calibration procedures, as well as calculations, based on existing legislation and on the output from laboratory procedures led by the AP subgroup, in particular for the pollutant emissions of ethanol, formaldehyde and acetaldehyde.
3) Drafting GTR text protocols and procedures including new measurement, technologies and proposing new on-line methods.

This paragraph will report on each of these objectives separately.

Ammonia

The phase 1a version of the GTR describes effective methods for measuring Ammonia from LD vehicles. The feasibility of these methods was assessed during phase 1b by validation of testing procedures

An experimental validation phase was performed for the new driving cycle (WLTC) in the Vehicle Emission Laboratory (VELA) at the European Commission Joint Research Centre (EC-JRC Ispra, Italy). This was done to understand the feasibility of measuring some new pollutants in the gaseous phase exhaust of LD vehicles and eventually, how to incorporate the text to the GTR during phase 1b.

Conclusions of the work of the AP Taskforce about the measurements of NH_3 in LD exhaust were drawn and transposed into a draft text for the GTR. The document with the information reporting the validation phase for different analytical instrumentation measuring ammonia from LD exhaust during WLTC from the campaign was uploaded to the UNECE website[17].

Summary of Validation phase results for NH_3

Four light duty vehicles were tested as part of the Validation Phase (VP). The raw vehicles' exhaust gas was analyzed in real-time using different instruments (FT-IR, Quantum Cascade Laser Infra-Red Spectrometer-QCL-IR and an integrated photo-acoustical analyzer with a Quantum Cascade Laser).

The obtained average ammonia concentrations and the emission profiles revealed that the three instruments were suitable to measure ammonia from the vehicles raw exhaust. The results showed that all instruments were in good agreement, presenting no significant differences. The three instruments also presented very good reproducibility. The results indicate that temperature of the sampling and analyzer is not important as long as there is no condensation.

The following was achieved on NH_3 measurements in the gas phase of LD vehicles' exhaust.

1. The VP demonstrated that is perfectly feasible to measure ammonia at the vehicle exhaust with an online method guaranteeing the reproducibility and repeatability of the results.[18]
2. The VP confirmed that three instruments are validated as a measurement method for NH_3 in the GTR.

Ethanol, formaldehyde and acetaldehyde

A new validation Phase during phase 1b focussed on finding new and alternative on-line methods for ethanol, formaldehyde and acetaldehyde to find out if they would qualify for the WLTP GTR.

An intercomparison exercise of the WLTP test was conducted in the VELA laboratories (JRC-IET Sustainable Transport Unit), aiming at measuring ethanol, formaldehyde and acetaldehyde emissions from a flex-fuel light-duty vehicle using E85 fuel. All instruments participating in the intercomparison allowed in situ measurements of these compounds directly from the diluted exhaust gas at the CVS, as it was established in the scope of this validation phase campaign.

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[17] https://www2.unece.org/wiki/display/trans/WLTP+6th+session, refer to documents WLTP-06-27e & WLTP-06-2e

[18] Reference: “Intercomparison of real-time tailpipe ammonia measurements from vehicles tested over the new Worldwide harmonized Light-duty vehicle Test Cycle (WLTC)”. Environmental Science and Pollution Research, 7450-7460, 2015.

Summary of Validation phase results for ethanol, formaldehyde and acetaldehyde

Measurements were done either in real time or immediately after the test. The measurement and analysis of exhaust emissions over the WLTC was done by means of Fourier transform infrared spectrometer (FTIR), proton transfer reaction-mass spectrometry (PTR-Qi-ToF-MS), photoacoustic spectroscopy (PAS) and gas chromatography (GC). The measured concentrations and the emission profiles revealed that all the used instruments are suitable to measure these compounds from the vehicle's exhaust (|Z-score| < 2). Results showed that online systems can perform measurements from the vehicle diluted exhaust assuring the reproducibility and repeatability of the results[19].

The achievements reached during phase 1b for measuring ethanol, formaldehyde and acetaldehyde in the gas phase of LD vehicles' exhaust are described below:

1. AP task force found new alternative on-line methods for ethanol, formaldehyde and acetaldehyde in addition to the classical methods already known for carbonyls (DNPH cartridges) and for ethanol (impingers). Both are considered reliable reference methods but quite time consuming.
2. Conclusions reached during VP in Phase 1b showed the possibility of measuring 3 additional pollutants (ethanol, formaldehyde and acetaldehyde) directly at the CVS (diluted exhaust).
3. All new methods have been validated and proposed as alternative methods to be included in the GTR

GTR drafting

The text referring to ammonia in the last version of the GTR (phase 1a, Annex 5 par.7.1.1) was modified according to the conclusions of the Validation Phase. The measurement methods of EtOH, formaldehyde and acetaldehyde were added to the GTR in the respective annexes: Annex 5 (Instrumentation and Methods) and Annex 7 (Calculations).

3.4.5.10 Mode selection and predominant mode

Background

A vehicle can be equipped with different operational modes which determine how the vehicle responds to the driver. For instance there can be a normal mode, an eco-mode and a sport-mode to choose from. The GTR has to specify which mode the vehicle should be tested in. Secondly, one of these modes may be automatically selected when the vehicle is started, and can be seen as a 'predominant mode'. For the conventional ICE vehicles the mode selection was already covered in phase 1a[20], but for the electrified vehicles this was still under discussion. That is why this was considered an open issue for phase 1b. The Subgroup EV was tasked with this issue.

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[19] Slides and progress report available at: https://www2.unece.org/wiki/display/trans/WLTP+12th+session
Document WLTP-12-23e by Audi presents applicable factors if ethanol content in the fuel is below 25%

[20] For more information about the mode selection for ICE vehicles refer to the Transmission section in paragraph 0 of this report.

Phase 1a mode selection

According to the phase 1a version of the GTR, the mode selection for testing the different classes of electrified vehicles was defined as follows:

1. OVC-HEV (Selection of a driver-selectable mode in for a charge-depleting Type 1 test): *"The charge-depleting test shall be performed by using the most electric energy consuming mode that best matches the driving cycle. If the vehicle cannot follow the trace, other installed propulsion systems shall be used to allow the vehicle to best follow the cycle."*

2. OVC-HEV, NOVC-HEV and NOVC-FCHV (Selection of a driver-selectable mode for a charge-sustaining Type 1 test):
   "For vehicles equipped with a driver-selectable operating mode, the charge-sustaining test shall be performed in the charging balance neutral hybrid mode that best matches the target curve."

3. PEV (Selection of a driver-selectable mode in for a charge-sustaining Type 1 test):
   "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."

Decision for phase 1b

During phase 1b, this issue was intensely discussed within the Subgroup EV. Reason for the discussion was on the one hand the imprecise description of the mode selection in the GTR15 (state of play end of phase 1a) and on the other hand the desire to bring the EV section in line with conventional vehicles concerning the mode selection in case of the existence of a predominant mode.

PEVs and OVC-HEVs tested in charge-depleting operating conditions have to drive consecutive cycles for the range and electric energy consumption determination up until the break-off criterion has been reached. Depending on the REESS capacity this may take a long time for testing. To avoid testing in multiple modes, it would make sense to apply the predominant mode for this, i.e. the mode which is automatically selected if the vehicle is switched on. However, the predominant mode might not always allow the vehicle to follow the prescribed test cycle. Therefore, an important question which had to be answered was the prioritisation of choosing the predominant mode versus a mode which enables the vehicle to follow the driving curve of the applicable test cycle.

The Subgroup EV requested a clear political guidance from the WLTP-IG during the meeting in Stockholm. The IG members decided that the following prioritisation should be observed:

1. First priority is being able to follow the applicable driving cycle
2. Second priority is choosing the predominant mode.

Based on this political guidance, the Subgroup EV developed a precise description for the selection of the driver-selectable modes. This was done in the format of flowcharts with a decision-tree for the following vehicles/conditions:

- OVC-HEVs under charge-depleting operating conditions
- OVC-HEVs, NOVC-HEVs and NOVC-FCHVs under charge-sustaining operating conditions
- PEVs

The flowcharts included in Appendix 6 of Annex 8 of the GTR will clearly guide the manufacturer and the responsible authority to select the appropriate mode for testing.

3.4.5.11 Other taskforces

Only those taskforces that resulted in a modification or addition to the GTR were listed in Table 2 and have been described in this report. However, it has to be mentioned that there have been more taskforces in place. Most of them were rather informal, with the purpose to tackle a small issue e.g. on the formulation of a definition.

There is one taskforce that should be mentioned here: the coasting taskforce. Coasting is the technology that decouples the engine from the transmission during decelerations. The engine is then stopped, or returned to idle speed. This can save fuel, but the reduction potential depends on how the technology is used by the driver. It was claimed by OICA that the strict speed trace of the test cycle would prevent the full potential of the coasting system being exploited. Therefore a taskforce was initiated by the IG to develop a methodology that would result in a fuel consumption benefit that would be representative.

The first suggestion -a modification of the testcycle- was not acceptable for the Contracting Party of Japan. The next proposal was to apply a mathematical approach calculates the fuel reduction potential. This led to controversial discussions on how the ‘average’ driver would adjust his driving behaviour, and to what extent the fuel reduction related to the change in driving behaviour could be attributed to the coasting technology. Finally, it had to be concluded by WLTP-IG that no agreement on coasting can be found. The issue might be reopened in phase 2 of WLTP, but only if there is a new proposal that will be able to meet the earlier expressed concerns.

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 was one of the main objectives to initiate the WLTP development process, apart from harmonization. By bringing the test conditions and driving characteristics of the test as close as possible to how vehicles are used in practice on the road, the fuel/energy consumption and emission 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 aspects. 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 under 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 the goal of repeatability.

b) *Reproducibility*
If the test is repeated under 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 may increase the complexity of the test or even require additional testing. The costs of a higher test burden will eventually be charged to the consumers, so there is a need to strike a balance between test effort and quality of the 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 tread depth. Normally, such requirements will also have issues relating to the other constraints such as the cost-efficiency. There may also be practical restrictions or safety 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 WLTP was therefore to primarily aim at a 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 in phase 1a 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 Appendix 3. 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 measuring a fuel/energy consumption that is similar as for average on-road 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 test procedure for 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 of this Technical Report. 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 will be detailed in Paragraph 4.4.

4.3 Improvements in the GTR

As a result of extensive analyses and discussions among the involved 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 additional pollutant emissions such as NO_2, N_2O, NH_3, ethanol, formaldehyde and acetaldehyde);

b) More stringent requirements imposed on the test vehicle and test track with the intention to determine a representative road load;

c) New or improved procedures to measure emissions, electric range and fuel/hydrogen/energy consumption of (hybrid) electric vehicles, as well as to determine the effect of other 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 main improvements on specific aspects of the testing methodology which have contributed to increase the representativeness or usefulness 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 first was called the ‘combined approach’ and later renamed into the ‘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 actual carrying capacity of the vehicle by including a percentage of the maximum vehicle load.
- Instead of using discrete inertia steps, the simulated inertia by the chassis dynamometer corresponds exactly to the vehicle test mass.
- The battery state-of-charge at the start of the test is set to a representative yet repeatable starting point. This is achieved by requiring a fully charged battery to be partially depleted by first driving a WLTC as preconditioning cycle.
- The difference in battery state-of-charge over the cycle is monitored and the fuel consumption is corrected according to the change in battery state-of-charge over the cycle (upon exceeding a certain threshold).
- The soak and test temperature in the laboratory is modified from a range of 20 to 30°C (as is currently prescribed in the NEDC procedure) to a setpoint of 23 °C. No systematic deviation is allowed from this setpoint.
- 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 by a mandatory brake procedure prior to the test;
    - Wheel alignment settings are specified (set to a worst-case setting or according to the prescribed value for normal on-road use)
    - Test track characteristics (e.g. road inclination) will be more stringent to reduce 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.
- Additional road load determination methods are added, e.g. the torque-meter method, the on-board anemometry method, the road load matrix family and the wind tunnel method.

- Wind tunnel criteria are added, both for the wind tunnel method as for the delta C_d.A determination, including provisions to approve the wind tunnel.
- An interpolation method for the calculation of the road load within a ‘road load family’ is included.
- A formula for the calculation of fuel consumption based on the CO_2 and pollutant emissions are added, including the interpolation of the fuel consumption.
- The GTR text is 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 for more clarity and to ensure unambiguous interpretation.
- Measurement procedures are added for additional pollutants, i.e. NO_2, N_2O, NH_3, ethanol, formaldehyde and acetaldehyde.
- 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/hydrogen/energy consumption, and emissions of (hybrid) electrified vehicles are defined in all-electric, charge-sustaining, and charge-depleting mode, and weighted by utility factors (where 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
  - REESS charge balance correction
  - Test procedure, separately for:
    - OVC-HEV,
    - NOVC-HEV,
    - PEV,
    - OVC-FCHV,
    - NOVC-FCHV.
  - Calculations of whole cycle and (where applicable) phase-specific results for:
    - Emission compound calculations,
    - CO_2 and Fuel Consumption Calculations including an interpolation method,
    - Electric Energy Consumption Calculations including an interpolation method,
    - Electric Range including an interpolation method.
  - Mode selection for driver-selectable modes
  - Cycle-downscaling and capped speed provisions for PEVs
  - A shortened test procedure for PEVs
- 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 (also for the additional pollutants),
  - 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%).
- WLTP post-processing procedures that specify the calculation order of the of the output values.

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 underlying principles, this paragraph will outline the main new concepts that were introduced.

4.4.1 Interpolation method

One of the key objectives 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. One barrier to achieve that goal, which was identified early in the development process, is 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: one vehicle to the ‘worst-case’ side and preferably one to the ‘best-case’ side 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 within 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 nearly 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 every individual vehicle of the interpolation family, 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 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).

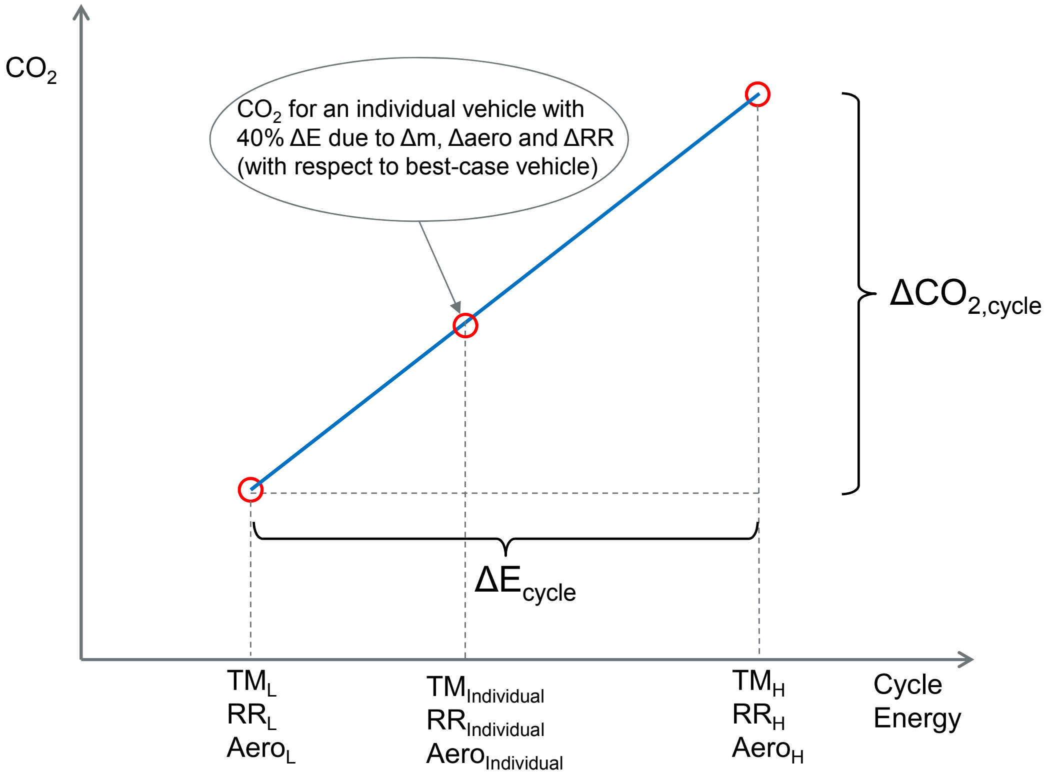

Figure 10: Example of the CO_2 interpolation method applied for road load relevant vehicle characteristics.

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) with the combination of road load relevant characteristics (i.e. mass, aerodynamic drag and tyre rolling resistance) producing the highest energy demand shall be selected from the interpolation family.” 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, there are no specific requirements as to what the test mass, aerodynamic drag and rolling resistance are for test vehicle H, since that is implicitly stated in paragraph 4.2.1.1. The same approach is followed for the selection of the best-case test vehicle L, but then of course aiming at the combination of road load relevant characteristics producing the lowest energy demand.

4.4.3 Interpolation/extrapolation range

The accuracy of the interpolation method for CO_2 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 interpolation method is accurate well within 1 g/km of CO_2 up to a ΔCO_2 of more than 30 g/km[21]. On the basis of these results the methodology was accepted and the allowed interpolation range was set to a maximum of 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 test-to-test 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. This interpolation range does not apply for vehicles which have been tested according to the road load matrix family approach (refer to paragraph 5 of Annex 4), which need a wider rang. It is assumed that the safety margin built in the calculation of the road load will implicitly limit the interpolation range.

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)[22]

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[23]:

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) A variable mass that depends on the carrying capacity of the vehicle (‘maximum vehicle load’). Depending on their category and/or anticipated usage (decided at regional level) the mass representative of the vehicle load 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 c) and the mass of the optional equipment as defined in par. 3.2.8., and

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

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

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

e) The mass of optional equipment (factory installed equipment that is selected by the customer[24]).

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 actual 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 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 3.2.25 of part II and is referred to in paragraph 4.2.1.6 of Annex 4. A graphical presentation of the mass definitions and how they relate to one another to build the test mass is provided in paragraph 3.4.5.2 of this report (see the section on Masses).

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 used 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 invalid. 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. Both modes should not activate, modulate, delay or deactivate the operation of any part that affects the emissions and fuel consumption under the test conditions.

The requirements for vehicle coastdown mode can be found in paragraph 4.2.1.8.5 of Annex 4, and for the dynamometer operation mode in paragraph 1.2.4.2.2 of Annex 6.

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[24] Since manufacturers cannot be held responsible for what is fitted to the production vehicle after it has left the production line, any items fitted by the car dealership and other after-sales equipment is not included in the mass of the optional equipment. This should however not create an incentive for manufacturers to shift the installation of vehicle options from the factory to the dealer. If this would become a common practice for the future, appropriate measures should be taken to avoid this loophole.

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[25].

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. At the point when the individual CO_2 values are calculated for vehicles in the family, the RRC class values are used. See paragraph 4.4.24

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

4.4.7 On-board anemometry

The Annex 4 Task Force was asked by the IG to better understand the background of the on-board anemometry method and its associated calculations. This should include –if considered necessary- the development of applicable criteria which provide statistical grounds for the validation of the resulting measurement data.

Task force discussions and in-depth bilateral reviews with on-board anemometry experts concerning the method's source material, SAE J2263, led to the joint proposal that was developed during phase 1b and adopted at the 12th IG meeting. Extreme cases of the method's parameters were studied to evaluate sensitivity, and a few deviations from the SAE method (and phase 1a GTR text) were introduced to enhance the method for WLTP implementation. The main changes to are the following:

- The option for contracting parties to opt for increased wind tolerances was removed from the GTR, as those wind tolerances were outside of the allowable winds in SAE J2263, and the applicability of the method's calculations were at risk under those conditions.
- In addition, overall wind speed tolerances were reduced slightly in an effort to further reduce potential test to test variation. The tighter tolerances fall within the guidelines set by the SAE J2263 (DEC2008) standard, ensuring its continued applicability.

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

- Once calculations are complete and the data is corrected to standard conditions, the resulting force equations must satisfy new convergence criteria.

Concerning the last point, it was determined that the statistical accuracy requirements of the stationary method were not applicable to the on-board method, since the output of the method is a quadratic force equation instead of the gated times from the stationary method. As such, the evaluation of the resulting forces using this convergence check was developed to ensure a level of statistical relevance within the dataset.

The method for measuring wind with on-board anemometry is included in Annex 4, paragraph 4.3.

Following the method's adoption during the 12th IG meeting there should not be any outstanding items remaining for Phase 2.

4.4.8 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[26]:

a) The table should be based on existing road load data, and should be oriented towards the "worst" case. More concrete, it should represent the 5% vehicles with the highest running resistances, rather than an "average" figure, in order not to create an incentive to apply the default values for vehicles that have a higher than average road load.

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 for the dynamometer.

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[27]. 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 formulas for the determination of the default f_0 and f_2 road load coefficients can be found in paragraph 5.2.2 of Annex 4.

4.4.9 Road load matrix family

The Road Load Matrix Family (RLMF) was developed as an additional road load determination method to facilitate low-volume vehicles for which the test effort of measuring a vehicle L and H is too high, but on the other hand the default road load values would be too pessimistic. More specific, the foreseen vehicle types to make use of this method are – amongst others- large vans and multi-stage vehicles. To target these types of vehicles, the

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

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

scope for application of the RLMF method was set to vehicles with a minimum technically permissible maximum laden mass of 3000 kg.

Rather than measuring the road load of the two vehicles at the extreme sides of the family, the RLMF is based on a single measurement of a representative vehicle of the family, and 'extrapolating' this by considering the differences of relevant road load parameters, i.e. test mass (TM), tyre rolling resistance (RR) and frontal area (A_f). Since the extrapolation of one measurement to either sides is less accurate as an interpolation between the extremes, an additional safety margin was built into the method by using a base vehicle with a worst-case aerodynamic drag, and by using conservative correlation factors for the influence of the parameters on the road load coefficients.

Much of the development work focused on the correlation factors. It was clear that these factors should be different for upward and downward correlation, and that the safety margin had to be similar to either sides. This approach should ensure that the further away from the measured vehicle, the more likely it is that the actual road load is overestimated (and consequently also the respective CO_2). As a result, an incentive is included for manufacturers to apply one of the standard road load methods. The requirement of a similar safety margin to both ends should encourage manufacturers to select a test vehicle in the mid-range of the family. In the case that the deviation from the actual road load would bring an unacceptable CO_2 disadvantage to the manufacturer, he could choose to split the vehicle family, or use one of the other road load determination methods.

The method is illustrated in Figure 11, and shows that the extrapolated road load (red line) for other vehicles in the family would follow the upper area of the actual road load bandwidth.

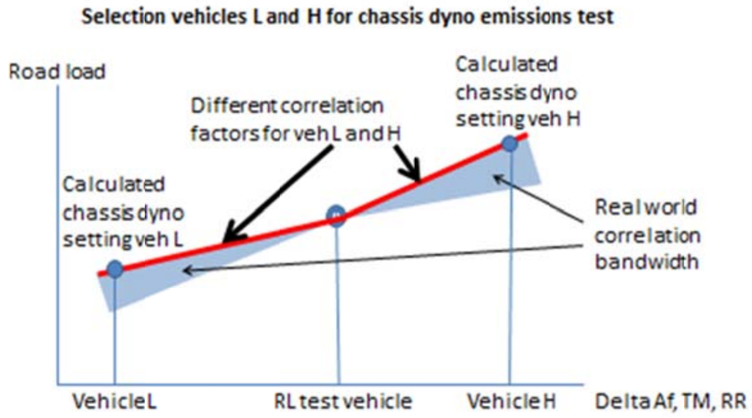


Figure 11: Upward and downward extrapolation for the road load matrix family

By extrapolation of the road load to vehicle L and H, the target road loads for measuring these vehicles at the chassis dynamometer can be found. The test vehicle is tested at the vehicle L and the vehicle H road loads, and the CO_2 results are used to draw an interpolation line for CO_2 against cycle energy. For any of the other vehicles in the RLMF, the cycle energy will be calculated from the extrapolated road load, and the calculated CO_2 follows from the interpolation method. Note that the CO_2 interpolation line does not have the kinked shape of red line in Figure 11.

A detailed description on the development of the RLMF method and the interpolation method is presented in Appendix 2.

The method of the RLMF itself is included in the GTR in chapter 5 of Annex 4.

4.4.10 Torque meter method

Background

The torque meter method was included in the phase 1a version of the GTR. At the time it was also acknowledged the method should be reviewed in phase 1b by the road load experts and a validation should take place to provide justification on the equivalence to other road load determination options.

Improvements in phase 1b

Apart from editing modifications to make the GTR text more robust on that part, the review of led to the following improvements:

- Additional speed points incremental steps of 10 instead of 20 km/h, to allow a more accurate least squares regression curve (valid for all road load determination options)
- Specification of wheel torque measurement accuracy for the whole vehicle defined.
- Determining the dynamic radius of the tire at 80 km/h and check this to limit the difference between on-road and chassis dynamometer testing
- A wind correction factor is has been added. The road load curve is now corrected by a wind compensation factor: $w_2 = 3.6^2 \times c_2 \times v_w^2$; this was not included in ECE83.
- Compensation for speed drift ensures a more correct value of the torque measurement result
- A procedure was added to convert the torque based running resistance curve into a force-based road load curve on the chassis dynamometer (see paragraph 8.2.4 of Annex 4)

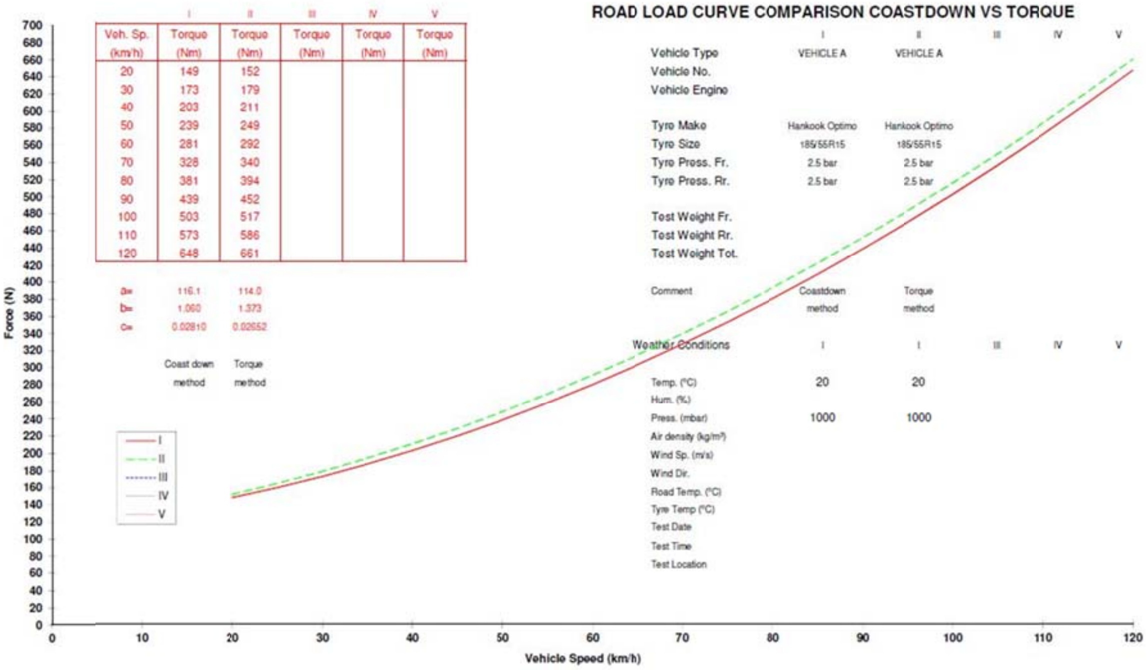
Validation

The torque-meter method was validated by Ford, and the road load curves were found to be in good agreement with the coastdown test results.

The following steps were taken to prove equivalency results between coast down method and torque method:

1. Vehicle ‘A’ was tested at Lommel Proving Ground by the coast down method and torque method using exact the same tires, tire pressure and ride heights. Test results for both methods used for further steps were selected based on testing in similar weather circumstances.
2. Wind tunnel testing was performed to evaluate the aerodynamic difference (C_d.A) between the vehicle with and without torque transducers.
3. A recalculation of the torque method road loads was performed towards the same conditions as the coast down results, and to correct for weight and C_d.A differences
4. A dyno setting was performed to the road load curve that was recalculated in step 3.
5. A coast down on the dyno was performed to determine the coast down times.
6. The road load forces were determined from the coast down method and torque meter method.

Note that the road load tests at Lommel Proving Ground, the aerodynamic tests, and the dyno setting procedures were witnessed by TÜV.

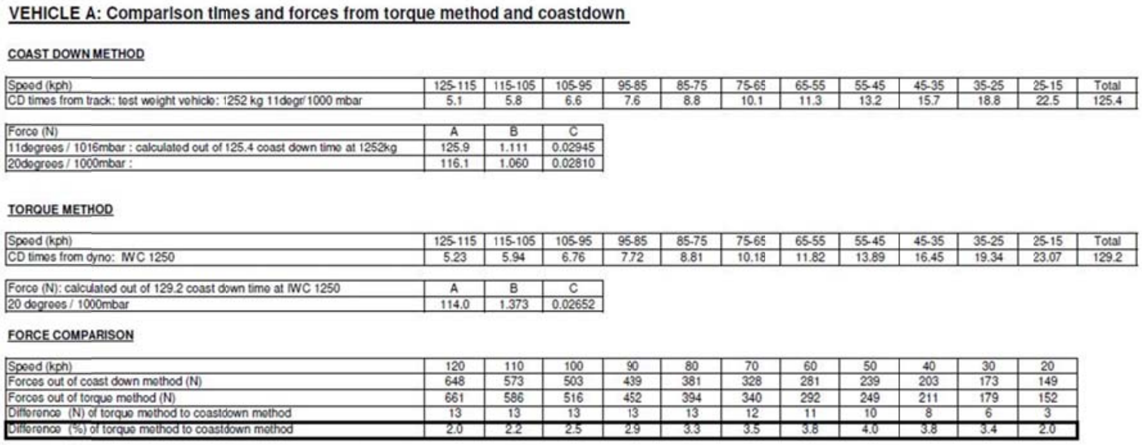


	I	II	III	IV	V
Veh. Sp. (km/h)	Torque (Nm)	Torque (Nm)	Torque (Nm)	Torque (Nm)	Torque (Nm)
20	149	152			
30	173	179			
40	203	211			
50	239	249			
60	281	292			
70	328	340			
80	381	394			
90	439	452			
100	503	517			
110	573	586			
120	648	661			

a=	116.1	114.0
b=	1.060	1.373
c=	0.02810	0.02652
	Coast down method	Torque method

	I	II	III	IV	V
Vehicle Type	VEHICLE A	VEHICLE A			
Vehicle No.					
Vehicle Engine					
Tyre Make	Hankook Optimo	Hankook Optimo			
Tyre Size	185/55R15	185/55R15			
Tyre Press. Fr.	2.5 bar	2.5 bar			
Tyre Press. Rr.	2.5 bar	2.5 bar			
Test Weight Fr.					
Test Weight Rr.					
Test Weight Tot.					
Comment	Coastdown method	Torque method			
Weather Conditions	I	I	III	IV	V
Temp. (°C)	20	20			
Hum. (%)					
Press. (mbar)	1000	1000			
Air density (kg/m³)					
Wind Sp. (m/s)					
Wind Dir.					
Road Temp. (°C)					
Tyre Temp (°C)					
Test Date					
Test Time					
Test Location					

Figure 12: Validation results for the torque meter method



VEHICLE A: Comparison times and forces from torque method and coastdown

COAST DOWN METHOD

Speed (kph)	125-115	115-105	105-95	95-85	85-75	75-65	65-55	55-45	45-35	35-25	25-15	Total
CD times from track: test weight vehicle: 1252 kg 11degr/1000 mbar	5.1	5.8	6.6	7.6	8.8	10.1	11.3	13.2	15.7	18.8	22.5	125.4

Force (N)	A	B	C
11degrees / 1016mbar : calculated out of 125.4 coast down time at 1252kg	125.9	1.111	0.02945
20degrees / 1000mbar :	116.1	1.060	0.02810

TORQUE METHOD

Speed (kph)	125-115	115-105	105-95	95-85	85-75	75-65	65-55	55-45	45-35	35-25	25-15	Total
CD times from dyno: IWC 1250	5.23	5.94	6.76	7.72	8.81	10.18	11.82	13.89	16.45	19.34	23.07	129.2

Force (N): calculated out of 129.2 coast down time at IWC 1250	A	B	C
20 degrees / 1000mbar	114.0	1.373	0.02652

FORCE COMPARISON

Speed (kph)	120	110	100	90	80	70	60	50	40	30	20
Forces out of coast down method (N)	648	573	503	439	381	328	281	239	203	173	149
Forces out of torque method (N)	661	586	516	452	394	340	292	249	211	179	152
Difference (N) of torque method to coastdown method	13	13	13	13	13	12	11	10	8	6	3
Difference (%) of torque method to coastdown method	2.0	2.2	2.5	2.9	3.3	3.5	3.8	4.0	3.8	3.4	2.0

Table 5: Validation results for the torque meter method

The results of this validation exercise are shown in Figure 12 and Table 5. The green dotted line in Figure 12 shows the torque meter method road load, while the red line is for the coast down method road load[28].

The conclusion from this validation exercise was that for this vehicle the differences between the forces derived out of the coast down method and torque meter method were generally

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[28] See document WLTP-11-15e at https://www2.unece.org/wiki/display/trans/WLTP+11th+session for more detailed validation results

within 4% at lower speeds, with a declining tendency towards higher speeds. The torque meter method showed a consistently higher road load. The absolute force differences was 13 N for speeds over 80 km/h, and smaller for the lower speed range.

Finally, a procedure was added to transform the running resistance curve determined by the torque meter method into a road load curve. This is achieved by coasting down a vehicle at the chassis dynamometer which was previously set to reproduce the torque-based running resistances. Of course this procedure can only be applied if the vehicle is capable to coast down in a repeatable way (i.e. no unrepresentative parasitic losses in the drivetrain). If that is not the case, the road load coefficients are calculated from the running resistance coefficients, taking into account the dynamic radius of the wheels and a default value for the drivetrain losses of 2%. This transformation procedure is described in paragraph 8.2.4 of Annex 4. The torque meter method itself can be found in paragraph 4.4 of Annex 4.

4.4.11 Wind tunnel method

This method determines the road load by using a combination of a wind tunnel and a flat belt[29] or a chassis dynamometer. Within the R&D activities of manufacturers the wind tunnel has become a widely used instrument. Up until the GTR was developed it was only defined in some standards. Within phase 1b the method has been worked out in detail, and validation measurements have been performed.

Motivation

The need for the wind tunnel method was already expressed during phase 1a of WLTP. Weather conditions in most parts of the world make coast down testing on the road only possible on a limited amount of days. For example in Germany on-road testing is limited to roughly 100 days per year.

It is also foreseen that optimizing the fuel efficiency will increasingly depend on improving the aerodynamic performance of the vehicle. To evaluate aerodynamic innovations properly, a measurement method of higher accuracy is needed, because the influence often searched for may be in the order of the inaccuracy of the coast down method. The wind tunnel method allows for accurate measurement of the physical vehicle drag in the absence of any external influences and no corrections and calculations over the speed, time and mass.

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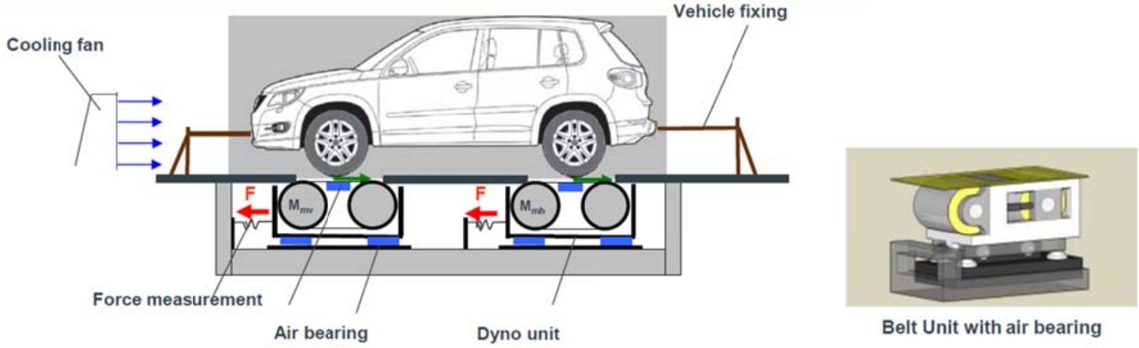
[29] This is a circular belt that is driven between two rollers. The contact with the tire is on the flat part of the belt which is supported by an air bearing, hence the name. This is similar to an on-road situation, while the contact surface on a chassis dynamometer is influenced by the radius of the roller. Each wheel can have its own flat belt, and the entire flat belt unit is supported by an air bearing to measure the reaction forces while the vehicle is restrained. The sum of reaction forces is the total rolling resistance.



Other advantages of the wind tunnel method are:

- measurements can also be done at a higher rate than the on-road alternatives;
- the repeatability is much higher;
- no atmospheric influences like wind, sun, humidity, etc.
- less corrections that compromise the accuracy (mass, temperature, air density, wind, measurement equipment, etc.);
- no influences related to the driver, the test track or traffic;

For these reasons the wind tunnel method was welcomed as a good alternative road load determination method. The only problem was the lack of a robust measurement procedure and appropriate wind tunnel criteria, apart from some available standards.

Description

The basic idea of this method is that the aerodynamic drag and rolling resistance of the vehicle can be separately determined. The wind tunnel is used to measure aerodynamic drag, expressed as the aerodynamic resistance coefficient multiplied by the frontal area: C_d*A_f. The combination of rolling resistance and the losses of the drivetrain (e.g. wheel bearings) is measured separately on a flat belt or on a chassis dynamometer. The sum of these two resistance components form the total road load as it would be measured on the road.

There are several options within the procedure, such as the coast down procedure (as on road) or a stepwise constant speed approach (as typically performed in today's development) for the rolling resistance determination. The advantage of the stepwise (or stabilized) approach is to not have any influence of rotational or inertia masses. The advantage of the coast down procedure is to be closer to on road testing and to the chassis dyno setting, so if there were any unknown dynamic effect it would have the same influence during the coast-down on the road and the coastdown on the dyno, thereby levelling out.

Another option is the warm-up procedure. The vehicle can be warmed up by driving the vehicle, quite similar to the on-road warm-up. There was also an option included to drag the vehicle by the dynamometer. This would eliminate the monotonous work and effort for the driver of the vehicle. Due to the significant lower power transferred through the drivetrain when the vehicle is dragged by the dynamometer, a higher warm-up speed is applied for this option in order to arrive at a similar warm-up of the vehicle that is warmed-up under its own power by a driver.

Any of these alternatives have to be confirmed and approved via a comparison to on road testing before they may be used. As there is no direct link to on-road testing, it was agreed to add a validation procedure. Every two years a correlation program has to be performed on similar vehicles as intended to be type-approved. The road load of these vehicles will be determined on the road and within the facilities (wind tunnel, flat belt/chassis dynamometer), and the equivalency between the results has to be demonstrated. On average, the cycle energy calculated from the road load may not deviate between these methods by more than 5% for a single vehicle, and more than 2% as an average of 3 vehicles.

Testing the rolling resistance on the chassis dynamometer requires an additional correction, as due to the radius of the roller the rolling resistance of a tyre on the dyno is higher compared to driving on a flat surface. A general correction formula is already available (based on an old ISO standard), but was found to not be accurate for every tyre. The data of an additional measurement series and the validation data produced by UTAC was used to develop a conservative default formula, for the GTR. There is also a possibility included to develop a more accurate formula, in close cooperation with the approval authority.

Validation and justification

To assess the validity of the method and the increased accuracy, a large measurement program was performed by UTAC. They applied the combination of a wind tunnel and a chassis dynamometer. After the measurements were concluded the same vehicles were transferred to VW to assess the validity of the method using the combination of a wind tunnel and a flat belt. The validation program included:

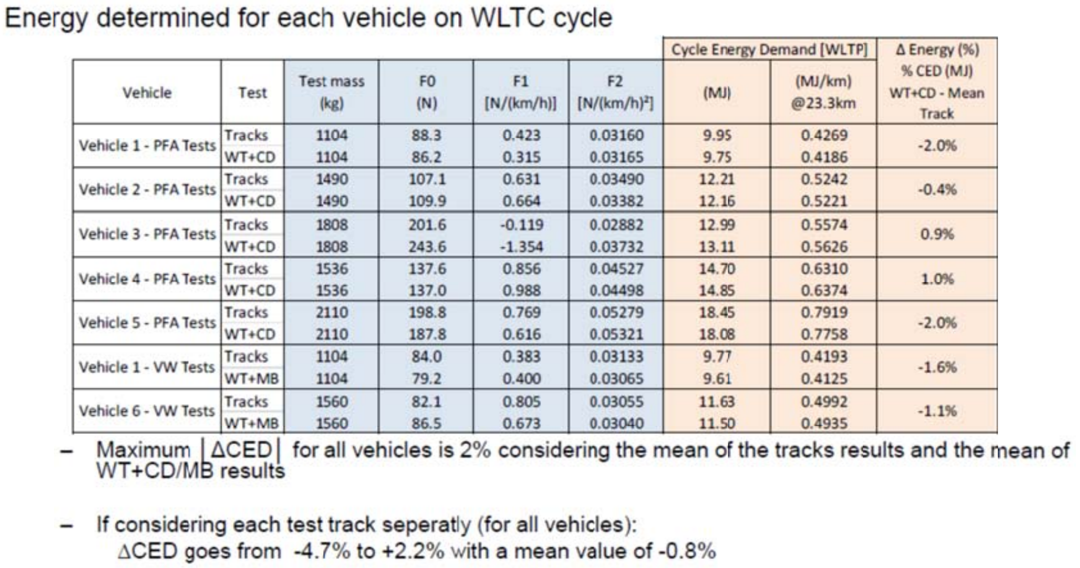
- 6 cars
- 4 tracks
- 2 wind tunnels
- 2 roller chassis dynamometer (two methods: decelerations and stabilized speeds)
- 1 flat belt dynamometer

The final results showed a good quality of the test execution, and the conclusions were:

- There is a high variation of on-road results (especially due to the different test tracks that have been used);
- The repeatability of the wind tunnel results is very good;
- There is a small systematic deviation between coast down and wind tunnel method, mostly the wind tunnel method yielded a lower road load result.

Apart from one vehicle (N1-vehicle) the systematic deviation was smaller than 10N. Some results of the validation program are shown in Table 6, Table 7, Figure 13 and Figure 14.

The overall difference in cycle energy demand between the wind tunnel method (with chassis dynamometer) and the coastdown method was -0.8%, within a range of -2.0% to 1.0%. Including outliers the range is between -4.7% and +2.2%. These variations are in the same order of magnitude of the differences found between the coastdown measurements on different test tracks. As a conclusion, the wind tunnel method -either with the chassis dyno or the flat belt- was considered an acceptable road load determination method.[30]



Energy determined for each vehicle on WLTC cycle

Vehicle	Test	Test mass (kg)	F0 (N)	F1 [N/(km/h)]	F2 [N/(km/h)²]	Cycle Energy Demand [WLTP] (MJ)	Cycle Energy Demand [WLTP] (MJ/km) @23.3km	Δ Energy (%) % CED (MJ) WT+CD - Mean Track
Vehicle 1 - PFA Tests	Tracks	1104	88.3	0.423	0.03160	9.95	0.4269	-2.0%
	WT+CD	1104	86.2	0.315	0.03165	9.75	0.4186	
Vehicle 2 - PFA Tests	Tracks	1490	107.1	0.631	0.03490	12.21	0.5242	-0.4%
	WT+CD	1490	109.9	0.664	0.03382	12.16	0.5221	
Vehicle 3 - PFA Tests	Tracks	1808	201.6	-0.119	0.02882	12.99	0.5574	0.9%
	WT+CD	1808	243.6	-1.354	0.03732	13.11	0.5626	
Vehicle 4 - PFA Tests	Tracks	1536	137.6	0.856	0.04527	14.70	0.6310	1.0%
	WT+CD	1536	137.0	0.988	0.04498	14.85	0.6374	
Vehicle 5 - PFA Tests	Tracks	2110	198.8	0.769	0.05279	18.45	0.7919	-2.0%
	WT+CD	2110	187.8	0.616	0.05321	18.08	0.7758	
Vehicle 1 - VW Tests	Tracks	1104	84.0	0.383	0.03133	9.77	0.4193	-1.6%
	WT+MB	1104	79.2	0.400	0.03065	9.61	0.4125	
Vehicle 6 - VW Tests	Tracks	1560	82.1	0.805	0.03055	11.63	0.4992	-1.1%
	WT+MB	1560	86.5	0.673	0.03040	11.50	0.4935	

- Maximum |ΔCED| for all vehicles is 2% considering the mean of the tracks results and the mean of WT+CD/MB results
- If considering each test track seperatly (for all vehicles):
  ΔCED goes from -4.7% to +2.2% with a mean value of -0.8%

Table 6: Cycle energy demand comparison of wind tunnel and coast down method

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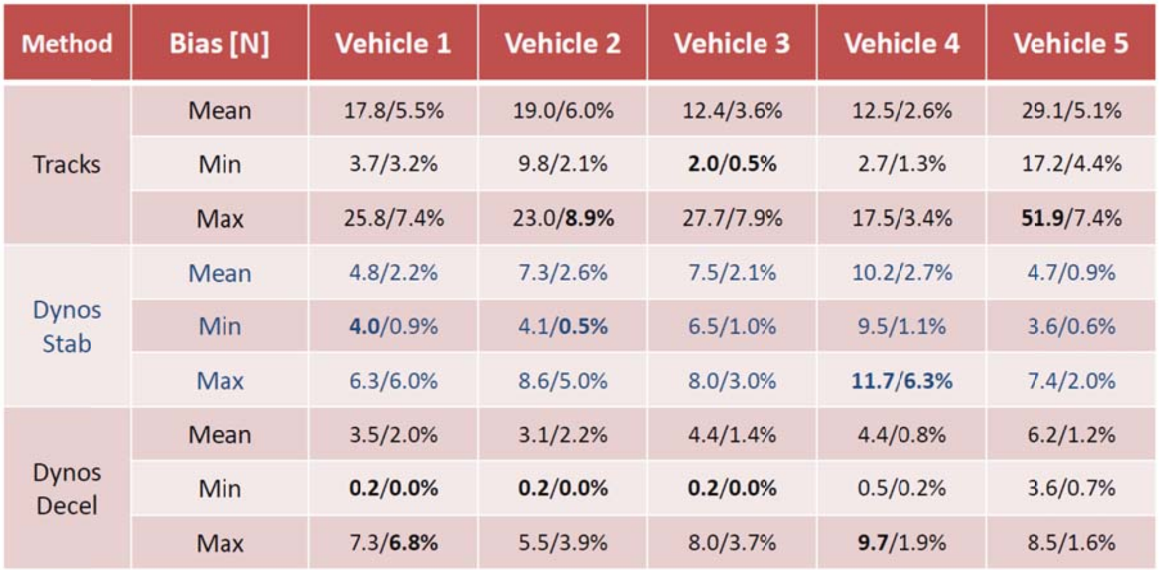
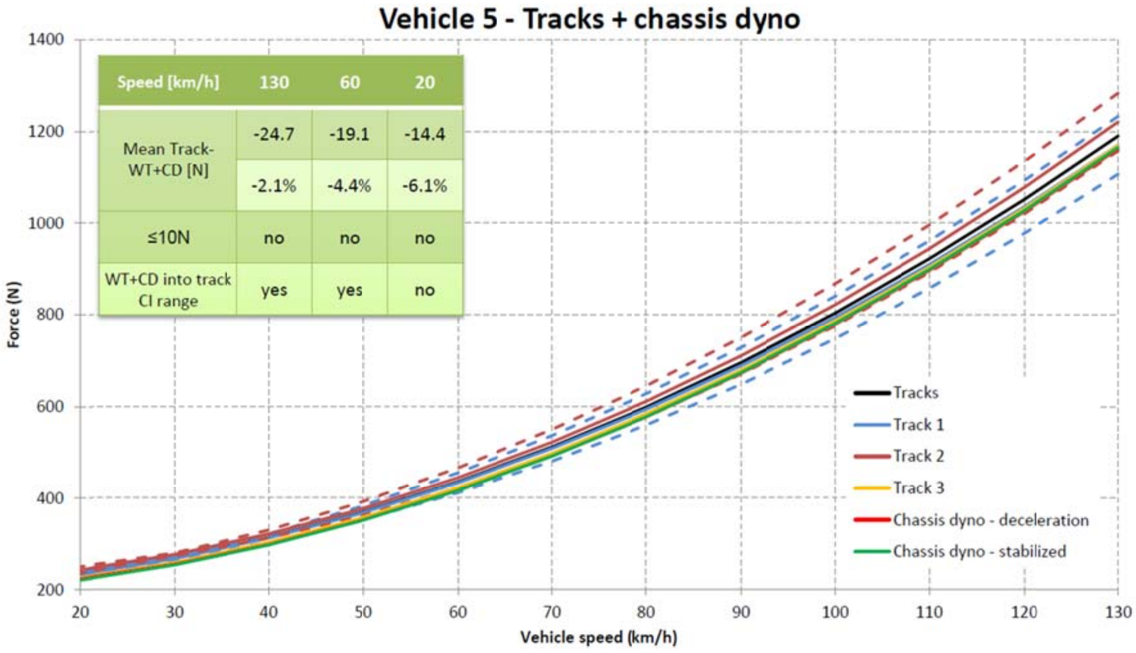
[30] See for more information documents WLTP-10-14e and WLTP-10-15e at https://www2.unece.org/wiki/display/trans/WLTP+10th+session



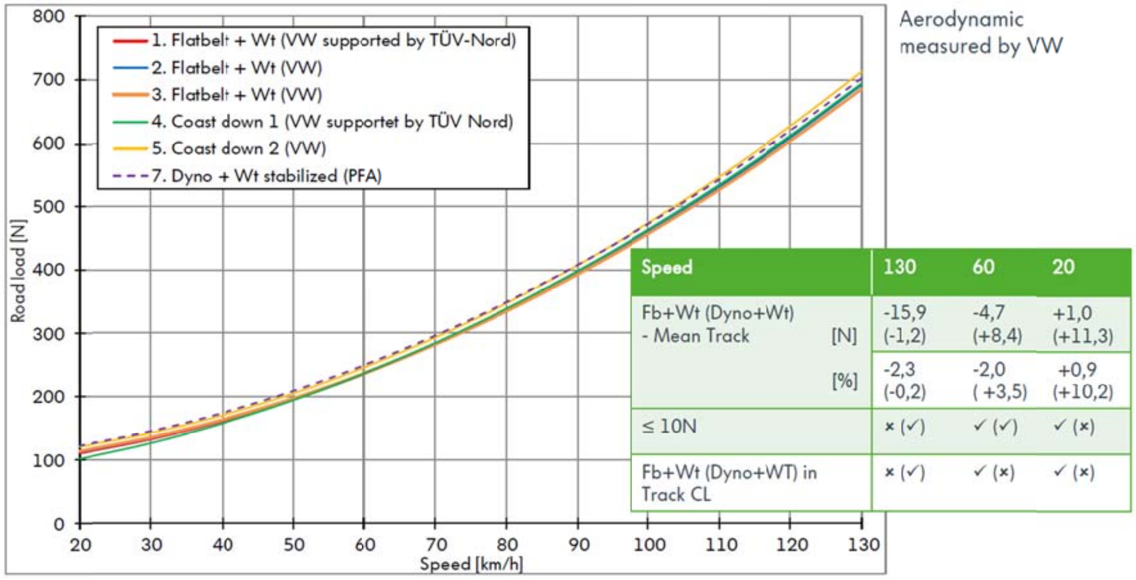
Method	Bias [N]	Vehicle 1	Vehicle 2	Vehicle 3	Vehicle 4	Vehicle 5
Tracks	Mean	17.8/5.5%	19.0/6.0%	12.4/3.6%	12.5/2.6%	29.1/5.1%
	Min	3.7/3.2%	9.8/2.1%	**2.0/0.5%**	2.7/1.3%	17.2/4.4%
	Max	25.8/7.4%	23.0/**8.9%**	27.7/7.9%	17.5/3.4%	**51.9**/7.4%
Dynos Stab	Mean	4.8/2.2%	7.3/2.6%	7.5/2.1%	10.2/2.7%	4.7/0.9%
	Min	**4.0**/0.9%	4.1/**0.5%**	6.5/1.0%	9.5/1.1%	3.6/0.6%
	Max	6.3/6.0%	8.6/5.0%	8.0/3.0%	**11.7/6.3%**	7.4/2.0%
Dynos Decel	Mean	3.5/2.0%	3.1/2.2%	4.4/1.4%	4.4/0.8%	6.2/1.2%
	Min	**0.2/0.0%**	**0.2/0.0%**	**0.2/0.0%**	0.5/0.2%	3.6/0.7%
	Max	7.3/**6.8%**	5.5/3.9%	8.0/3.7%	**9.7**/1.9%	8.5/1.6%

Table 7: Absolute and relative range between the averages of measurements done at each test facility in N and as a percentage (=bias of the methods)



Speed [km/h]	130	60	20
Mean Track-WT+CD [N]	-24.7	-19.1	-14.4
	-2.1%	-4.4%	-6.1%
≤10N	no	no	no
WT+CD into track CI range	yes	yes	no

Figure 13: Comparison of road load curves for the coastdown method on the tracks and the windtunnel + chassis dyno method (deceleration and stepwise method). Dashed lines show confidence intervals for the tracks

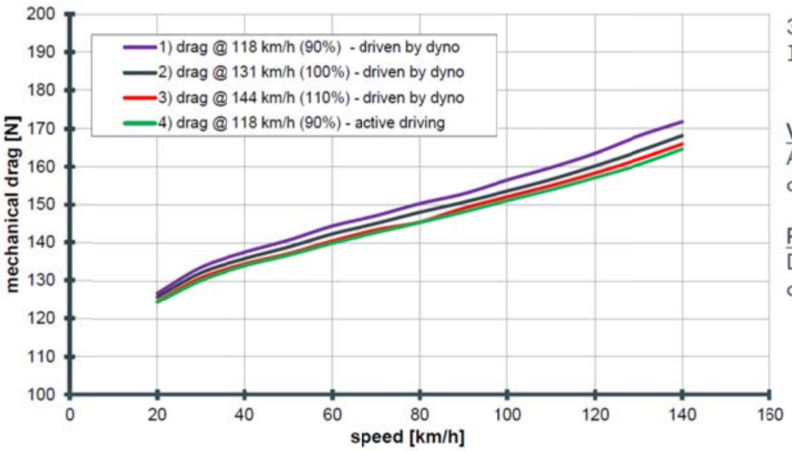


Aerodynamic measured by VW

Speed		130	60	20
Fb+Wt (Dyno+Wt) - Mean Track	[N]	-15,9 (-1,2)	-4,7 (+8,4)	+1,0 (+11,3)
	[%]	-2,3 (-0,2)	-2,0 (+3,5)	+0,9 (+10,2)
≤ 10N		× (✓)	✓ (✓)	✓ (×)
Fb+Wt (Dyno+WT) in Track CL		× (✓)	✓ (×)	✓ (×)

Figure 14: Comparison of road load curves for the coastdown method on the tracks and the wind tunnel + flat belt method

The validity of the alternative warm-up was measured as well. Figure 15 shows the effect of different (dyno driven) warm up strategies on the mechanical drag of the vehicle in comparison to a warm-up by driving the vehicle itself.



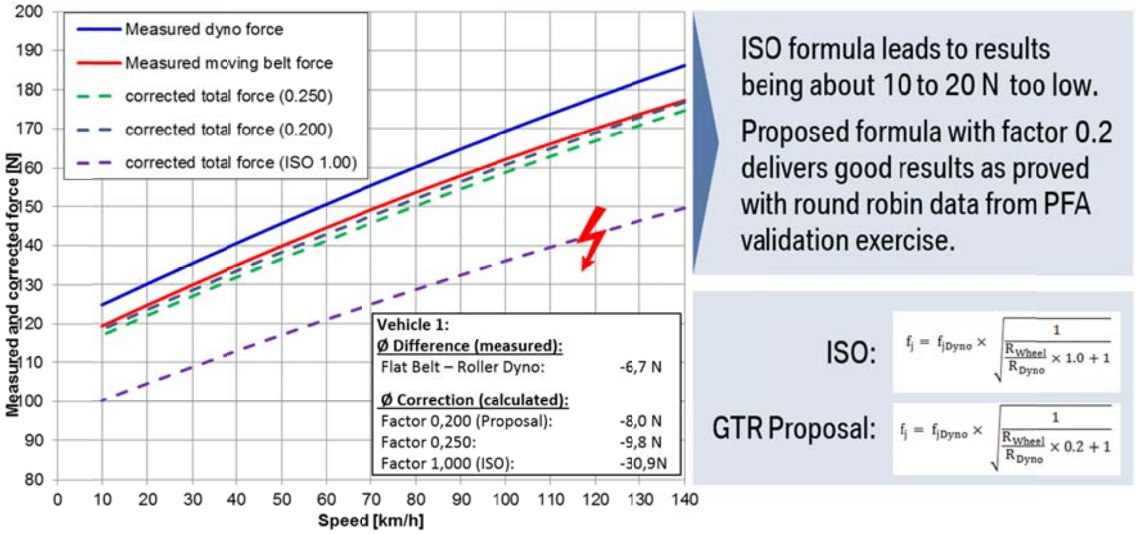
3 warm-ups were driven by dyno.
1 warmu-up was driven by car (active driving).

Warm up like on the road:
Active driving at 90% of maximum cycle speed.

Proposal VW
Driven by dyno at 110% of maximum cycle speed.

Figure 15: Evaluation of the effect for different warm-up strategies on mechanical drag

The formula for the correction of the rolling resistance force due to the roller radius was also evaluated. The results are shown in Figure 16. The correction formula suggested by the ISO procedure proved to be incorrect (purple dashed line). Lowering the coefficient of 1.0 in the formula to 0.2 resulted in a good match to the force measured on the flatbelt. This was included in the GTR as a default coefficient for the correction.



Vehicle 1:

Ø Difference (measured):

Flat Belt – Roller Dyno: -6,7 N

Ø Correction (calculated):

Factor 0,200 (Proposal): -8,0 N

Factor 0,250: -9,8 N

Factor 1,000 (ISO): -30,9N

ISO formula leads to results being about 10 to 20 N too low.

Proposed formula with factor 0.2 delivers good results as proved with round robin data from PFA validation exercise.

ISO: $f_j = f_{jDyno} \times \sqrt{\frac{1}{\frac{R_{Wheel}}{R_{Dyno}} \times 1.0 + 1}}$

GTR Proposal: $f_j = f_{jDyno} \times \sqrt{\frac{1}{\frac{R_{Wheel}}{R_{Dyno}} \times 0.2 + 1}}$

Figure 16: Evaluation of the correction formula for the roller radius of the chassis dynamometer

Development process

The wind tunnel method was already described in some existing standards. However, these standards rely on good engineering judgement and can therefore not be applied as a test procedure for the GTR as such. This meant that the text of the existing standards had to be completed in a much higher level of detail, e.g. by setting criteria and specifying requirements. This also included the need for a correlation program between on-road and wind tunnel tests.

During the process, the GTR text was developed within a small sub-group and in a very constructive manner to create a robust test procedure with guidance how to apply the method and to perform the testing.

The need for the inclusion of the wind tunnel method was acknowledged during phase 1a, but in the absence of sufficient validation data it was decided to postpone the adoption until phase 1b. This gave an opportunity to set up a validation test program, and use the results to develop the text for the GTR.

Within the taskforce on the wind tunnel method doubts were raised towards the validity of wind tunnel results, especially from Japanese side. As Japan has no concept of round robin comparison of wind tunnel results like in Europe, the concerns were well understood. Therefore the following precautions have been taken:

- wind tunnel criteria have been scrutinised and tightened where possible,
- the approval of the facilities via a correlation with on road testing was added, and
- two validation studies were executed (by UTAC and by VW).

Having delivered the required validation data and a robust description of the method, IG agreed on adopting the wind tunnel method with the flat belt at the 10th IG meeting. Additional testing was needed for the correction function on the chassis dynamometer, so that part was adopted later at the 12th IG meeting.

The wind tunnel method is included in paragraph 6 of Annex 4.

Windtunnel criteria

It should be mentioned here that a windtunnel can be used for two purposes in the GTR:

a) to determine the 'delta C_d.A' between options to the vehicle exterior and/or bodyshapes for the purpose of interpolation between vehicle L and H, and
b) to determine the overall C_d.A of the whole vehicle to derive the target road load coefficients, i.e. the windtunnel method described in this paragraph.

The basic windtunnel criteria are laid down in paragraph 3.2 of Annex 4, but due to the differences between these purposes the criteria for the wind tunnel method are more stringent (see paragraph 6.4.1).

The reasons for these different criteria are as follows:

1. The difference between the delta C_d.A of vehicle L and H is much smaller than the overall C_d.A of the whole vehicle. Therefore the absolute effect of an error in the determination of the delta C_d.A has less consequences.
2. The sum of the delta C_d.A for the set of options on vehicle H is aligned by the C_d.A difference between vehicle L and H. This means that any error in the measurement is largely compensated.

For these reasons a bigger solid blockage ratio can be accepted for the wind tunnel used for the delta C_d.A determination, and a higher deviation is allowed between front and rear pressure coefficient. Also the blockage due to the vehicle restraint system has no influence, because its influence levels out during the delta C_d.A determination.

4.4.12 Alternative delta C_d.A determination

For the interpolation method on CO_2 as described in paragraph 4.4.1 there is a need to determine the variation in the value of C_d.A for each vehicle option that has an influence on the aerodynamic performance of the vehicle. In the GTR this is referred to as the delta Cd.A determination, which is an input for the calculation of the cycle energy for an individual vehicle. Examples of vehicle options which' aerodynamic resistance would have to be determined are wheel rims and tires, spoilers, adjustable vehicle height system, grille shutters, etc.

It was acknowledged by the Annex 4 taskforce that:

1. Variations in the delta C_d.A or vehicle options are in the same order of magnitude as the measurement tolerance. This makes it virtually impossible to determine an accurate value for the delta C_d.A by performing e.g. a coast-down with and without the option installed on the vehicle. Only the wind tunnel method may be sufficiently accurate to measure this due to the absence of uncontrollable influences.

2. The determination of the delta C_d.A for all the options in a vehicle family may take a lot of effort in the windtunnel, and is therefore time consuming and costly. At the same time, not all manufacturers may have unlimited access to a windtunnel.

3. There are simulation methods available which are able to accurately determine the influence on aerodynamic performance for different body styles and options installed at the vehicle exterior.

For this reason an alternative method was proposed which –under strict requirements- would allow the calculation of the delta C_d.A by e.g. computer simulations based on the method of Computational Fluid Dynamics (CFD). The basic principle for this alternative method is that it should always be validated by demonstrating equivalency with measured aerodynamic results. Therefore, the following requirements and restrictions were set to this method:

a) The method may only be used after agreement by the responsible authority, and after fulfilling the other requirements and restrictions.

b) It has to be demonstrated that the method has an accuracy of ±0.015 m^2 delta C_d.A.

c) The method has to be validated, not only by demonstrating the accuracy requirement, but also to yield similar flow patterns, air velocities, pressures and forces.

d) It can only be used for those kind of aerodynamic influencing parts (e.g. wheels, body shapes, cooling system) for which equivalency was demonstrated.

e) The evidence of equivalency is presented in advance to the responsible authority, for each road load family (if a simulation method is used) or by a correlation test programme (if a measurement method is used).

f) Only the wind tunnel method is allowed to be used for the equivalency demonstration.

g) The method may not be applied for vehicle options with a delta C_d.A that is more than 100% higher than the option for which equivalency was demonstrated.

h) Whenever the simulation model is changed or updated, the validation needs to be re-demonstrated.

Note that the alternative delta C_d.A method may *only* be used to determine the *difference* in aerodynamic drag, it is not allowed to evaluate the *absolute* aerodynamic resistance of the whole vehicle. For the measurement of the overall aerodynamic resistance e.g. the wind tunnel method of paragraph 4.4.11 should be applied.

The alternative delta C_d.A method is described in paragraph 3.2.3.2.2.3. of Annex 7.

4.4.13 Road load family

The "Road Load Family" is a concept which allows to calculate road load coefficients instead of measuring them. Within that framework, the interpolation is limited to a vehicle family with similar characteristics but is independent for example of the vehicle's engine. Hence, a diesel and a gasoline variant of the same vehicle model may be in the same "Road Load Family". The method is based on a linear interpolation principle of the relevant road load properties: aerodynamics, rolling resistance and mass. The effect of these properties is calculated into a cycle energy value, quite similar to the approach for road load and CO_2 calculation within the ‘Interpolation family’.

Motivation

The consequence of bringing in the concept of the interpolation family leads to an increase in the test effort for road load determination because for every Interpolation Family at least two vehicles ("High" and "Low") have to be tested. At the same time, the interpolation family approach offers the use of a road load interpolation method based on relevant parameters. This gives an opportunity to create a road load family that is larger than the interpolation family, mainly by attributing the effect of the engine by means of a difference in vehicle mass and –if appropriate- aerodynamic drag difference.

Scope

The following family criteria are specified in the GTR:

- same drivetrain and gearbox;
- limits to n/v ratio 25% (with respect to the most common installed transmission type);
- limits to interpolation range min. 4%, max. 35% cycle energy (based on vehicle H_R);
- some additional provisions for electrified vehicles.

This means that different engines (diesel, gasoline, different displacements) can be in the same Road Load Family, but different types of drivetrains (e.g. two-wheel or four-wheel drive) or gearboxes (MT/AT) will be in different Road Load Families.

These family criteria are described in par. 5.7 of part II of the GTR.

Validation and justification

Within the concept of the Interpolation method (see par. 4.4.1 of this report) it was already confirmed that road load and CO_2 have a linear response to differences in aerodynamic drag, rolling resistance and mass.

Different engines have no direct influence on road load, apart from the parameters that can be interpolated (aerodynamics, mass). This is valid for all powertrains where the engine is decoupled from the drivetrain during road load determination. Therefore, as long as the drivetrain -starting at the clutch and ending at the wheels- is the same, the road load of different vehicles within that family can be calculated by interpolating the three road load relevant parameters, i.e. aerodynamic drag, mass and rolling resistance. See Figure 17.

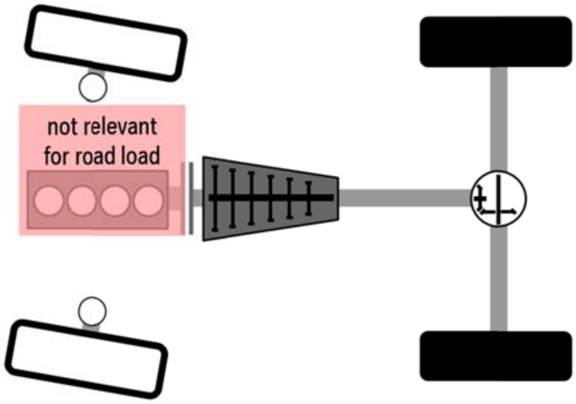


Figure 17: Road load relevant components of the drivetrain for an ICE vehicle

Apart from this technical argumentation, a validation by testing was considered necessary in order to verify the linearity of this approach and to establish a maximum range. The IG gave the mandate to BMW to perform some road load tests for this purpose.

Due to the restrictions of vehicle availability and weather conditions only four vehicles were tested. Two vehicles were selected to represent a vehicle High and Low of a range that typically would encompass a road load vehicle family. The other two were selected in between vehicle L and H. The first two formed the basis for the interpolation, based on which the road load for the last two vehicles could be calculated. By comparing the measured and calculated road loads, the accuracy of the road load interpolation could be validated.[31] The vehicle selection is shown in Figure 18 and the results are presented in Figure 19. The vehicles were all rear-wheel driven, equipped with the same automatic transmission, and their n/v ratio was within 11%.

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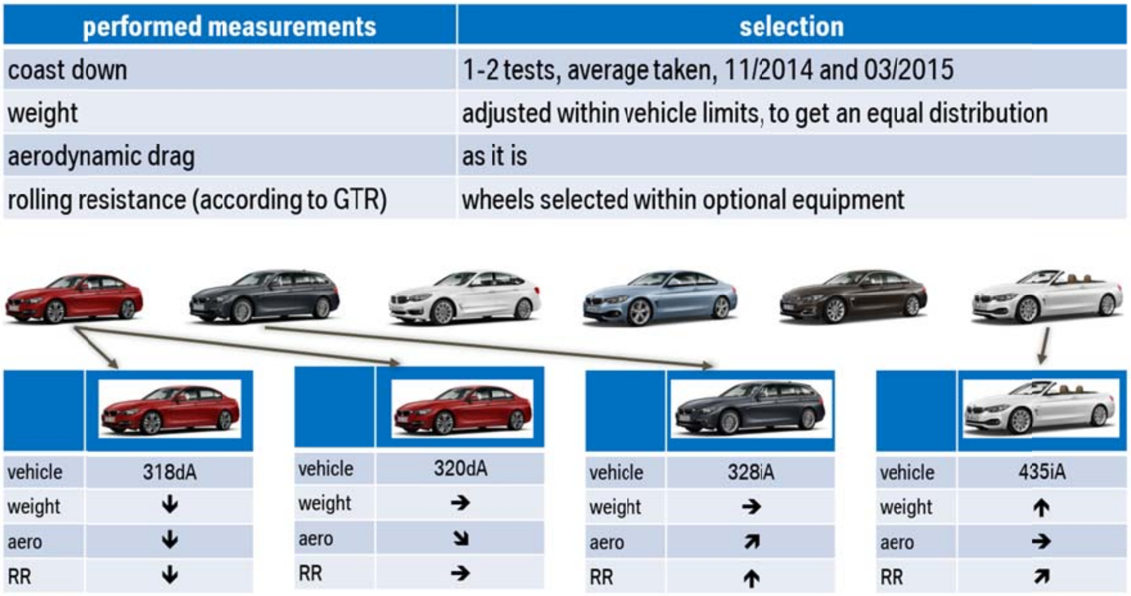
[31] It should be acknowledged that any such difference may also be attributed to the inaccuracy of the coastdown method itself. To eliminate that influence as much as possible, the coastdown procedure was done twice, and the results were averaged.



performed measurements	selection
coast down	1-2 tests, average taken, 11/2014 and 03/2015
weight	adjusted within vehicle limits, to get an equal distribution
aerodynamic drag	as it is
rolling resistance (according to GTR)	wheels selected within optional equipment

vehicle	318dA
weight	↓
aero	↓
RR	↓

vehicle	320dA
weight	→
aero	↘
RR	→

vehicle	328iA
weight	→
aero	↗
RR	↑

vehicle	435iA
weight	↑
aero	→
RR	↗

Figure 18: Vehicles selected for road load family validation tests

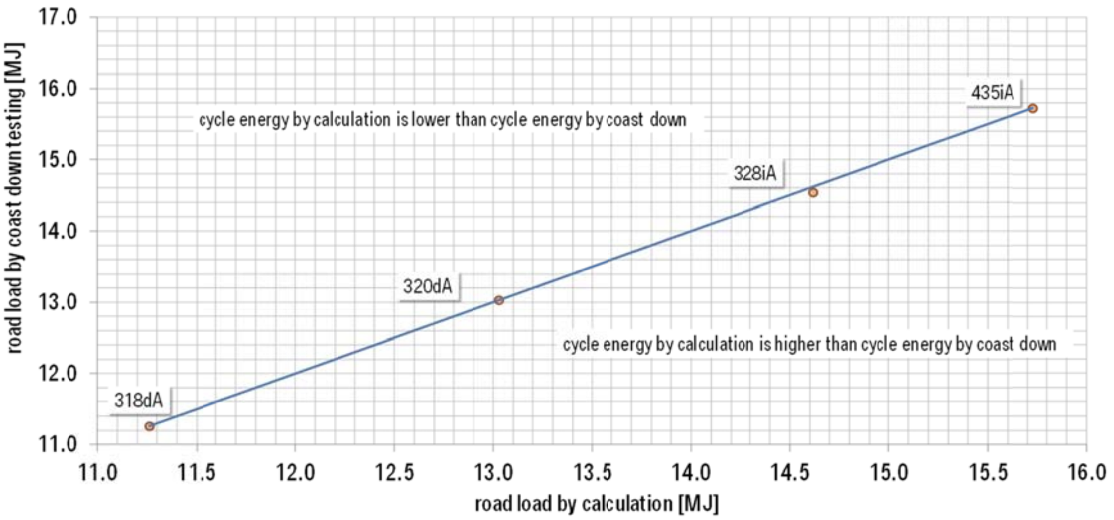


Figure 19: Results of the road load family validation tests

For this particularly wide range of vehicles the validation results show a very good agreement with the calculated interpolation line. Generally, the accuracy is within 0 to 0.5% of the cycle energy, with a maximum absolute error of 0.08 MJ. Over the WLTP test cycle this error would correspond to a difference in CO_2 of approximately 0.5 g/km. Therefore it was concluded that the approach of the road load family was validated, having an accuracy that is at least equal to the coastdown method.

Development process

As the formulas were already available from the Interpolation Family, the development mainly focused on the family criteria, the maximum range and a robust drafting text for the GTR. Also the description of the test vehicles "High" and "Low" was reworked and improved, in order to have a robust definition and a clear basis for the interpolation. The proposed range by BMW of 4 to 35% of the cycle energy for vehicle H was considered acceptable.

The method was finally adopted at the 10th IG meeting[32]. It was accepted as a method which significantly reduces testing effort without changing the accuracy of the results and is therefore a clear improvement of the emission legislation, compared to the ones existing in today's legislation worldwide.

The road load family is described in par. 4.2.1.3 of Annex 4.

4.4.14 Manufacturer’s responsibility on road load

The concept of ‘manufacturer responsibility’ on road load is also a new concept to the GTR, not so much being a measurement or calculation concept but more like a principle. This statement in paragraph 3 of Annex 4 needs to ensure that despite the variety of road load measurement methods provided in the GTR and the tolerances allowed within these methods, the road load reported for an individual vehicle should be confirmed and not underestimated.

The gtr contains different methods to determine the road load of a vehicle, based on different measurement options and calculation options:

- Coast down with stationary anemometer
- Coast down with on-board anemometer
- Torque meter method
- Wind tunnel with flat belt
- Wind tunnel with chassis dynamometer
- Road load family
- Road load matrix family
- Default road load parameters

Even though the measurement methods are developed to arrive at an accurate road load by setting appropriate tolerances, accuracies and precisions, the road load values of a vehicle may depend on the (combination of) method(s) and calculation(s) chosen. This choice of method is up to the manufacturer. A selection of methods with the intention to determine road load values that underscore the real world road load of production cars should be avoided. Therefore the following text was included in par. 3 of Annex 4:

> *“The manufacturer shall be responsible for the accuracy of the road load coefficients and will ensure this for each production vehicle within the road load family. Tolerances within the allowed road load determination, simulation and calculation methods shall not be used to underestimate the road load of production vehicles. At the request of the responsible authority, the accuracy of the road load coefficients of an individual vehicle shall be demonstrated.”*

This statement basically ensures that if the road load of a production vehicle was verified by the responsible authority, its road load would have to be in agreement with what was declared at type approval.

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[32] See document WLTP-10-17-rev1e at https://www2.unece.org/wiki/display/trans/WLTP+10th+session

Since neither Conformity of Production or In-Service Conformity requirements are included in this version of the GTR, the proposed wording was selected with care. It was not able to agree on a reference road load determination method, and this issue should be further discussed in Phase 2 of WLTP.

4.4.15 Alternative vehicle warm-up procedure

The WLTC based warm-up procedure takes 30 min time and adds 23 km on the odometer provisions. To reduce this effort it was decided that there was a need for an alternative warm up procedure, but this would only be accepted if could be demonstrated that it would yield at least a similar warm-up of the vehicle. The alternative warm-up procedure would only be valid for vehicles within the same road load family.

To demonstrate equivalent warm-up at least one vehicle representing the road load family has to be selected and warmed up on the dynamometer according to the alternative procedure. After this warm-up the dynamometer load setting is determined. The alternative warm-up procedure is considered valid if the calculated cycle energy demand within each cycle phase is equal to or higher than the energy of the same phase driven with dynamometer load settings according to a warm up with a WLTC. The details of the procedure and its equivalency have to be reported to the responsible authority.

4.4.16 REESS charge balance (RCB) correction for ICE vehicles

Under Regulation 83, the vehicle battery is normally 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 recognized as an issue which has an unrealistic effect on the fuel consumption at type approval, and whose influence is too high to be ignored[33].

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.

Secondly, a pragmatic approach was developed 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 A6.App2/2, and is based on the ΔE_{REESS} divided by the equivalent energy of the consumed

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[33] 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)

fuel. In the case that it is below 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 CO_2 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 CO_2. 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.

The correction method for the RCB is outlined in Appendix 2 of Annex 6. The procedure for the REESS charge balance correction of electrified vehicles is described in paragraph 4.4.18.

4.4.17 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)

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. Instead, all Annex 8 vehicles are classified as Class 3 vehicles and therefore the WLTC Class 3a or 3b driving curve is the reference cycle (depending on their maximum speed). 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's 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 are 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 are tested by 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. Via the Utility Factor (UF), which is dependent on the electric range in charge-depleting mode, the CO_2 emissions and fuel consumption results of the CS and CD test are transformed into a weighted average.

For the electric range determination 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.

4.4.18 RCB correction for OVC-HEVs, NOVC-HEVs and NOVC-FCHVs

The RCB correction for hybrid electrical vehicles which are tested according to Annex 8 have a different correction procedure as used for conventional vehicles because they have more than one battery while the energy content of the traction battery is much higher.

Background

The RCB correction for hybrids was already developed within phase 1a but a clear demand was identified to further discuss this during the WLTP phase 1b. This decision was taken in order to improve on the procedure, make it more robust and to be able to perform a deeper analysis of the discussed approaches. This was considered essential as the determined correction coefficient is not only required for the correction of whole cycle test results but also for the determination of the phase specific values – see paragraph 4.4.20.

Phase specific values can also be determined by correcting each phase with a phase specific correction coefficient. But due to the vehicle operation strategy it is not always possible to determine in each and every phase a positive and negative charging balance, which is a prerequisite for the correction coefficient determination.

In phase 1a, only a procedure under cold conditions was developed, which means that the vehicle is starting in ambient temperature conditions at each correction coefficient determination test. Ambient temperature conditions can be reached by soaking the vehicle as defined in the GTR for a time period of 12-36 hours. This procedure was already applied in the past but has proven to be very time consuming due to the long soak period in between the tests. Therefore a more practical solution would be welcomed.

The main questions to be answered were defined as follows:

a) Under which conditions does an REESS energy change-based correction of the charge-sustaining fuel consumption and CO_2 mass emission have to be applied

b) How should the procedure for the correction coefficient determination be properly defined?

c) Which boundary conditions for the correction coefficient determination tests should be defined?

These questions were addressed by the Subgroup EV in phase 1b.

Application criteria for the RCB correction

The conclusion of the discussions within Subgroup EV level was that a correction is only required if the REESS has been discharged *and* the correction criterion '*c*' between the absolute value of the REESS electric energy change and the fuel energy is higher than 0.5%[34].

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[34] c is the ratio between the absolute value of the REESS electric energy change and the energy content of the consumed fuel. The limit of 0.5% applies for an applicable test cycle consisting of a L,M,H and ex-H phase; it is 1.0% if the applicable test cycle consists of a L,M and H phase, and it is 1.5% if the applicable test cycle consists of a L and M phase only. Refer to Appendix 2 of Annex 8.

In all other cases a correction may be omitted and the uncorrected values may be used. This is graphically illustrated in Figure 20.

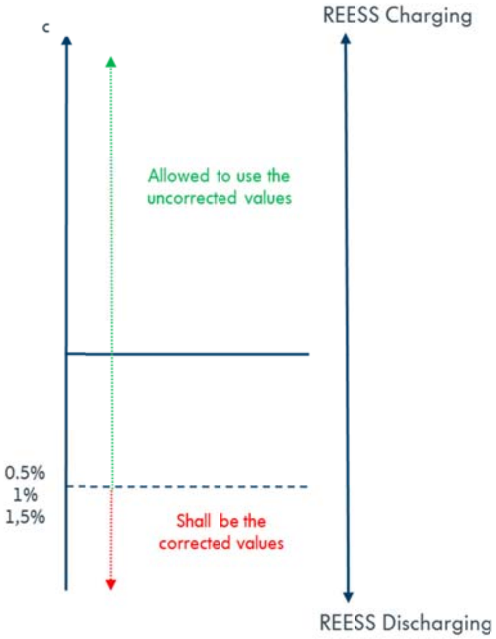

Figure 20: Graphical illustration of the application criteria for RCB correction

Figure 20 is only referring to whole cycle test results. Individual phases have to be corrected irrespective of the energy change, at least if these values are required by the Contracting Party.

Procedures for the correction coefficient determination

During phase 1b, Subgroup EV experts discussed intensively a new approach with respect to the procedure for the determination of the correction coefficient. This new approach is a determination procedure under warm conditions, which can be selected by the manufacturer as an alternative option to the procedure under cold conditions.

The correction procedure under warm conditions was reviewed and evaluated during phase 1b by the members of the WLTP Subgroup EV. For this purpose both VW and BMW provided simulation and measurement results to the group.[35] The results of the evaluation of this procedure showed robust and repeatable values for the correction coefficient determination due to the reproducible conditions and vehicle behaviour. An additional benefit of the procedure under warm conditions is the fact that this procedure is less time consuming because no soak period is necessary in between the required tests.

Similar to the procedure under cold conditions, the manufacturer is allowed to set the state of charge of the traction REESS for the correction coefficient determination, with the aim to trigger a positive or negative delta REESS over the test. The break time during which this REESS adjustment takes place should be less than 60 minutes, and the same break time should be applied for each of the tests for reason of repeatability.

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[35] For details refer to document WLTP-SG-EV-06-11e and document WLTP-SG-EV-08-02 at https://www2.unece.org/wiki/pages/viewpage.action?pageId=23101485

For the procedure under warm conditions the manufacturer has to ensure these warm conditions prior to each driven cycle for the correction coefficient determination in order to arrive at repeatable results. If necessary the manufacturer may conduct an additional warm-up procedure before each test. In that case, the same warm-up has to be applied to each of the tests required for the correction coefficient determination.

Both the procedure under cold conditions and the procedure under warm conditions can be applied for NOVC-HEVs and OVC-HEVs. The same principle is also be applied for NOVC-FCHVs.

The flowcharts in Figure 21 show the sequence of activities within the procedures under cold and warm conditions.

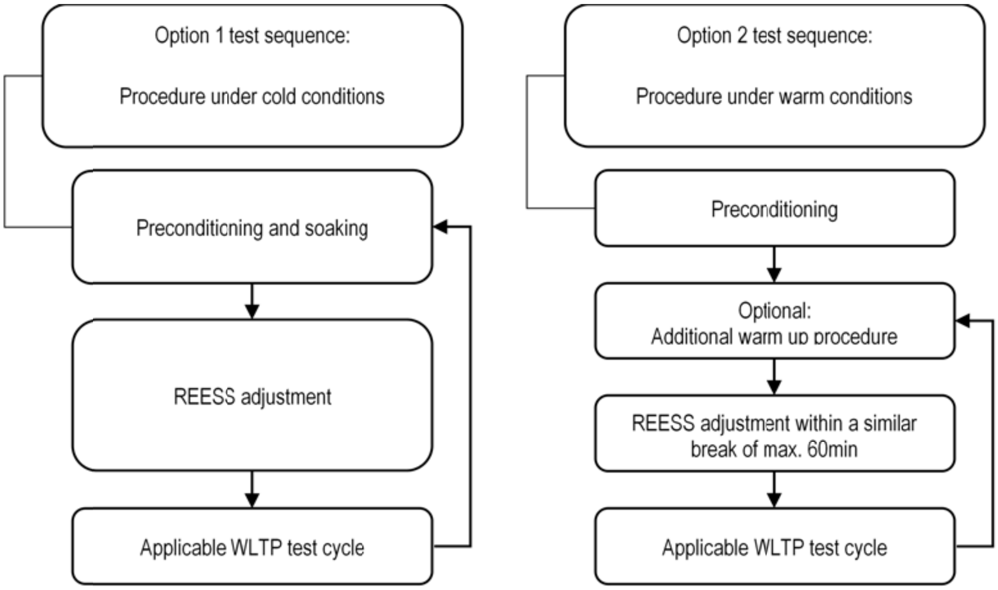

Figure 21: Flowcharts of procedures for the determination of the correction coefficient under cold and warm conditions

Both procedures are repeated until the set of measurement results fulfil the boundary conditions for the correction coefficient determination.

Boundary conditions for the correction coefficient determination

The RCB correction function is basically determined by the slope of the linear regression line through the test results, with CO_2/FC on the vertical axis and the energy balance of the REESS on the horizontal axis ($\Delta E_{REESS,CS}$). The accuracy of this slope can be increased by adding more test results, but is also sensitive to the placement of these points. Therefore it was decided to apply the following two-step approach in order to receive a set of tests which are meaningful for the correction coefficient determination:

1. The first step requires at least five tests (randomly placed) with two criteria two fulfil
2. The second step requires only three tests but with additional criteria to ensure that the same accuracy is provided as with five randomly placed tests

In the first step, the manufacturer has to be provide at least a set of five tests for the correction coefficient determination to the responsible authority. The set of test results have to fulfil the following criteria:

a) The set shall contain at least one test with $\Delta E_{REESS,CS} \leq 0$ and at least one with $\Delta E_{REESS,CS} > 0$

b) The difference in CO_2 between the test with the highest electric energy change and the test with the highest positive electric energy change, both are the outer tests related to the electric energy change, shall be equal or more than 5 g/km.

The criteria for the first step are shown for an the example vehicle in Figure 22.

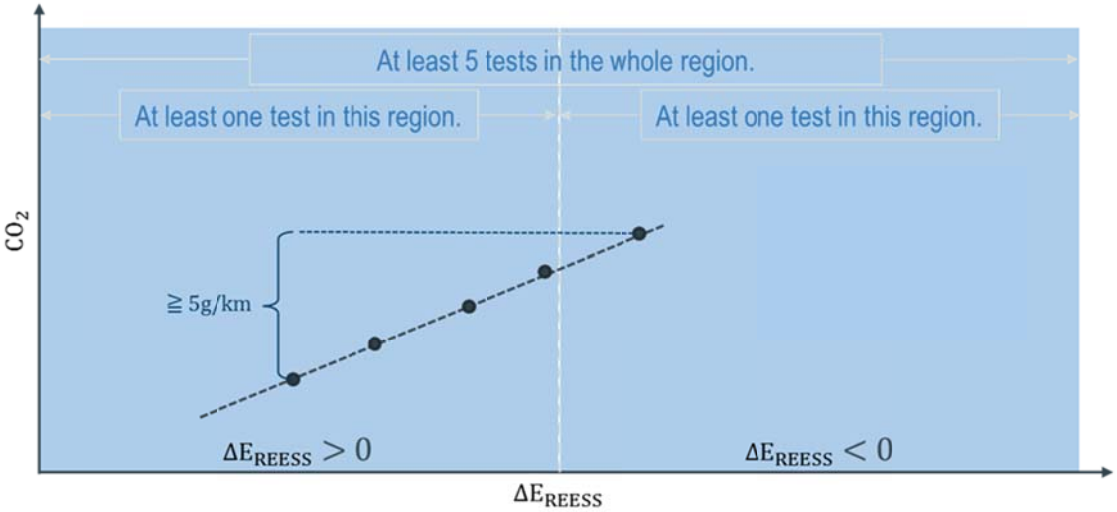

Figure 22: Graphical representation of the criteria for the first step (at least 5 tests)

In the second step, the required number of tests can be reduced to three test if the following criteria are fulfilled with respect to the placement of these tests:

a) The difference in CO_2 between two adjacent measurements, related to the electric energy change during the test, shall be less than or equal to 10 g/km.

b) The difference in CO_2 between the test with the highest negative electric energy change and the test with highest positive electric energy change shall not be less than 5 g/km.

c) In addition to b) the test with the highest negative electric energy change and the test with highest positive electric energy change shall not be within the region defined by $-1\% \leq \frac{\Delta E_{REESS}}{E_{Fuel}} \leq +1\%$.

d) The test in between the test with the highest negative electric energy change and the test with the highest positive electric energy change shall be within the region defined in b) and c).

The criteria for the second step are shown for 3 example vehicles in Figure 23. The areas defined by b) and c) are highlighted in brown.

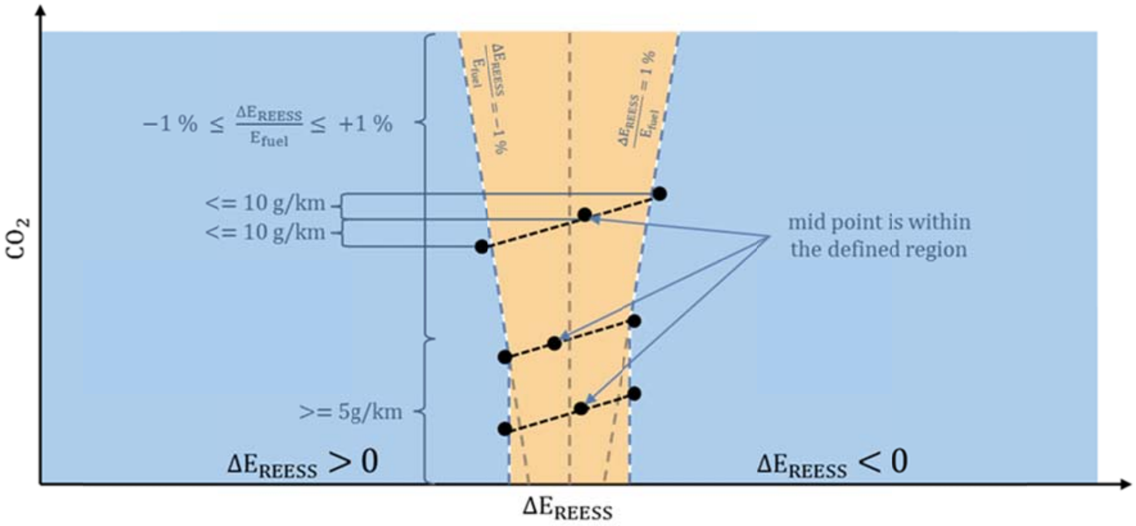

Figure 23: Graphical representation of the criteria for the second step (3 tests)

After intense discussions and careful consideration of these criteria they were finally adopted for the GTR in the Tokyo meeting.

The procedure for RCB correction of OVC-HEVs, NOVC-HEVs and NOVC-FCHVs is described in Appendix 2 of Annex 8.

4.4.19 Shortened test procedure for PEV range test

The test procedure developed in phase 1a to determine the range of a pure electric vehicle (PEV) requires to drive the applicable cycle consecutively until the vehicle is no longer capable to follow the prescribed speed trace. This procedure can take a lot of time, and also has a repeatability issue. Therefore a shortened test procedure with a calculation method for the range determination of PEVs was proposed in phase 1b. This method provides better repeatability on the test results. This new methodology will also reduce the test burden considerably.

Repeatability issue

With the consecutive cycle test procedure of phase 1a, the test will finish at an undefined point of the applicable test cycle at the moment that the usable electric energy has been depleted. The actual vehicle speed and acceleration at that point (and therefore the demanded electrical power from the REESS) is not the same from test to test. The electricity cut point by the vehicle control system is sensitive to the actual electric power demand, hence the driver behavior in terms of accelerating and braking may influence the test results. This causes a poor repeatability of the phase 1a test method of driving consecutive cycles.

Test procedure

The method proposed in phase 1b determines the range of a PEV by a combination of the following:

- a shortened test procedure (STP) to determine the usable battery energy (UBE), and
- a calculation approach to determine the pure electric range.

The function to obtain the pure electric range over the whole cycle (PER_{WLTC}) is determined as follows:.

$$\mathrm{PER_{WLTC}} = \frac{\mathrm{UBE_{STP}}}{\mathrm{EC_{DC,WLTC}}}$$

where :

UBE_{STP} is the usable battery (REESS) energy determined from the beginning of the shortened Type 1 test procedure until the break-off-criterion has been reached.

$EC_{DC,WLTC}$ is the weighted electric energy consumption for the applicable WLTP test cycle of segment 1 and 2 of the shortened test procedure (see Figure 24)

In order to shorten and simplify the test procedure duration, a test sequence with a higher consumption of electricity from the REESS was proposed to determine the usable battery energy. This test sequence would reduce the length of the test procedure due to this higher energy consumption, and is shown in Figure 24.

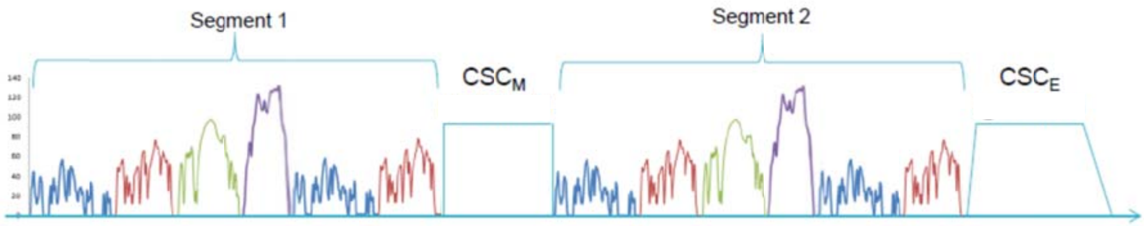

Figure 24: Sequence of the shortened test procedure for PEVs

The shortened test procedure (STP) consists of the following segments:

- Segment 1 is used to measure the electric energy consumption at a cold start and at a high SOC level of the REESS. Segment 1 has a repetition of L and M phases at the end, to differentiate between cold and hot phases of L and M.
- Segment 2 is used to measure the electric energy consumption at a low level of SOC of REESS.
- The constant speed cycle in the middle of segments 1 and 2, CSC_M, is intended to deplete the REESS more rapidly than by driving the normal applicable cycle. The length of this segment depends on the REESS capacity.
- The constant speed cycle at the end of segment 2, CSC_E, is intended to deplete the remaining energy from the REESS (this is limited to a maximum of 10% UBE), until the break-off criterion has been reached.

By integrating the measured energy [36]from the REESS over the whole STP, the total usable battery energy UBE_{STP} is derived. The selected speed of the CSC segments is the same for both and should have a minimum of 100 km/h.

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[36] Note that the current from the REESS needs to be measured, but for the voltage there are other alternative methods: either a measurement, or a nominal voltage, or the on-board signal for REESS voltage (see Annex 8, Appendix 3).

The pure electric range PER_{WLTC} is obtained not by the actual distance driven during this test sequence but by the calculation formula provided. Due to the constant energy demand at the CSC_E segment, the influence of the electricity cut by vehicle control systems at the final moment on test results is minimized. As a consequence, this method yields better repeatability than the method provided in the phase 1a version of the GTR.

Boundary condition to use shortened test

When a PEV has an expected range equal to or longer than 3 applicable WLTP test cycles, the shortened test procedure should be applied. In the case the Extra High Phase is excluded from the applicable cycle, this condition is replaced by a boundary of 4 applicable WLTP test cycles.

If the expected range is shorter, the consecutive cycle test procedure should be applied.

These criteria are specified in table A8/3 of Annex 8.

REESS energy determination

The REESS energy is determined by measuring the current and voltage of the REESS in each phase. Current transducers are clamped on the cables that are directly connected to the REESS. Alternatively, the on-board current measurement data may be used. In this case, the accuracy of these data shall be demonstrated to the responsible authority.

Voltage measuring equipment is required to measure voltage at the terminals of REESS. Alternatively, the on-board voltage measurement data may be used. In this case, the accuracy of these data shall be demonstrated to the responsible authority. For NOVC-HEVs, NOVC-FCHVs and OVC-HEVs, the nominal REESS voltage may be used instead of the measured voltage.

Validation of the shortened test procedure

Main discussion point for the new proposal was the difference of results between the phase 1a and 1b methods. Especially the impact of the selected constant speed on the range was questioned. In order to take care of the concerns, ACEA and JAMA provided data to support the STP method, both by measurements and simulations.

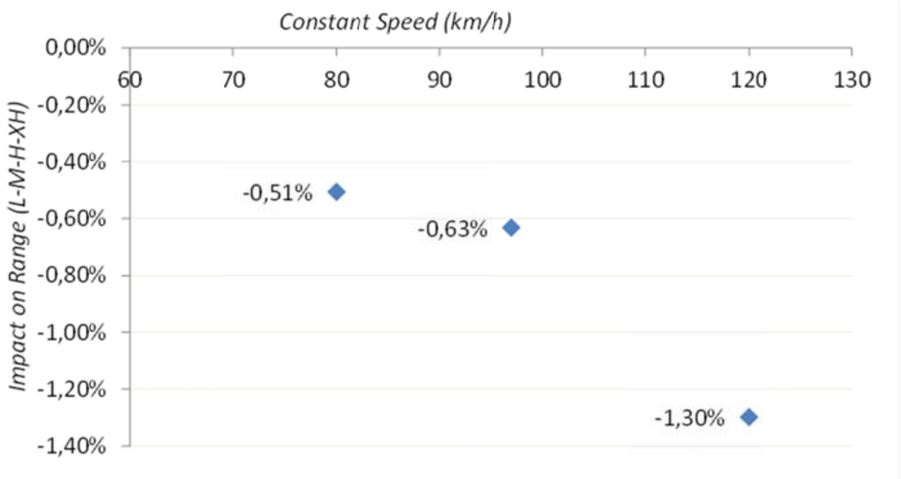

Figure 25: Validation data for shorten test procedure provided by ACEA (Renault)

Figure 25 shows the variation of the pure electric range against a selected constant speed for the CSC segments. On the vertical axis the calculated range is shown as a ratio against the range determined by the consecutive cycle test. The range gradually decreases with an increasing constant speed. The difference of range between the shortened and consecutive test is 1.3% at 120km/h. The variation width in range against the constant speed is within 1% between 80 km/h and 120 km/h. As a conclusion, the STP yields a slightly worse electric range, but is fairly close to the outcome of the consecutive cycle test result. Note that the speed of the CSC segments should be 100 km/h or higher according to the GTR.

Figure 26 shows the variation of the pure electric range against constant speed of a different PEV as in Figure 25. The range variation clearly shows same tendency. The difference of range between the shortened and consecutive test was about 1.8 km at 120km/h. The variation width in range against constant speed was below 2 km of the ratio between 80 km/h and 120 km/h.

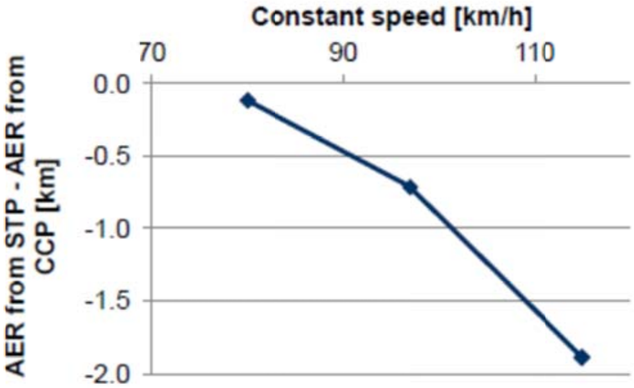

Figure 26: Validation data for shorten test procedure provided by ACEA (BMW)

A similar evaluation on another vehicle is presented in Figure 27 which also shows the range variation of a PEV against the selected constant speed. The range variation shows the same tendency as for the other vehicles. The difference in range between the shortened and consecutive test is about 1.2% at 120km/h. The variation width in range against constant speed is below 1% between 80 km/h and 120 km/h.

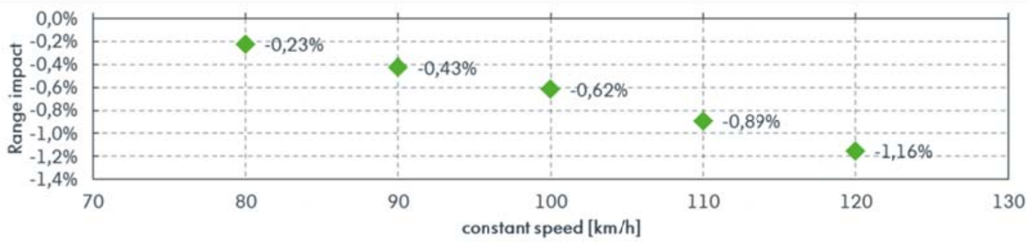

Figure 27: Validation data for shorten test procedure provided by ACEA (VW)

Figure 28 shows an additional result provided by JAMA to see the impact of constant speed variations on electric range. The variation width in the range against constant speed was 0.6% between 80km/h and 120km/h. The same variation also accounts the UBE and the energy consumption. Figure 28 only shows results from the shortened test procedure, so there is no comparison to the results for the consecutive test.

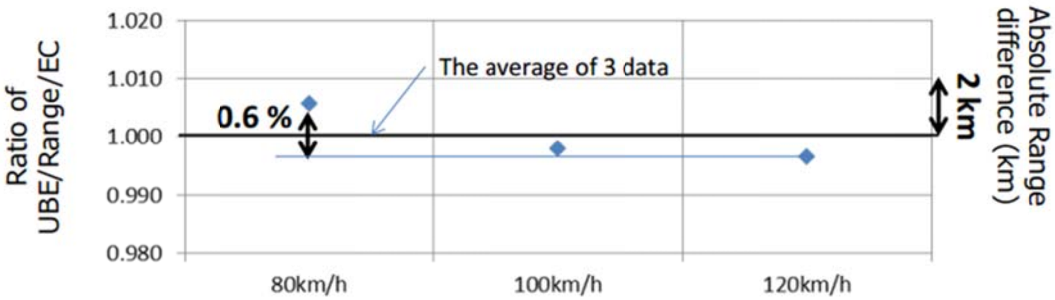

Figure 28: Validation data for shorten test procedure provided by JAMA

From the Figure 25 through Figure 28 it can be concluded that:

a) the results from the STP have a good agreement to the consecutive test result;

b) the impact of the selected constant speed on the test result is not significant, generally within 1% between 80 and 120 km/h;

c) the difference between the shortened test procedure and the consecutive test in range is below 2% up to constant speeds of 120 km/h;

d) the shortened test procedure yields slightly less favorable results consistently.

Since the STP has considerable benefits in terms of increased repeatability and reduced test effort, it was accepted as an attractive method for electric range determination.

A possible item to be discussed in phase 2 is the applicability of capped speed to the method. PEVs which have a capped speed have a longer range because the energy demand is less. The test burden for capped speed PEVs could be effectively be decreased by this method. However, the applicability of this method to capped speed PEVs has not been discussed during phase 1b.

4.4.20 Phase-specific values for EVs

Background

During the development of the phase 1a GTR a request to obtain phase-specific parameters for electrified vehicles was made by the Contracting Party of Japan. Phase-specific means separate parameters for the low, mid, high and (optionally) extra high phase of the WLTC, in addition to the overall cycle results. This request was driven by the desire to compare more than only the overall parameters between different vehicle types, including conventional ICE vehicles. This should enable the customer to compare the CO_2 emission and the fuel and/or electric consumption also for driving in different areas (urban or extra-urban areas).

While these phase-specific parameters had been available for conventional vehicles since the beginning of phase 1a, this was not the case for electrified vehicles. The main reason for that is because the test procedure itself is different between the OVC-HEVs (charge depleting and (CD) and a charge sustaining (CS) test) and PEVs (range test). A second important reason is that the higher battery capacity of OVC- and NOVC-HEVs under charge-sustaining operation conditions may cause these vehicles to drive individual phases with an SOC imbalance, because the charging or discharging during a phase depends on the operation strategy. So while the vehicle may drive SOC neutral over the whole cycle, the phases within the cycle may show a non-neutral SOC. If this potential imbalance would not be corrected for each individual phase, the phase specific fuel consumption would have an offset each time that an imbalance occurs.

An overview of the phase-specific parameters that are available for the different EVs is presented in Table 8, Table 9 and Table 10.

Phase specific values for PEVs

The PEV test procedure to determine the range consists of a certain amount of consecutive driven cycles using the consecutive cycle procedure (CCP) or the shortened test procedure (STP). This procedure is explained in the previous paragraph 4.4.19. For the PEV the approach was to find a mathematical methodology that delivers accurate phase-specific values without additional testing by driving the same phase consecutively until the battery is depleted.

A new method that weights the respective electric consumptions of the same phase within each of the cycles was evaluated. This methodology calculates a weighting factor for each phase based on the ratio between used energy over that phase and the total usable battery energy. This weighting factor implicitly includes physical impacts such as the warm up of the vehicle and the efficiency behavior of the traction battery. Hence, this method leads to a similar phase specific electric energy consumption and range compared to a vehicle being tested by driving consecutively the same phase. This evaluation was validated through range measurements and simulations[37] and was then agreed by the EV subgroup in phase 1b.

The parameters available for PEVs are listed in Table 8. Phase-specific values are included where an ‘x’ is marked under Low, Mid, High and ExHigh.

Parameter	**WLTC** (Low + Mid + High + exHigh)	**WLTC city** (Low + Mid)	**Low**	**Mid**	**High**	**ExHigh**	**Explanation**
EC	x	x	x	x	x	x	**Electric energy consumption determined from the recharged energy and the equivalent all electric range**
E_{AC}	x						**Recharged electric energy**
PER	x	x	x	x	x	x	**Pure electric range**

Table 8: Parameters for PEVs

Phase specific values for NOVC-HEVs

As explained above, it is important to take care about a potential non-neutral electric energy charging balance over one phase for NOVC-HEVs. Therefore it was concluded by the Subgroup EV that an RCB correction for each phase needs to be applied. This correction methodology ensures a proportional fuel consumption correction over the phase to the charged or discharged electric energy during the charge-sustaining test.

The parameters available for NOVC-HEVs are listed in Table 9. Phase-specific values are included where an ‘x’ is marked under Low, Mid, High and ExHigh.

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[37] For more information on the validation refer to documents WLTP-SG-EV-09-14, WLTP-SG-EV-06-09-rev1, and WLTP-SG-04-10 at https://www2.unece.org/wiki/pages/viewpage.action?pageId=23101485

Parameter	WLTC (Low + Mid + High + exHigh)	WLTC city (Low + Mid)	Low	Mid	High	ExHigh	Explanation
$M_{CO2,CS}$	x		x	x	x	x	CO_2 determined from the charge-sustaining (CS) test
FC_{CS}	x		x	x	x	x	Fuel consumption determined from the CS test

Table 9: Parameters for NOVC-HEVs

Phase specific values for NOVC-HEVs

The same need for RCB correction on each phase of course also applies for the OVC-HEVs charge-sustaining test. However, the NOVC-HEVs are tested in charge-depleting mode as well, and these additional parameters make the determination of phase-specific parameters even more complex. For some of the parameters a weighting according to the utility factors has to be applied (see paragraph 3.4.5.8). The group decided to exclude these from the phase-specific calculation. The main reason is that the utility factors are not available at a phase-specific level, which means that it is not sensible to calculate phase-specific weighted values. Furthermore, the non-weighted phase-specific values already meet the requirement of being comparable to conventional and pure electric vehicles.

Some more investigations had to be done to determine the phase-specific electric energy consumptions and electric ranges by a calculation methodology from the charge-depleting test results. Due to the primary requirement to deliver parameters that can be compared with the electric energy consumption and electric range of PEVs, the group focused on the parameters EC (electric consumption) and EAER (equivalent all electric range). Supported by simulations[38] it was shown that a similar weighting approach as applied for the PEVs leads to sufficiently accurate values, which can also be interpolated for individual values.

The parameters available for NOVC-HEVs are listed in Table 10. Phase-specific values are included where an ‘x’ is marked under Low, Mid, High and ExHigh.

Parameter	WLTC (Low + Mid + High + exHigh)	WLTC city (Low + Mid)	Low	Mid	High	ExHigh	Explanation
$M_{CO2,CD}$	x						CO_2 determined from the charge-depleting test (UF weighted)
$M_{CO2,CS}$	x		x	x	x	x	CO_2 determined from the charge-sustaining (CS) test
$M_{CO2,weighted}$	x						Utility factor weighted CO_2 determined from the CD and CS test
FC_{CD}	x						Fuel consumption determined from the CD test (UF weighted)
FC_{CS}	x		x	x	x	x	Fuel consumption determined from the CS test

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[38] For more information on the validation refer to documents WLTP-SG-EV-05-08, WLTP-SG-EV-08-05-rev1, WLTP-SG-EV-09-08, WLTP-SG-EV-09-13 at https://www2.unece.org/wiki/pages/viewpage.action?pageId=23101485

$FC_{weighted}$	x						**Utility factor weighted fuel consumption determined from the CD and CS test**
$EC_{AC,CD}$	x						**Electric energy consumption determined from the CD test (UF weighted)**
$EC_{AC, weighted}$	x						**Utility factor weighted electric energy consumption determined from the CD test**
EC	x	x	x	x	x	x	**Electric energy consumption determined from the recharged energy and the equivalent all electric range**
E_{AC}	x						**Recharged electric energy**
R_{CDC}	x						**Charge-depleting cycle range**
AER	x	x					**All electric range determined from the CD test (distance until first engine start)**
$EAER$	x	x	x	x	x	x	**Equivalent all electric range determined from CD and CS test (pure electrically driven distance)**
R_{CDA}	x*						**Actual charge-depleting range determined from CD and CS test (distance driven in CD operation)**

Table 10: Parameters for OVC-HEVs

4.4.21 Interpolation method for electrified vehicles

Background

During the development of the phase 1a version of the WLTP GTR an interpolation method was introduced for conventional vehicles that enables the calculation of individual CO_2 emission and fuel consumption values based on the specific cycle energy demand of an individual vehicle. Basis for the interpolation is the measurement of two extreme vehicle configurations regarding their fuel consumption/CO_2 emission within one vehicle family. To ensure the accuracy between interpolation and measurement, vehicle family criteria had been defined. For more information on the interpolation method see paragraph 4.4.1.

The aim of the Subgroup EV was to adopt a similar interpolation methodology -tailored to electrified vehicles- to be also capable to calculate vehicle-individual values for these vehicles[39]. To identify which modifications might be necessary to the existing method the group decided to evaluate this separately for NOVC-HEVs, OVC-HEVs and PEVs. Originally the need for this vehicle classification was based on the fact that the main component-based criteria for the vehicle family building are different between these vehicle groups. For example it is important to focus on the electric components of all electrified vehicles for the family building but in the case of NOVC- and OVC-HEVs one has to consider the ICE as well. Since OVC-HEVs can be driven in charge sustaining and charge-depleting operation, the methodology has to take care about much more parameters having to be interpolated.

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[39] For an overview of which values are determined in the GTR for EVs, see the tables in paragraph 4.4.20

Interpolation method for NOVC-HEVs

Due to minor differences between the test procedure of conventional vehicles and NOVC-HEVs the evaluation started with this vehicle type. The road load and interpolation family criteria were extended with the electric components that might have an impact on road load, CO_2 emission or fuel consumption but are not covered by the cycle energy based interpolation. The CO_2 interpolation range within one family compared to conventional vehicles was reduced to avoid the potential risk of non-linear effects; an additional test with a vehicle in the middle of the outer ones of the family (regarding the cycle energy) is required if the CO_2 interpolation range should be extended above 20 g/km. This is described in paragraph 4.5.1 of Annex 8.

Interpolation method for OVC-HEVs

Since OVC-HEVs have to conduct two tests under different test conditions (charge-depleting and charge-sustaining), the number of values to be interpolated is much larger than for other vehicle categories. This variety in parameters and the fact that some values are calculated from both tests leads to more complex handling of cycle- and phase-specific values. Therefore it is not always possible -or only under certain conditions- to interpolate the parameters that are determined for OVC-HEVs. Hence the following amendments were necessary:

a) The charge-depleting cycle range R_{CDC} and the actual charge-depleting cycle range R_{CDA} are excluded from the interpolation method due to their non-linear behaviour.
b) The all-electric range AER can only be interpolated if it fulfils a specific criterion.
c) An additional restriction for the application of the interpolation method is introduced.

Ad a): The charge-depleting cycle range R_{CDC} is a discontinuous parameter because it is defined as the number of complete cycles driven in CD operation multiplied by the cycle distance. This means that a different number of cycles within one family leads to a jump from x*23.3 km to (x+1)*23.3 km. The second parameter to be excluded is the actual charge-depleting range – R_{CDA}. This describes the distance at which the REESS is fully depleted and the vehicle is only capable to continue in charge-sustaining operation. This parameter cannot be interpolated due to the rising power demand (coming from vehicle L towards vehicle H), while the available electric power is the same within one family. This is illustrated by the following example. Coming from vehicle L to vehicle H the logical response for individual vehicles is that the R_{CDA} first will start to decline due to higher electric energy consumption. This relation is linear until the power demand exceeds the available electrical power of the driveline. This will trigger the ICE to assist the electric motor, so for this individual vehicle also energy from the combustion engine is used to follow the drive cycle. This leads to an increase of the R_{CDA}. For the remaining vehicles towards vehicle H it depends on the operation strategy what the R_{CDA} value will arrive at. Due to this non-linearity the R_{CDA} is excluded from the interpolation.

Ad b): Consider the following example. Vehicle L has just sufficient electric power to fulfil the cycle without the ICE having to assist. This means that the first engine start of vehicle L will not take place until the REESS has been depleted. The other vehicles in the family would have an engine start in each of the cycles at the point(s) where the electric power is not sufficient to follow the prescribed speed trace. This leads to a discontinuity in the AER that prevents an accurate interpolation. However, this situation may not always be the case. Therefore a criterion was developed to detect if a discontinuity is present or not. This criterion is the ratio of AER to R_{CDA}, which should not differ more than 0.1 between vehicle L and H. If this criterion is met, the interpolation of AER is permitted, otherwise the worst-case AER value applies to the whole family. This is described in paragraph 4.5.7.1 of Annex 8.

Ad c): An additional restriction for the interpolation is that the number of whole cycles driven in the CD test should not differ more than 1 between vehicle L and H. On the one hand this requirement allows to build an interpolation family even if the number is not the same for all vehicles, and on the other hand restricts that the interpolation range is so wide that the linearity is compromised.

All other parameters listed in Table 10 can be interpolated without further requirements.

Interpolation method for PEVs

For the pure electric vehicles (PEVs), the ICE-based interpolation family criteria had to be converted from those that apply to a conventional driveline to those that apply to the "electric machine", "electric converters" and the "REESS". The PEV relevant parameters "electric consumption – EC" and "pure electric range – PER" are well suited for interpolation because the relation between cycle energy demand and EC is also linear. The PER also responds linear because it depends on the recharged energy, which will be constant as the same REESS required to be used throughout the interpolation family. These linear relations are independent from applying the consecutive cycles testing method or applying the shortened test procedure. To ensure the linearity of the PER for the CCP it was concluded in phase 1b that it should be calculated from the electric energy consumption and the usable battery energy, rather than just measuring the range from the test directly. Otherwise a non-linearity could be introduced because the energy consumption itself depends on the specific phase considered.

Validation

The development of the interpolation method and the additional required criteria and restrictions took a lot of effort by the Subgroup EV participants. During the course of phase 1b the group produced evaluations of measurement data and performed simulations to substantiate the proposed interpolation methods[40]. In the end they could all agree to the approaches described in this paragraph, and the methods were adopted.

In phase 2 of WLTP the group will focus on the interpolation method and criteria for FCHV.

4.4.22 End of PEV range criteria

Background

According to the GTR phase 1a, the range test for PEVs is terminated when the break-off criterion is reached, which means that the vehicle is not capable to follow the prescribed speed trace for 4 consecutive seconds or more[41]. For vehicles with a speed cap (i.e. a maximum speed limiter) lower than the maximum speed of the applicable WLTP test cycle this would result in a non-representative pure electric range. This is because the break-off criterion would already be reached during the first cycle, even though the REESS is not yet depleted. The Subgroup EV was tasked to develop a solution for this issue.

Discussions during phase 1b and adopted solution

The discussions first focused on PEVs but soon extended to OVC-HEVs, which also have a purely electrically driven range. This is referred to as the all-electric range AER, and this range would also be unrepresentatively small for OVC-HEVs with a capped speed.

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[40] For more information about the validation refer to documents WLTP-SG-EV-05-02, WLTP-SG-EV-06-04, WLTP-SG-EV-06-05, WLTP-SG-EV-08-04, WLTP-SG-EV-08-05, WLTP-SG-EV-09-02 at https://www2.unece.org/wiki/pages/viewpage.action?pageId=23101485

[41] Refer to paragraph 3.4.4.1.3 of Annex 8

One of the issues during the discussions was that a manufacturer who has designed a vehicle for urban conditions and applies a speed cap at e.g. 90km/h would get penalized by a very small electric range, for example only 17 km. This unrepresentative electric range would not serve as a useful consumer information either, since the driver would not experience a range of just 17 km but would be able to drive maybe 150 km or more (just as an example). Therefore it was clear that a solution had to be found for this issue.

Another concern of this capped speed is that it consumes less energy during the cycle, because the energy demand is reduced at a lower speed. At the same time, that vehicle would be driving a shorter distance during the test, which is also not representative.

Taking these concerns into account, a methodology was developed to lengthen the cycle to such an extent that the capped speed cycle covers the same distance as the normal (uncapped) cycle. During this elongation the vehicle is driven at its highest (capped) speed. This approach is considered representative for real-life driving, since a capped speed vehicle in extra-urban areas would have to drive longer at its maximum speed to cover the same distance.

Figure 29 shows how this lengthening of the capped cycle is taking place for different speed caps. Each cycle shown has the same overall distance. Note that the elongation is done per individual phase.

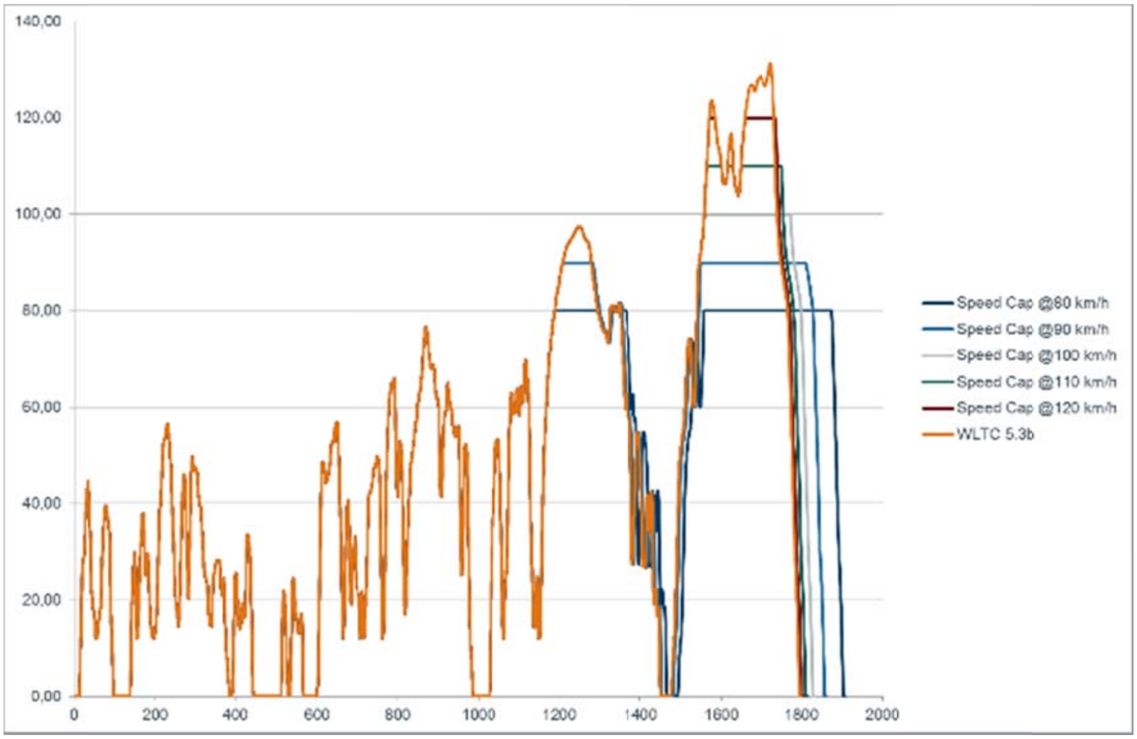

Figure 29: Capped speed cycle profiles for different speed caps

This topic was intensively discussed as there had been two opposite positions by the Contracting Parties of Europe and Japan.

Position of the European Commission was that this methodology should be applied for each capped speed and in any phase where the capped speed would modify the speed profile. The position of Japan was not to apply this methodology at all, motivated by their starting point that the cycle should not be modified, in order to ensure that test results remain comparable and therefore have to be based on the same cycle.

Due to these opposite positions a regional solution was implemented in the GTR as follows:

For Europe:

If the (capped) maximum speed of the vehicle is lower than the maximum speed of the applicable WLTP test cycle, Europe will apply the capped speed cycle with a proportional elongation of the cycle to arrive at the same cycle distance.

For Japan:

If the maximum speed of the vehicle is lower than the maximum speed of the applicable WLTP test cycle, Japan will abstain from driving the applicable WLTC. Only the WLTCcity results will be reported.

The disharmonization between Japan and Europe is fairly limited because for Japan the 'Extra-High' phase is excluded from the applicable WLTC. Effectively this means that there is only a difference between Europe and Japan for vehicles with a capped speed below the maximum speed of the 'High' phase (i.e. 97.4 km/h). Taking the speed trace tolerance into account, this speed border is further reduced to 95.4 km/h.

The capped speed approach is also reflected in the context of the selection of the driver-selectable mode, which is described in paragraph 3.4.5.10.

The capped speed cycle modification can be found in paragraph 9 of Annex 8.

4.4.23 FCV test procedure

The NOVC-FCHV test procedure was developed for the phase 1b version of the GTR. It is basically the same procedure as for NOVC-HEVs, but replaces the measurement of CO_2 by a method to determine the hydrogen consumption of NOVC-FCHVs.

Typical methods used today to measure hydrogen consumption are the following:

a) *Gravimetric method:*

   The weight of the consumed hydrogen is measured as a weight difference of an external hydrogen tank before and after the test.

b) *Flow method:*

   The integrated value of a hydrogen flow through a tube between the tank and the fuel cell system is measured.

c) *Pressure method:*

   The pressure decrease of the hydrogen tank is measured, and calculated into a hydrogen consumption.

The gravimetric method provides a direct way to measure the amount of consumed hydrogen, while the flow and pressure method need to be calculated and are influenced by ambient conditions. For the phase 1b version of the GTR the gravimetric method is therefore prescribed as the primary method. The measurement procedure is largely based on the procedure described in ISO 23828.

At the request of the manufacturer and upon approval of the responsible authority the consumption may be measured using either the pressure method or the flow method as an alternative to the gravimetric method. In this case, the manufacturer has to provide technical evidence that the method yields equivalent results.

In order to obtain a sufficient degree of accuracy with the pressure and the flow method it is required to give special attention towards e.g. the temperature management of the test tank and the preparation/calibration of the high accuracy flow meter. The pressure and flow methods are also described in ISO 23828, which can be used as a basis for these requirements.

Just as for NOVC-HEVs also NOVC-FCHVs have to be corrected towards a neutral charging balance if they do not meet the tolerance criteria. More information on the RCB correction procedure can be found in paragraph 4.4.18. As the configuration of the power train of NOVC-FCHVs is similar to that of (N)OVC-HEVs, this means that the hydrogen consumption of NOVC-FCHVs needs to be corrected for the electric energy change of all REESSs.

The NOVC-FCHV test procedure is described in paragraph 3.5 of Annex 8, and the RCB correction is included in Appendix 2 to Annex 8.

Due to the time constraints of phase 1b and the lower priority that FCVs received, not all the open issues could be solved. Therefore the scope of WLTP phase 2 should include the following issues:

- Test procedure for OVC-FCHV
- Interpolation approach for NOVC-FCHV and OVC-FCHVs

4.4.24 WLTP post-processing

Within the "Drafting Taskforce" (see paragraph 3.4.1), which was in charge of implementing editorial changes to the GTR, the following problem was identified: For historical reasons, every correction, such as RCB correction, Ki-factors or averaging of tests was handled separately. Therefore it was not clear, in which order which correction should be applied. Especially, it was unclear how to apply corrections on fuel consumption, because that is based on CO_2 and criteria emissions, which are both subject to correction requirements. In addition some of the references were incorrect, due to the fact that the correction steps were developed in parallel.

This called for the need of putting the calculation steps into a logical order, provide a complete overview of the post-processing procedure in the GTR, and to set the references accordingly.

Motivation

The requirement of applying corrections is obvious, because test results can only be comparable if they are corrected towards standard conditions. But as the order may have a slight influence on the end result (due to fact that some corrections are additive yet others are multiplicative), this needs to be specified to avoid confusion between industry, authorities and organizations performing in-use tests. An addition bonus is that a clear overview makes references easier and the list of the corrections more transparent.

Description

The need for including an order into the corrections is due to the interdependency between the following issues:

a) Calculation of phase specific values;

b) Calculation of fuel consumption out of CO_2 and criteria emissions;

c) Additive corrections, e.g. the Ki factors (creating non-linearity if the order is changed);

d) Averaging of tests;

e) Concept of a "declared value";

f) Regional options (e.g. 14°C test in Europe, different declared value concept).

As there will be always a small error induced when the order of calculation steps is changed, the following priority was decided:

1) Calculate criteria emissions and CO_2.

2) Calculate fuel consumption based on 1).

Apart from the requirement that the end result should be meaningful and accurate, the following objectives were also strived for:

- Enable an alignment with calculations for hybrid vehicles;
- Enable regional correction(s) within one step (a placeholder in the GTR);
- Reduce unnecessary calculation and correction efforts,

As a result of the last point, it was decided to shift the fuel consumption calculation towards the end of the calculation process.

The final post-processing scheme that was adopted is shown in the scheme of Figure 30. The charge-sustaining calculations for NOVC- and OVC-HEVs and ICE vehicles have been aligned as much as possible. The order of applying the calculation/correction steps is from top to bottom. The small columns on the right show the output values of each step. For fuel cell vehicles the same process can be applied, but in that case the mass emissions are replaced by fuel consumption.

1	test	measurement, calculation of mass emissions [Annex 7, 3.]	phase CO_2				phase emiss.	comb. emiss.
2	comb.	combined value (3-/4-phases, weighted by distance) [in new draft]	phase CO_2	comb. CO_2			phase emiss.	comb. emiss.
3	RCB	RCB correction [for ICEs: Annex 6, App. 2; for HEVs: Annex 8, App. 2]	phase CO_2	comb. CO_2		inter-mediate comb. FC		comb. emiss.
4	Ki	K_i correction [Annex 6, App. 1]	phase CO_2	comb. CO_2				comb. emiss.
(5	regional	Regional corrections (EU: ATCT 14°C test, DF) [e.g. EU Sub-Annex 6a]	phase CO_2	comb. CO_2				comb. emiss.)
6	AVG	averaging of tests, declared value (regional) [Annex 6, new Japanese proposal]	phase CO_2	comb. CO_2				comb. emiss.
7	align	alignment of phase values [Annex 6, new Japanese proposal]	phase CO_2	comb. CO_2				comb. emiss.
8	FC	calculation of fuel consumption values [Annex 7, 6.]	phase CO_2	comb. CO_2	phase FC	comb. FC		comb. emiss.
9	approval	averaging of emissions L and H (?), final interpolation line [in new draft]	phase CO_2	comb. CO_2	phase FC	comb. FC		comb. emiss.
10	vehicle	interpolation method, rounding. (Europe → "CoC") [Annex 7, 3.2.3.]	phase CO_2	comb. CO_2	phase FC	comb. FC		comb. emiss.

For fuel cells whole process is done with fuel consumption instead of CO_2.

Figure 30: Post-processing scheme with the order of calculations and corrections within the GTR for ICE and HEV

Validation and justification

To check the validity of the proposed post-processing, an Excel-tool was provided to enable stakeholders to check the order of the sequence and the effect this has on the results.

The proposal of Figure 30 was concluded to deliver meaningful and sound results, and therefore no further validation was considered necessary.

Development process

From the moment that this issue was identified there was a broad support of clarifying the calculation/correction order within the GTR itself. After the first starting note in summer 2015 the development was mainly done via e-mail exchange and the final proposal was adopted at the 12th IG meeting. Due to the short timeline, the drafting text was agreed shortly after that meeting in October 2015.

The scheme for post-processing is included in Table 7/1 in paragraph 1.4 of Annex 7. For the calculations in charge-sustaining condition of hybrid electric vehicles (NOVC-HEVs and OVC-HEVs) it can be found in Table A8/5 and A8/6.

Due to the fact that for fuel cell hybrids (NOVC-FCHVs):

a) the interpolation method for will be handled in phase 2,

b) a calculation of fuel consumption is not necessary because it is measured directly, and

c) the K_i-correction is not applicable,

some of the steps shown in Figure 30 are removed and/or amended. This alternative post-processing scheme is shown in Table A8/7 of Annex 8.

The post-processing scheme for the calculation of electric ranges, electric consumptions and weighted parameters for OVC-HEVs and PEVs will be discussed in phase 2.

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.

In conclusion, the list of reference fuels included in the Annex 3 serve as a guideline, albeit non-binding.

The structure can and probably will change with any attempt to harmonise reference fuels in later phases of WLTP.

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 road load is a 2nd order polynomial approximation of the vehicle's losses determined by using one of the available methods.

In this paragraph the options and the procedure are briefly outlined and explained.

General requirements

Road load can be determined using the coast down method, torque meter method and the wind tunnel method. In addition, road load may be estimated at a (conservative) default value, or may be ‘extrapolated’ from a measured representative 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 movable aerodynamic body parts has 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 paragraph 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

If the vehicle is tested on the road or at a track, it is warmed up by driving 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

The GTR provides in five 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.

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.

c) Matrix family method: The road-load is measured on one representative member of a family, and ‘extrapolated’ to other family members by considering the difference in the dominant road load parameters.

d) Windtunnel method: The aerodynamic drag of the vehicle is determined in a windtunnel, and the rolling resistance is added by measurement on a flat belt or a normal chassis dynamometer.

e) 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

The road load is presented as a second order polynomial approximation of the vehicle's losses when dragged or when it is coasting. In general road load has to be determined in the speed range of the applicable test cycle, but due to regional deviations also up to higher speeds, to use a test result for more than one region[42].

An overview of the available road load determination options and references to the paragraphs describing the procedure and the results is provided in Table 11.

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[42] For example Japan does not include the extra-high phase of the WLTC in their applicable test cycle.

Road load determination methods and their options and alternatives		Reference to method	Reference to result	Road load coefficients
coast down *(road-based)*	Coast down with stationary anemometry	4.3.1.	4.3.1.4.5. and 4.5.	f_0, N f_1, N/(km/h) f_2, N/(km/h)^2
	- with or without split runs			
	Coast down with on-board anemometry (with different possible positions of the anemometry)	4.3.2.	4.3.2.6.7. and 4.5.	f_0, N f_1, N/(km/h) f_2, N/(km/h)^2
	- with or without split runs			
torque meter *(road-based)*	Measurement of running resistance using the torque meter method	4.4.	4.4.4. and 4.5.	c_0, Nm c_1, Nm/(km/h) c_2, Nm/(km/h)^2
	- with or without split runs			
	- if coast down on dynamometer according to 8.2.4. has been performed			f_0, N f_1, N/(km/h) f_2, N/(km/h)^2
	- with or without split runs			
matrix *(road-based +calc.)*	Calculation for road load for a road load matrix family	5.1.	5.1.	f_0, N f_1, N/(km/h) *) f_2, N/(km/h)^2
	- based on coast down or torque meter measurement			c_0, Nm c_1, Nm/(km/h) *) c_2, Nm/(km/h)^2
default *(calc.)*	Calculation of default road load based on vehicle parameters	5.2.	5.2.	f_0, N f_1, N/(km/h) *) f_2, N/(km/h)^2
wind tunnel *(lab-based)*	Measurement of road load within labs by wind tunnel and a dynamometer	6.	6.7.3.	f_0, N f_1, N/(km/h) f_2, N/(km/h)^2
	- with a flat belt dynamometer			
	- - with stabilised speeds or with deceleration			
	- - - with warm-up by driving or warm-up by dragging the vehicle			
	- with a roller chassis dynamometer plus correction function			
	- - with stabilised speeds or with deceleration			
	- - - with warm-up by driving or warm-up by dragging the vehicle			

***) This coefficient is set to zero for this method**

Table 11: Overview of available road load determination methods and options, with reference to paragraphs in the GTR on the procedure and the results.

The characteristic differences between these methods are shown in Table 12

Method	**Coast down**	**Torque meter**	**RL matrix family**	**Default RL**	**Wind tunnel**
Focus/scope	passenger vehicles	passenger vehicles, wheel hub motor	Large vans above 3 tons max. laden mass	for small series	passenger vehicles
Measured value	velocities and times during coastdown	wheel torque at constant speeds	(extrapolate measured RL)	Nothing is measured	air drag and drivetrain plus RR losses
Positive and negative attributes	+ well known + simple measurement equipment - long test track needed - weather dependent - inaccurate	+ shorter test track + measures "real" road load - weather dependent - complex process	+ balanced compromise between test effort and accuracy - slightly worse road load (safety margin)	+cheapest method + no test effort - worst case road load	+ reproducible and weather independent + accuracy + suitable for secret designs - expensive equipment

Table 12: Characteristic differences between the road determination methods

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): Reference speeds are selected over the speed range of the applicable cycle from 20 km/h upwards in steps of 10 km/h. The highest reference speed is 130 km/h or the reference speed point immediately above the maximum speed of the applicable test cycle. 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 as stable as possible. 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. During testing, the anemometer may be located on the centreline of the vehicle via a boom approximately 2 meters in front, at the midpoint of the vehicle's hood (bonnet), or at least 30cm back of the windshield on the vehicle's roof. The maximum allowed overall average wind speed during the test activity is 7 m/s and peak wind speeds should not exceed 10 m/s. In addition, the vector component of the wind speed across the road shall be less than 4 m/s. The wind criteria were chosen to fall within the restrictions specified in SAE J2263, with lower tolerances to decrease potential test variability due to wind influence. 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. For the test to be validated for WLTP, the results must pass the statistical convergence requirement.

Measurement procedure – Torque-meter method

One 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 use of fixed reference speeds from 20 km/h upwards in incremental steps of 10 km/h to a maximum of 130 km/h (see paragraph 3.4.5.5). 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.

Measurement procedure – Road load matrix family

The road load matrix family method is intended for vehicles produced in low-volumes, and its scope is reduced to vehicles above 3 tons. The road-load is measured on one representative member of a family, and 'extrapolated' to other family members by considering the difference in the dominant road load parameters. This method is introduced in paragraph 4.4.9 of this report, and is further detailed in Appendix 2 of this report.

Measurement procedure – Windtunnel method

The resisting force on a vehicle is a combination of the aerodynamic drag, and the rolling resistance. The windtunnel method determines these resistances separately:

a) the aerodynamic drag of the vehicle is determined in a windtunnel, and

b) the sum of rolling resistance and drive train losses is measured on a flat belt or a chassis dynamometer.

This method allows road load measurements to be independent from the weather conditions and produces accurate, repeatable and reproducible results.

The method is described in paragraph 4.4.10 of this report.

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 is 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.

The result of the chassis dynamometer setting is a second order polynomial, which represents the difference between the target road load (f_0,f_1 and f_2) and the losses of the vehicle on the chassis dynamometer. Effectively the dynamometer will simulate the difference compared to the on-road losses of the vehicle.

There are 2 different methods allowed in the GTR for the setting of the chassis dynamometer, see Table 13.

Chassis dynamometer setting method		**Reference to method**
iterative method	The vehicle is accelerated under its own power. Coast down on and adjustment of the chassis dynamometer is repeated until a tolerance of 10 N on 2 consecutive coast down runs is met (after regression).	General: paragraphs 7. and 8. Specifically: 8.1.3.4.2.
	- as an alternative a new (shorter) warm-up cycle may be used when evidence on the equivalency to a WLTC warm-up is provided; see paragraph 7.3.4.3.	
fixed run method	The vehicle is accelerated by its own power, or by the chassis dynamometer. Executed by a software program, the dynamometer will perform 3 coast downs after a first stabilization and one dynamometer setting coastdown run. The set coefficients are derived from the average of the 3 coast downs, and no tolerance is applied.	General: paragraphs 7. and 8. Specifically: 8.1.3.4.1.

Table 13: Chassis dynamometer setting methods and alternatives in the GTR

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 satisfies a tolerance of ±10 N×r' from the target running resistance at every speed reference point.[43] After the chassis dynamometer setting, the running resistance is transformed into road load coefficients by a coastdown of the vehicle on the chassis dynamometer, unless the vehicle is not suitable for coasting down. This procedure is described in par. 8.2.4 of Annex 4.

There are 2 appendices to Annex 4:

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[43] r' is the dynamic radius of the tyre in metres on the chassis dynamometer obtained at 80 km/h

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. During phase 1b a critical review on the test equipment and calibrations was performed. Clarifications concerning additional sampling and measurement methods were included where necessary.

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 was 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 accuracy requirements of difference in speed and distance covered within a test between the front and rear rollers were reviewed and confirmed during phase 1b. 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.

In addition, Annex 5 describes several methods to measure non-limited gaseous exhaust species. The methods include laser spectrometry and Fourier transform infrared (FTIR) to measure NH_3, gas chromatography to measure N_2O and methods for ethanol, formaldehyde and acetaldehyde.

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 (including CO_2), particulate matter, particle number, and fuel consumption over the Type 1 test, using the WLTC applicable to the vehicle family. The scope of Annex 6 is restricted to internal combustion engine vehicles (ICE). Electrified vehicles, i.e. having a battery used for driving the vehicle, are tested according to the procedure in Annex 8.

General requirements

Testing is done in a conditioned environment on a chassis dynamometer. Diluted exhaust emissions are continuously diluted with ambient air by a constant volume sampler (CVS) and a proportional sample of exhaust gas collected for analysis. 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 of vehicle H, which was determined according to Annex 4, has to be set. If at the request of the manufacturer the interpolation method is used on CO_2 (see paragraph 4.4.1 of this report), an additional Type 1 test 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 ‘interpolation family’, whose criteria are specified by par. 5.6 in part II of the UN-GTR. These criteria have been chosen in such a way that the emission and fuel consumption behaviour of vehicles in the interpolation family are likely to be similar, e.g. same engine, same transmission type and model, same operating strategies, etc.

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 for the respective procedure (refer to paragraph 4.4.5 of this report). Auxiliaries such as an airconditioning system and radio 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 behaviour, 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 'a single mode that is always selected when the vehicle is switched on regardless of the operating mode selected when the vehicle was previously shut down'.

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 the speed is kept 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 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 stabilization 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. If the battery discharge energy over the cycle is above a set limit, the CO_2 mass emissions and fuel consumption have to be corrected via a formula with default values on alternator accuracy and a Willans factor. This RCB correction procedure is explained in detail in paragraph 4.4.16 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 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 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 properties, the fuel consumption is calculated for each of the cycle phases and for the complete test. This is included in paragraph 6 of Annex 7. For more information on the fuel consumption calculations refer to paragraph 3.4.5.6 of this report.

4.5.6 Annex 8 - Pure electric, hybrid electric and fuel cell hybrid vehicles

This annex is dedicated to pure electric (PEV), hybrid electric (NOVC-HEV, OVC-HEV) and compressed hydrogen fuel cell hybrid (NOVC-FCHV) vehicles, and is structured into the following paragraphs, which will be briefly summarized:

1. **General requirements**

This sets the requirements of the test procedures for pure electric, hybrid electric and compressed hydrogen fuel cell hybrid vehicles. It is pointed out that for vehicles tested under Annex 8 the RCB correction procedure according to Appendix 2 of Annex 8 is applied, as well as Appendix 3 of Annex 8 for the measurement of REESS current and voltage. For conventional ICE vehicles the RCB correction procedure according to Appendix 2 of Annex 6 is applicable. See also paragraphs 4.4.16 and 4.4.18 of this report

Unless stated otherwise in Annex 8, all requirements of Annex 6 also apply to vehicles tested according to Annex 8.

All Annex 8 requirements shall apply to vehicles with and without driver-selectable modes, if not stated otherwise.

1.1. Units, accuracy and resolution of electric parameters

This prescribes the units used for the electric parameters, as well as the accuracy and resolution requirements the measurement system has to fulfil.

1.2. Emission and fuel consumption testing

For vehicles tested according to Annex 8, the same measurement requirements have to be fulfilled as for conventional ICE vehicles.

1.3. Units and precision of final test results

This sets the precision requirements for the final test result values and states that for the purpose of calculation the unrounded values shall be used.

1.4. Vehicle classification

This specifies that all Annex 8 vehicles are classified as Class 3 vehicles and therefore the WLTC Class 3a or 3b driving curve is the reference cycle (depending on their maximum speed). Due to the downscaling procedure for PEVs and the capped speed cycle modification for all Annex 8 vehicles, the applicable test cycle may differ from the reference cycle.

1.5. OVC-HEVs, NOVC-HEVs and PEVs with manual transmissions

The vehicles shall be driven according to the manufacturer’s instructions, as incorporated in the manufacturer's handbook of production vehicles, and as indicated by a technical gear shift instrument.

2. **REESS and fuel cell system preparation**

This paragraph defines the run-in of the test vehicle in advance of the WTLP test procedure.

3. **Test procedure**

3.1 General requirements

The applicable test cycles and requirements for the preparation of the test are described. If the vehicle 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 (see also paragraph 1.4).

3.2 Test procedure for OVC-HEV

Requirements for the testing of OVC-HEV under WLTP conditions are specified, including:

a) the operating conditions for both charge-depleting Type 1 test and charge-sustaining Type 1 test procedure,

b) the preconditioning procedure,

c) soak procedure of the vehicle,

d) setting of the driver-selectable mode, both in charge-depleting and charge-sustaining operating condition, and

e) end of test criteria (break-off criterion).

Charge-depleting Type 1 tests and Charge-Sustaining Type 1 tests may be driven independent from each other but may also be combined (see Figure A8/1 in Annex 8).

3.3 Test procedure for NOVC-HEV

Requirements for the testing of NOVC-HEV under WLTP conditions are specified, including:

a) the operating conditions for the Type 1 test procedure,

b) the preconditioning procedure,

c) soak procedure of the vehicle, and

d) setting of the driver-selectable mode for the vehicle.

3.4 Test procedure for PEV

Requirements for the testing of PEV under WLTP conditions, including:

a) the applicable test procedure and its operating conditions,

b) the preconditioning procedure,

c) soaking of the vehicle,

d) setting of the driver-selectable mode for the vehicle, and

e) end of test criteria (break-off criterion).

For PEVs with a higher range, a shortened test procedure (STP) is applied, from which the electric range is calculated - see paragraph 4.4.19 of this report.

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

3.5 Test procedure for NOVC-FCHV

Requirements for the test procedure of NOVC-FCHV under WLTP conditions, including:

a) the operating conditions for the Type 1 test procedure

b) the preconditioning procedure,

c) soaking of the vehicle, and

d) setting of the driver selectable mode for the vehicle.

4. Calculations

This paragraph specifies the calculations of the test results, including gaseous emission compounds, particulate matter emission and particle number emission, CO_2 mass emission, fuel consumption, electric energy consumption and range.

Gaseous emission compounds, particulate matter emission and particle number emission

For NOVC-HEVs and OVC-HEVs, gaseous emission compounds, particulate matter emission and particle number emission shall be calculated by the same requirements as for conventional ICE vehicles according to Annex 7.

In addition, a calculation method for OVC-HEVs is applied to weigh the mass emissions of gaseous compounds, particulate matter emission and particle number emission of the charge sustaining and the charge depleting test according to the utility factor.

CO_2 mass emission

For NOVC-HEVs and for OVC-HEVs under charge-sustaining operating condition, the calculation procedures for the CO_2 mass emission of the whole cycle but also for each individual cycle phase are included. Where necessary, these results are corrected towards a zero charge balance of the REESS according to Appendix 2 of Annex 8.

In addition, a calculation method for OVC-HEVs is applied to weigh the CO_2 emissions of the charge sustaining and the charge depleting test according to the utility factor.

Fuel consumption

For OVC-HEVs under charge-sustaining operating conditions, NOVC-HEVs and NOVC-FCHVs, the fuel consumption will not be measured directly, but determined from the gaseous emission compounds by the described post processing procedure for the charge-sustaining values – see Table A8/5, /6 and /7 of Annex 8.

Charge-depleting as well as utility factor-weighted fuel consumption values are calculated and determined by the calculation methods provided.

Electric energy consumption

For PEVs and OVC-HEVs, the determination of the electric energy consumption is described. The electric energy consumption is determined for the whole cycle as well as for each individual phase. Basis for the measured energy consumption is the measured recharged electric energy from the mains, so as to include the charging losses.

For OVC-HEVs, there are also calculation methods provided for the utility factor-weighted as well as the charge-depleting electric energy consumption.

Range

For PEVs, an electric range is determined which is referred to a the ‘pure electric range’ (PER). This range has to be provided for the whole cycle as well as for each individual phase. This is calculated from the usable battery energy and the average energy consumption over the cycle or phase.

For OVC-HEVs, there are three ranges to be determined:

a) All electric range (AER): the distance driven up to the first engine start.

b) Actual charge-depleting range (R_{CDA}): the distance driven to the point where it was not in a charge-depleting operating condition anymore and had entered into a charge-sustaining operating condition.

c) Equivalent all electric range (EAER): the portion of the R_{CDA} which was driven electrically

The AER range has to be determined both for the whole WLTC and for the WLTCcity cycle.

The EAER has to be determined for the whole WLTC, for the WLTCcity cycle and for each individual cycle phase.

The R_{CDA} has only to be determined for the whole cycle.

Interpolation of parameters for individual vehicles

Paragraph 4.5. of Annex 8 describes the interpolation method to calculate the values for individual vehicles between vehicle H and vehicle L.

The basic concept of the interpolation approach is the same as that of conventional vehicles but due to the interaction of the electric power train and conventional power train (depending on the vehicle's operation strategy) as well as the calculation schemes to arrive at the output values, additional requirements have to be fulfilled. During phase 1b of WLTP this was investigated and evaluated for all of the Annex 8 output values. Result of this investigation and evaluation was that for some values, the linearity between vehicle H and vehicle L cannot be ensured in each and every case without additional requirements. The required conditions to apply the interpolation approach are further specified in this chapter.

One example on the case of NOVC- HEVs and OVC-HEV is the allowed CO_2 mass emission difference between vehicle H and vehicle L in charge-sustaining condition. This range is limited to 20 g/km if only a vehicle H and L is measured and can be extended to 30 g/km if an additional vehicle M is measured.

Further requirements to complement the main body of Annex 8 is provided in the following appendices:

Appendix 1 - REESS state of charge profile

This appendix is a visualisation of the different Type 1 test procedures for OVC-HEVs, NOVC-HEVs, NOVC-FCHVs and PEVs. It contains figures showing example SOC profiles for charge-depleting and/or charge-sustaining tests.

Appendix 2 - REESS energy change-based correction procedure

This appendix describes the procedure to determine the CO_2 correction coefficient, which is needed if a correction of the charge-sustaining Type 1 test CO_2 mass emission for NOVC-HEVs and OVC-HEVs is required. The correction procedure is mandatory for the determination of the determination of the phase specific values. See also paragraph 4.4.18 of this report

Also included is a correction procedure for NOVC-FCHVs with the determination of a fuel correction coefficient as a function of the electric energy change of all REESSs.

Appendix 3 - Determination of REESS current and REESS voltage for NOVC-HEVs, OVC-HEVs, PEVs and NOVC-FCHVs

This Appendix describes the required instrumentation and measurement methods to determine the REESS current and the REESS voltage of NOVC-HEVs, OVC-HEVs, PEVs and NOVC-FCHVs.

Appendix 4 - Preconditioning, soaking and REESS charging conditions of PEVs and OVC-HEVs

This Appendix defines the procedure for the REESS and combustion engine preconditioning in preparation of the test as well as the charging procedure of the REESS.

Appendix 5 - Utility factors (UF) for OVC-HEVs

This Appendix describes the formula and the coefficients of the regional UFs. Each Contracting Party may develop its own UFs, but is recommended to apply the procedure of SAE J2841. See also paragraph 3.4.5.8 of this report.

Appendix 6 - Selection of driver-selectable modes

This Appendix describes which mode should be selected for the Type 1 test procedure, for which flowcharts are included. The prioritisation concerning the mode selection is as follows:

1. First priority is being able to follow the applicable driving cycle
2. Second priority is choosing the predominant mode.

In case of OVC-HEVs, the mode selection has to be evaluated for both charge-depleting and charge-sustaining operation conditions. See also paragraph 3.4.5.10 and Appendix 1 of this report.

Appendix 7 - Fuel consumption measurement of compressed hydrogen fuel cell hybrid vehicles

This Appendix is describes the method to measure the fuel consumption of NOVC-FCHV. See also paragraph 4.4.23 of this report.

4.5.7 Annex 9 – System equivalency

Other measurement methods can be used for testing if they yield equivalent results to the testing methods described in the GTR. To prove system equivalency, the accuracy and the precision of the candidate method has to be equal or better than the reference method, and this evidence will have to be based on statistical data.

To show the difference between accuracy and precision, please refer to Figure 31.

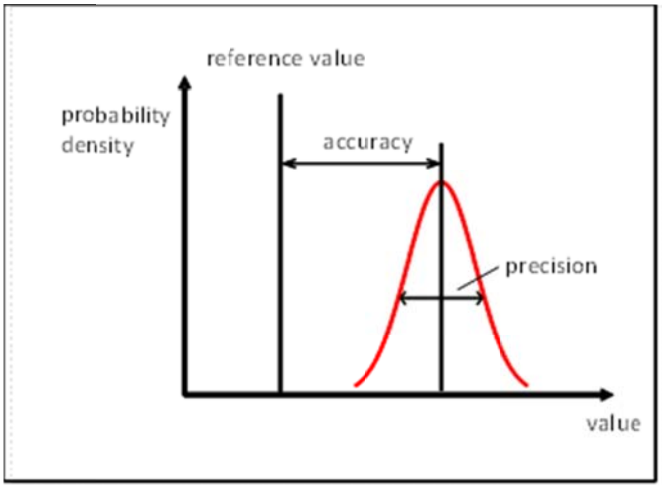

Figure 31: Difference between accuracy and precision with respect to a reference value

Guidance for the correlation between an existing and a candidate method is provided in ISO 5725 Part 6 Annex 8.

The implementation of system equivalency will be further detailed in a phase 2 of the GTR development.

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)[44]. 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. All of the validation tests and analyses were executed during phase 1a timeframe of WLTP. Apart from the Round Robin tests (see paragraph 3.4.4) there were no further testing or validation activities included in phase 1b.

5.1 Validation 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 dated 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. Table 14 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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[44] 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 14: 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 15.

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 15: Overview of the validation 2 vehicle sample categories and numbers

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 larger part of the vehicles only the basic tests were performed. The base test consists of the WLTP test with a cold start at the test mass of vehicle H (TMH). For 92% of the ICE vehicles an additional hot start test was 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 the 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 16 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 the

‘30 minutes power’ is considered 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 concluded that a power-to-mass ratio determination is not yet feasible for PEV’s due to the absence of a robust system power definition. Therefore it was decided that all PEV’s are tested at class 3 cycles.

All class 1 and class 2 vehicles with ICE are from India. Table 17 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 18).

All M1 class 3 vehicles were tested at all 4 cycle phases (see Table 19 and Table 20), while 1 of the 7 N1 class 3 vehicles was tested without the extra high speed phase (see Table 21).

			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 16: 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 17: Overview of tests for class 1 ICE vehicles

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 18: Overview of tests for class 2 ICE vehicles

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 19: Overview of tests for class 3 M1 vehicles (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 20: Overview of tests for class 3 M1 vehicles (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 21: Overview of tests for class 3 N1 vehicles

5.1.2 Evaluation issues

The following evaluation issues were discussed within 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 this longlist, 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 32 shows an example for coolant and air temperature monitoring of 7 different tests on 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 23 °C and the tolerance of the actual value shall be within ± 3 °C on a 5 minute running arithmetic average and shall not show a systematic deviation from the set point. The temperature shall be measured continuously at a minimum frequency of 1 Hz.”

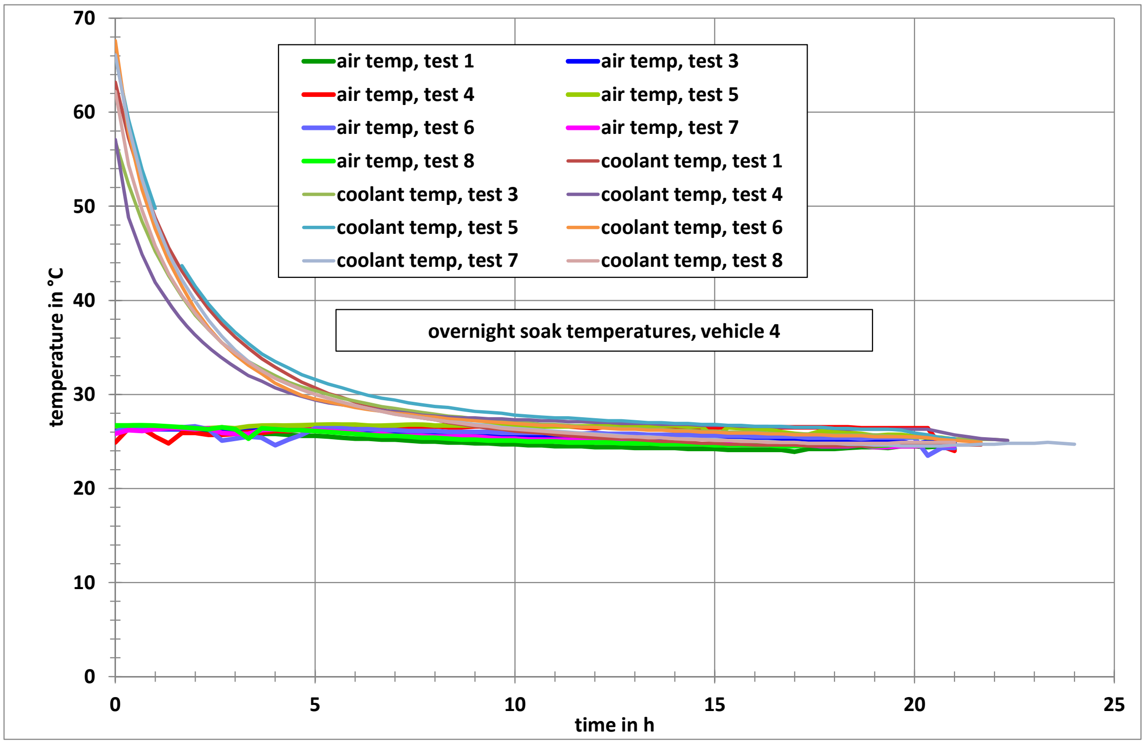

Figure 32: Example of overnight soak temperature monitoring

5.2.2 Test cell temperatures

The next validation point was the variation of the test cell temperature during the tests. The class 3 cycle was used for the evaluation. Figure 33 shows the time history of the test cell temperature with the lowest variation, Figure 34 shows the case with the highest variation. The variation ranges for all tests are shown in Figure 35.

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

“The test cell shall have a temperature set point of 23°C. The tolerance of the actual value shall be within ± 5 °C. The air temperature and humidity shall be measured at the vehicle cooling fan outlet at a minimum frequency of 1 Hz.”

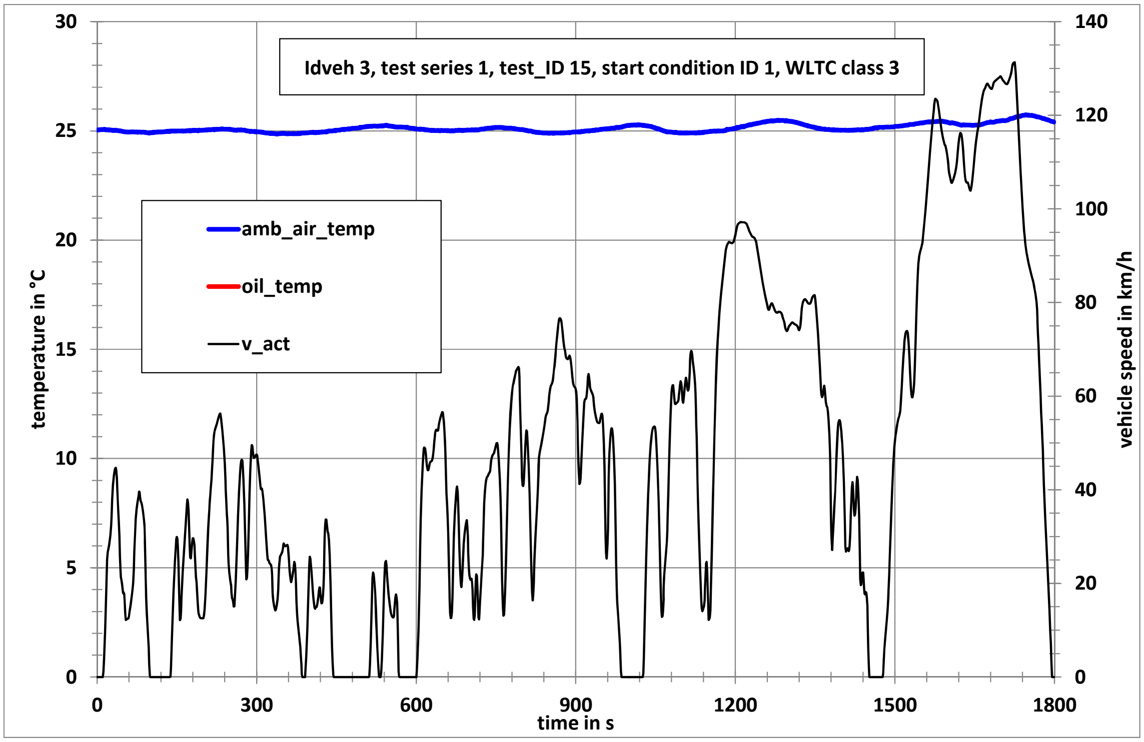

Figure 33: Best case of test cell temperature over all 4 phases of the class 3 WLTC

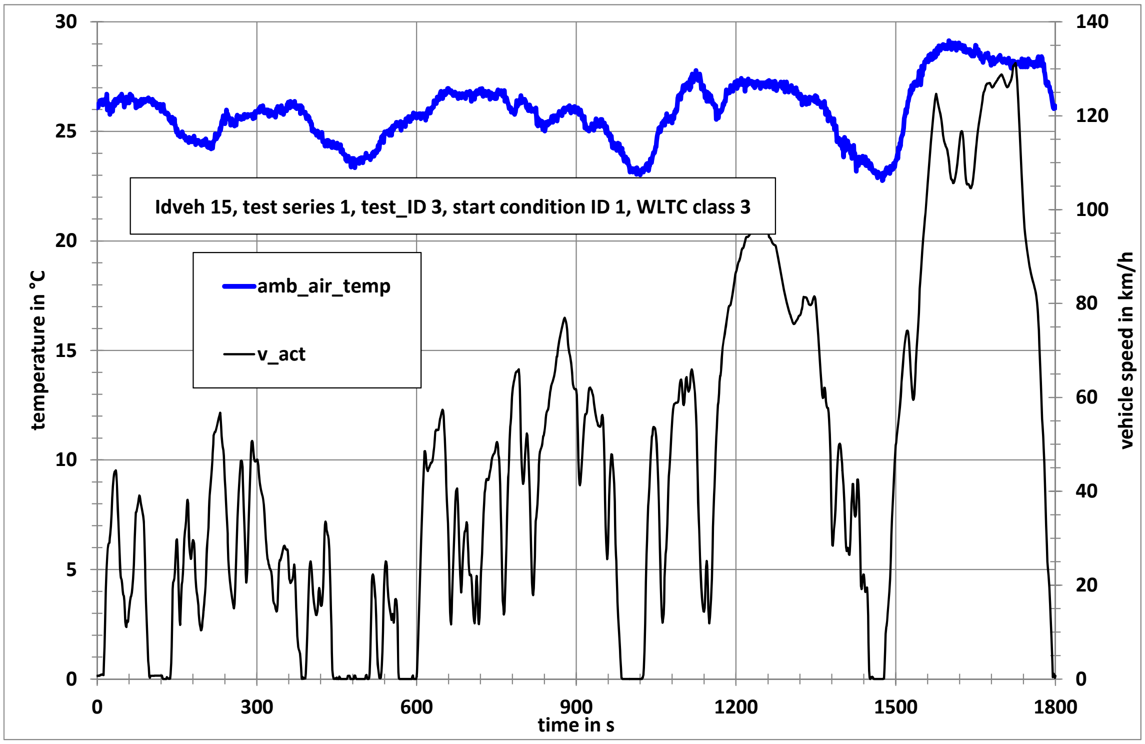

Figure 34: Worst case of test cell temperature over all 4 phases of the class 3 WLTC

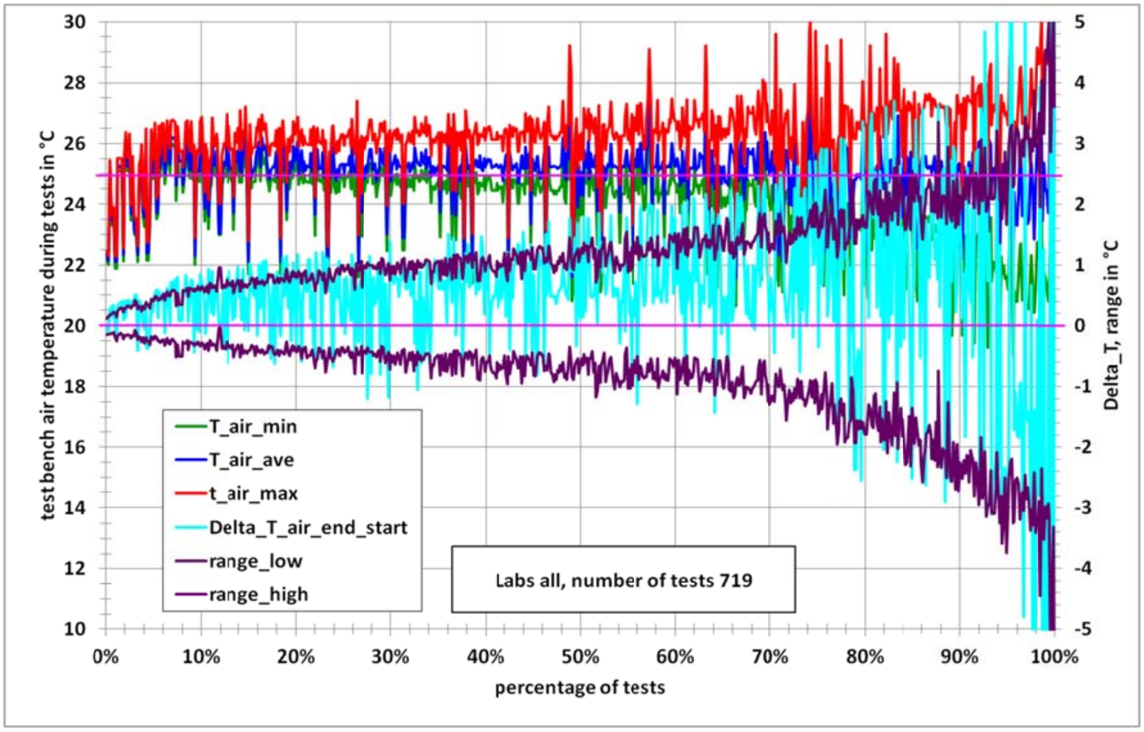

Figure 35: Test cell temperature variation range during class 3 WLTC, all tests

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 36 to Figure 38).

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

“The specific humidity H of either the air in the test cell or the intake air of the engine shall be such that: $5.5 \leq H \leq 12.2$ (g H_2O/kg dry air).

“Humidity shall be measured continuously at a minimum of 1 Hz.

Specific humidity H shall be measurable to with a resolution of ±1 g H_2O/kg dry air.”

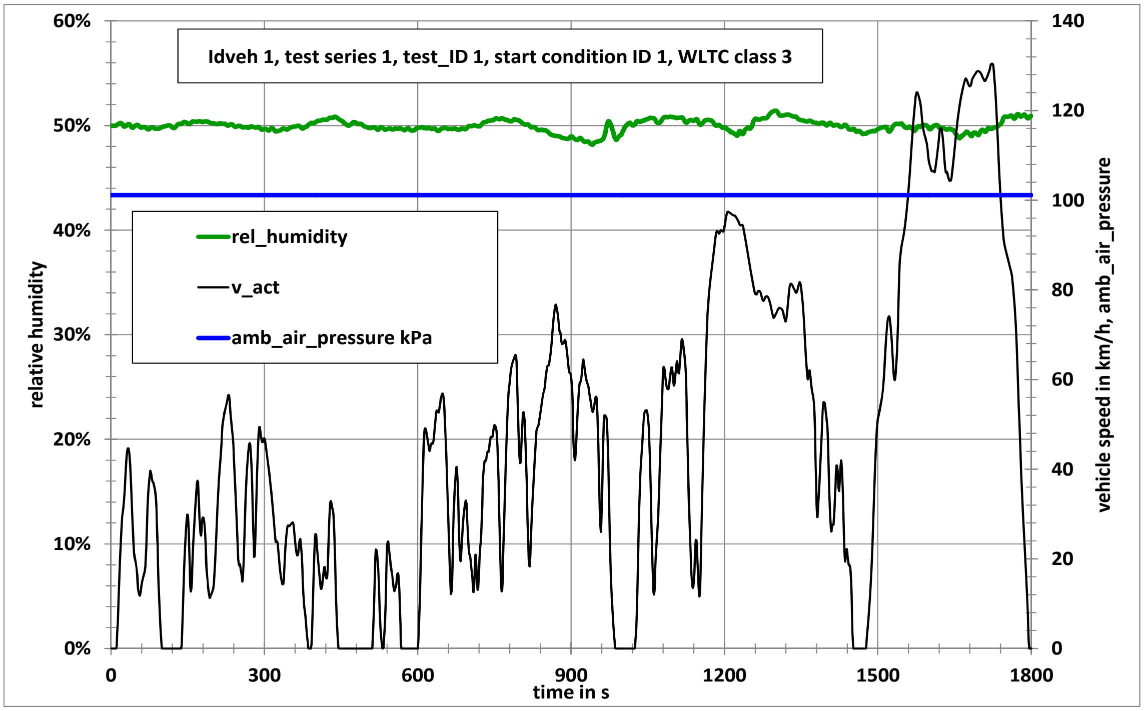

Figure 36: Example for the time history of the test cell humidity over the class 3 WLTC

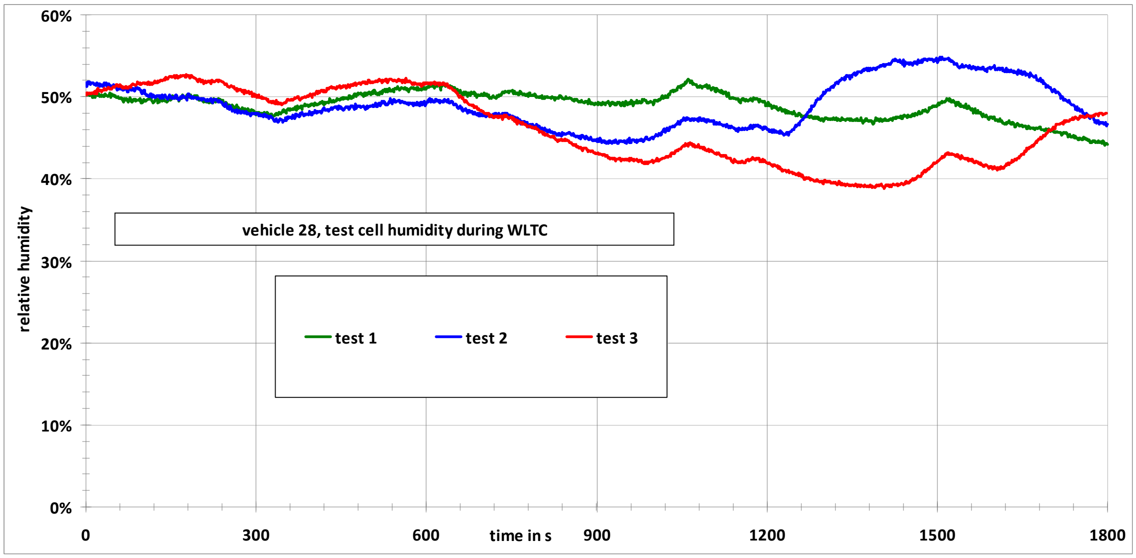

Figure 37: Examples for the time history of the test cell humidity over the class 3 WLTC

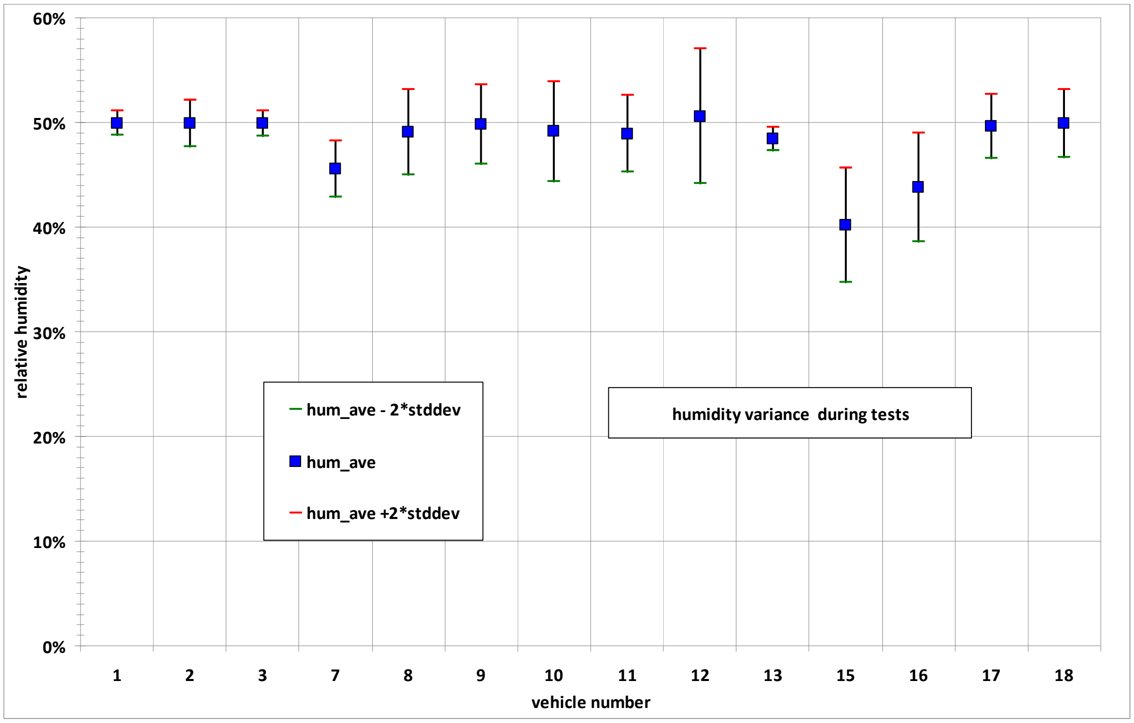

Figure 38: Test cell humidity variances during the tests

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 39 shows an 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). No speed trace violations occurred in either of these tests.

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 40 and Figure 41).

Figure 40 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.

When this vehicle was tested on natural gas, the rated power reduced to 68 kW, resulting in a pmr value just below the borderline of 34 kW/t. The speed trace violations shown in Figure 40 would not occur if the vehicle had been tested on the class 2 cycle, since this cycle has less demanding accelerations and a lower top speed.

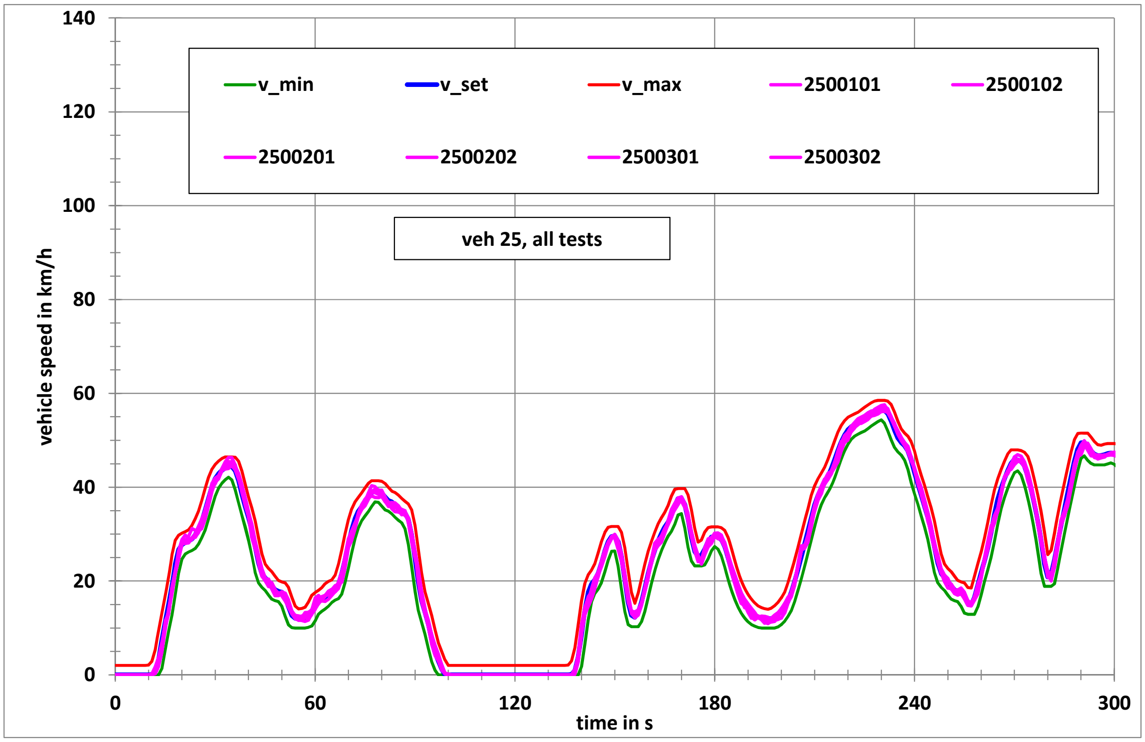

Figure 39: Example for speed trace and tolerance band for the class 3 WLTC

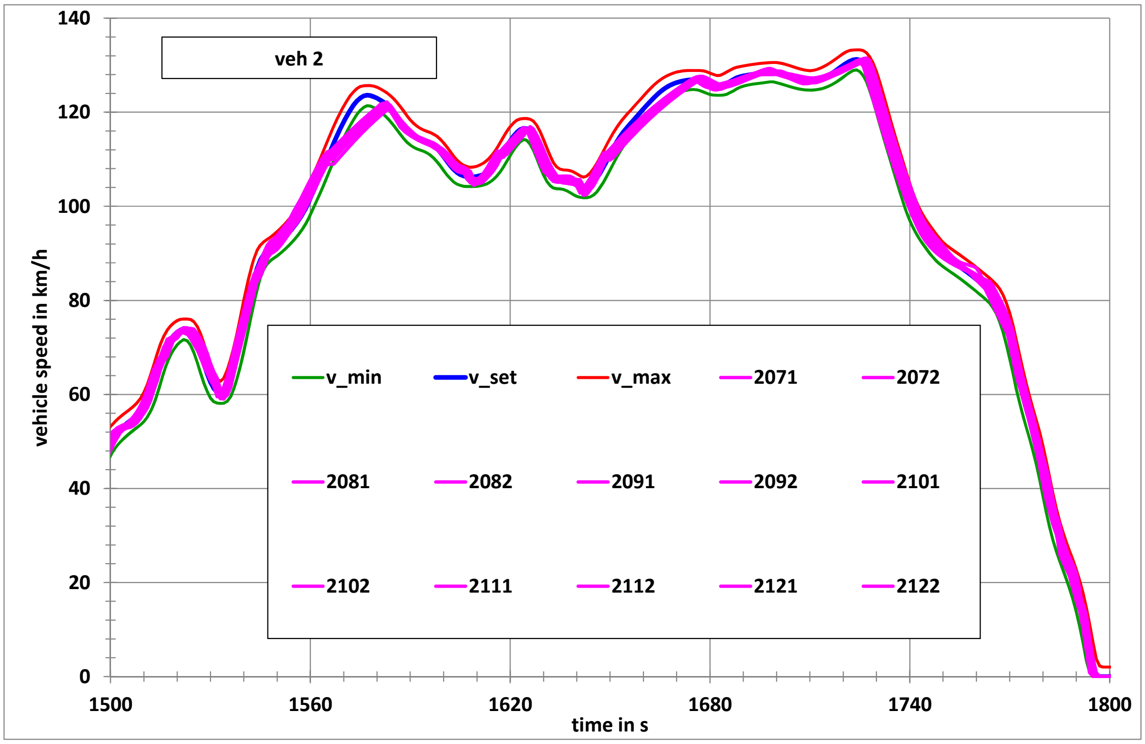

Figure 40: Example for tolerance band violations for the extra high speed phase of the class 3 WLTC (CNG fueled vehicle, pmr = 33.4 kW/t)

A more severe example is shown in Figure 41. This vehicle from India was tested on natural gas, which obviously reduced the maximum power compared to the operation on petrol and would therefore qualify as class 2 vehicle. In this particular case it would even 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 41 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 because the acceleration is too high.

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 report[44].

Based on the results of the speed compliance/violation analysis the ±2 km/h at ±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.

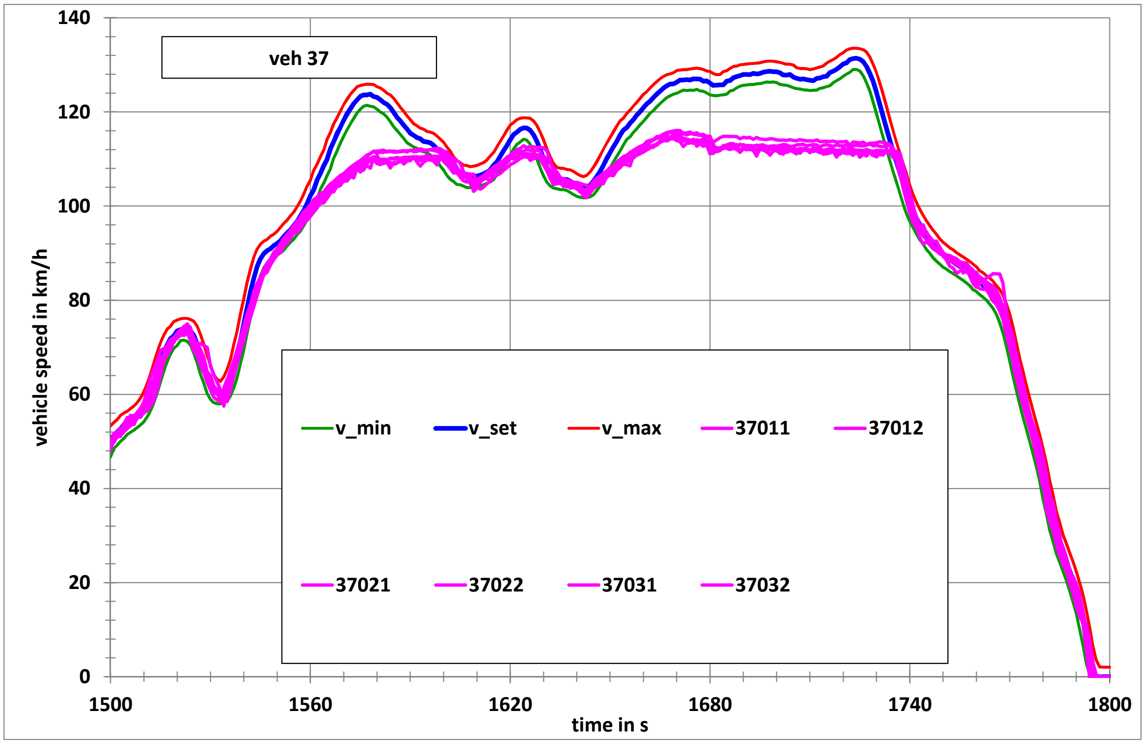

Figure 41: Example for tolerance band violations for the extra high speed phase of the class 3 WLTC (CNG fueled vehicle)

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 PEVs with respect to vehicle classes, the cycle version allocation was interpreted differently by the participating labs. One lab used the ‘30 minutes maximum power’ of the electrical motor and classified the vehicles by calculating the power to (kerb) mass ratio based on that power indicator.

This led to the situation that vehicle 58 with a kerb mass of 1860 kg and a peak power of 120 kW, but a 30 minutes power of only 60 kW, 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, which does not include an extra high speed phase. With the 3 phases (Low, Medium and High) of the class 2 cycle the vehicle was able to drive more than 250 km i.e. more than 17 cycles before the batteries were depleted.

Two CD tests on this cycle were performed with vehicle 58. The cumulative discharge curves are shown in Figure 42 and Figure 43. At 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 discharged 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 the charge depleting test) is significantly different in both tests (for a more detailed overview see Figure 44, Figure 45 and Figure 46). This leads to a difference in the range determination of about 9 km (253.5 km to 263.2 km) or 3,5% with respect to the average range.

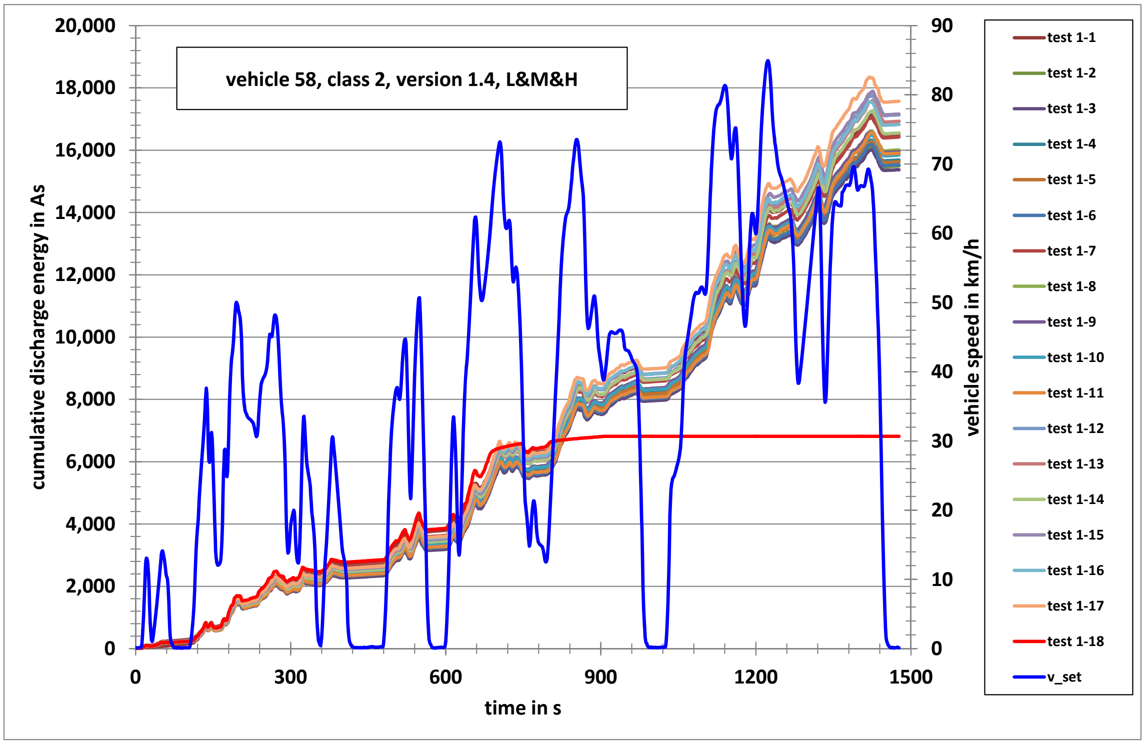

Figure 42: Cumulative discharge energy during the CD test 1 for vehicle 58 on the class 2 cycle (version 1.4)

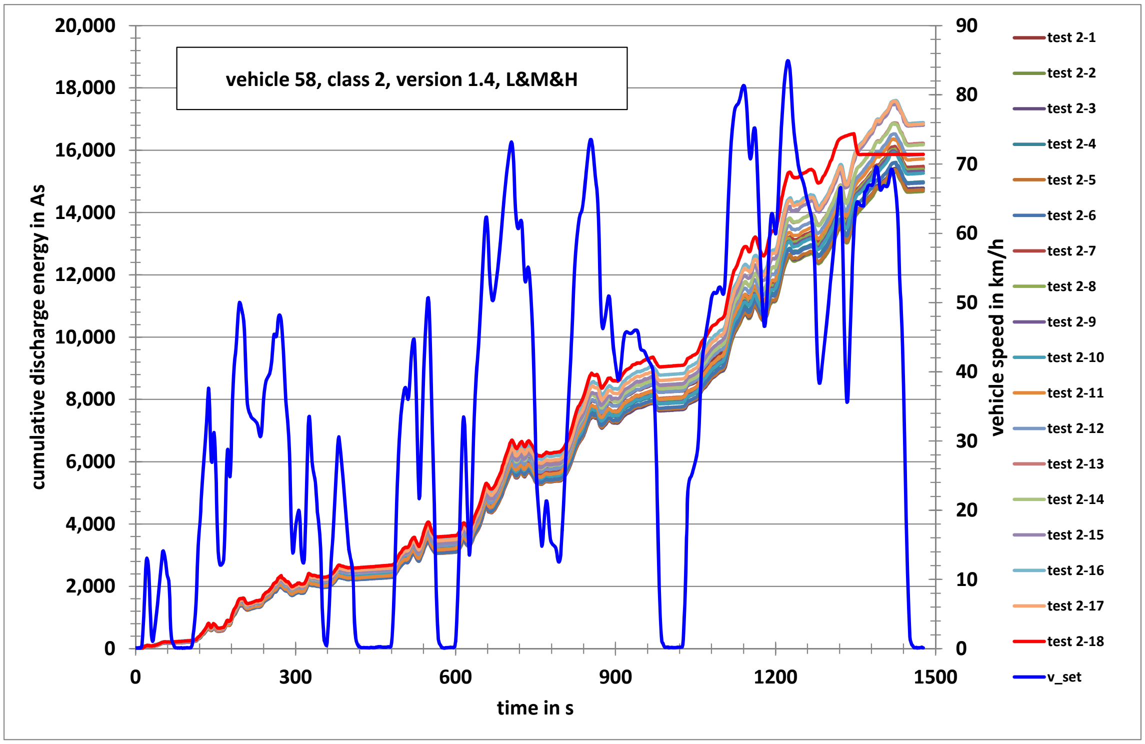

Figure 43: Cumulative discharge energy during CD test 2 for vehicle 58 on the class 2 cycle (version 1.4)

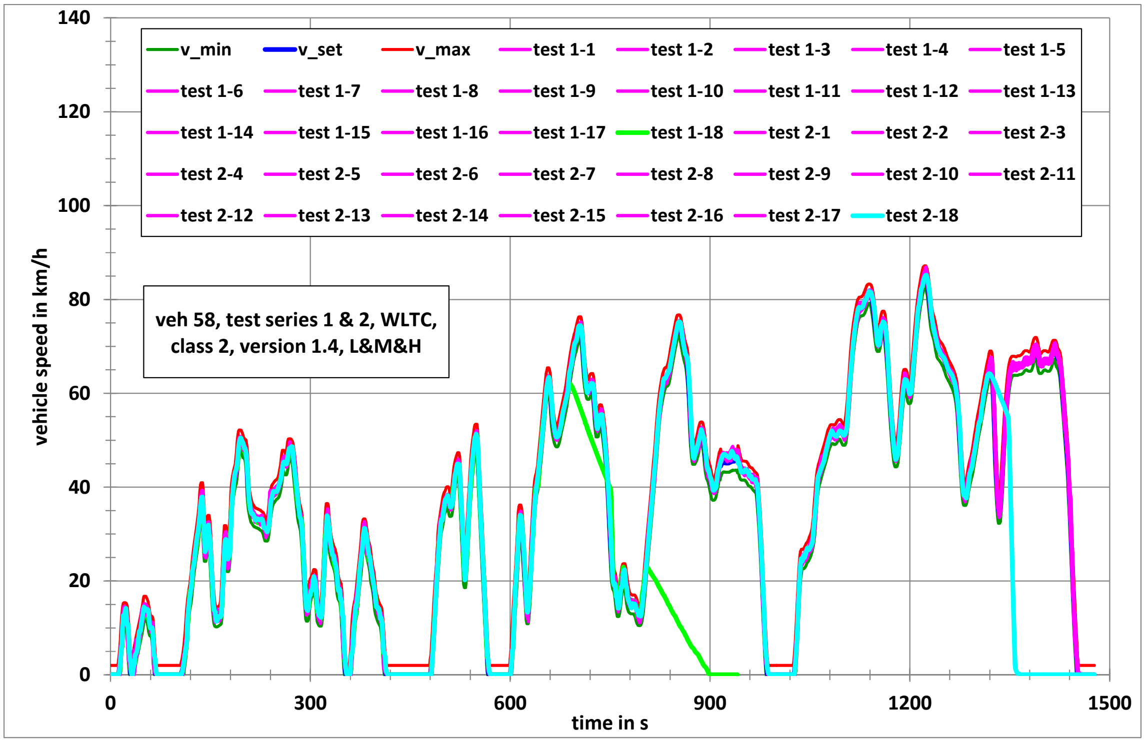

Figure 44: Time series of the vehicle speed for CD tests 1 and 2 for vehicle 58

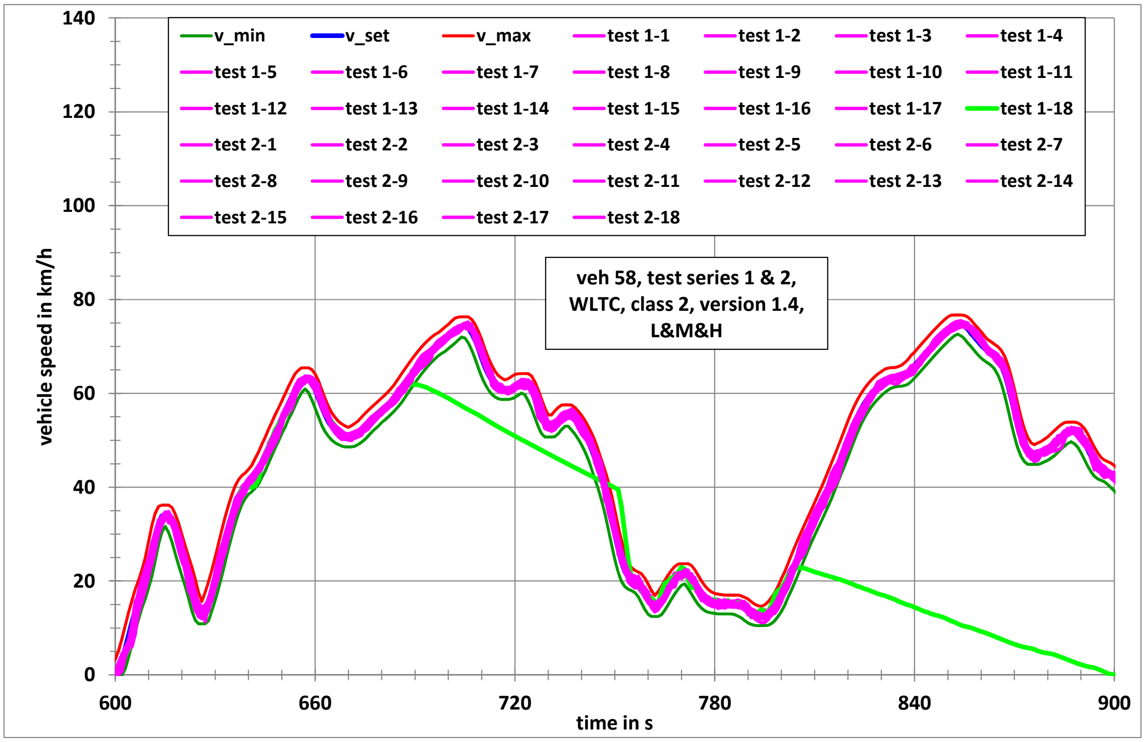

Figure 45: Time series of the vehicle speed for CD test 1 for vehicle 58 at break-off point

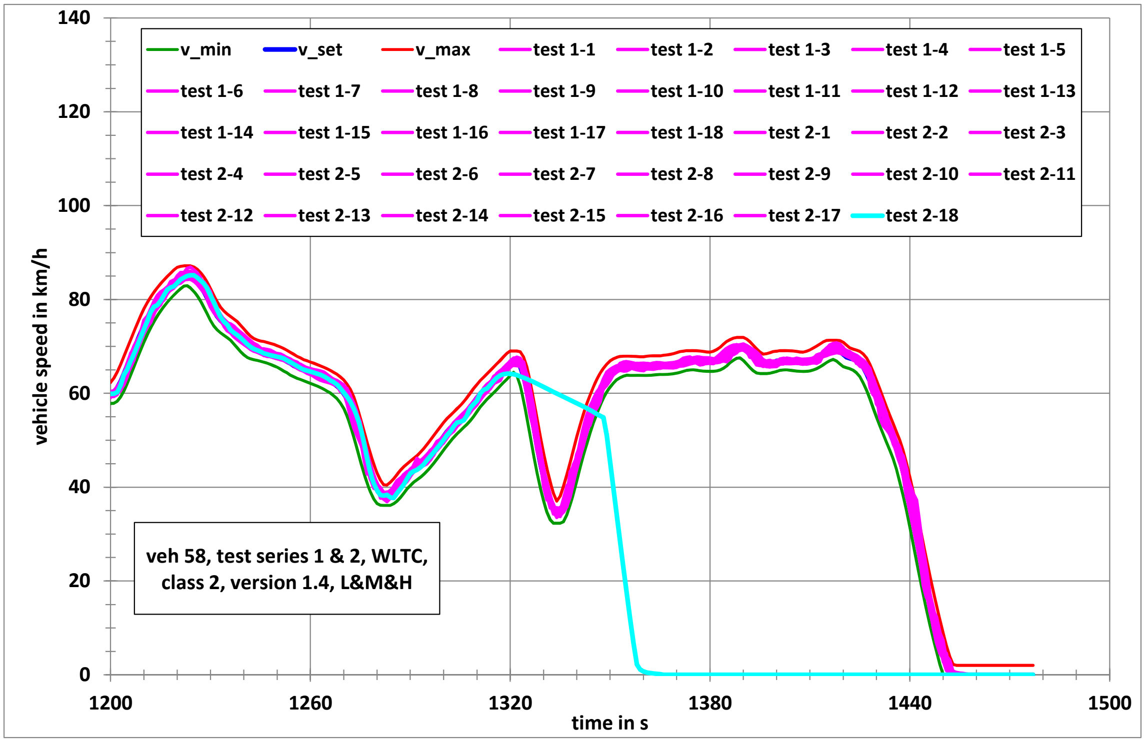

Figure 46: Time series of the vehicle speed for CD test 2 for vehicle 58 at break-off point

The driver instruction for the end of a charge depleting test was as follows: If the vehicle speed falls below the tolerance for a time of 4 seconds or more, the vehicle should be brought to standstill within the following 15 seconds. As can be seen in Figure 45 and Figure 46, this instruction was not strictly followed. This was also the case for the other vehicles. On the contrary, Figure 46 shows that the driver was aware that the batteries became fully depleted but still tried to drive as long as possible with full power so that the actual speed trace was significantly *above* the speed trace within a deceleration phase.

In any case, the charge depleting tests especially at the break-off sections were very helpful for the definition of suitable break-off criteria for the GTR.

Vehicle 59 was also tested by the same lab. 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). As a consequence it was 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 example for a PEV that was tested by the same lab is shown in Figure 47 (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, when 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 (Low, Medium and High speed) of the class 3 cycle. The 4th phase of the class 3 cycle was skipped, because the vehicle could was not even able to reach the maximum speed of the extra high speed phase of the class 2 cycle. Figure 48 shows the break-off section for the class 3 cycle of this vehicle.

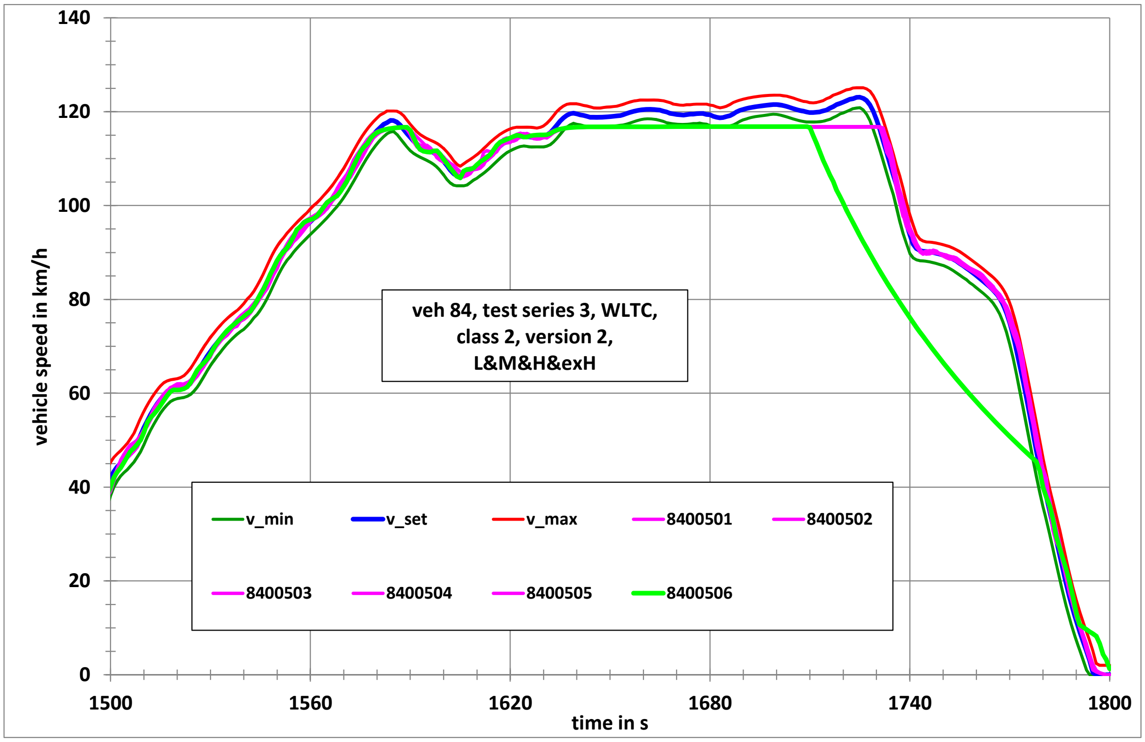

Figure 47: Time series of the vehicle speed for CD test 3 for vehicle 84 at break off section

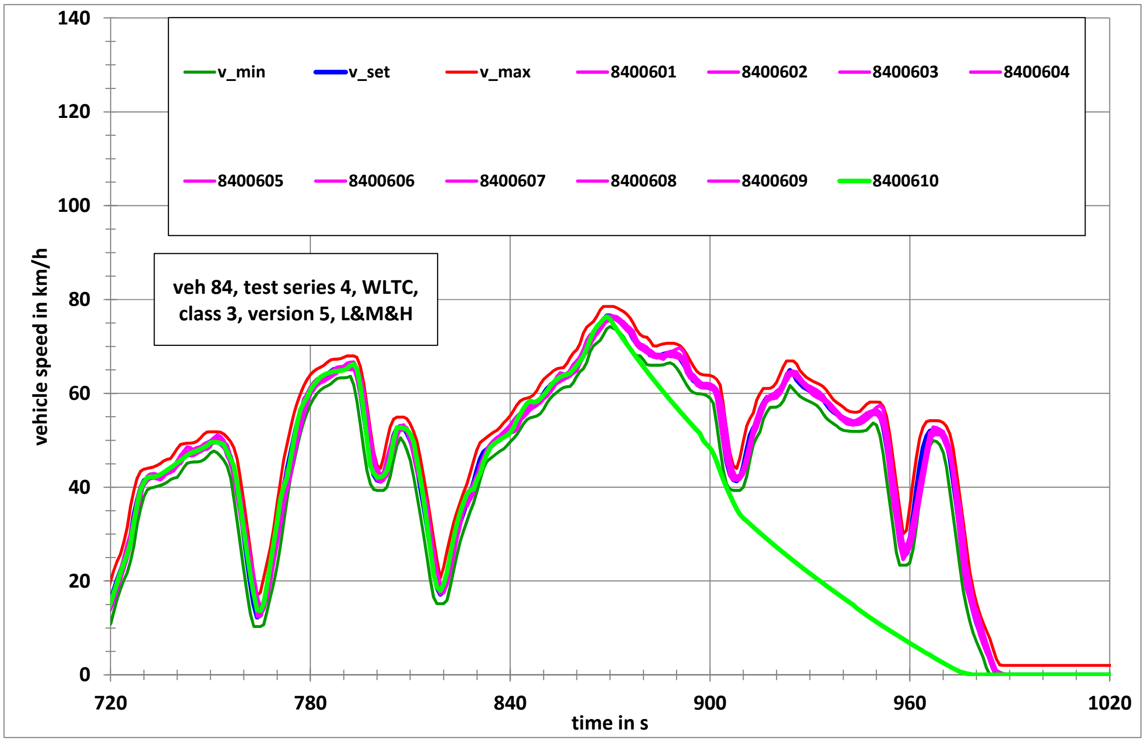

Figure 48: Time series of the vehicle speed for CD test 4 for vehicle 84 at break off section

The remaining PEV's were all 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 49).

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 phase.

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

The results of all CD tests for the PEV's are summarised in Table 22. 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 50).

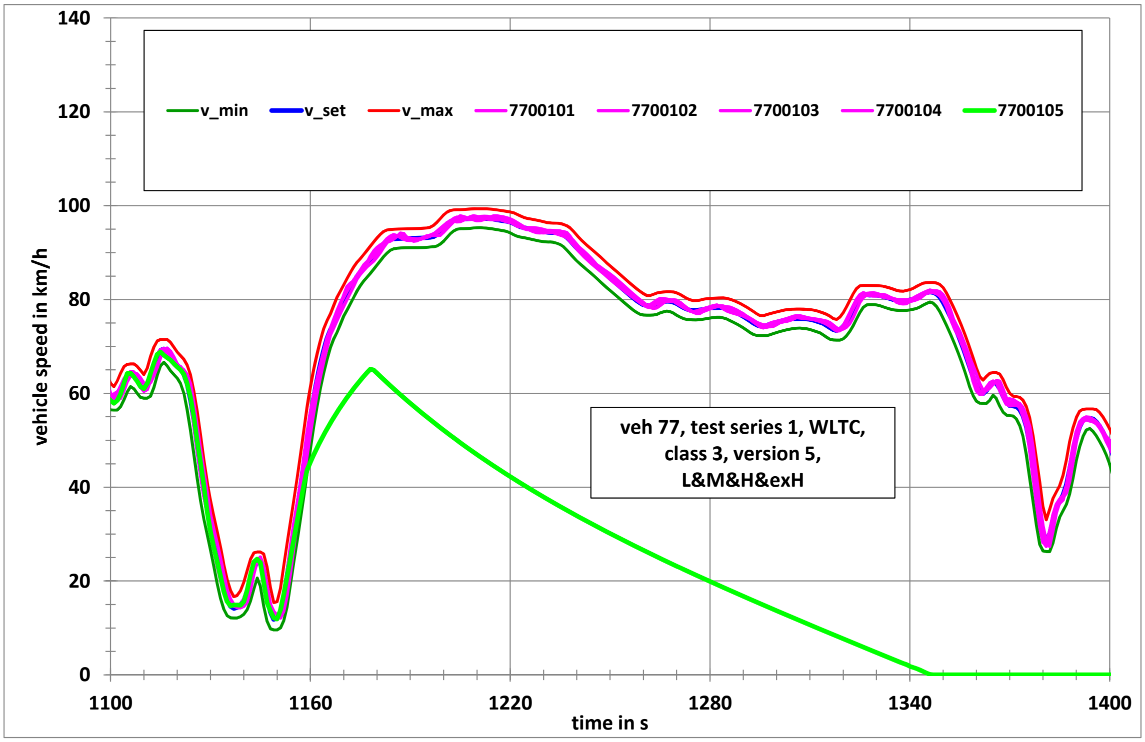

Figure 49: Time series of the vehicle speed for the CD test for vehicle 77 at break off section

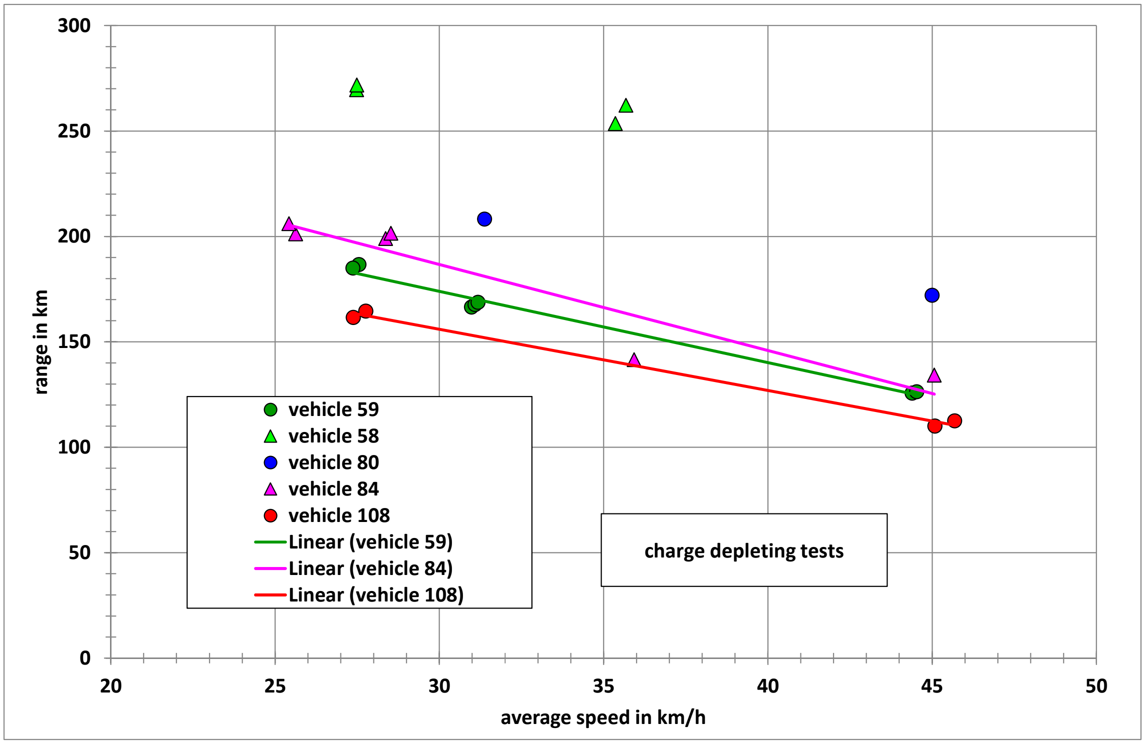

Figure 50: Range of the CD tests for the PEVs versus average speed of the cycles

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/s^2	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 22: 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 in CD mode (vehicles 60 and 65). Vehicle 60 had a kerb mass of 1730 kg, a 1.4 litre 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 kg, a 1.8 litre petrol engine with a rated power of 73 kW and an electric motor with 60 kW power, which is presumably the peak power. Both vehicles would be classified as class 3 vehicles when only the rated power of the ICE is considered. The difference in kerb mass is due to 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 51 to Figure 54). Vehicle 60 was able to 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 phases of one class 3 cycle in full electrical mode (this can be seen from the comparison of Figure 51 and Figure 53).

Another difference between these vehicles was that the traction battery of vehicle 60 recharged to a certain extent during subsequent CS tests, while this was not the case for vehicle 65 (this can be seen from the comparison of Figure 52 and Figure 54).

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 also show quite convincingly that the current vehicle classification for PEV and OVC-HEV in the GTR is not satisfactory. For that reason a downscaling procedure was developed during phase 1b, as well as a procedure to deal with vehicles that have a capped maximum speed.

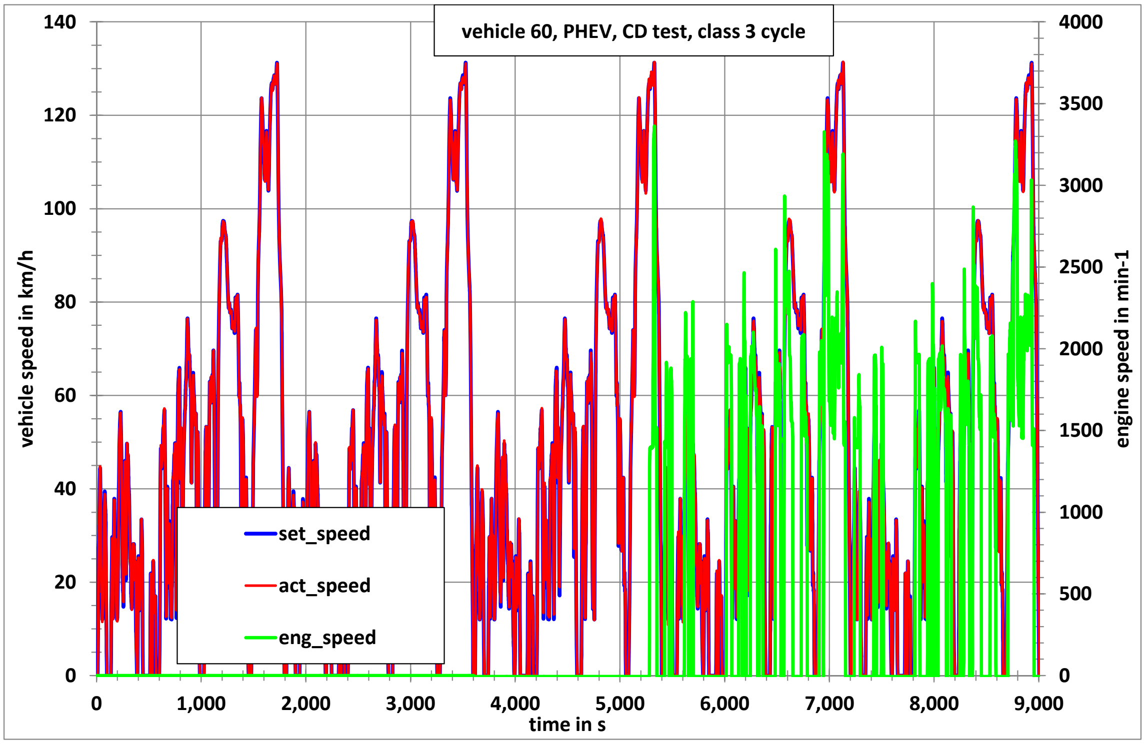

Figure 51: Charge depleting test for OVC HEV vehicle 60, vehicle speed and engine speed

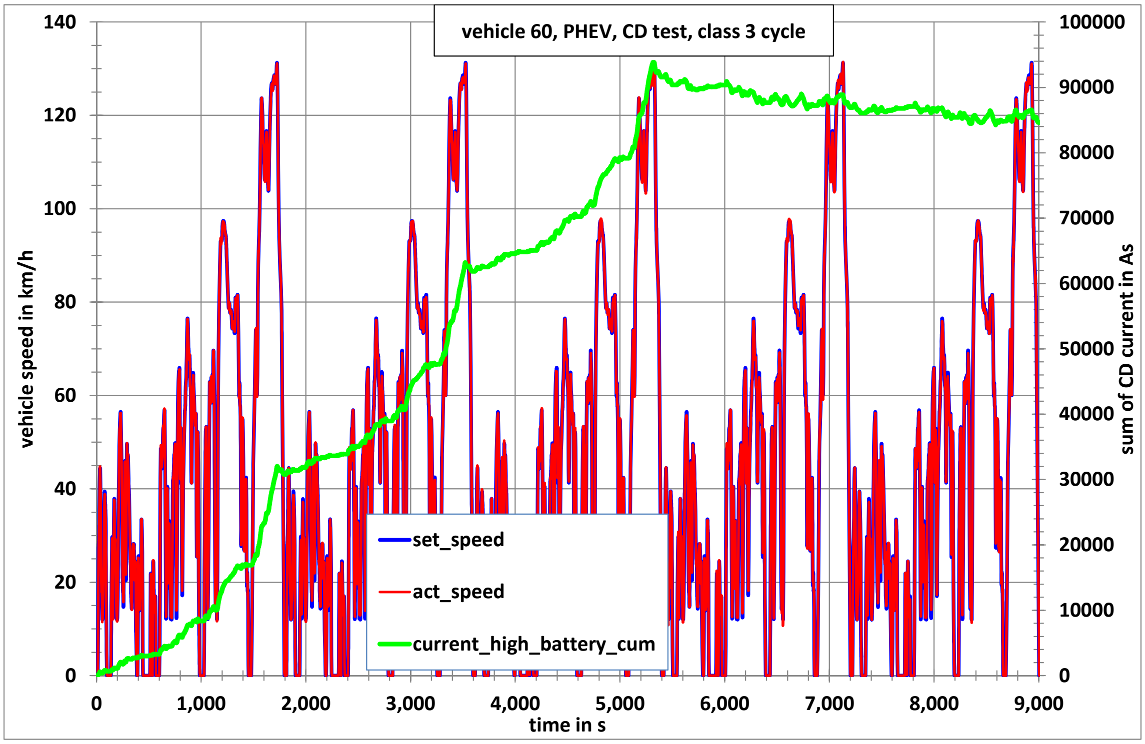

Figure 52: Charge depleting test for OVC HEV vehicle 60, vehicle speed and current

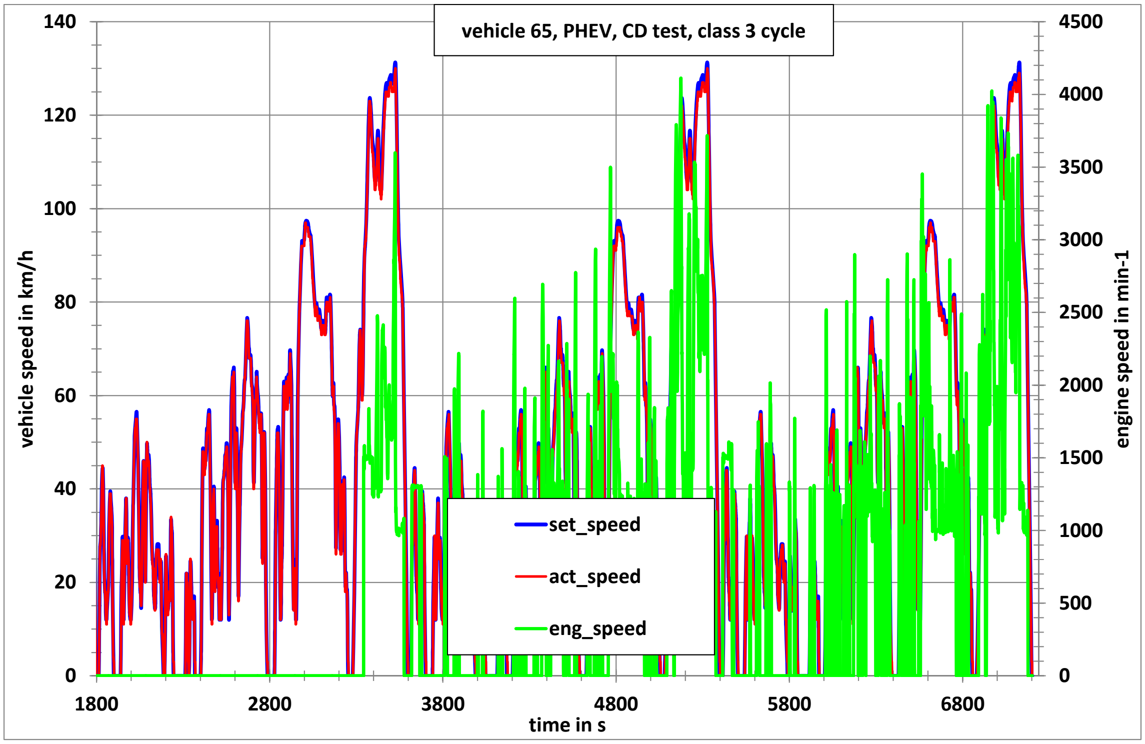

Figure 53: Charge depleting test for OVC HEV vehicle 65, vehicle speed and engine speed

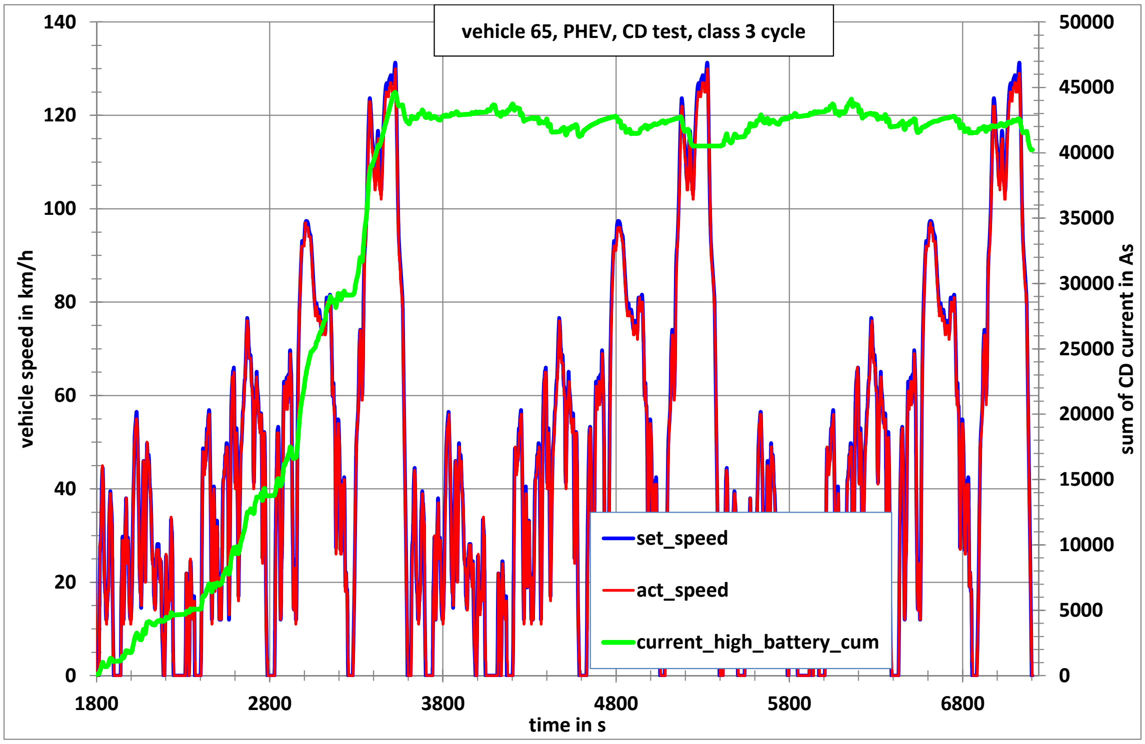

Figure 54: Charge depleting test for OVC HEV vehicle 65, vehicle speed and current

Appendix 1 – Utility Factors

Subject: Development of a European Utility Factor Curve for OVC-HEVs for WLTP

Authors: A. Eder[45], N. Schütze[46], A. Rijnders[47], I. Riemersma[48], H. Steven[49]

Date: November 2014

Introduction

In contrast to vehicles with combustion engines or NOVC-HEVs (not off vehicle chargeable hybrid electric vehicles), an OVC-HEV **(**off vehicle chargeable hybrid electric vehicle**)** can be operated in two distinct driving modes:

1.) Charge Depleting mode (electric energy is dissipated from the storage)**,** and
2.) Charge Sustaining mode (electric storage is on a minimum level and only able to support the driving with regenerated energy; the energy for driving is provided by the combustion engine, see Figure 55)

The extent to which a vehicle will be driven in either of these modes depends on a combination of the following factors:

- The capacity of the electric energy storage system;
- The electric energy consumption of the vehicle while driving in charge depleting mode;
- The distance that the vehicle is able to drive in charge depleting mode (resulting from the first two factors);
- The length and frequency distribution of trips made with the vehicle; and
- The (off-vehicle) charging frequency for the electrical energy storage system.

The share between driving in ‘charge depleting’ and ‘charge sustaining’ mode can be calculated from these factors, and is expressed as the ‘Utility Factor’ (UF). The UF is defined as the ratio between the distance driven in ‘charge depleting’ mode divided by the total driven distance, and can therefore range from 0 (e.g. *for a conventional vehicle or for an HEV*) to 1 (for a pure electric vehicle or OVC-HEV that is driven in charge depleting mode only). Since the fuel and energy consumption, as well as the emissions, are very different between the two driving modes, Utility Factors are needed in order to calculate weighted emissions, electric energy consumption, fuel consumption and CO_2 values. UFs are based on driving statistics and the ranges driven in ‘charge-depleting’ and ‘charge-sustaining’ mode for OVC-HEVs in practical use. From these data, a Utility Factor (UF) curve can be generated which facilitates a weighting between the measured (emission/electric consumption/CO_2/fuel consumption) values in the two driving modes (‘charge-depleting’ and

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‘charge-sustaining’) in dependence of the measured range that was driven in charge depleting test on the WLTC.

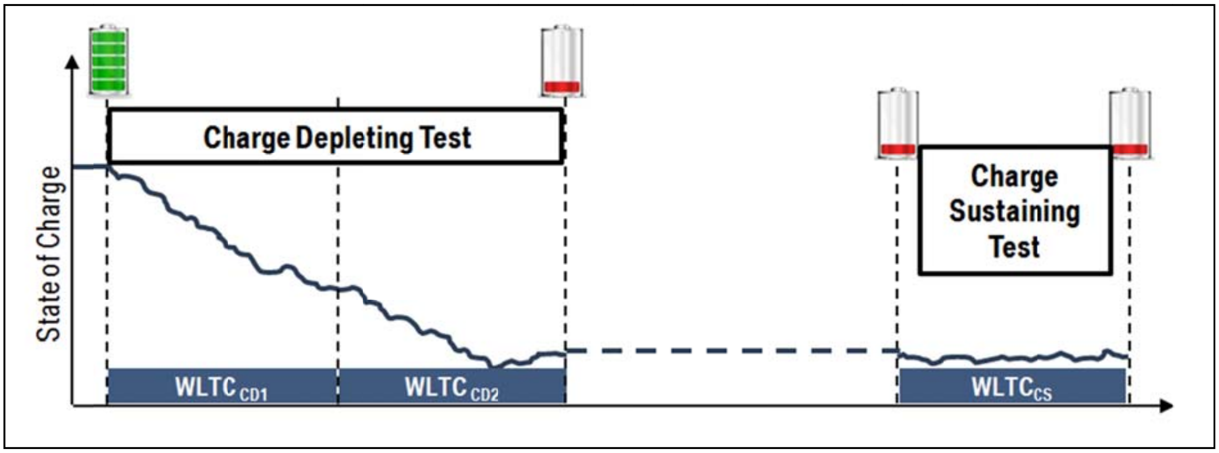


Figure 55: Procedure with charge depleting and sustaining test

The current version of the WLTP Global Technical Regulation (GTR) does not contain a uniform UF curve; each contracting party may develop its own UF curve based on the regional driving statistics. For the purpose of further harmonization between regions, a methodology for the UF calculation and how to analyse available driving data needs to be defined, which should then be used for the determination of the regional Utility Factor. This Technical Report describes the methodology that was applied to determine the UF curve for the European Union, and is intended to also provide a template for UF determination in other regions.

Methodology for UF determination

In order to develop a methodology for the UF in such a way that the test result will be as representative as possible for real-life driving situations of an average OVC-HEV fleet, it is in general important to follow the procedure as described as follows (Riemersma [9]):

1. Search for all available databases with vehicle trips that can be used as input;
2. Exclude the data that is erroneous or outside the scope (in this case, that might include taking out data from vehicles that have an extreme high or low daily average distance);
3. Verify the balance in UF relevant characteristics, such as road types (city, rural, highway), vehicle types, share between EU member states, etc.;
4. Where necessary and appropriate, apply weighting to correct any imbalance in these characteristics;
5. Develop a UF curve for the individual (weighted) databases, and explain differences through analysis; and
6. Based on the analysis, decide which weight should be applied to each database in order to reach the most representative UF curve.

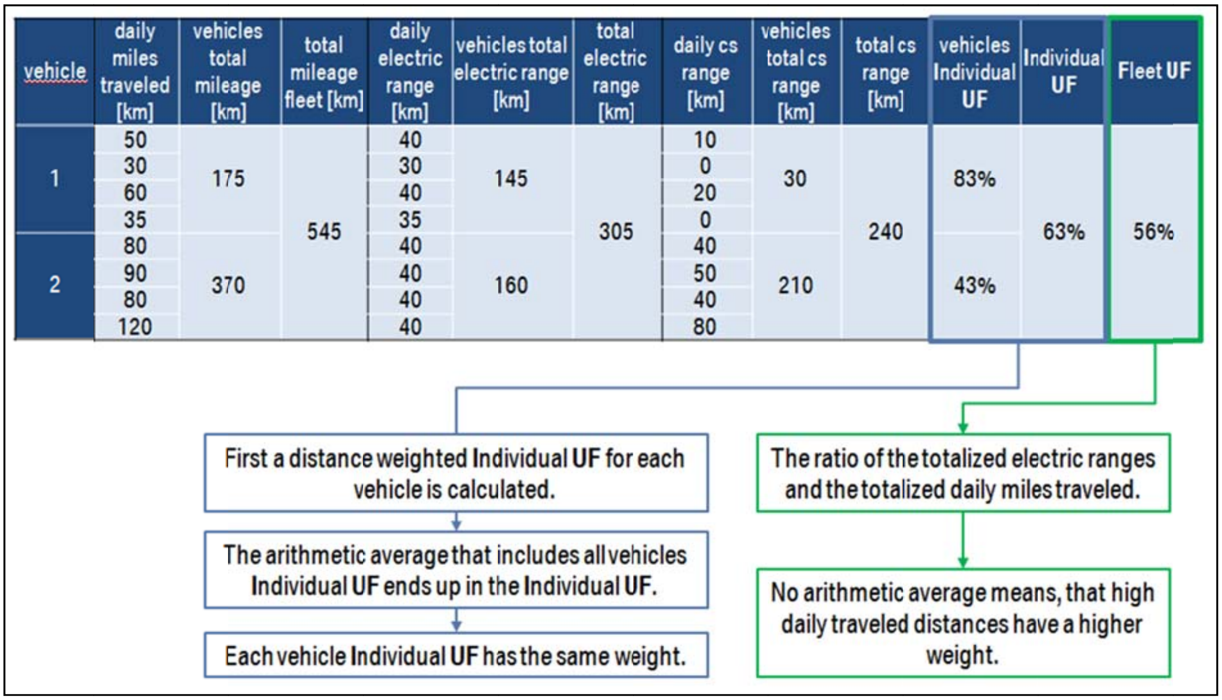
In SAE J2841 [1] several methodologies for UF determination are described, which are defined for different purposes. Two of them in principal are suitable for the above described purpose using travel survey data:

- Fleet UF (FUF) – Parameters for the UF curve are determined at fleet level, assuming the distribution within the database is representative for the target fleet (in this case: EU region); and
- Individual UF (IUF) – Parameters for the UF curve are first determined at individual vehicle level, and are weighted to reflect the distribution within the target fleet.

The Fleet UF is only an adequate method for the calculation of UF if a representative database of OVC-HEVs is available. For the FUF, the ratio of the total electric ranges and the total daily kilometres travelled for all vehicles in the database are taken into consideration.

This therefore leads to vehicles with high daily travelled distances receiving a higher weight in the UF calculation than those with lower daily travelled distances. As a result this method is liable to produce inaccurate results if the database is not a valid statistical sample, for example if it contains an unrepresentative share of vehicles travelling longer or shorter distances than that travelled by average OVC-HEV drivers.

In order to avoid this effect, SAE J2841 provides the method for calculating an Individual UF. For this method, a distance weighted individual UF for each vehicle is determined. The IUF is calculated by the arithmetic average over all the vehicles in the database and therefore, each vehicle's (individual) UF has the same weight. In Figure 56, a comparison of both methods is shown.



vehicle	daily miles traveled [km]	vehicles total mileage [km]	total mileage fleet [km]	daily electric range [km]	vehicles total electric range [km]	total electric range [km]	daily cs range [km]	vehicles total cs range [km]	total cs range [km]	vehicles Individual UF	Individual UF	Fleet UF
1	50	175	545	40	145	305	10	30	240	83%	63%	56%
	30			30			0					
	60			40			20					
	35			35			0					
2	80	370		40	160		40	210		43%		
	90			40			50					
	80			40			40					
	120			40			80					

First a distance weighted Individual UF for each vehicle is calculated.

The arithmetic average that includes all vehicles Individual UF ends up in the Individual UF.

Each vehicle Individual UF has the same weight.

The ratio of the totalized electric ranges and the totalized daily miles traveled.

No arithmetic average means, that high daily traveled distances have a higher weight.

Figure 56: Comparison of Individual UF (IUF) and Fleet UF (FUF) calculation methods (cs range = driven distance in charge sustaining mode). In this example, the assumed max. electric range of a vehicle is 40 km.

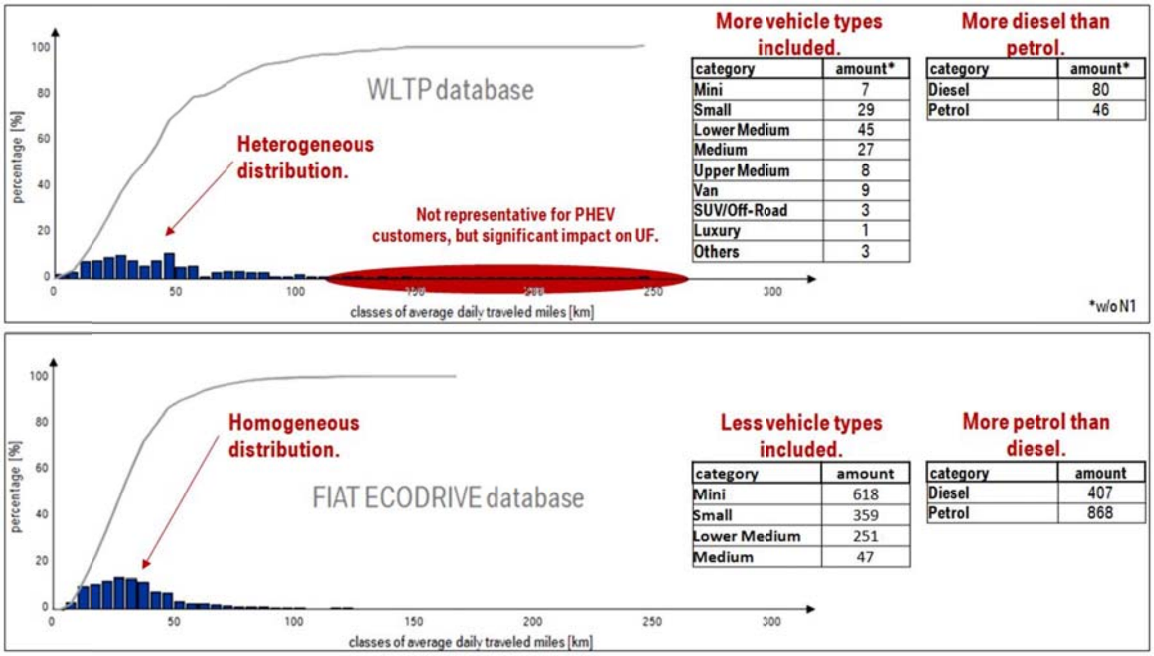
The databases available today contain a very high share of conventional vehicles (see Sect. 0). As a result the individual UF method has been used for the current evaluation of the European UF, whereas for a recommended re-evaluation of the UF curve with a pure OVC-HEV database, the fleet UF is regarded as the more accurate calculation method. However some preparatory work would be required in order to have a representative data set available for such a re-evaluation (see Sect. 0).

Another assumption necessary for the determination of UF is the charging frequency of the OVC-HEV performed by the customers. As it is currently not possible to evaluate the future OVC-HEV customer charging behaviour, the assumption of one charging event per day (overnight charge), according to SAE J2841, is used for the further analysis. In the future this charging frequency might be modified if more accurate data is available.

Database for the calculation of European Utility Factor

The main influence on the UF curve by using the methodology from SAE J2841 is the quality and resolution of input data. In order to get the most representative IUF, regional differences such as in customer behaviour (e.g. utilization, daily driven distance, shares of different vehicle classes) or infrastructure conditions (e.g. density and practicality of opportunities to charge the vehicle) cause the need to focus on a special weighting of the input data to correct imbalances within a data base.

Since OVC-HEVs are fairly new vehicle types on the European market, there is currently no representative statistical data available in Europe about their practical use. Therefore it was decided to use statistics about the use of conventional vehicles instead. Two comprehensive databases are currently available. One is the European WLTP database [2] that had already been used for the development of the WLTC speed profile. The second one is a database that was provided by FIAT [3]. After the exclusion of erroneous data (e.g. implausible start or end dates of recorded trips that leads to unrealistic trip durations), the databases combined contain in total about 1,400 conventional vehicles within the European Union.



category	amount*
Mini	7
Small	29
Lower Medium	45
Medium	27
Upper Medium	8
Van	9
SUV/Off-Road	3
Luxury	1
Others	3

category	amount*
Diesel	80
Petrol	46

category	amount
Mini	618
Small	359
Lower Medium	251
Medium	47

category	amount
Diesel	407
Petrol	868

Figure 57: Percentage composition of average daily travelled kilometers and vehicle types of WLTP and FIAT database

A comparison of both databases is shown in Figure 57. The EU WLTP database shows a very wide distribution of driving data and consists of a high share of diesel vehicles. Some of the vehicles have travelled very long daily distances on average (> 100 km/day) which is – at least from today's perspective - considered to be not representative for an OVC-HEV use in the near future, as these long-distance driving customers would have significantly lower total cost of ownership with a conventional diesel vehicle compared to an OVC-HEV. As the absolute number of vehicles, especially in some segments, is relatively low, the distribution of average daily travelled kilometres is very heterogeneous, but on the other hand, all relevant vehicle segments for Europe are represented at least once in the database.

In contrast, the FIAT database consists of a four times higher total fleet mileage and a high share of petrol vehicles, but covers only the mid-to-small vehicle segments. Due to the high number of vehicles in this database and the limited available vehicle segments, the distribution of the daily travelled kilometres is very homogeneous.

Neither database reflects the situation in Europe to the full extent with respect to vehicle segments and mileage distributions. Therefore both databases were consolidated for further evaluation, with the following steps being taken to improve the representativeness of the combined database. In a first step, the N1 vehicles were excluded from the EU WLTP database, as OVC-HEVs as replacements for conventional N1 vehicles are not currently in wide use. In a second step different weighting procedures based on mileage and statistics about new registrations were applied. This weighting makes sure that the distribution of different categories, e.g. vehicle types and/or engine types, can be corrected to be representative of the vehicles on the European market (see Sect. 0).

The UF curves developed on the basis of the databases are shown in Figure 58.
The red dashed curve is based on a simple merge of both databases, however in this curve the Fiat data is dominating due to the significantly higher total fleet mileage in the Fiat database compared to the EU WLTP database.

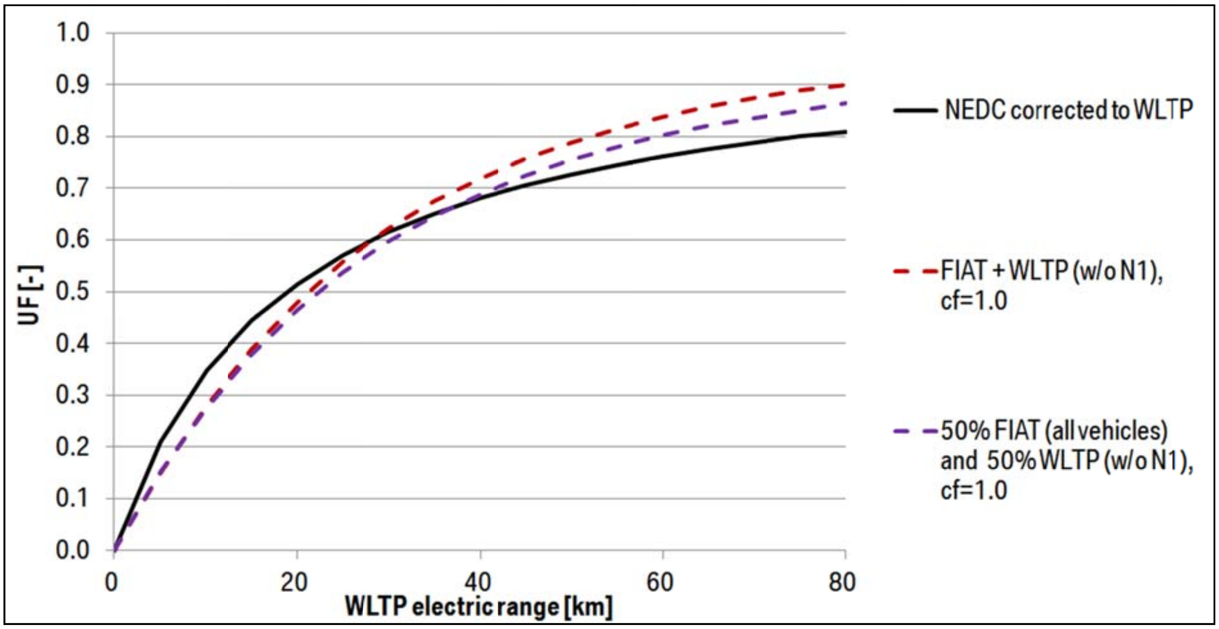


Figure 58: Comparison of NEDC UF and WLTP UF scenarios based on different weightings; cf=1.0 means charging frequency of one (full) overnight charge per day (see Sect. 0).

In order to compensate for this effect, a 50 % / 50 % weighting approach was applied. For each electric range the respective UF was calculated for both databases and weighted by 50 % for the calculation of the total UF (dashed purple line).

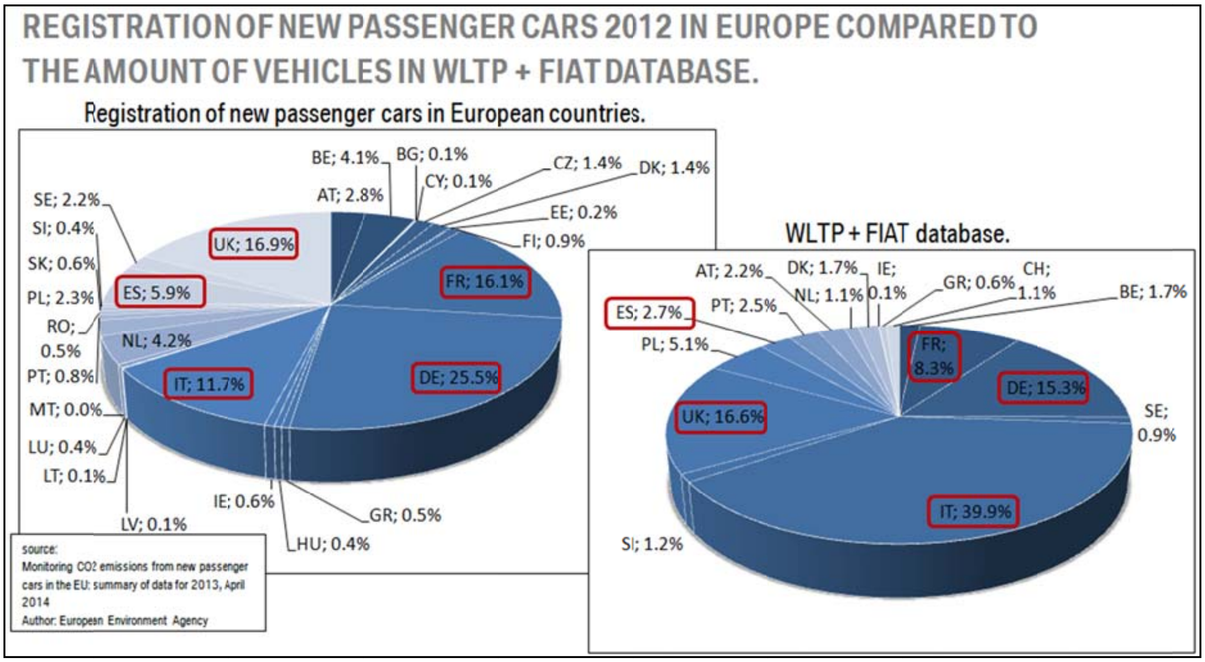
For comparison, the UF curve from the NEDC regulation UN/ECE R101 [4] is also shown in this graph (black solid line – “NEDC corrected to WLTP”). This curve was adjusted to the reduced electric range in WLTP (due to the higher energy demand of the WLTP) in order to ensure the comparability of all curves depicted against the electric range of a vehicle driving the WLTP driving cycle. The corrected NEDC–UF curve that is shown in Figure 58 was developed using the assumption that the electric range of a vehicle in NEDC is reduced by about 25% due to driving the WLTC, similar to the reductions found from simulations of electrified vehicles. Hence, the NEDC-UF is plotted to the WLTP electric range, which leads to a compression in the electric range (e.g. the UF of 0.5 in NEDC @ 25 km electric range moves back to 18.75 km electric range in WLTP).

Scientific Analysis of European UF Curves

As mentioned above, the analysis of the composition of the databases shows that both databases neet to be further complemented in relation to the following aspects:

- The number of vehicles from each country in the database, compared to the number of new registrations in the EU,
- The average annual vehicle mileage driven within each country,
- The percentage split of the different vehicle classes within the EU (mini, subcompact, compact, middle, luxury …),
- The percentage of conventional vehicles with diesel- and petrol combustion engine within each country,

In order to achieve this, statistics from the European Environment Agency, as well as data from representative institutes, were applied European Environment Agency [5], ICCT [6], and Transport & Mobility Leuven [7].



source:
Monitoring CO2 emissions from new passenger cars in the EU: summary of data for 2013, April 2014
Author: European Environment Agency

Figure 59: Comparison of registrations of new passenger cars and amount of vehicles in each country within WLTP and FIAT database

As an example, Figure 59 illustrates the differences between the amounts of new passenger car registrations for each country compared to the amount of vehicles from each country within the data base. Three different approaches were applied to determine the consolidated European UF curve:

a) New vehicle registration numbers

The first step of the process was to identify the intersection of countries in the database and in the European Union. If there is only data available for a number of the countries, the percentage shares for country specific data should be normalized to receive a total of 100%. Afterwards each vehicle belongs to a country specific sub-database.

The second step is to divide the vehicles of each sub-database into categories of engine types (e.g. diesel, petrol, etc.). Accordingly country and engine type specific UF curves can be determined in the third step.

The last two calculations of the balancing process are to consolidate the number of UF curves to a corrected European UF curve. Therefore the engine type specific UF curves of each country are weighted according to the country specific engine type percentages. Finally the engine type balanced, but country specific, UF curves are consolidated by applying the country specific percentages of new vehicle registrations.

b) Sum of annual vehicle mileage

Consolidation of the country-specific curves is done according to the sum of annual vehicle mileage instead of new vehicle registrations.

c) Vehicle segments

Before consolidation of the UF, the database was separated into different vehicle segments and then weighted according to the distribution of vehicle types in the European Union.

The different weightings described above result in three UF curves, as shown in Figure 60.

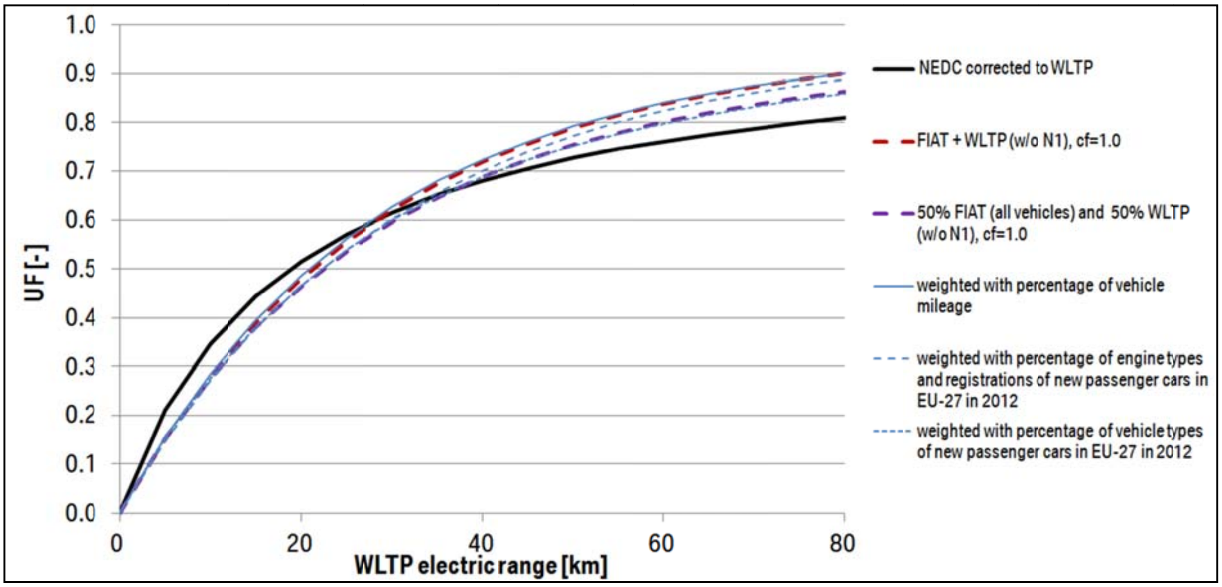


Figure 60: Comparison of different UF balancing approaches

All three curves are located between the uncorrected UF that is represented by the dashed red line (approach that consolidates both data bases without any weighting) and the 50/50 approach represented by the dashed purple line (approach that weights the WLTP UF curve and the FIAT UF curve each with 50 %).

A further option would have been to apply a combined weighting for each of the above mentioned criteria. However, there is not enough statistical data available to cover all vehicle segments and therefore this option was not further evaluated.

From Figure 60 it can be seen that the 50/50 UF curve is a good fit for the trend line which was weighted to the vehicle type percentages. Based on this analysis, it was decided and agreed in EU WLTP Meeting in June 2014 that the 50/50 UF curve should be used in Europe until more representative data are available (see Sect. 0).

The SAE J2841 also provides a method for how to describe the curve in a mathematical way. Therefore the following exponential approach can be used. A number of coefficients are provided to fit the curve towards an acceptable accuracy.
The described process to determine the coefficients ensures that several mathematical requirements and characteristics are fulfilled.

For the calculation of a specific UF for each of the 4 cycle phases in the WLTC, the following equation is applied:

$$UF_i(d_i) = 1 - \exp\left(-\left(\sum_{j=1}^{k} C_j * \left(\frac{d_i}{d_n}\right)^j\right)\right) - \sum_{l=1}^{i-1} UF_l$$

Where:

UF_i	Utility factor for phase i.
d_i	Distance driven from the beginning of the charge depleting test up to the end of phase i (phase i is the phase for which the delta UF is calculated) in km.
C_j	jth coefficient (see Table 23)
d_n	Normalized distance (see Table 23).
k	Amount of terms and coefficients in the exponent (see Table 23).
i	Number of considered phase.
j	Number of considered term/coefficient.
$\sum_{l=1}^{i-1} UF_l$	Sum of calculated utility factors up to phase (i-1).

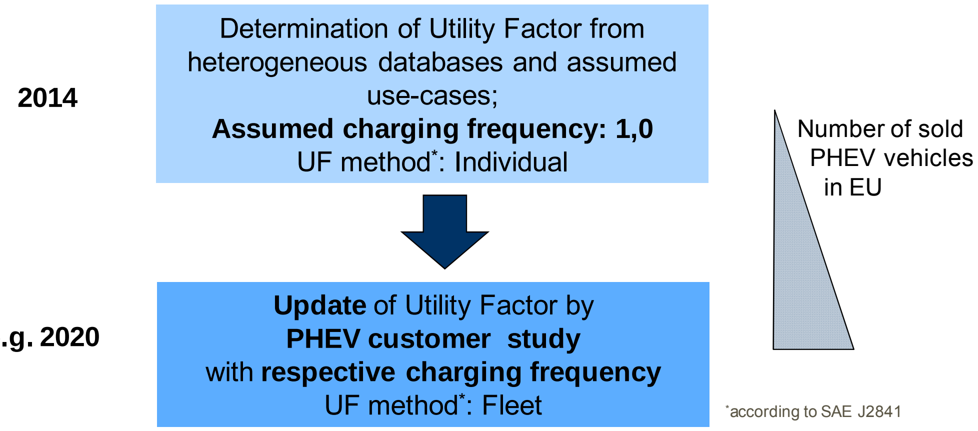
For the approximated curve, terms and coefficients in the exponent are applied up to the tenth order. The coefficient values shown in Table 23 are determined according to the process described in SAE J2841 and fit the 50/50 curve with a maximum error of 0.001 (ΔUF_{max} = 0.1 %).

C_1	26.25
C_2	-38.94
C_3	-631.05
C_4	5964.83
C_5	-25094.60
C_6	60380.21
C_7	-87517.16
C_8	75513.77
C_9	-35748.77
C_{10}	7154.94
d_n[km]	800
k	10

Table 23: Coefficients for the UF calculation equation

Review and recommended application of the European Utility Factor

As this UF was derived from data based on conventional vehicles it is planned to re-evaluate UF and charging frequencies by a customer study once a significant number of OVC-HEV has been placed in the European market, see Figure 61.



*according to SAE J2841

Figure 61: Schematic representation of re-evaluation

It is recommended that UFs are continuously checked for their robustness concerning the application of future OVC-HEVs. In order to have a representative UF-study, it is recommended to use a fundamental robust and scientific approach as described in Sampath [8]. An established method that could be used is the stratified sampling. This methodology can be applied if it is necessary to divide a population into sub-populations.

Generally there are two main tasks: The first one is the sampling of vehicle data itself and the second one the determination of weightings of sub-populations according to important criteria concerning the evaluation of the UF-curve. The choice of customers that are considered to represent a sub-population shall fulfil special criteria like a minimum annual mileage and should be measured continuously during a minimum duration. It is recommended to use a survey as outlined in Reiser [10] in order to select appropriate customers for the re-evaluation of real-life UFs.

In addition to each specific OVC-HEV having to be analysed in each specific market (including the separation of manufacturers, diesel- or petrol-OVC-HEV, different electric ranges, vehicle-type (from mini to luxury), etc.), the following criteria could also be indicators for different sub-populations of customers:

- Road category mainly used (highway, A-road, B-road) and home environment (urban, suburban, rural);
- Driving style (more economic or more sporty); and
- Daily access to public and non-public charging infrastructure.

In order to get representative sub-populations, it is recommended that at least 20 vehicles are available per survey for the re-evaluation described above. It is also important, that the driving behaviour is recorded comprehensively for each driving mode (charge depleting and charge sustaining) for at least 5,000 km per vehicle, in order to ensure that the whole variety of driving states has been captured (see Reiser [10]).

The main focus of the Utility Factor approach described above is to calculate average values which are mainly used for fleet monitoring. In contrast to conventional vehicles, the OVC-HEV customers' fuel consumption depends not only on driving behaviour and ambient conditions, but also on driven range and charging frequency.

It is therefore recommended for customer information to provide not just a single fuel consumption value, but instead to provide, for example, information on consumption depending on the driven distances.

References

[1] SAE International J2841 "Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using Travel Survey Data", Revision from 2010/09, Issued 2009/03

[2] For access to database, please contact Heinz Steven, heinz.steven@t-online.de

[3] For access to database, please contact Luigi Orofino, Luigi.orofino@fiat.com.

[4] ECE/TRANS/WP.29/343 "Uniform provisions concerning the approval of passenger cars powered by an internal combustion engine only, or powered by a hybrid electric power train with regard to the measurement of the emission of carbon dioxide and fuel consumption and/or the measurement of electric energy consumption and electric range, and of categories M1 and N1 vehicles powered by an electric power train only with regard to the measurement of electric energy consumption and electric range",

http://www.unece.org/trans/main/wp29/wp29wgs/wp29gen/wp29fdocstts.html (2014/07/21)

[5] European Environment Agency "Monitoring CO_2 emissions from new passenger cars in the EU: summary of data for 2013", 2014/04

[6] ICCT "European vehicle market statistics 2013", 2013

[7] Transport & Mobility Leuven, “TREMOVE - economic transport and emissions model”, http://www.tmleuven.be/methode/tremove/home.htm (2014/07/21)

[8] S. Sampath “Sampling theory and methods”, 2001, Narosa Publishing House

[9] Riemersma I., “Review of Utility Factor development”, Library of WLTP on CIRCABC - https://circabc.europa.eu (2014-04-17)

[10] Reiser C.: Kundenverhalten im Fokus der Fahrzeugentwicklung (“Customer behaviour in the context of vehicle development“), Technical University Dresden, Germany, PhD Thesis, 2010

Appendix 2 – Road Load Matrix Family

WLTP IG asked the Annex 4 Task Force to develop the Road Load Matrix Family as an alternative road load determination option to the coast down, torque meter and wind tunnel method on the one hand and the calculation method (default road load) on the other hand.

The objective is to deliver realistic road load values for low-volume vehicles, in particular for large vans, under reduced test burden but without opening a loophole for unwanted application. The IG indicated a conservative approach as the guiding principle when developing the Road Load Matrix Family method. Although the Road Load Matrix Family is built on physical laws, a safety margin should prevent the new method delivers profitable values compared to standard methods (coast down, torque meter, wind tunnel) and should provide an incentive to use, if possible, these standard methods.

Principle of the road load matrix family

The basic principle of the Road Load Matrix Family is only one generic road load measurement, and extrapolation[50] of the outcome of this measurement to derive the settings of vehicle H and L for chassis dynamometer tests. This is in contrast to the standard road load determination methods, which always use two measurements at the extremes for vehicle H and L.

Scope

For the Road Load Matrix Family it was decided that the method should not be applicable for high-volume main stream vehicles. This was achieved by setting an objective criteria by means of a minimum limit to the technically permissible maximum laden mass of 3000 kg. The scope of vehicles within the GTR itself is limited to a technically permissible maximum laden mass of 3,500 kg.

Safety margin

The safety margin implemented in the Road Load Matrix Family method is ensured by the following two elements:

1. **Estimated worst C_d**
   An important principle of the Road Load Matrix Family method is the selection of a representative test vehicle. On the one hand the test vehicle should be as representative as possible for the vehicle family (estimated average mass of optional equipment, representative body shape) in order to keep the actual average production vehicle as close as possible to the measured test vehicle. On the other hand the aerodynamic parameters are not considered in the extrapolation of the road load values to vehicle H and L, therefore the representative body of the test vehicle should have a configuration with the estimated worst-case C_d value (e.g by installing external body options such as spoilers and roofrails, and by selecting the least aerodynamic wheel rims).

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[50] Strictly speaking this is not an extrapolation, but an extension. The term ‘extrapolation’ is selected as this was the standard expression used in WLTP meetings. In the gtr-text the use of the term ‘extrapolation was avoided.

2. **Correlation factors:** The road load values for vehicles H and L are calculated from the value of the tested vehicle by extrapolation. To establish a safety margin conservative correlation factors are introduced. In this appendix a correlation factor is defined as the value to which the dominant vehicle parameters are assumed to correlate with the road load. The correlation factor has a value between 0 and 1. To ensure a safety margin for upward and downward extrapolation, the correlation factors are different in both directions.

Correlation factors

Conservative correlation factors were introduced in order to derive road load values of each individual vehicle and vehicles H and L that are very likely to be higher than the actual values if they had been measured. The correlation factors are based on:

a) The best available scientific knowledge of the dependency of road load values to vehicle parameters. Besides C_d, for which the worst case approach is chosen, the dominant parameters are test mass (TM), tyre rolling resistance (RR) and frontal area (A_f). These parameters are selected as parameters in the correlation formulas.

b) Observed real world correlations. Only a very limited number of measurements was available to the Task Force, indicating a direct correlation of typically 85-90% on the selected vehicle parameters.

c) The determination of the conservative correlation factors was based on the following assumptions and scientific evidence[51]:

   i. the parameters selected to be included in the correlation are a selection of the main influences. By assuming they together account for all of the road load influences, consequently their impact will overrepresented.

   ii. total rolling resistance is a combination of tyre and the drivetrain losses. Drivetrain resistances are only slightly vehicle mass dependent. Typically drivetrain losses make up for 10%-20% of the total f_0 coefficient. The share is typically lower for vehicle H than for vehicle L.
   An EC study yielded 14% of drivetrain losses for a front wheel drive vehicle with manual transmission. Larger effects for automatic transmissions and all-wheel drive can be expected.

   iii. remaining unexplained effects occur. The separation between rolling resistance and air drag is not as straightforward as the f_0 and f_2 equations suggest. In the standard coast down method this is overcome by the introduction of f_1. Yet in the Road Load Matrix Family method, f_1 is set to 0.

d) The outer envelope of observed correlation is considered to be the conservative approach, implying a higher correlation factor for calculation of road load values towards vehicle H and a lower correlation factor towards vehicle L. This is shown in Figure 62. The further away from the measured road load on the test vehicle, the higher the extrapolated road load will be above the actual road load value.

Based on the evidence listed above, and discussions within the Annex 4 Task Force, a final decision was made to use a correlation factor of 0.95 for upward extrapolation, and 0.80 for downward extrapolation. These values should ensure similar safety margins to either sides. A comparable stringency for upward and downward extrapolation brings an incentive to select the test vehicle in the middle of the range of CO_2 bandwidth.

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[51] Refer to document WLTP-11-17 at https://www2.unece.org/wiki/display/trans/WLTP+11th+session

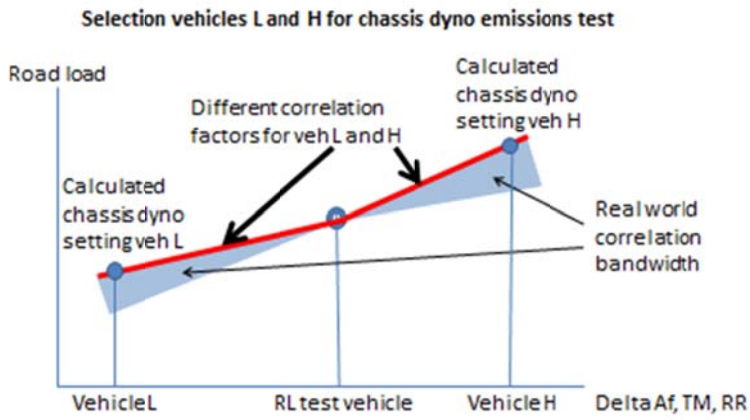

Figure 62: Upward and downward extrapolation for the road load matrix family

Effect of the correlation factor on the safety margin

The safety margin for the selected correlation factors was calculated based on a (limited) database of road load measurements of heavy LCV's, which was provided by ACEA[51]. This was done to verify if the correlation factors would lead to comparable safety margins for vehicle L and H. These LCV's have CO_2 emissions in the order of 260 to 300 g/km. The absolute and relative safety margins for the selected correlation factors are indicated in the table below for a typical example vehicle:

	Correlation factor	Safety margin[1]	
		Delta CO_2 in g/km	Relative delta CO_2
X_{up}[2]	0.95	2.7	1%
X_{down}[3]	0.80	2.7	1%

1. *Safety margin is the calculated road load values of vehicle H or L minus the measured road load values for the vehicles in the database, expressed in resulting delta CO_2-figures.*
2. *X_{up} is the correlation factor for the calculation of the road load values of vehicle H*
3. *X_{down} is the correlation factor for the calculation of the road load values of vehicle L*

Table 24: CO_2 safety margin for upward and downward extrapolation

CO_2 calculation

By extrapolation of the road load to vehicle L and H, the target road loads for measuring these vehicles at the chassis dynamometer can be found. The test vehicle is tested at the vehicle L and the vehicle H road loads, and the CO_2 results are used to draw an interpolation line for CO_2 against cycle energy. For any of the other vehicles in the RLMF, the cycle energy will be calculated from the extrapolated road load, and then the CO_2 follows from the interpolation method. Note that the CO_2 interpolation line does not have the kinked shape of red line in Figure 62.

The effect of the safety margin on the resulting CO_2 value by a higher calculated road load is graphically represented in Figure 63. For the middle vehicle, the road load is measured, hence there is no difference. However, both vehicle L and H have received a higher CO_2 value because of their higher road loads.

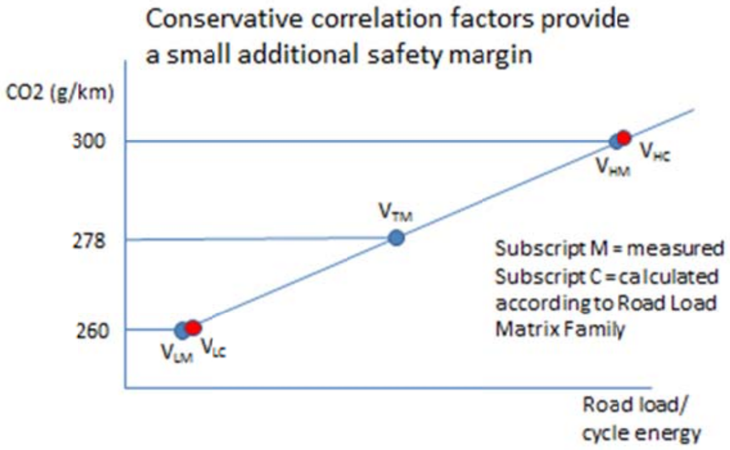

Figure 63: Graphical representation of the effect of the safety margin on CO_2

Family range and extension

Whereas the family range of the standard road load family is 35% of the cycle energy demand of vehicle H_R, no direct limitation for the Road Load Matrix Family was proposed. This limitation was not deemed necessary since:

a) The scope of application is limited to vehicles with a technically permissible maximum laden mass above 3 tons
b) A representative vehicle (with worst-case aerodynamic drag) is used as a basis for the road load determination
c) The built in safety margin ensures that the difference to the actual road load worsens for vehicles further away from the tested vehicle.

The method of the road load family matrix is included in the GTR in chapter 5 of Annex 4.

CO_2 interpolation

In addition to the determination of the road load for individual vehicles, the road load matrix family approach is also extended to the CO_2 determination in order to reduce the test burden and to avoid wind tunnel measurements for vehicles falling in the scope of the RLMF.

The vehicles within a RLMF for which CO_2 interpolation is applied have to fulfill the same criteria as for the Interpolation Family of normal passenger vehicles. However, the RLMF is not limited to a 30g/km CO_2-range. The larger the range of CO_2 the RLMF, the wider the safety margin of the road load will be and as a consequence also for the CO_2.

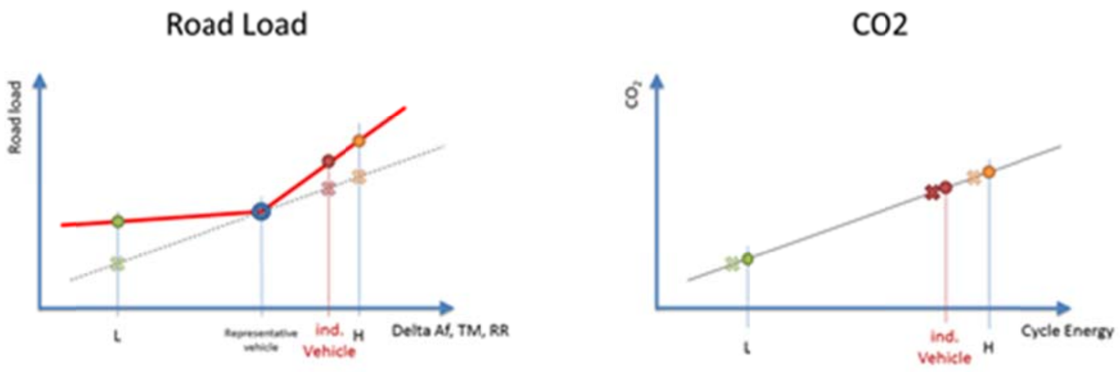

Figure 42: Link between safety margin on Road Load and CO_2

The CO_2 measurements for vehicle L and H are performed on a chassis dyno using the road loads of the RLMF calculation. These measured CO_2 values are used for the interpolation of individual CO_2 values based on the individual cycle energy, which is an output of the RLMF calculation. This method is similar to what is already described in the GTR on the CO_2 interpolation for normal passenger cars, and is illustrated in Figure 63.

It is also possible to reduce the safety margin by performing additional coast down measurements between the representative vehicle and the vehicles L and/or H. With the resulting cycle energies and using the CO_2 measurements for vehicle L and H, the CO_2-value for an individual vehicle can then be calculated more precisely.

Appendix 3 - 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[52]

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

ECE-R 83

ECE-R 101

ECE-R 24

GTR no.2 (Two-wheeled motorcycles)

GTR no.4 (Heavy duty vehicles)

Japan

Automobile Type Approval Handbook for Japanese Certification

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[52] 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.

Brazil

ABNT NBR 15598 (Brazilian Standard for Ethanol)

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- Greg Archer, Transport & Environment
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