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A complementary emissions test for light-duty vehicles: Assessing the technical feasibility of candidate procedures

Conclusions of the Real-Driving Emissions — Light-Duty Vehicles (RDE-LDV) working group

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Executive summary

Light-duty diesel vehicles emit on the road substantially more nitrogen oxides (NO_X) than permitted by regulatory emissions standards. With regard to the European air quality targets, the European Commission addresses this problem by developing a complementary emissions test procedure to be applied for the type approval and in-service conformity testing of all light-duty vehicles. The procedure is to be gradually implemented from 2014 onward and should limit NO_X and other pollutant emissions over a wide range of normal operating conditions. To facilitate the technical development, the European Commission established in January 2011 the Real-Driving Emissions - Light-Duty Vehicles (RDE-LDV) working group that is open to stakeholders. Up to June 2012, the RDE-LDV working group carried out a technical assessment of candidate procedures. As the result of an initial screening process, two procedures were assessed in detail: (i) emissions testing with random driving cycles in the laboratory and (ii) on-road emissions testing with Portable Emissions Measurement Systems (PEMS). This report presents the results of the assessment.

Both candidate procedures are technically feasible. However, PEMS on-road testing may be more effective than random-cycle testing in limiting the pollutant emissions of light-duty vehicles because it (i) allows a wider range of driving conditions to be covered and (ii) appears to be more effective in preventing the detection of emissions tests by vehicles and thus the use of defeat strategies under normal conditions of vehicle use. These two aspects are considered key priorities by the European Commission. PEMS on-road testing faces, however, practical challenges, including open safety issues, the currently limited availability of PEMS equipment, and potential climatic, geographical, and seasonal constraints for the execution of emissions tests. Random-cycle testing presents advantages over PEMS on-road testing in that it allows established laboratory equipment and know-how to be used.

The present assessment is subject to uncertainty because the implementation and running costs as well as the overall effectiveness of the two candidate procedures depend on the definition of concrete boundary conditions (e.g., permitted test temperatures, severity of driving patterns). These definitions are not yet agreed. Accounting for the resulting uncertainty, it has been decided that the JRC will develop a PEMS-based test procedure by the end of 2013. Vehicle manufacturers are given the opportunity to develop a random cycle-based test procedure in the same time period. A decision will be made regarding implementation for type approval and in-service conformity testing based on a comparison of the two fully developed procedures. The European Commission will ultimately support the adoption of the RDE-LDV test procedure as a complementary and globally-harmonized test procedure in the second phase of the WLTP process.

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ACEA	-	European Automobile Manufacturers' Association
^{o}C	-	Degrees Centigrade
CADC	-	Common Artemis Driving Cycle
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
CVS	-	Constant Volume Sampler
DG ENTR	-	Directorate-General for Enterprise and Industry
EC	-	European Commission
ECE	-	United Nations Economic Commission for Europe
EGR	-	Exhaust Gas Recirculation
EPA	-	United States Environmental Protection Agency
EU	-	European Union
EUDC	-	Extra Urban Driving Cycle
g	-	Gram
GDI	-	Gasoline Direct Injection
h	-	Hour
HC	-	Hydrocarbons
JRC	-	Joint Research Centre of the European Commission
km	-	Kilometer
km/h	-	Kilometers per hour
LDV	-	Light-duty vehicle
min	-	Minute
MS	-	Member State(s)
NEDC	-	New European Driving Cycle
NGO	-	Non-Governmental Organization
NH_3	-	Ammonia
NO_2	-	Nitrogen dioxide
NO_X	-	Nitrogen oxides
OEM	-	Original Equipment Manufacturer
PEMS	-	Portable Emissions Measurement System(s)
PM	-	Particle mass
PM-PEMS	-	PEMS capable of determining particle mass
PN	-	Particle number
RDE-LDV	-	Real-Driving Emissions - Light-Duty Vehicles
s	-	Second
SCR	-	Selective Catalytic Reduction
THC	-	Total hydrocarbons
WLTP	-	Worldwide-harmonized Light-vehicles Test Procedure

Disclaimer and acknowledgements

With this report, the authors aim to provide an objective assessment of the emissions test procedures discussed in the RDE-LDV working group. This aim is to some extent hampered by the limited data availability and the currently unspecified boundary conditions for the candidate test procedures. Any biases in the assessment are unintentional. The views expressed here may not represent in every detail the official position of the European Commission or the opinion of participants of the RDE-LDV working group. The authors thank the members of the RDE-LDV working group for contributing their expertise to this technical report. Acknowledgements go to Stefano Alessandrini, Massimo Carriero, Rinaldo Colombo, Giorgio Cornetti, Jan Cortvriend, Henk Dekker, Oliver Eberhardt, Francis Flaherty, Fausto Forni, Gaston Lanappe, Philippe Le Lijour, Urbano Manfredi, Francois Montigny, Alessio Provenza, Stephan Redmann, Mirco Sculati, and Juliana Stropp for their assistance in vehicle testing, data analysis, and the drafting of this report. Errors are solely the responsibility of the authors.

1 Introduction

On-road emissions tests conducted by the Joint Research Centre (JRC) with Portable Emissions Measurement Systems (PEMS) show that the real-world nitrogen oxides (NO_X) emissions of Euro 3-6 light-duty diesel vehicles substantially exceed the regulatory emissions standards (Rubino et al., 2007, 2009; Weiss et al., 2011a,b; 2012). These findings are confirmed by independent PEMS on-road tests (Vojtisek-Lom et al., 2009; Gauss, 2011; Lee, 2012) as well as remote sensing data (Carslaw et al., 2011). On-road emissions tests, furthermore, indicate that the distance-specific NO_X emissions of Euro 3-5 light-duty diesel vehicles show no reasonable reduction in the past decade. Preliminary analyses of Euro 6 light-duty vehicles confirm the technical potential of selective-catalytic reduction (SCR) systems to achieve more stringent emissions standards (Vonk and Verbeek, 2010; Weiss et al., 2012). However, Gauss (2011) finds that the on-road NO_X emissions of Euro 6 diesel vehicles equipped with various emissions reduction technologies may exceed the emissions levels of current Euro 5 vehicles, if driven under similar conditions. The existing on-road tests unequivocally point to weaknesses in the current type-approval procedure and raise concerns whether the introduction of Euro 6 will considerably reduce NO_X emissions of light-duty diesel vehicles.

To address these concerns, the European Commission set up in January 2011 the Real-Driving Emissions - Light-Duty Vehicles (RDE-LDV) working group with the aim of developing a complementary emissions test procedure for light-duty vehicles. The test procedure is to be gradually implemented from the Euro 6 dates in 2014 onward and should ensure that pollutant emissions are effectively controlled under normal vehicle operation and use (EC, 2011a). The RDE-LDV working group is open to Member States, industry stakeholders, and NGOs. The mandate for the working group is based on Regulation 715/2007 (EC, 2007) supported by Regulation 692/2008 (EC, 2008a). The European Commission originally intended to address real-driving emissions in the context of the Worldwide harmonized Light-vehicles Test Procedures (WLTP). However, on-road emissions may only be addressed in Phase 2 of WLTP after 2014. Given the air quality problems (EEA, 2011) and the regulatory provisions, such a time frame was considered to be unacceptable for Europe. This report presents the achievements of the RDE-LDV working group by June 2012. During this period, the working group has established on-road emissions values for light-duty vehicles and assessed the technical feasibility of candidate procedures. The results of the assessment provide the rationale for the technical development of the complementary RDE-LDV test procedure for the type approval and in-service conformity testing of light-duty vehicles.

The remaining parts of the report are structured as follows: Section 2 presents the objective and outline of activities of the RDE-LDV working group. Sections 3 and 4 present background information and milestone achievements. Section 5 focuses on the technical assessment of candidate procedures. The report ends with an outlook (Section 6) and principal conclusions (Section 7).

2 Objective and outline of activities

The objective of the RDE-LDV working group is to: (i) assess the real-driving on-road emissions of light-duty vehicles and (ii) coordinate the technical development of a complementary emissions test procedure for the type approval and in-service conformity testing of light-duty vehicles (EC, 2011a). The activities of the working group were initially structured in four phases:

- In Phase 1 (April 2011 - May 2012), the on-road emissions of light-duty vehicles are to be established and the technical feasibility of candidate procedures is to be assessed. Special attention should be paid to the drivability of test cycles in the laboratory and methods to be used for analyzing emissions measurements. The JRC provides guidelines (EC, 2011b,c) to support stakeholders in conducting emissions tests in the laboratory and on the road.
- In Phase 2 (May - June 2012), the assessment of candidate procedures is to be finalized and a decision should be made regarding the further development of test procedure(s).
- In Phase 3 (July 2012 – September 2013), a complementary test procedure is to be developed. This task should be supported by a pilot test campaign and includes, e.g., the definition of boundary conditions, not-to-exceed limits, and methods for data analysis as well as the preparation of a draft description of test procedure(s).
- In Phase 4 (depending on the selected procedure(s) until December 2013), the protocol for the complementary RDE-LDV test procedure (including emissions testing and data evaluation) is to be finalized.

Phases 3 and 4 also include the dissemination of know-how about procedural elements and technologies considered to be relevant for implementation of the complementary RDE-LDV test procedure.

This report summarizes the activities in Phases 1 and 2 of the RDE-LDV working group and describes in detail the assessment of candidate procedures. The conclusions from this assessment provide the basis for the European Commission and the Member States to decide on the test procedure(s) to be developed further. The present report thus lays the foundations for activities in Phases 3 and 4 from the second half of 2012 onwards. The assessment of candidate procedures is based largely on the stakeholder input provided during the meetings of the RDE-LDV working group. Nevertheless, this report does not present the consensus position of the RDE-LDV working group as several points in the assessment remain controversial. The report refers to this controversy wherever relevant for an objective evaluation of the candidate test procedures. The next section presents background information about the emissions measurements conducted by the JRC on light-duty vehicles that led to the establishment of the RDE-LDV working group.

3 Background

3.1 Standard emissions testing and legal background

For type approval in the European Union, light-duty vehicles currently have to comply with Euro 5 emissions standards (Regulation 715/2007; EC, 2007). Compliance with the emissions standards is verified by the so-called Type I test that is used to measure the tail-pipe emissions of vehicles after cold start by following a standardized test procedure in the laboratory (EC, 2008a,b; UNECE, 2011b). Currently, the New European Driving Cycle (NEDC) is used as test cycle. The NEDC is a modal driving cycle that consists of four repeated urban driving cycles (the so-called ECE-15 cycles, each lasting 195 s) and one extra-urban driving cycle (EUDC) of 400 seconds duration (Figure 1). The entire NEDC covers a distance of 11.007 km in 1180 s at an average speed of 34 km/h.

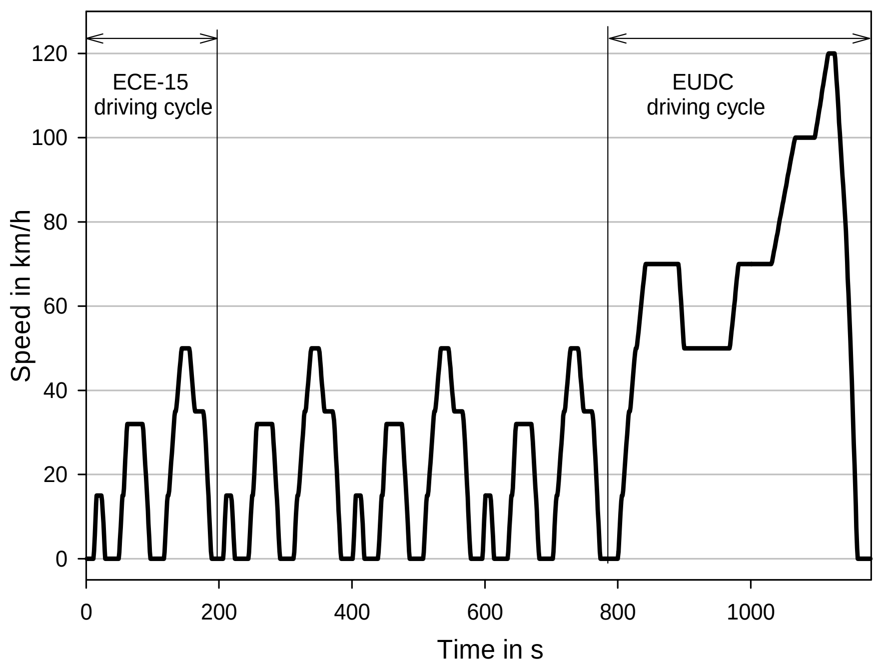

Figure 1: Speed profile of the New European Driving Cycle (NEDC)

Regulation 715/2007 (EC, 2007) defines in addition to the Euro 5 emissions standards also more stringent Euro 6 emissions standards to be enforced gradually from 2014 onward. This Regulation also contains provisions to ensure that the emissions standards are effective under real-world vehicle operation and use.

- Recital 15 demands that: "The Commission should keep under review the need to revise the New European Drive Cycle as the test procedure that provides the basis of EC type approval emissions regulations. Updating or replacement of the test cycles may be required to reflect changes in vehicle specification and driver behavior. Revisions may be necessary to ensure that real world emissions correspond to those measured at type approval [*sic*]. The use of portable emission measurement systems and the introduction of the 'not-to-exceed' regulatory concept should also be considered."

- Article 14(3) requires that: "The Commission shall keep under review the procedures, tests and requirements [...] as well as the test cycles used to measure emissions. If the review finds that these are no longer adequate or no longer reflect real world emissions, they shall be adapted so as to adequately reflect the emissions generated by real driving on the road."

Following these provisions, the JRC has been testing since 2007 the on-road emissions of light-duty vehicles with PEMS. The principal findings of these tests are presented next.

3.2 On-road emissions of light-duty vehicles

The JRC has been conducting on-road emissions tests with light-duty diesel and gasoline (i.e., petrol)[1] vehicles on four dedicated test routes. These routes were designed over the past years to investigate the emissions behavior of vehicles under urban, rural, uphill/downhill, and high-speed driving conditions (Figure 2). The test routes capture, as far as possible, the range of on-road driving in Europe but do not necessarily reflect the average European driving conditions. The methodological details of on-road emissions testing at the JRC are described in Weiss et al. (2011a,b; 2012). The results of the emissions tests conducted with 12 light-duty vehicles (including six Euro 3-5 diesel vehicles, five Euro 3-5 gasoline vehicles, and one Euro 4 gasoline-hybrid vehicle) are reported by Weiss et al. (2011a,b) and provide the empirical basis for the establishment of the RDE-LDV working group in January 2011. Since then, the JRC has tested three more vehicles, including a novel Euro 6 diesel vehicle.

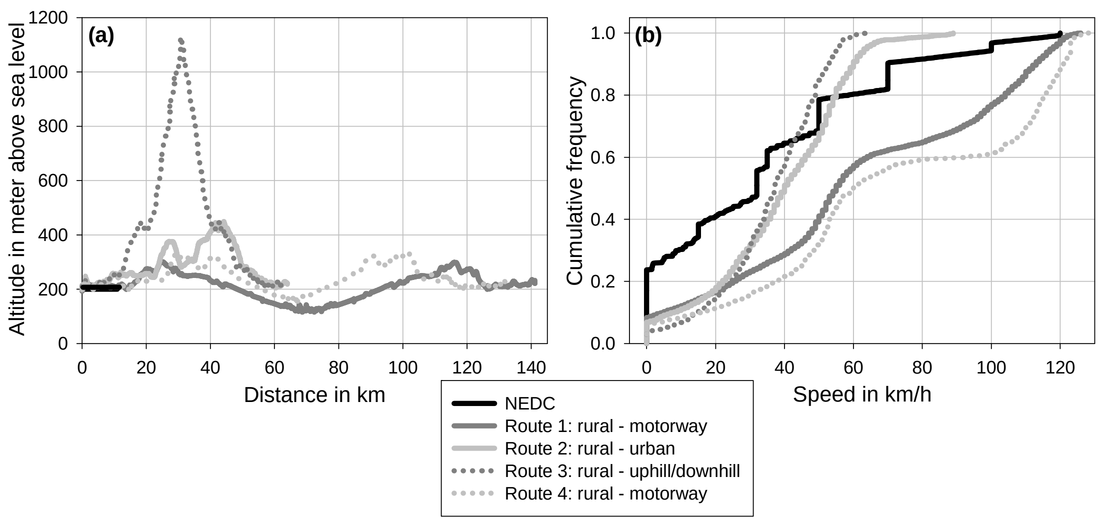

Figure 2: Altitude profile (a) and typical speed distribution (b) of the four JRC test routes as compared to the NEDC; the NEDC does not simulate altitude changes, the altitude of NEDC testing depicted here reflects the geographical location of the vehicle emissions laboratory of the JRC

[1] Throughout this report, the terms 'gasoline' and 'petrol' are used synonymously.

The results suggest that the on-road THC and CO emissions of light-duty diesel and gasoline vehicles (Figures 3 and 4) as well as the on-road NO_X emissions of light-duty gasoline vehicles generally remain below the respective emissions standards (Figure 5). By contrast, the on-road NO_X emissions of diesel vehicles substantially exceed the Euro 3-6 emissions standards (Figure 5). In the case of NO_X emissions, three aspects are relevant:

- Considering the average distance-specific emissions over entire test routes, the on-road NO_X emissions of the tested Euro 3-6 diesel vehicles reach 350 ± 125% of their emissions standards, whereas the on-road NO_X emissions of the tested Euro 3-5 gasoline vehicles remain at only 44 ± 22% of the respective emissions standard.
- There appears to be no appreciable reduction in on-road NO_X emissions from Euro 4 to Euro 5 diesel vehicles. Our results indicate, however, substantially decreased on-road NO_X emissions of the one Euro 6 vehicle as compared to the tested Euro 5 diesel vehicles.
- NO_X emissions vary between test routes and vehicles certified according to the same emissions standard (e.g., compare the NO_X emissions levels of Euro 5 Vehicles H-K). On-road tests conducted by Gauss (2011) likewise suggest that the NO_X emissions of Euro 6 vehicles span a wide range; the results presented here for Euro 6 Vehicle O should thus not be considered as representative of the emissions performance of Euro 6 diesel vehicles currently offered on the market.

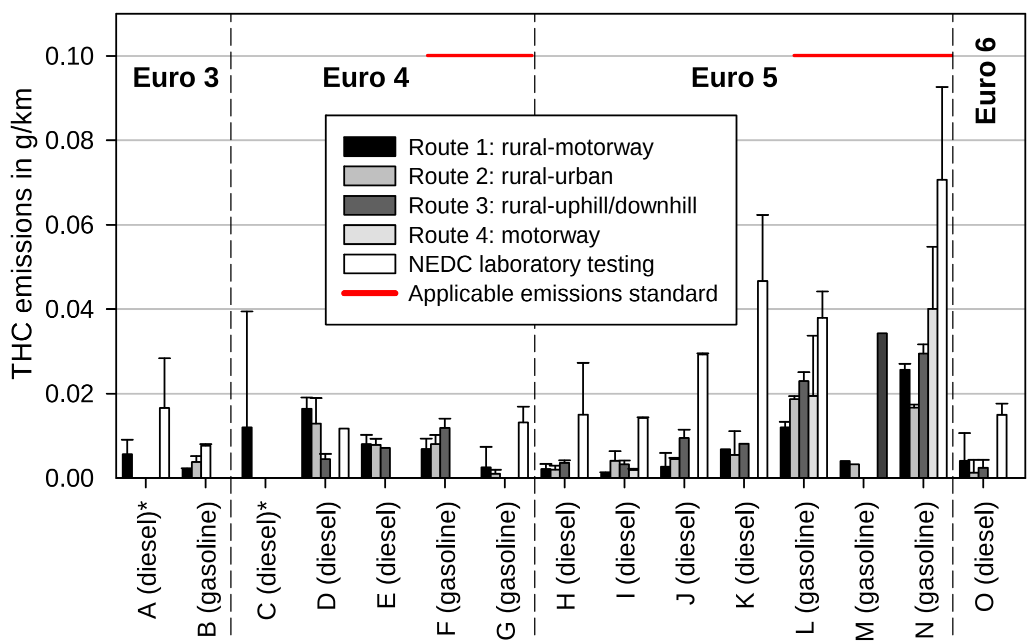

Figure 3: THC emissions during on-road driving as compared to laboratory testing with the NEDC; vertical bars represent emissions averages over the NEDC and over each test route; error bars represent the maximum average emissions observed for each vehicle over the NEDC and on each test route; no THC emissions standards are defined for light-duty diesel vehicles; the Euro 3 THC emissions standard of 0.2 g/km for gasoline vehicles is not shown here; *vehicles represent light-commercial vehicles (data sources: Weiss et al., 2011a,b; 2012)

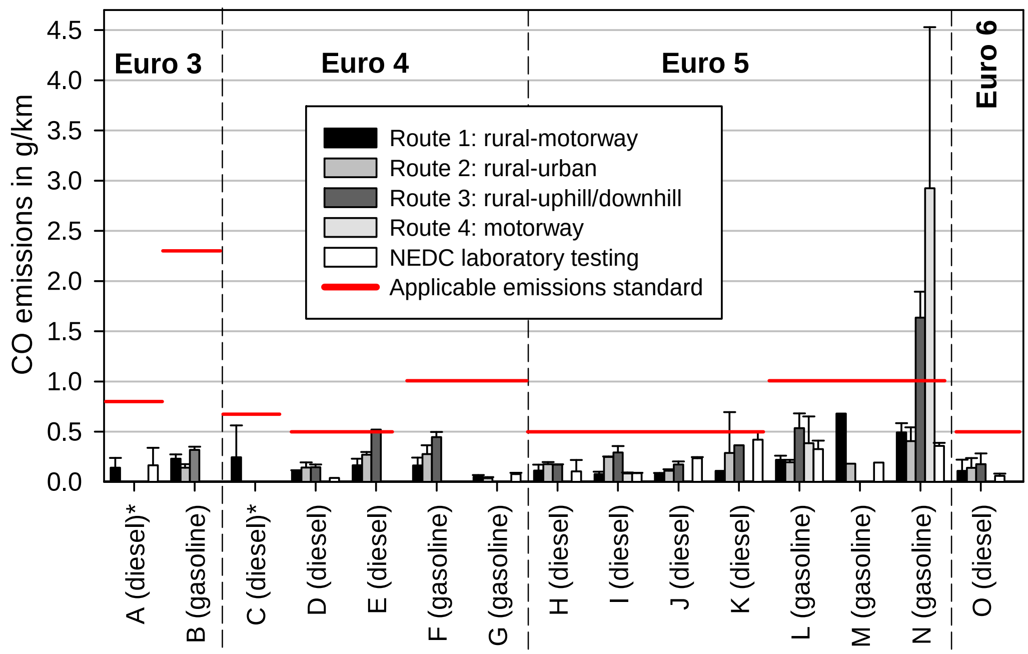

Figure 4: CO emissions during on-road driving as compared to laboratory testing with the NEDC; vertical bars represent emissions averages over the NEDC and over each test route; error bars represent the maximum average emissions observed for each vehicle over the NEDC and on each test route; *vehicles represent light-commercial vehicles (data sources: Weiss et al., 2011a,b; 2012)

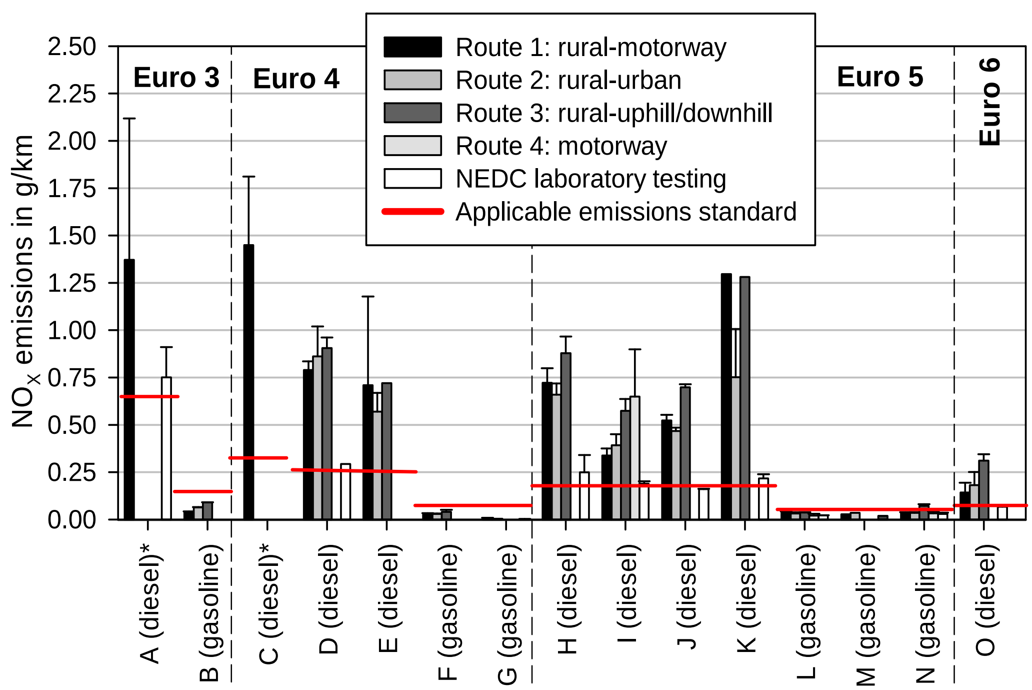

Figure 5: NO_X emissions during on-road driving as compared to laboratory testing with the NEDC; vertical bars represent emissions averages over the NEDC and over each test route; error bars represent the maximum average emissions observed for each vehicle over the NEDC and on each test route; *vehicles represent light-commercial vehicles (data sources: Weiss et al., 2011a,b; 2012)

Detailed insight into the on-road NO_X emissions of light-duty diesel vehicles can be obtained by applying the averaging window method. The method was first applied to heavy-duty vehicles (Regulations 582/2011 and 64/2012; EC, 2011d; 2012a) and has been adapted later by the JRC to analyze the on-road emissions of light-duty vehicles (Weiss et al., 2011a,b; 2012). Averaging windows represent subsections of entire on-road emissions tests. Each averaging window covers exactly the amount of CO_2 [kg] that a test vehicle has emitted over the complete NEDC during type approval. If, for example, a vehicle is type approved at 100 g CO_2/km, this vehicle has emitted 1.1 kg CO_2 during type approval over the NEDC; thus, an averaging window for this vehicle covers the distance driven until the vehicle has emitted 1.1 kg CO_2. The first window starts at cold-start and ends when the reference CO_2 mass has been emitted. The window then moves at time increments of one second along the test, always covering the reference CO_2 mass emitted over the NEDC. This way, several thousand windows are generated over a typical on-road emissions test. The distance [km] covered by each window varies with instantaneous fuel consumption on the road. The average distance-specific NO_X emissions over each window are calculated by dividing the total mass of NO_X emitted in a window [g] by the window distance [km]. The resulting emissions averages can be presented as cumulative frequency plots, in which the first dot on the left represents the lowest average distance-specific NO_X emissions and the last dot on the upper right side represents the highest average distance-specific NO_X emissions (see Figure 6).

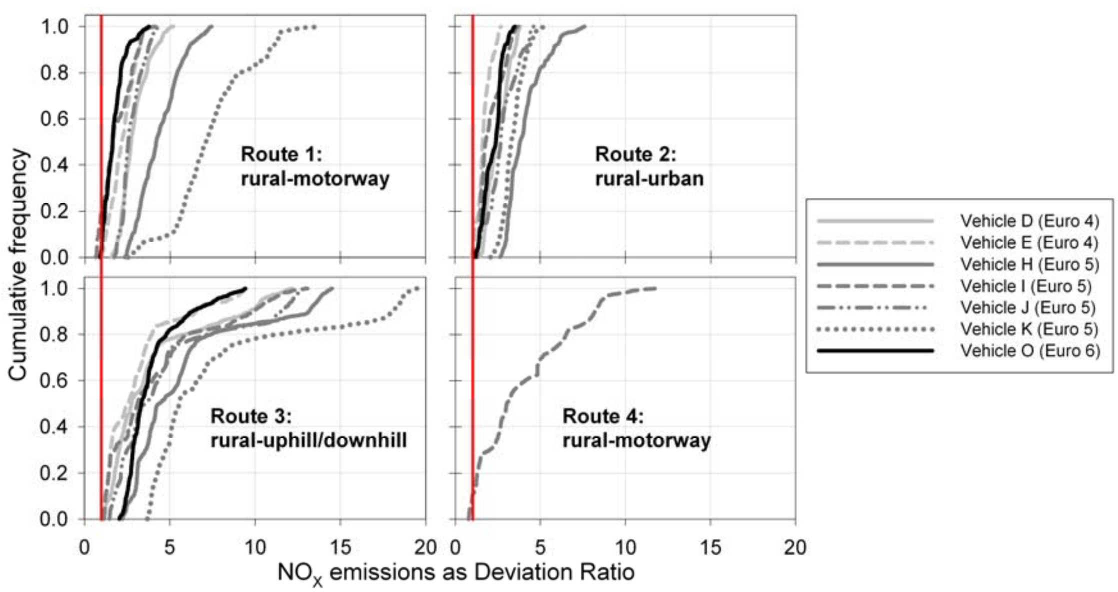

Figure 6: Cumulative frequency plot of averaging window NO_X emissions of Euro 4-6 light-duty diesel vehicles as measured during one selected emissions test for each vehicle on each test route (Data sources: Weiss et al., 2011a,b; 2012)

The cumulative frequency plots in Figure 6 present emissions as deviation ratios, i.e., the observed distance-specific emissions [g/km] divided by the respective emissions standard [g/km]. A deviation ratio of ten thus indicates that the average emissions over a window are ten times the emissions standard.

The results in Figure 6 show that:

- the average NO_X emissions of almost all averaging windows exceed the emissions standards for the tested Euro 4-6 diesel vehicles;
- there are substantial differences in the deviation ratios on individual test routes: Route 2 yields a maximum deviation ratio of 7 while the uphill/downhill Route 3 shows deviation ratios of up to 19;
- the deviation ratios of Euro 5 diesel vehicles appear to be larger than those of the one Euro 6 vehicle. However, the substantial variability in deviation ratios between individual Euro 5 vehicles suggests caution when drawing conclusions based on the results for one Euro 6 vehicle only.

Gauss (2011) finds substantial variability in the distance-specific on-road NO_X emissions of Euro 6 diesel vehicles, which in some cases exceed the emissions levels of Euro 5 vehicles. The emissions found here for the Euro 6 diesel vehicle are indicative of the technical capabilities of SCR systems, but may not represent the overall trend in the on-road NO_X emissions of new Euro 6 diesel vehicles.

The elevated NO_X emissions of light-duty diesel vehicles during on-road driving as compared to laboratory testing with the NEDC may be explained by several factors:

- Polluting driving conditions, e.g., characterized by medium/high engine loads are covered by the NEDC for only a short time while these conditions occur for longer time intervals during on-road driving.
- Polluting driving conditions, such as high engine loads during acceleration events, uphill/downhill and high-speed driving, as well as micro-transient driving, are not covered by the NEDC.
- Ambient conditions occurring during on-road driving (temperature, humidity, precipitation) may be outside of the narrow specifications of NEDC testing.
- Road-load factors as applied during laboratory testing may deviate from the conditions of real-world on-road driving; the use of accessories such as air-conditioning or headlights may raise the actual on-road emissions levels.

Preliminary insight into the contribution of these factors to the actual NO_X emissions of light-duty diesel vehicles suggests that the NEDC indeed covers only a small part of the acceleration values and NO_X emissions encountered over the entire speed range of on-road driving (Figures 7 and 8).

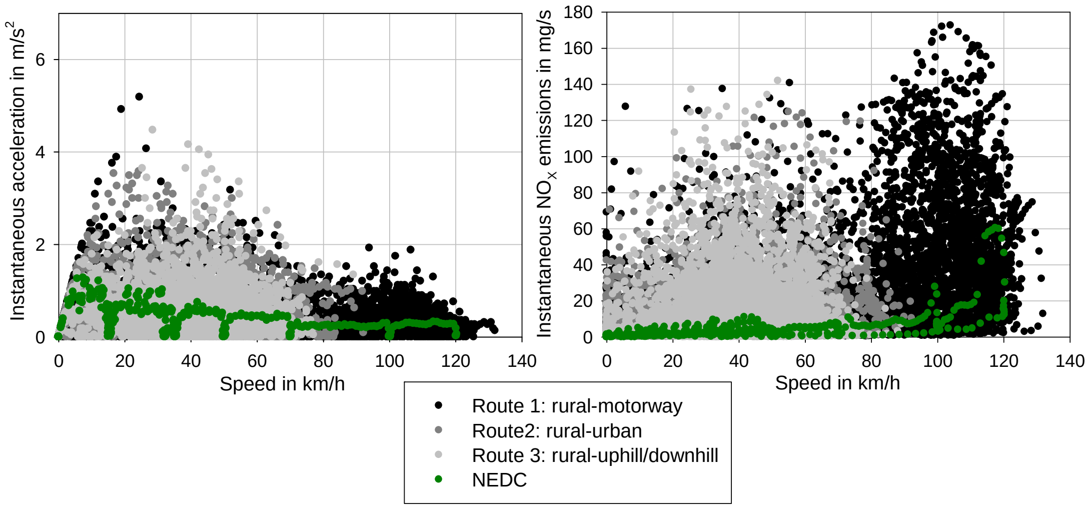

Figure 7: Acceleration and NO_X emissions during on-road driving and laboratory testing with the NEDC; example of Euro 5 diesel Vehicle K

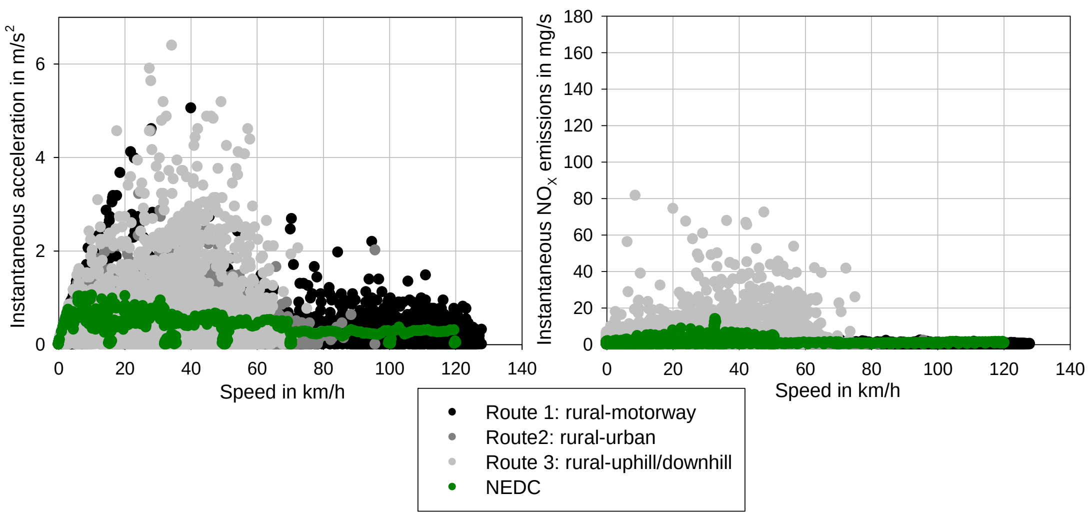

Figure 8: Acceleration and NO_X emissions during on-road driving and laboratory testing with the NEDC; example of Euro 6 diesel Vehicle O

High-speed driving (i.e., at speeds up to 130 km/h) results in considerably elevated NO_X emissions for the tested Euro 5 diesel vehicle. NO_X emissions from high-speed driving are effectively limited by the SCR after-treatment system in the Euro 6 vehicle (Figure 8). For the Euro 6 diesel vehicle, high NO_X emissions result from uphill/downhill driving on Route 3 and might be related to high engine loads during uphill driving and to thermal cooling of the SCR system during downhill driving.

Complementary tests over the NEDC suggest furthermore that ambient conditions affect the NO_X emissions of light-duty diesel vehicles. Kühlwein (2012) tested a Euro 5 diesel vehicle over the NEDC and found a strong dependency of NO_X emissions on the engine temperature at test start (Figure 9).

This observation suggests that the emissions performance of diesel vehicles could indeed be optimized for an overly narrow set of test conditions that translate into false technology drivers. Kwon (2012) supports this observation by identifying substantially elevated NO_X emissions for a Euro 5 diesel vehicle tested on the NEDC with activated air conditioning.

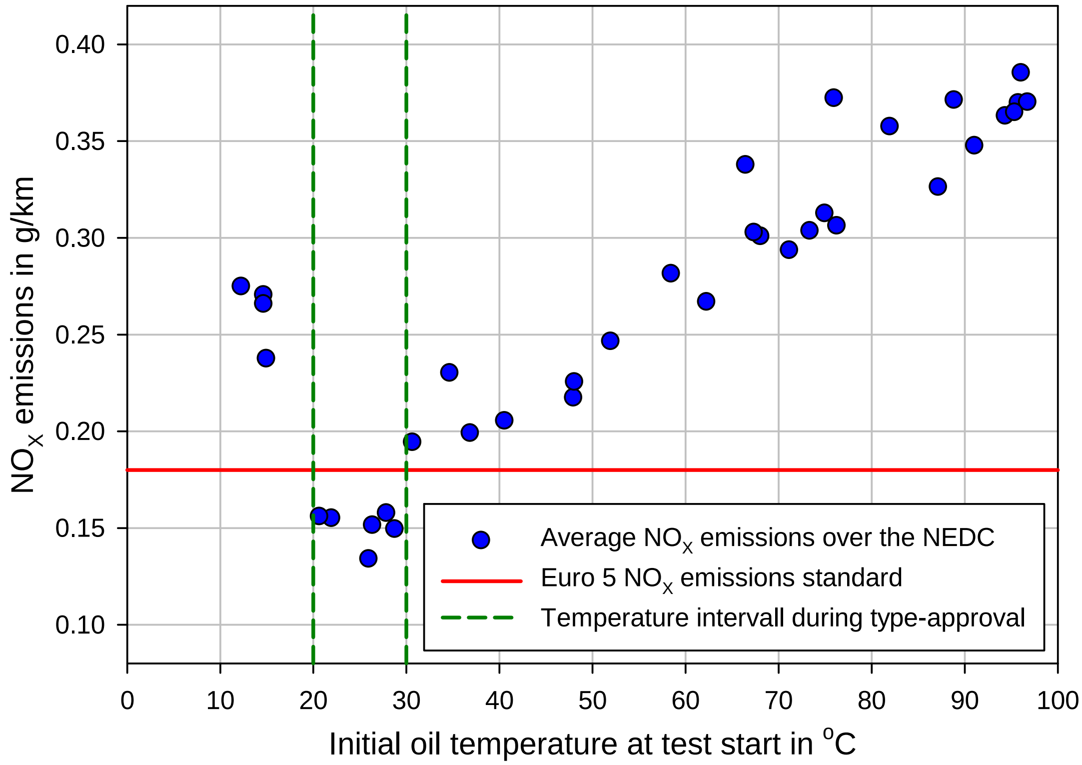

Figure 9: Average NO_X emissions of a Euro 5 diesel vehicle over the NEDC at various initial engine temperatures (Data source: Kühlwein, 2012)

The test results presented in this section point to the weaknesses of the current Type I emissions testing for type approval: While ensuring a high repeatability and reproducibility of emissions tests, the test procedure forces the adaptation of vehicle technologies to an overly narrow set of operating conditions that no longer sufficiently capture the normal conditions of vehicle use. Specifically, the findings of Kühlwein (2012) and Kwon (2012) suggest that the emissions performance of vehicles is optimized only for emissions testing under the precisely defined type-approval conditions. This problem could be addressed by widening the range of boundary conditions (i.e., driving and ambient conditions) permissible for the complementary test procedure[2] as well as by introducing randomness into emissions testing. The next section outlines the work of the RDE-LDV working group from its establishment in January 2011 until June 2012.

[2] The terms ‘complementary test procedure’, ‘RDE-LDV test procedure’, and ‘complementary RDE-LDV test procedure’ are used synonymously throughout this report.

4 Milestones of the RDE-LDV working group

4.1 Legal mandate

The RDE-LDV working group was set up by DG ENTR in January 2011. The working group is open to stakeholder experts and should accompany the technical development of a complementary emissions test procedure lead by the JRC. Its mandate is limited to providing technical advice, acting as a platform for the exchange of information and standpoints between Member States, industry stakeholders, and NGOs. The political elements and legal implications of implementing the complementary RDE-LDV test procedure for Euro 6 vehicles will be discussed elsewhere (EC, 2011a).

4.2 Purpose of the RDE-LDV test procedure

The RDE-LDV test procedure should complement the current Type I test procedure for the type approval of light-duty vehicles. The test procedure should be applicable to a wide range of light-duty vehicles and address the limitations of the current type-approval testing with the NEDC, thereby preventing the optimization of engines and emissions control systems for an overly narrow range of driving and ambient conditions. Achieving this objective requires ensuring that emissions control systems function properly under normal vehicle operation and use.

4.3 Results of the RDE-LDV working group until June 2012

The presentations, documents, and tools produced by the RDE-LDV working group are available on the *Circa* web server of the European Commission, which is open to members of the working group and upon request to the public (EC, 2012b). A timeline of key activities and results covering the period from the opening meeting in January 2011 until June 2012 is presented in Figure 10. At the opening meeting in January 2011, four candidate procedures were proposed:

- fixed driving cycles for emissions testing in the laboratory
- random driving cycles for emissions testing in the laboratory
- on-road emissions testing with PEMS
- emissions modeling

Key activities		Key results
Kick-off meeting; presentation of JRC report 62639; discussion of a generic road map of activities and presentation of candidate procedures	January 2011	• Actual on-road NO_X emissions of light-duty diesel vehicles substantially exceed type-approval levels • Suggested candidate procedures: fixed laboratory cycles; random laboratory cycles; PEMS on-road testing, vehicle modeling
Discussions about: objectives of the working group, time schedule, technical details of candidate procedures; initiating the technical assessment of random cycles and PEMS on-road testing	March 2011	• Exclusion of fixed laboratory cycles and vehicle modeling • Industry stakeholders and Member States confirm active participation
JRC presents the work plan and additional emissions tests of a Euro 5 diesel vehicle with PEMS and randomly designed speed traces in the laboratory; one equipment manufacturer demonstrates the installation of PEMS	May 2011	• Stakeholders agree on the work plan • Speed traces can be easily implemented in the laboratory; drivability unproblematic • Use of speed points instead of speed traces is unfeasible
Mr. Steven presents statistical analyses of European driving data used for the WLTP; discussions on the boundary conditions of the random cycle	July 2011	• Presentation of three random cycles comprising low, medium, and high severity driving by Mr. Steven
JRC tests a Euro 6 diesel vehicle; BMW presents information on test capacities; additional technical discussions; PEMS workshop at the Daimler AG (Germany)	September 2011	• The Euro 6 vehicle shows low on-road NO_X emissions that, however, exceed the respective emissions standard • Good drivability of the three random cycles • PEMS workshop provided guidance for on-road emissions testing
ACEA and the Netherlands present emissions results for diesel vehicles; ACEA presents a tool for analyzing emissions data	October 2011	• ACEA results confirm that the three random cycles are drivable; • PEMS data analysis needs further development
ACEA presents ideas for designing a random cycle generator; JRC presents analyses on the ACEA data evaluation tool	December 2011	• The ACEA data evaluation tool is functional and yields similar results as the evaluation tool used by the JRC
ACEA presents a random cycle generator; JRC presents preliminary tests of random cycles and a matrix to evaluate the candidate procedures; the Netherlands present critical aspects of emissions testing and analyses	March 2012	• The implementation of random cycles is feasible; random cycles can cover a wide range of driving conditions • More in-depth emissions analyses are required
Audio-web conference: JRC presents draft boundary conditions, an overview of stakeholder contributions to the evaluation of the two candidate procedures, and the results of back-to-back vehicle testing with random cycles and PEMS	April 2012	• The random cycle generator functions and the generated cycles are drivable • The NO_X emissions of the tested Euro 5 diesel vehicle are higher over the random cycle than over the NEDC but lower than during PEMS on-road testing
ACEA and JRC test Euro 6 vehicles with random cycles and PEMS; discussions about the evaluation of candidate procedures; JRC presents an overview of indicative boundary conditions; DG ENTR proposes several approaches for the implementation of the complementary RDE-LDV test procedure	May 2012	• ACEA and JRC yield comparable test results • ACEA disagrees with several aspects in the evaluation of candidate procedures and favors the random cycle for type approval and ISC testing but could consider an approach where MS challenge test results by using a PEMS procedure
ACEA presents a standpoint on the RDE-LDV test procedure; DG-ENTR informs the working group about the stand point of MS; JRC reports on the final evaluation and the revisions of the work plan; agreement is reached about the work until the end of 2013	June 2012	• MS request that the RDE-LDV test procedure contains PEMS elements. • JRC will lead the development of a PEMS-based test procedure • ACEA will lead the development of random cycles • A final decision on the implementation of the complementary test procedure will be made in 2013 (details see text)

Figure 10: Time line of key activities and results of the RDE-LDV working group in the period from January 2011 to June 2012

Fixed driving cycles were excluded because of concerns about the lack of randomness in emissions testing and potentially insufficient coverage of driving conditions. Predictability of driving cycles enables cycle-based emissions control technologies that may not function properly under normal vehicle use. Emissions modeling was excluded due to, the potentially challenging model validation, which may itself require substantial emissions testing in the laboratory and on the road. The RDE-LDV working group therefore focused from March 2011 onward on the technical assessment of random driving cycles and on-road emissions testing with PEMS. The aim was to identify whether the two procedures have fundamental weaknesses that would exclude them from further consideration. For the technical assessment, additional vehicles were tested on the road and in the laboratory. A workshop at Daimler AG was organized on 27 September 2011 to demonstrate the handling of PEMS equipment and the conducting of on-road emissions tests. In parallel, ACEA has developed a random cycle generator based upon short trips contained in the WLTP database. The random cycle generator was presented during a dedicated workshop at the Audi AG in Munich (Germany) on 22 March 2012 and has been assessed regarding its technical feasibility and functionality. Additional tests addressed the drivability of cycles and the emissions behavior of vehicles when driven over random cycles in the laboratory. The next section presents the results of the technical assessment of the two candidate procedures.

5 Results of the assessment of candidate procedures

5.1 Assessment approach

The candidate procedures are assessed based on criteria agreed by the RDE-LDV working group (Table 1). The criteria are chosen to ensure a comprehensive evaluation of the technical feasibility with regard to the objectives of the complementary RDE-LDV test procedure (EC, 2011a).

Table 1: Overview of assessment criteria

Category	Criteria
Coverage	Covers a wide range of driving conditions, and allows specific driving conditions to be targeted (e.g., urban driving)
	Covers a wide range of road profiles
	Covers a wide range of ambient conditions (temperature, humidity, altitude)
	Covers the regulated pollutants
Applicability	Applicable to a wide range of LDVs and powertrain technologies
	Neutrality in terms of engine and after-treatment technologies
	Availability of test facilities and equipment
	Availability and dissemination of know-how
	Extent to which methods are available for characterizing emissions
	International attractiveness (contributes to the harmonization of international emissions tests and standards)
	Safety and health impacts of emissions measurements
	Planning reliability of type-approval schedules and necessary lead time
	Accuracy of analytical equipment
	Equal treatment of OEMs from different countries regarding, e.g., speed limits, orographic conditions
Costs	Initial costs of implementation
	Running costs for performing emissions tests
Effectiveness	Prevents the optimization of vehicle technologies to an overly narrow range of operating conditions
	Reproducibility and repeatability of tests
	Influence of test procedure on the representativeness of test results for real-driving emissions
Legal implications and other issues	Legal certainty regarding pass/fail decision
	Usefulness of test procedure for development purposes

The two candidate procedures are compared according to each criterion individually, assuming that the other characteristics remain homogenous for both procedures (Table 2). The assessment is based on the results of emissions tests supplemented by expert judgment obtained from the members of the RDE-LDV working group. Often, test results are limited and incomplete or the assessment depends on assumptions regarding boundary conditions that have yet to be defined. The present assessment tries to account for these uncertainties as far as possible and has been conducted to the best of our knowledge. Nonetheless, given the limited insight into details (e.g., the precise boundary conditions for the future RDE-LDV test procedure), the assessment may not be entirely free of subjective judgments. The technical assessment should guide the decision making process but may not be regarded as a definitive judgment regarding the suitability of either of the two candidate procedures.

Table 2: The semi-quantitative assessment scale

Increments of the assessment scale	Interpretation
+	The procedure is superior with respect to the criterion considered.
-	The procedure is inferior with respect to the criterion considered.
o	Both procedures are equally suitable with respect to the criterion considered.
unknown	Current knowledge is insufficient to evaluate the procedure.

After assessing the two candidate procedures, we present the rationale for the selected criteria. We, furthermore, discuss the capabilities of test procedures to prevent the optimization of emissions control technologies/strategies for an narrow set of operating conditions.

5.2 Definitions

The RDE-LDV working group applies the following definitions for the assessment of the two candidate procedures:

Boundary conditions represent the set of conditions that specify the design of an emissions test. Defining the boundary conditions of the RDE-LDV test procedure, i.e., selecting parameters and value ranges is important for distinguishing between valid and invalid emissions tests.

On-road testing with PEMS refers to any test procedure that employs Portable Emissions Measurement Systems (PEMS) to measure the tail-pipe emissions of light-duty vehicles as they occur on the road during normal vehicle operation and use.

Orographic conditions comprise the local and regional elevation characteristics of a location. They typically include the absolute altitude and the altitude gradient of and around a location.

Random-cycle testing refers to any test procedure that employs driving cycles composed of randomly or semi-randomly arranged short trips to measure the tail-pipe emissions of light-duty vehicles on chassis dynamometers in the laboratory.

Repeatability refers to the degree to which emissions measurements on one specific vehicle can be replicated in one test facility under the given boundary conditions with the same analytical equipment. A high repeatability of an emissions test procedure may lead to emissions results that differ only negligibly from each other.

Reproducibility refers to the degree to which emissions measurements on one specific vehicle can be replicated within the range of permissible boundary conditions of a test procedure by various suitable analytical equipment and test facilities. P*ass-fail reproducibility* is an extension of this definition and refers to the likelihood that a pass-fail conclusion obtained based on one valid emissions test can be maintained after additional other valid emissions tests have been conducted.

Robustness refers to the capability of an emissions test procedure to determine whether the emissions control system of a vehicle sufficiently limits emissions levels over the wide range of operating conditions occurring during normal vehicle operation and use.

Box 1: Repeatability and reproducibility

Intense discussions among the members of the RDE-LDV working group concerned the definition of the terms *repeatability* and *reproducibility*. In science and engineering, repeatability and reproducibility are typically defined by considering the results of experiments, referring to the degree that multiple measurements conducted under similar conditions yield similar results. Repeatability can be regarded as the degree of accuracy that individual measurements can achieve if conducted by a single person on the same item and instrument under the same boundary conditions. Reproducibility can be defined as the degree of accuracy that can be achieved by measurements conducted on the same item under the same boundary conditions but in different locations and by different persons. These definitions somewhat assume that the properties of the analyzed items remain homogenous during measurements and that the variability in the results only depends on the accuracy of test equipment and the variability of test conditions. For light-duty vehicles, this assumption may hold for type-approval testing because the emissions behavior of vehicles is optimized for the narrow set of type-approval test conditions. However, this assumption may not necessarily hold for the normal conditions of vehicle use. The emissions behavior of modern light-duty vehicles is managed by complex control systems that may show a range of responses under seemingly identical test conditions (see Box 2 on cycle detection and the use of defeat devices). We would therefore exclude from the definition of repeatability and reproducibility the emissions results for vehicles and refer here only to the degree that test conditions within the boundary conditions of test procedures can be repeated and reproduced.

The definitions presented here are linked to the objectives of the RDE-LDV test procedure, which should control the emissions from light-duty vehicles more effectively than the current NEDC emissions testing. Achieving this objective requires a lower *repeatability* and *reproducibility*, i.e., allowing higher levels of randomness into emissions testing. In other words: If the RDE-LDV test procedure is to cover a wide range of operating conditions, a lower repeatability and reproducibility of individual RDE-LDV tests may need to be accepted. The repeatability and reproducibility of a test procedure is critical for vehicle manufacturers, who need confidence in the results of emissions tests and the possibility to retrieve useful information for designing vehicles and their after-treatment systems. In the next section, we apply the presented terminology to assess the two candidate procedures.

5.3 Assessment of random-cycle testing and PEMS on-road testing

The summary assessment in Table 3 indicates that both candidate procedures are technically feasible, albeit displaying distinct strengths and weaknesses. Detailed information for summary assessment is presented in Table 4.

The principal conclusions are:

- Both test procedures are technically feasible.
- PEMS on-road emissions testing may cover a wider range of driving and ambient conditions than random-cycle testing in the laboratory and may thus be regarded as potentially more effective in ensuring that the pollutant emissions of a wide range of light-duty vehicles are properly limited during normal vehicle operation and use. However, the implementation of PEMS on-road emissions testing faces practical challenges, including the currently limited availability of PEMS equipment and know-how, constraints on performing emissions tests due to the geographical locations of test sites, traffic conditions, and seasonal climate variations, as well as open safety issues.
- Random-cycle testing is more effective than emissions testing with the NEDC but may potentially cover a smaller range of driving conditions than on-road testing with PEMS. Specific concerns arise from the relatively short test durations, the potentially insufficient coverage of severe acceleration for high-power vehicles, and the limited ability to simulate micro-transient driving. However, random-cycle testing in the laboratory also presents advantages over on-road testing in that it allows: (i) using established analytical equipment of high accuracy and (ii) repeating and reproducing individual emissions tests under defined conditions. The latter characteristics may enable manufacturers better to validate emissions results as compared to PEMS testing on the road.
- Random-cycle testing will likely be detected by light-duty vehicles and may allow the application of defeat strategies to larger extend than PEMS on-road testing does.
- Random-cycle tests can be repeated and reproduced at high accuracy while PEMS on-road testing shows a considerably lower repeatability and reproducibility. The uncertainties resulting for type-approval and in-service conformity testing should be accounted for when defining concrete not-to-exceed emissions limits.
- The implementation and running costs of both candidate procedures depend to a large extent on the definition of the system boundaries, which are not agreed upon yet.

The present assessment is subject to uncertainty, specifically due to the absence of concrete system boundaries for the two candidate procedures. Depending on the permissible ranges of driving and ambient conditions, the results of the assessment presented here may change to some extent. The definition of boundary conditions affects the implementation and running costs of the RDE-LDV test procedure; thus, no detailed quantitative cost assessment is possible at this moment. As a rough approximation, however, it is reasonable to assume that adopting system boundaries that cover a wide range of ambient and driving conditions will reduce the relative costs of PEMS emissions testing as compared to random-cycle testing.

Conversely, adopting system boundaries that cover a narrow range of ambient and driving conditions will reduce the relative costs of random-cycle testing.

The following text presents the detailed quantitative information available to assess and evaluate the two candidate procedures. For reasons of brevity, we limit our explanations to criteria deemed to be particularly relevant in view of the objectives of the RDE-LDV test procedure.

The technical feasibility of applying PEMS to light-duty vehicles has already been demonstrated by Rubino et al. (2007, 2009) and Weiss et al. (2011a,b; 2012). Tests conducted by the JRC suggest that the accuracy and linearity of PEMS under laboratory conditions are in the range of the established laboratory equipment. These findings have been confirmed by official PEMS instrumentation validation programs launched by EPA (2008a). The PEMS equipment of several manufacturers fulfills the requirements specified for type-approval and in-service conformity testing of heavy-duty vehicles in the EU (EC, 2011d; UNECE, 2011a,b) and for in use-compliance testing of heavy-duty engines in the USA (EPA, 2008b).

However, the feasibility of random cycles to evaluate the emissions of light-duty vehicles as they occur under real-world conditions has not been demonstrated before the establishment of the RDE-LDV working group. The experience with random cycles that were designed based on the European short trips contained in the WLTP database suggests indeed that designing, implementing, and performing emissions tests with random driving cycles is technically feasible. The design of a random cycle with the currently available software tool and the implementation of the cycle in the laboratory can usually be achieved within 1-2 hours. If multiple cycles are designed, scale effects can reduce this time considerably. After the implementation, time requirements for performing emissions tests depend on the drivability of cycles and the operations necessary to precondition vehicles and test facilities. Detailed specifications for both aspects have not yet been agreed. Our preliminary results indicate that the random driving cycles designed with the software tool available as of June 2012 are drivable, assuming standard deviation margins of 2 km/h between actual and the scheduled vehicle speeds are applied (Figure 11, Table 5).

Table 3: Overview assessment of random-cycle testing and on-road testing with PEMS; scores represent the evaluation based on a pairwise comparison of the two candidate procedures with regard to each assessment criterion

	Score random-cycle testing	Score on-road testing with PEMS
Coverage		
Covers a wide range of driving conditions and allows specific driving conditions to be targeted (e.g., urban driving)	-	+
Covers a wide range of road profiles	-	+
Covers a wide range of ambient conditions	o	o
- temperature and humidity	+	-
- altitude	-	+
Covers the regulated pollutants	+	-
Applicability		
Applicable to a wide range of LDVs and powertrain technologies	o	o
Neutrality in terms of engine and after-treatment technologies	o	o
Availability of test facilities and equipment	+	-
Availability and dissemination of know-how	+	-
Extent to which methods are available for characterizing emissions	o	o
International attractiveness (contributes to the harmonization of emissions tests and standards)	-	+
Safety and health impacts of emissions measurements	+	-
Planning reliability of type-approval schedules and necessary lead time	+	-
Accuracy of analytical equipment	+	-
Equal treatment of OEMs from different countries regarding, e.g., speed limits, orographic conditions	+	-
Costs[1]		
Initial costs of implementation	**unknown**	**unknown**
Running costs for performing emissions tests	**unknown**	**unknown**
Effectiveness		
Prevents the optimization of vehicle technologies to an overly narrow range of operating conditions	-	+
Reproducibility and repeatability of tests	+	-
Influence of test procedure on the representativeness of test results for real-driving emissions	-	+
Legal implications and other issues		
Legal certainty regarding pass/fail decision	o	o
Usefulness of test procedure for development purposes	-	+

[1] The initial costs of implementing and executing a test procedure strongly depend on the definition of boundary conditions and on the possibility of defining families for the testing and type approval of vehicles. Decisions on these two parameters have not yet been made as of June 2012.

Table 4: Semi-quantitative assessment of random-cycle testing and on-road testing with PEMS

	Random-cycle testing	On-road testing with PEMS
Coverage		
Covers a wide range of driving conditions and allows specific driving conditions to be targeted (e.g., urban driving)	**(-)** Strongly dependent on the definition of boundary conditions; short trips used for cycle generation cover a relatively wide range of driving conditions (in particular urban driving) but (i) are limited to the WLTP database and (ii) may not be sufficiently severe for high-power vehicles; technical restrictions of test benches limit severity of driving conditions; limited ability to reproduce the dynamic transients encountered in real-world conditions, especially for high-power vehicles	**(+)** Depending on the definition of boundary conditions, technically any driving patterns could be covered (including urban, aggressive, or micro-transient driving); practically, however, traffic conditions and traffic rules limit the coverage of normal driving conditions
Covers a wide range of road profiles	**(-)** Modern chassis dynamometers can cover a wide range of road profiles by varying the road loads during emissions testing; however, information on road gradients are not available from the WLTP database; thus covering changes in road gradients may be infeasible at least in the mid-term	**(+)** A wide range of road profiles can technically be covered; however, the geographical location of test facilities may limit actual coverage
Covers a wide range of ambient conditions (temperature, humidity, altitude)	**(+)** Temperature and humidity**;** **(-)** Altitude; covering the wide range of ambient conditions is technically possible but practically unfeasible due to high investment and running costs and limited capacities for vehicle conditioning and testing especially at national technical services	**(-)** Temperature and humidity; **(+)** Altitude; the full range of ambient conditions could potentially be covered; however ranges of ambient conditions are restricted in practice by the geographical location of the test facilities and the occurrence of annual seasons
Covers the regulated pollutants	**(+)** Complete coverage of regulated gaseous and particulate pollutants; additional pollutants that may be regulated in future (e.g., NO_2, NH_3) can be measured at limited or no additional costs	**(-)** Covers regulated gaseous pollutants; PM-PEMS systems have recently become available; PN currently cannot be measured with PEMS but PN-PEMS may become available in the near future; omitting HC measurements in the first step of the RDE-LDV procedure can substantially decrease the costs and weight of PEMS equipment
Applicability		
Applicable to a wide range of LDVs and powertrain technologies	**(o)** Applicable to conventional powertrains and complex tailpipe configurations**;** limited availability of test benches for testing 4-wheel-drive vehicles; comparatively short test durations may limit the effectiveness of tests of hybrid-electric vehicles; test capacities at type-approval services are potentially limited if a wide range of ambient conditions is to be covered	**(o)** Applicable to most light-duty vehicles; tail-pipe attachments, available flow meter sizes, and the testing of two-seaters could be problematic in some cases; acquisition of customers' cars for in-service conformity testing could potentially be problematic due to concerns about vehicle damage
Neutrality in terms of engine and after-treatment technologies	**(o)** Generally neutral; however, concerns persist as to the ability to capture the degradation in SCR efficiency during low-speed and urban driving as well as during longer phases of high engine loads	**(o)** Generally neutral; weight of PEMS may introduce a bias in emissions measurements of small vehicles; vehicle performance regarding PM/PN emissions difficult to assess

Table 4 (cont.): Semi-quantitative assessment of random-cycle testing and on-road testing with PEMS

	Random-cycle testing	On-road testing with PEMS
Applicability		
Availability of test facilities and equipment	**(+)** Test facilities are available but may be, depending on boundary conditions, partially insufficient; lower test capacity than for standard laboratory testing; soak and test facilities would need to be upgraded considerably to accommodate a wide temperature range; Member States may not have access to fully climatized test facilities with four-wheel chassis dynamometers	**(-)** Test equipment not yet widely available; acquisition of PEMS equipment necessary for manufacturers and Member States
Availability and dissemination of know-how	**(+)** Know-how is widely available; driver training may be required; drivability of severe random cycles needs to be investigated further	**(-)** Know-how for PEMS measurements available for heavy-duty vehicles; most OEMs are already testing PEMS equipment but knowledge still needs to be disseminated; afterward, PEMS application is likely to be unproblematic
Extent to which methods are available for characterizing emissions	**(o)** Integrated bag measurements available; CVS measurements may not be suitable depending on the procedure; not all test cells can measure modal mass of pollutants; methods for analyzing/averaging data are partially available but should be further developed	**(o)** Averaging methods available for heavy-duty vehicles; however, further development and data analyses are necessary
International attractiveness (contributes to the harmonization of emissions tests and standards)	**(-)** Some potential to contribute to the international harmonization of emissions legislation; however, using short trips based on the European WLTP database limits the potentials for harmonizing international standards	**(+)** Larger potentials for international harmonization of emissions legislation; PEMS is already introduced with Euro VI legislation and used in other regions of the world; enables real-world emissions testing for a wide range of fuel and powertrain technologies; however, method and equipment is relatively new; Japan does not authorize the use of PEMS on public roads[1]
Safety and health impacts of emissions measurements	**(+)** Low impacts; expected to be identical to standard emissions testing in the laboratory	**(-)** Several issues may need to be resolved such as the proper fitting of PEMS equipment inside/outside vehicles, crash safety, transport of hydrogen-helium mixture in the drivers cabin, risks of CO exposure; general compliance with national road safety standards needs to be ensured
Planning reliability of type-approval schedules and necessary lead time	**(+)** Limited uncertainty may result depending on the chosen boundary conditions (e.g., variability of test durations, required temperature range) and the cooling-heating capacity of soak and test facilities; possibility to define vehicle families may increase planning reliability	**(-)** Depending on the definition of boundary conditions; annual seasons, weather and traffic conditions may be critical**;** PEMS installation and calibration in vehicles requires two hours or less for trained personnel
Accuracy of analytical equipment	**(+)** Identical to current laboratory equipment; high accuracy also due to relatively constant ambient conditions and the absence of vibrations; limited inter-laboratory variability in measurement accuracy	**(-)** Sufficiently accurate as confirmed in the testing of heavy-duty vehicles; instrumentation performance identical to that of laboratory equipment under laboratory conditions; accuracy requirements laid down in regulations (e.g., UNECE, 2011a); larger uncertainties can be expected on the road due to variability of temperature and altitude and the occurrence of vibrations, resulting uncertainties can be addressed by the definition of not-to-exceed limits; GPS data may generally be too inaccurate for monitoring road gradients but could be integrated/combined with data from air pressure sensors to achieve sufficient accuracy

Table 4 (cont.): Semi-quantitative assessment of random-cycle testing and on-road testing with PEMS

	Random-cycle testing	On-road testing with PEMS
	Applicability	
Equal treatment of OEMs from different countries regarding, e.g., speed limits, orographic conditions and the possibility to execute tests during the whole year	**(+)** Equal treatment ensured because boundary conditions are identical for all OEMs; depending on the definition of boundary conditions, provision of test facilities could incur additional costs especially for technical services of Member States; tests can be executed throughout the year	**(-)** Equal treatment ensured because boundary conditions are identical for all OEMs; depending on the definition of boundary conditions, high-speed driving may be limited by local and national speed limits (e.g., 110 km/h in Sweden and 112 km/h in the UK); covering a wide range of ambient, driving, and orographic conditions might not be achievable all year around at manufacturers' sites
	Costs[2]	
Initial costs of implementation	**(unknown)** Strongly dependent on the definition of boundary conditions; if additional laboratories need to be constructed to cover, e.g., four-wheel-drive vehicles, a wide range of ambient conditions, and variable road loads costs might be substantial; costs of new test facilities typically range between 1 and 2 million Euro); potential requirement for modal mass measurements may incur additional costs	**(unknown)** PEMS equipment will have to be procured at a limited cost of 0.13-0.3 million Euro per PEMS unit; additional costs for training/recruiting personnel; depending on the range of pollutants tested, PEMS may incur higher costs than random-cycle testing for manufacturers and technical services of Member States
Running costs for performing emissions tests	**(unknown)** Strongly dependent on the definition of boundary conditions; randomization of ambient and driving conditions may lead to high running costs (environmental chassis dynamometers, variable-resistance chassis dynamometers, soak facilities; high severity of cycles might require repetitive testing	**(Unknown)** Strongly dependent on the definition of boundary conditions and the location of OEMs; potentially higher/lower than for random cycle depending on a narrow/wide definition of boundary conditions
	Effectiveness	
Prevents the optimization of vehicle technologies to an overly narrow range of operating conditions	**(-)** Depending on the definition of boundary conditions, a wide range of driving patterns and ambient conditions can be covered; potentially limited effectiveness with regard to effects like uphill-downhill and micro-transient driving, driving pattern may not be sufficiently severe for high-power vehicles; shorter test durations than for on-road tests may limit effectiveness	**(+)** Depending on the definition of boundary conditions; theoretically any driving patterns and ambient conditions could be covered for long time periods; practically, there are limitations due to local climate, seasons, orographic conditions, and speed limits; long test durations allow a robust assessment of vehicle emissions; particularly effective in ensuring sufficient severity for high-power vehicles; good coverage of micro-transient driving

Table 4 (cont.): Semi-quantitative assessment of random-cycle testing and on-road testing with PEMS

	Random-cycle testing	On-road testing with PEMS
	Effectiveness	
Repeatability and reproducibility of tests[3]	**(+)** Due to randomness in test conditions, emissions tests for type approval show low repeatability and reproducibility; the resulting statistical uncertainty could be addressed by the definition of not-to-exceed limits, by conducting multiple emissions tests, and by the proper design of emissions control systems that have to function properly at least within the agreed boundary conditions; individual emissions tests can technically be repeated and reproduced with high accuracy	**(-)** Due to randomness in test conditions, emissions tests for type approval show low repeatability and reproducibility; the resulting statistical uncertainty could be addressed by defining appropriate 'not-to-exceed limits', by conducting multiple emissions tests, and by the design of the emissions control systems that has to function properly at least within the agreed boundary conditions; individual PEMS tests can technically be repeated with low to medium accuracy (as compared with the standards of laboratory testing); however, low reproducibility of on-road tests at different test facilities
Influence of test procedure on the representativeness of test results for real-driving emissions	**(-)** Engine cooling in the laboratory is usually different from that on the road; control systems may go into safety or *fallback* mode; laboratory tests could be detected by the vehicle or require the activation of test modes prior to emissions testing; influence of road-load requirements on emissions results	**(+)** PEMS imposes additional weight (5-15% of the mass of light-duty vehicles) and minor changes to the vehicle's aerodynamics and stability; in the context of RDE-LDV, these effects can be regarded as negligible and may be even considered as more representative for real-world driving than the road load used for laboratory testing
	Legal implications and other issues[4]	
Legal certainty regarding pass/fail decision	**(o)** Depending on the definition of boundary conditions, the randomness of the test procedure will lead to a certain statistical uncertainty, which could be addressed by conducting multiple emissions tests and by defining appropriate 'not-to-exceed' limits; see also repeatability and reproducibility of test results	**(o)** Depending on the definition of boundary conditions, the randomness of the test procedure will lead to a certain statistical uncertainty, which could be absorbed by conducting multiple emissions tests and by defining appropriate 'not-to-exceed' limits; see also repeatability and reproducibility of test results
Usefulness of test procedure for development purposes	**(-)** Useful for developing effective emissions control systems; emissions values can be related to engine load and driving conditions; for development purposes, a certain target setting will be necessary, which is impossible for a random cycle; may potentially not be sufficiently severe for high-power vehicles	**(+)** Useful for developing robust emissions control systems; emissions values can be related to engine load and driving conditions; however, for development purposes, a certain target setting will be necessary, which is impossible for PEMS; sufficiently severe for high-power vehicles

[1] OEMs partially disagree with this evaluation and suggest that PEMS is not appropriate for harmonizing international emissions testing and standards.

[2] The initial implementation costs and running costs strongly depend on the boundary conditions for the RDE-LDV test procedure. Costs are furthermore affected by the possibility to test and approve vehicle families. Decisions have not yet been taken on either issue.

[3] Randomness in emissions testing is desired for the RDE-LDV test procedure but it effectively reduces the reproducibility of emissions tests. By properly designing emissions control systems, manufacturers can ensure pass-fail decisions are reproducible. This requires that emissions control systems function properly within the agreed boundary conditions for the RDE-LDV test procedure.

[4] The criteria listed under this category are only weakly related to the technical assessment of the two candidate procedures. However, it has been decided to include them here given their relevance for OEMs.

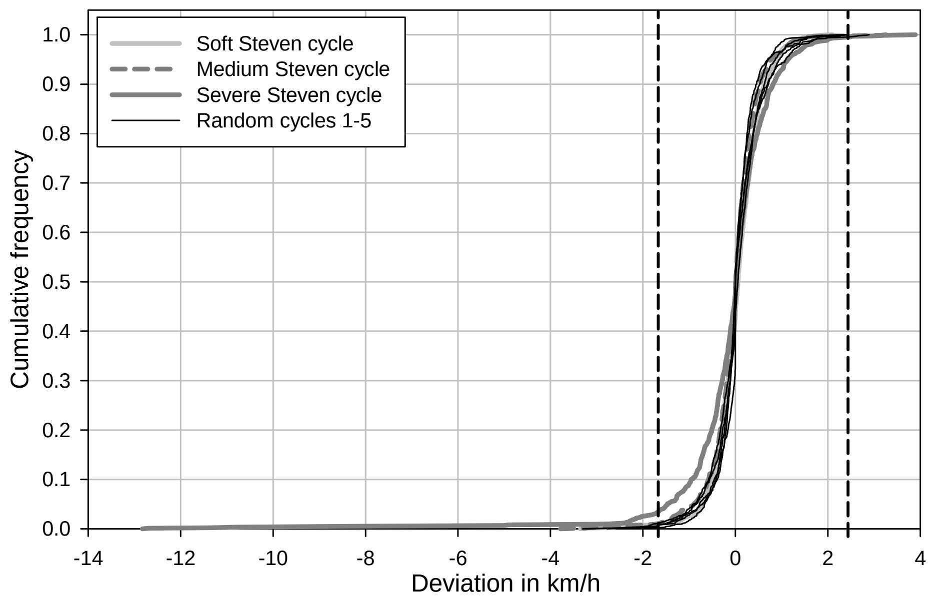

Figure 11: Deviations between actual and scheduled vehicle speed – example of Euro 5 diesel Vehicle K equipped with a manual transmission

Table 5: Breaching of the 2 km/h tolerance margin during random-cycle testing – example of a Euro 6 diesel vehicle equipped with an automatic transmission

	Speed margin in km/h								
	2	3	4	5	6	7	8	9	10
	Number of seconds over a cycle in which the deviation between actual and scheduled speed is larger the margin given above								
Soft Steven cycle	8	2	0	0	0	0	0	0	0
Medium Steven cycle	10	5	0	0	0	0	0	0	0
Severe Steven cycle	32	11	8	7	6	6	5	4	4
Random cycle 1	9	1	0	0	0	0	0	0	0
Random cycle 1 (repetition)	7	1	0	0	0	0	0	0	0
Random cycle 2	5	0	0	0	0	0	0	0	0
Random cycle 2 (repetition)	9	1	0	0	0	0	0	0	0
Random cycle 3	4	0	0	0	0	0	0	0	0
Random cycle 3 (repetition)	2	0	0	0	0	0	0	0	0
Random cycle 4	2	0	0	0	0	0	0	0	0
Random cycle 4 (repetition)	2	0	0	0	0	0	0	0	0
Random cycle 5	9	1	0	0	0	0	0	0	0

Preliminary analyses addressing the drivability of random cycles on chassis dynamometers suggest that:

- Designing, implementing, and performing emissions tests with random cycles in the laboratory all are technically feasible.
- A high severity of cycles increases the time duration in which test vehicles breach the ±2 km/h deviation margin; increasing severity thus decreases the drivability of random cycles. This finding highlights the challenge of designing random cycles that are (i) drivable by vehicles with both high and low power-to-mass ratios and (ii) sufficiently severe for vehicles with a high power-to-mass ratio. Achieving this objective requires adapting the acceleration profile of the random driving cycles to the test vehicle concerned.

- Even if cycles involve acceleration patterns that are among the most severe in the European driving data contained in the WLTP database, the time during which the (medium-size) Euro 6 vehicle deviates from the prescribed speed trace is less than 3% of the whole cycle duration.
- Driver practice on individual random cycles substantially reduces the deviations between actual and scheduled speed (the largest marginal reductions are observed between the first, second, and third repetition of a random cycle; Table 5).

Once the technical feasibility of emissions testing with random driving cycles in the laboratory is verified in principle, arguably the most important assessment criterion for the two candidate procedures is their ability to cover a wide range of driving conditions, thereby preventing the overly narrow optimization of emissions control technologies/strategies for a few operating conditions. A wide coverage of driving and ambient conditions is critical to address a severe shortcoming of the NEDC, i.e., its limited coverage of real-world acceleration-speed patterns (see, e.g., Kågeson, 1998; Demuynck et al., 2012). Figure 12 shows that both random cycle and PEMS on-road testing can reproduce transient real-world driving conditions; in addition, on-road emissions testing with PEMS enables longer test durations and may thus capture potentially polluting urban and/or high-speed driving conditions for longer time periods.

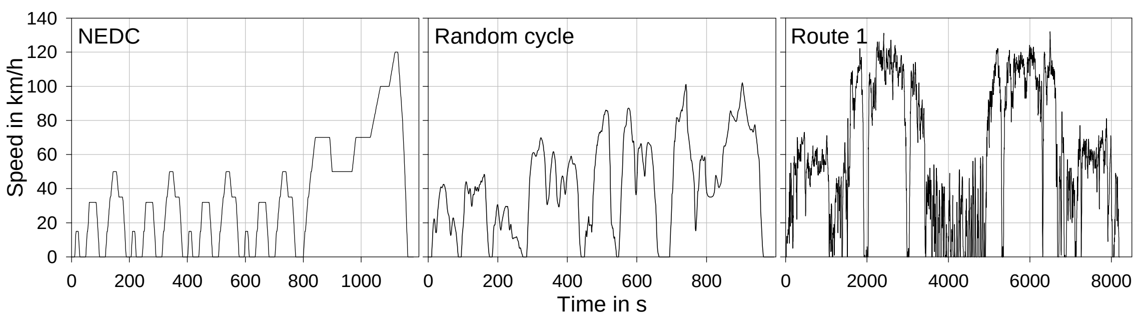

Figure 12: Speed profiles of the NEDC, one random cycle, and on-road driving on test Route 1

The severity of the test procedures with respect to driving conditions can be depicted in acceleration-speed plots (Figures 13-15). While the NEDC covers only a limited range of the acceleration-speed spectrum, both random-cycle and on-road testing achieve a higher coverage of driving conditions. However, Figure 13 also suggests that random-cycle testing may not cover certain acceleration events at low to medium speeds and low-acceleration events at high speeds. Even an extension of emissions testing to 5 random cycles does not sufficiently coverage of these driving conditions (Figure 14) although the maximum acceleration value of on-road driving, i.e., 2.5 m/s^2 appears to be relatively low. The maximum achievable acceleration during random-cycle testing is limited here by the random cycle generator tool that adapts the maximum acceleration of short trips to the driving capabilities of the tested vehicle; the acceleration values here are not limited by the technical capabilities of the chassis dynamometer.

The currently open questions regarding the severity of random cycles can be addressed by (i) ensuring sufficient inclusion of appropriate short trips in the database used for cycle construction and (ii) designing suitable algorithms for the selection of short trips, e.g., that mandatorily include short trips containing high acceleration values. The second point is deemed critical because a random selection of short trips will likely result in random cycles that represent average driving rather than the wide range of normal on-road driving. This conclusion will also remain valid if the database of 20,000 short trips currently used to design random cycles is considerably extended in the future. Random cycles comprising short trips of low, medium, and high severity with respect to their maximum acceleration value (Steven, 2011) allow indeed covering a larger range of driving conditions (compare Figures 13-14 with Figure 15).

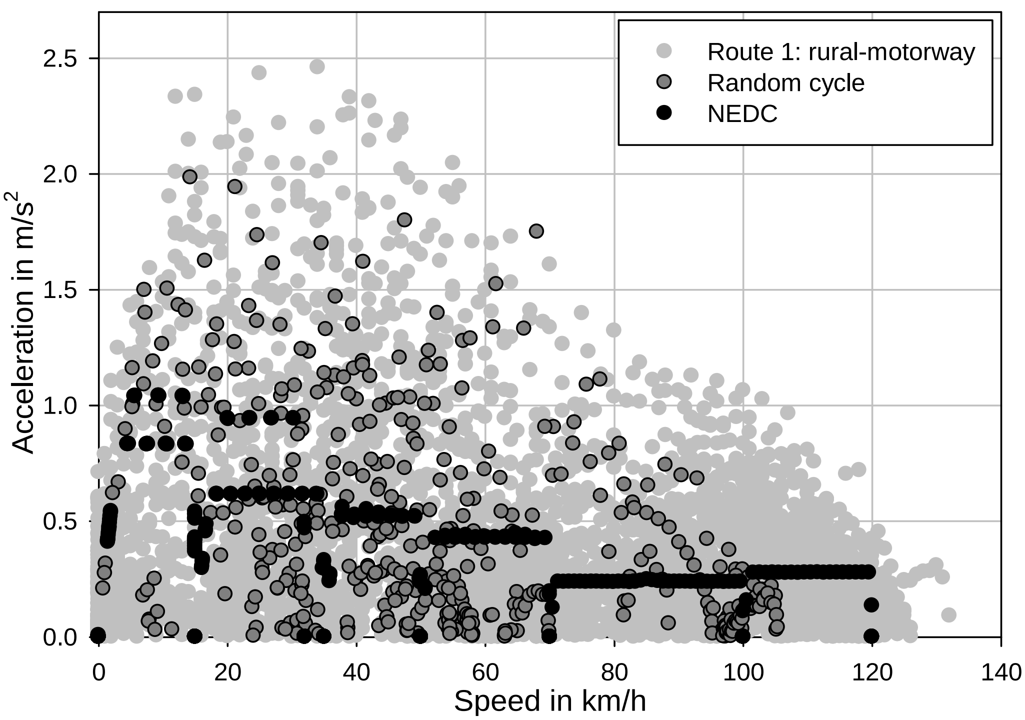

Figure 13: Acceleration-speed points of the NEDC, one random cycle, and on-road driving on test Route 1

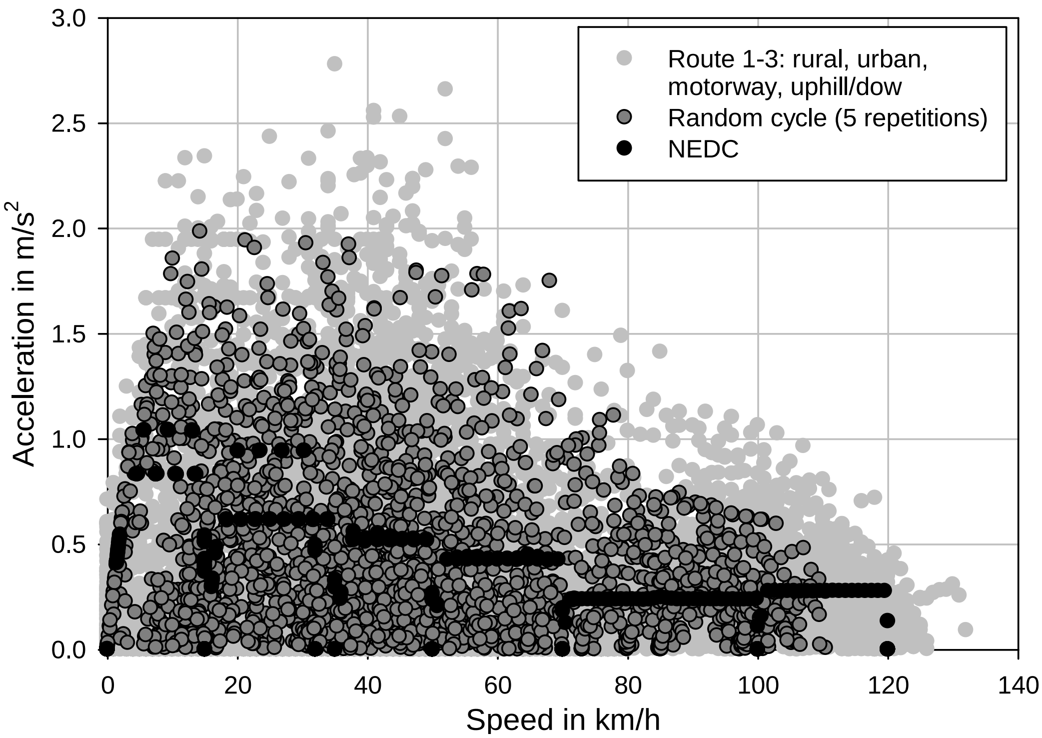

Figure 14: Acceleration-speed points of the NEDC, five random cycles, and on-road driving on test Routes 1-3

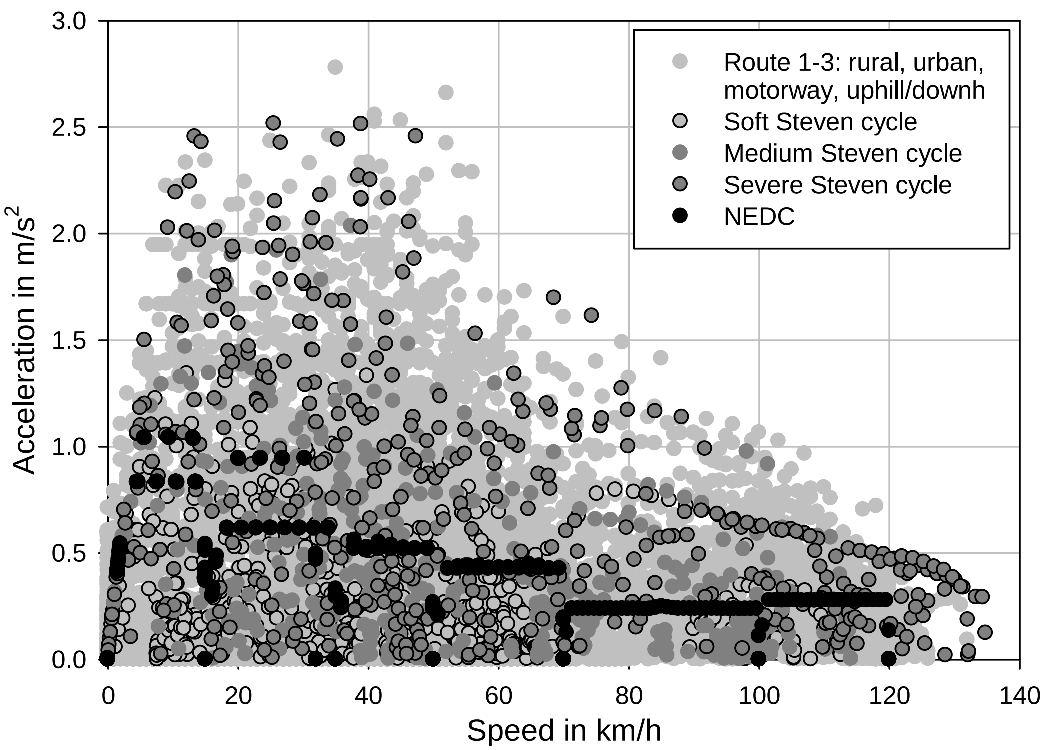

Figure 15: Acceleration-speed points of the NEDC, the soft, medium, and severe random cycle designed by Steven (2011), and on-road driving on test Routes 1-3

Together, Figures 12-15 suggest that on-road testing with PEMS may cover driving patterns more completely, and may hence be more robust, than random driving cycles. However, driver behavior remains a concern for PEMS testing: while driving patterns are *a priori* described for random cycles, this is not the case for PEMS on-road testing. Here, the freedom of the driver to limit on-road driving to a few acceleration-speed events of the engine map could be addressed by defining appropriate system boundaries or *a posteriori* by implementing suitable indicators to evaluate/weigh the severity of each on-road test.

Covering changes in road gradients is feasible both with modern chassis dynamometers and on the road. However, the short trips available in the WLTP database contain no information on road gradients; the reproduction of variable road gradients by random-cycle testing is thus not feasible in the mid-term as long as short trips from the WLTP database are used for cycle generation. With regard to on-road testing, the geographical location of test facilities limits the degree to which uphill and downhill driving can be covered in practice.

The wider coverage of driving patterns translates, in turn, into a more complete coverage of emissions events. Figure 16 suggests that random cycles result in a wider range of NO_X emissions than the NEDC. However, the long test durations and the potentially more diverse driving conditions during PEMS on-road testing provide an even more complete coverage of emissions events. The frequency distributions of NO_X emissions observed for Euro 5-6 diesel vehicles confirm these assessments (Figures 17 and 18).

Caution is, however, necessary when analyzing distance-specific emissions values because the driving patterns over averaging windows and the random cycles generally differ from each other, e.g., averaging windows obtained during urban driving may contain large idling shares mixed with low-speed driving whereas each random cycle contains an element of high speed driving. In addition, other effects such as road gradients and wind may strongly effect on-road emissions. Furthermore, PEMS on-road emissions tests conducted by manufacturers with one diesel vehicle on one single test route have resulted in average NO_X emissions that deviate from one another by a factor of five. This observation suggests on the one hand that the emissions control system of the vehicle may not function properly during on-road driving. On the other hand, it highlights the need to define suitable boundary conditions that ensure on-road emissions testing is conducted within the agreed ranges of *normal* vehicle operation and use.

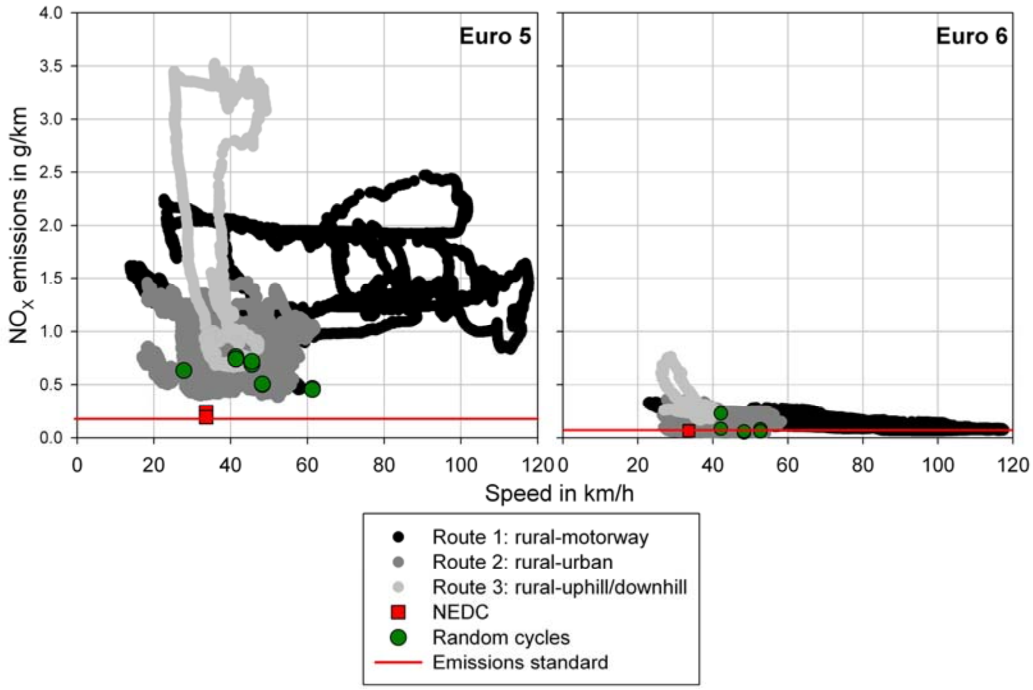

Figure 16: NO_X emissions as function of vehicle speed – averages over the NEDC, individual random cycles, and averaging windows during on-road driving of Euro 5 Vehicle K and Euro 6 Vehicle O

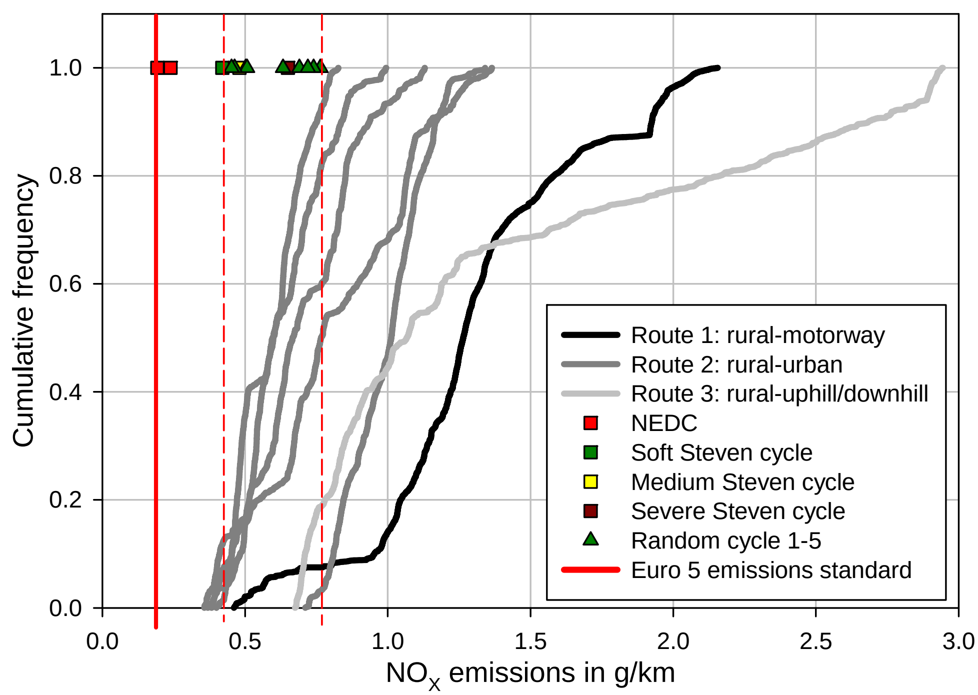

Figure 17: Average NO_X emissions over the NEDC and individual random cycles as well as frequency distribution of averaging window NO_X emissions during on-road driving of Euro 5 Vehicle K; dashed lines represent the emissions ranges of random-cycle testing

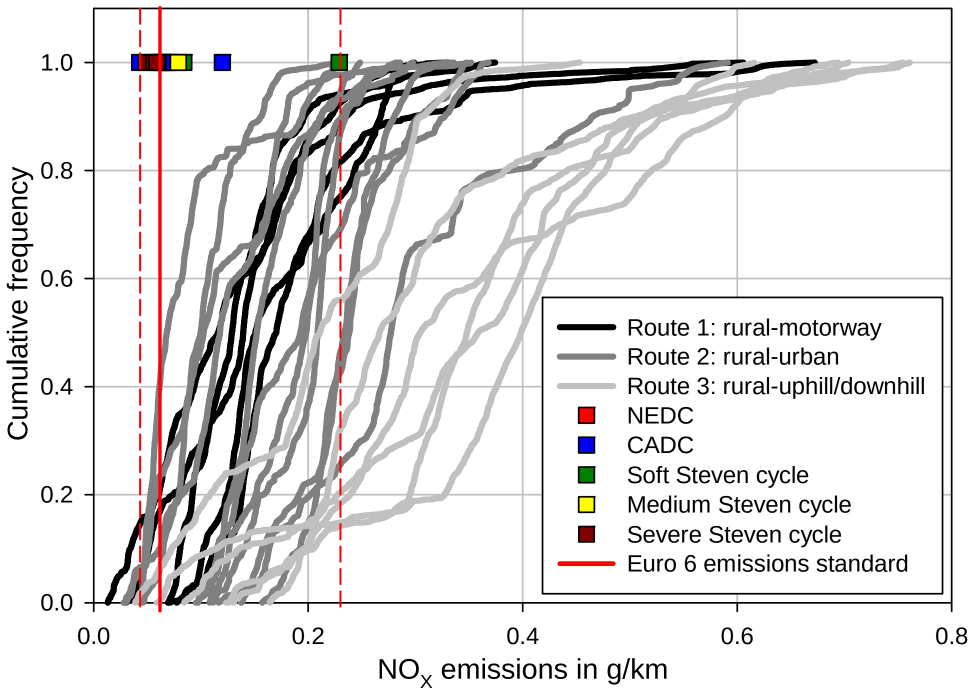

Figure 18: Average NO_X emissions over the NEDC and individual random cycles as well as frequency distribution of averaging window NO_X emissions during on-road driving of Euro 6 Vehicle O; dashed lines represent the emissions ranges of random-cycle testing

In addition to covering a wide range of driving conditions, the RDE-LDV procedure should also cover a wider range of ambient conditions than the current Type I type-approval testing. Wider coverage can indeed be achieved by both candidate procedures, although practical limitations exist. In the case of random cycles, testing and conditioning capacities to cover, e.g., a wide temperature range may be limited. Data from OEMs indicate that it may take up to 5 h to cool a test cell from 25 ^oC to 10 ^oC and then heat it up again to 25 ^oC. The time required to perform one standard emissions test will increase for a test temperature of 10 ^oC from 80 min to 320 min (other things being equal). Adjusting dynamometer settings, designing and implementing driving cycles, and running potential preconditioning cycles before each random cycle test will add considerably to the time, and hence the cost of random-cycle testing. As a result, covering a wide temperature range in the laboratory could be extremely costly and will likely require additional facilities for the testing and conditioning of vehicles. Covering a wide temperature range with PEMS, on the other hand, is in practice limited by ambient conditions around test sites and the temperature variability due to annual seasons.

Differences exist between the two candidate test procedures regarding the coverage of regulated pollutants and applicability to a wide range of light-duty vehicles. The analytical equipment of both test procedures can measure NO_X emissions with sufficient accuracy; this aspect may be especially important for the current air quality problems in Europe. However, the PEMS equipment used so far by the RDE-LDV working group is not suitable for measuring particle mass. Recently, the measurement principles for PM-PEMS equipment have been validated (see Mamakos et al., 2011). PM-PEMS equipment is also commercially available for application in heavy-duty vehicles and could, at a later stage, also be used in light-duty vehicles. Hydrocarbons can be measured with PEMS, but this requires the on-board transport of hydrogen/helium bottles to operate flame-ionization detector.

Box 2: Cycle detection and the use of defeat devices

Sensors and electronic components in modern light-duty vehicles are capable of ‘detecting’ the start of an emissions test in the laboratory (e.g., based on acceleration sensors or not-driven/not-rotating wheels). Some vehicle functions may only be operational in the laboratory, if a predefined test mode is activated. Detecting emissions tests is problematic from the perspective of emissions legislation, because it may enable the use of defeat devices that activate, modulate, delay, or deactivate emissions control systems with the purpose of either enhancing the effectiveness of these systems during emissions testing or reducing the effectiveness of these systems under normal vehicle operation and use. While the use of defeat devices is generally prohibited, exceptions exist in cases where it is necessary to protect the engine against damage and to ensure safe vehicle operation (EC, 2007). These exceptions leave room for interpretation and provide scope, together with the currently applied test procedure, for tailoring the emissions performance of light-duty vehicles to a narrow set of type-approval conditions.

Detecting the use of defeat devices is, strictly speaking, outside of the scope of the RDE-LDV working group. Nonetheless, the RDE-LDV test procedure should prevent the optimization of emissions control technologies/strategies for an overly narrow set of operating conditions such as driving dynamics, ambient temperatures, and engine coolant temperatures. The RDE-LDV procedure should also ensure that the use of defeat strategies is decreased as far as possible. Although controversial among the participants of the RDE-LDV working group, the authors of this report regard PEMS on-road testing as more effective in achieving this objective than random-cycle testing in the laboratory. PEMS on-road testing involves more diverse and dynamically changing operating conditions as well as longer test durations. On-road testing might therefore make it more difficult to tune vehicles to specific operating conditions and will restrict possible interpretations of Regulation 715/2007 (EC, 2007) on the use of defeat devices. Although theoretically possible, detecting on-road emissions tests is difficult in practice if not infeasible.

A PEMS on-road test procedure could address the resulting safety concerns by covering in the first phase only NO_X emissions. At later stages, the use of PEMS in the RDE-LDV procedure could be extended to additional pollutants if analyses suggest that standard type-approval testing in the laboratory is inadequate for covering the real-world on-road emissions of these pollutants.

Both candidate procedures can be used for virtually all light-duty vehicles. However, limitations exist for the random-cycle testing of (i) four-wheel drive vehicles due to the potentially limited availability of suitable chassis dynamometers and (ii) hybrid vehicles due to the limitation of laboratory tests to around 30 minutes. Limitations on the use of PEMS may exist for some two-seaters and vehicles with unconventional tail-pipe configurations.

Regarding several other assessment criteria, random-cycle testing shows distinct advantages over a PEMS-based test procedure, e.g., regarding the availability of know-how, additional safety issues of emissions measurements, as well as the reliability of type-approval schedules. These advantages arise because random-cycle testing can draw on existing laboratory infrastructure and the long-term experience in laboratory emissions testing. By contrast, the introduction of PEMS: (i) will require the acquisition of new know-how and its dissemination and (ii) incurs additional organizational efforts and the resolution of open safety issues. The authors of this report regard the resulting challenges as minor and manageable within the anticipated implementation schedule for the RDE-LDV test procedure. Two final points are worth mentioning:

- The implementation and running costs of the two candidate procedures will to a large degree depend on the ranges of boundary conditions and options for family testing of light-duty vehicles. At this point, the available information is not detailed enough to compare the two candidate procedures with regards to their costs of implementation and performance.
- Random-cycle and PEMS on-road testing differ regarding the impact the vehicle driver may have on each emissions test. Random-cycle testing is based on a speed trace and thereby limits the freedom of the driver in performing emissions tests. However, PEMS on-road testing allows the driver to choose driving patterns. Aspects of on-road driving that remain unregulated may lead to both overly cautious and overly severe driving and enable the adaptation of vehicles to accommodate such driving patterns. It may thus be crucial to define *a priori* trip requirements and/or *a posteriori* weighing factors for emissions results to account for the variability of on-road driving in a PEMS based test procedure.

6 Next steps and outlook

The assessment presented in Section 5 has shown that both random-cycle testing and on-road testing with PEMS are technically feasible. While PEMS on-road testing incurs additional organizational efforts for manufacturers and may require addressing yet unresolved safety issues, the procedure will ensure a relatively robust coverage of emissions during normal vehicle operation and use. Random-cycle testing, by contrast, can draw on existing laboratory infrastructure and knowledge but can be detected by the tested vehicles and will likely be less effective in covering a wide range of driving and operating conditions. A more robust assessment of both test procedures is currently hampered by the absence of agreed boundary conditions (such as temperature ranges, permissible road gradients, severity requirements regarding vehicle acceleration and speed). The definition of boundary conditions can severely impact the effectiveness and costs of both candidate procedures.

Based on this technical assessment, and considering also persisting uncertainties, the following standpoints were presented at the June 2012 meeting of the RDE-LDV working group:

- Member States expressed their intention to base the final complementary test procedure, comprising the initial type approval test, in-service conformity testing and (possibly) surveillance testing, on a PEMS reference procedure. This means that the final test process should at least contain some element of PEMS on-road emissions testing.
- Vehicle manufacturers expressed interest in demonstrating compliance with the PEMS reference procedure via emissions testing with random cycles in the laboratory. Member States agreed that this option should be possible at least for the initial type-approval and possibly also for in-service conformity testing, depending on the availability of resources in the Member States for independent in-service conformity testing and provided that the equivalency of random cycles and PEMS on-road testing can be established.

Given these standpoints, the following way forward has been agreed:

- The final complementary test procedure for type approval, in-service conformity testing, and potentially surveillance testing should be applied at the latest by 1 September 2017.
- Both random-cycle testing and PEMS on-road testing as complementary test procedure will be further developed. The JRC will take the main responsibility for developing the PEMS reference procedure. Industry will be responsible for developing the random cycle.
- The development of both procedures in parallel does not prejudice the decision on the test procedure to be implemented later. After the development of the two procedures,

PEMS on-road testing could still be chosen as the only complementary RDE-LDV test procedure.

- The development of the complementary RDE-LDV test procedure focuses primarily on limiting the NO_X emissions of diesel vehicles. Given the technical challenges and the current air quality situation, the exclusion of THC measurements from PEMS on-road emissions testing should be considered at least for the initial implementation phase. Measuring THC is currently considered of little relevance in light of the NO_X problems but would, on the other hand, make the entire test procedure considerably more complicated and costly.
- The procedure for the assessment of PN emissions of GDI vehicles is not pre-determined by the choice of the RDE-LDV test procedure. However, Member States have stated their interest in applying the same RDE-LDV method to all pollutants, if appropriate and technically feasible.

Putting this decision into practice, the following actions have been agreed upon:

- JRC will draft a revised work plan and distribute it to stakeholders for comments.
- JRC will coordinate a proposal for boundary conditions of the RDE-LDV test procedure. All stakeholders (including industry and Member States) should provide their respective input to the JRC until the end of 2012.
- Draft specifications for the random cycle generator will be provided by ACEA.
- ACEA and other stakeholders will provide a list of vehicles types that could be made available for on-road and laboratory testing.

Until the drafting of the complementary RDE-LDV test procedure, vehicle testing both in the laboratory and on the road is foreseen (Table 6). The definition of system boundaries will be critical for the effectiveness of both random-cycle testing and PEMS on-road testing. The statistical uncertainties that may result from limited repeatability and reproducibility of emissions tests could be addressed by defining appropriate ‘not-to-exceed’ limits. Although primarily designed as independent activities, speed traces for laboratory testing could be repeated on the road and *vice versa*. Such back-to-back testing could provide insight into the robustness of test results and may potentially detect the by-passing of test cycles by defeat strategies. The duplication of driving patterns by back-to-back testing in the laboratory and on the road may be a viable option that could be discussed for the implementation of the final RDE-LDV procedure.

Table 6: Revised schedule for developing the complementary RDE-LDV test procedure (meetings, reporting, and drafting tasks to be added later)

	2012						2013											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Boundary conditions																		
Provision of building elements	■	■	■															
Establishing value ranges			■	■	■	■												
Random driving cycles																		
Specifications of the random cycle generator		■	■	■														
Software modifications					■	■			■									
Small scale trials							■	■										
Pilot phase										■	■	■	■	■	■			
PEMS on-road testing																		
Selecting and providing vehicles		■	■	■	■	■	■											
Testing vehicles with PEMS							■	■	■	■	■	■	■	■	■			
Vehicle 1 - PEMS 1 - JRC								■										
Vehicle 1 - PEMS 1 - Site 2									■									
Vehicle 2 - PEMS 1 - JRC										■								
Vehicle 2 - PEMS 1 - Site 3											■							
Vehicle 3 - PEMS 2 - JRC									■									
Vehicle 3 - PEMS 2 - Site 4								■										
Vehicle 4 - PEMS 2 - JRC												■						
Vehicle 4 - PEMS 2 - Site 5											■							
Defining methods for data evaluation		■	■	■	■	■	■	■	■									
Data consolidation										■	■	■	■	■	■			

The future European emissions legislation, including the introduction of the complementary RDE-LDV test procedure, will pose new challenges to vehicle manufacturers. These will have to accommodate: (i) more stringent Euro 6 emissions standards from 2014 onwards, (ii) the application of 'not-to-exceed' emissions limits to a wide range of operating conditions, and (iii) a lower repeatability and reproducibility and thus a greater degree of randomness in emissions testing. The authors of this report therefore regard it important that the development of the RDE-LDV test procedure continues to be a transparent process that identifies as completely as possible the strengths and limitations of the two candidate procedures, as well as the associated technical, financial, administrative, and environmental implications.

7 Conclusions

In the period from January 2011 to June 2012, the RDE-LDV working group has assessed the potentials of random-cycle and on-road emissions testing to be implemented as complementary RDE-LDV test procedure for light-duty vehicles in Europe. This assessment is based on emissions testing and expert judgment. Both candidate procedures are found to be technically feasible, i.e., no major technical obstacles hamper their design, implementation, and execution. However, the assessment suggests that PEMS on-road testing may: (i) potentially cover a wider range of driving conditions than random-cycle testing and (ii) be more effective in limiting the application of defeat strategies and the detection of emissions tests by vehicles. These criteria are directly linked to the objectives of the RDE-LDV test procedure and are therefore given key priority by the European Commission.

The practical effectiveness and costs of both candidate procedures largely depend on the boundary conditions chosen, which have not yet been defined. The present assessment also points to advantages of random-cycle testing in terms of, e.g., the availability of know-how, the safety of emissions testing, and the planning reliability of type-approval schedules. These advantages arise largely because random-cycle testing can draw on the available (though potentially insufficient) infrastructure and knowledge of laboratory emissions testing. The introduction of PEMS on-road testing will require the acquisition of analytical equipment, know-how and its dissemination, as well as the resolution of open safety issues. The authors of this report regard the resulting challenges as manageable within the anticipated implementation schedule for the complementary RDE-LDV procedure.

Based on the present assessment, the European Commission and the Member States conclude that the RDE-LDV test procedure should contain an element of PEMS on-road testing. The JRC will take the lead to develop PEMS on-road testing as a complementary test procedure until the end of 2013. Given the current knowledge gaps, specifically regarding costs of implementing and executing emissions tests, and accounting for the opposition of some OEMs to PEMS on-road testing, it has been decided to provide OEMs with the opportunity to develop random-cycle testing as a complementary test procedure. By the end of 2013, the two fully developed test procedures will be compared with respect to, e.g., effectiveness, coverage, applicability, and costs. Based on the outcome of this comparison, decisions will be made on how to implement the final complementary RDE-LDV test procedure for type-approval testing and in-service conformity testing of light-duty vehicles. The European Commission will continue supporting the use of the RDE-LDV test procedure as a globally-harmonized complementary test procedure in the second phase of the WLTP.

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Abstract
Light-duty diesel vehicles emit on the road substantially more nitrogen oxides than permitted by regulatory emissions standards. The European Commission addresses this problem by developing a complementary emissions test procedure for the type approval and in-service conformity testing of light-duty vehicles. To facilitate the technical development of this procedure, the Real-Driving Emissions - Light-Duty Vehicles (RDE-LDV) working group was established in January 2012. The working group is open to Member States, NGOs, and industry stakeholders. This scientific and policy report presents the results of the first year of the RDE-LDV working group that focused on the technical assessment of two candidate procedures: (i) emissions testing with random driving cycles in the laboratory and (ii) on-road emissions testing with Portable Emissions Measurement Systems (PEMS). Both procedures are found to be technically feasible. However, PEMS on-road testing appears to be more effective than random-cycle testing in limiting the pollutant emissions of light-duty vehicles because it (i) allows covering a wider range of driving conditions and (ii) might be more effective in preventing the detection of emissions tests by vehicles and the use of defeat strategies. Nonetheless, PEMS on-road testing faces practical challenges, including open safety issues, the currently limited availability of PEMS equipment, and potential climatic, geographical, and seasonal constraints for the execution of on-road tests. Random-cycle testing presents further advantages over PEMS on-road testing in that already established laboratory equipment and know-how to be used. The present assessment is subject to uncertainty because the implementation and running costs as well as the overall effectiveness of the two candidate procedures depend on the definition of concrete boundary conditions (e.g., permitted test temperatures, severity of driving patterns). These definitions are not yet agreed. Accounting for the resulting uncertainty, it has been decided that the JRC will develop a PEMS-based test procedure while vehicle manufacturers are given the opportunity to develop a random cycle-based test procedure. A decision will be made regarding the implementation of these procedures for type approval and in-service conformity testing based on a comparison of the two final and fully developed test procedures by the end of 2013.

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