Earth, Life & Social Sciences
Van Mourik Broekmanweg 6
2628 XE Delft
P.O. Box 49
2600 AA Delft
The Netherlands

www.tno.nl

T +31 88 866 30 00

TNO report

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Assessment of road vehicle emissions: methodology of the Dutch in-service testing programmes

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Author(s)	J.S. Spreen G. Kadijk R.J. Vermeulen V.A.M. Heijne N.E. Ligterink U. Stelwagen R.T.M. Smokers P.J. van der Mark G. Geilenkirchen (PBL)
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Samenvatting

De Nederlandse emissie-meetprogramma's
De Nederlandse overheid zet zich in voor het terugbrengen van schadelijke emissies en brandstofverbruik van wegvoertuigen. Om over objectieve gegevens te kunnen beschikken, voert TNO in opdracht van het Ministerie van Infrastructuur en Milieu metingen uit om de emissies en het brandstofverbruik van wegvoertuigen vast te stellen. Er bestaan daartoe twee emissiemeetprogramma's:

1. het steekproefcontroleprogramma **light-duty** voertuigen, voor het meten van emissies van personen- en bestelwagens, en;
2. het steekproefcontroleprogramma **heavy-duty** voertuigen, voor het meten van emissies van vrachtwagens en bussen.

Het doel van de meetprogramma's
De meetprogramma's dienen twee hoofdoelen:

1. het verkrijgen van inzicht in de emissies van wegvoertuigen bij de inzet in de praktijk. Emissies worden gemeten tijdens metingen op de weg en in het laboratorium;
2. het afleiden van emissiefactoren, op basis van de meetresultaten. Emissiefactoren worden gebruikt om de effecten van huidig en toekomstig verkeer op luchtverontreinigende emissies en luchtkwaliteit te beoordelen.

De methodologie van de meetprogramma's
Dit rapport beschrijft de huidige methodologie van twee emissiemeetprogramma's. Het beschrijft het proces van voertuigselectie en –voorbereiding en de verschillende aspecten van wegmetingen en metingen in het lab, en legt uit welke analyses TNO uitvoert op de data en hoe emissiefactoren worden afgeleid. Het rapport besluit met een overzicht van de wijze waarop TNO de in de steekproeven opgebouwde kennis publiek beschikbaar maakt.

Nieuwe versies van dit rapport
De wereld van voertuigemissies is volop in beweging. Zo nodig zal TNO de meetprogramma's in nauwe samenwerking met het Ministerie van Infrastructuur en Milieu zo aanpassen dat deze blijven aansluiten bij de behoeftes van het Ministerie en bij actuele ontwikkelingen op het gebied van voertuigemissies en meetmethodieken. In het geval van wijzigingen in de meetprogramma's wordt dit rapport geactualiseerd.

TNO-webpagina over voertuigemissies
Een overzicht van TNO-rapporten met betrekking tot praktijkemissies van wegvoertuigen is te vinden op de website van TNO[1]:

www.tno.nl/voertuigemissies

[1] De Engelstalige webpagina is te vinden op www.tno.nl/vehicle-emissions

Summary

The Dutch in-service testing programmes

For designing effective policy instruments for reducing vehicle emissions, legislators have to be able to rely on objective data on emissions and other vehicle performance parameters. To this end, TNO has been commissioned by the Dutch Ministry of Infrastructure and the Environment to collect information on the emission performance of road vehicles. This information is collected within two testing programmes:

1 the **light-duty** in-service testing programme to assess the emissions of passenger cars and vans; and;
2 the **heavy-duty** in-service testing programme to assess the emissions of trucks and buses.

Goals of the emission testing programmes

The testing programmes serve the following two main goals:

1 to obtain insight into the real-world emission behaviour of road vehicles under varying operating conditions. Emissions are assessed by means of on-road emission testing as well as measurements in the lab.
2 to derive emission factors from the measurement results. Emission factors are used for emission inventories, models for environmental impact analyses, and air quality monitoring and assessment.

The methodology explained

This report describes the current working methodology of the Dutch light-duty and heavy-duty in-service testing programmes. It leads the reader through the process of vehicle selection and preparation, presents all aspects of on-road and laboratory emission measurements and explains how the measurements are analysed and emission factors are derived. The report ends in giving an overview of the ways in which results stemming from the in-service testing programmes are disseminated.

Updates of this report

Numerous developments are going on in the field of vehicle emissions as well as measurement methods. In case these developments call for changes in the working methodology of the emission testing programmes, TNO, in close cooperation with the Ministry of Infrastructure and the Environment, will develop and implement the required adjustments and update this report accordingly.

TNO webpage on vehicle emissions

All emission reports are made available through TNO's website[2]:

www.tno.nl/vehicle-emissions

[2] Dutch readers may refer to www.tno.nl/voertuigemissies

Contents

1 Introduction

Road vehicles are a major source of air pollutant emissions which are harmful to health and the environment. In addition, road vehicles that run on fossil fuels emit carbon dioxide (CO_2), a greenhouse gas that contributes to global warming. Vehicle emissions must be reduced to meet European requirements for local air quality and for emissions at national level. European legislation is therefore setting increasingly stringent requirements on road vehicle emissions.

1.1 Background

For designing effective policy instruments for reducing vehicle emissions, legislators have to be able to rely on objective data on emissions and other vehicle performance parameters. TNO has, therefore, been commissioned by the Dutch Ministry of Infrastructure and the Environment to collect information on the emission performance of road vehicles. To this end, two testing programmes exist:
1. the light-duty in-service testing programme to assess the emissions of passenger cars and vans; and
2. the heavy-duty in-service testing programme to assess the emissions of trucks and buses.

1.2 Objectives of the in-service testing programmes

The goals of the in-service testing programmes are twofold.

1.2.1 Insight into the real-world emission performance of road vehicles

The first goal of the testing programmes is to obtain insight into the real-world emission behaviour of road vehicles under varying operating conditions. Emissions are assessed by means of different emissions measurement techniques, both in the lab as well as on the road. As circumstances in type-approval testing are not always representative for real-world conditions, the measurements in the in-service testing programmes focus on establishing the real-world vehicles emissions. As of 2009 for heavy-duty vehicles, and since 2014 for light-duty vehicles, this is mainly done by measuring the vehicle emissions while performing test trips on the road.

The in-service testing programmes thus provide objective and representative vehicle emission data that is used to develop effective emission legislation in the Netherlands and Europe. The insights obtained serve as input for the activities of the Dutch government and the RDW[3] in the context of decision making processes in Brussels (European Commission) and Geneva (GRPE[4]) to improve emission legislation and the associated test procedures for light-duty and heavy-duty vehicles, all with the aim to reduce real-world emissions and improve air quality.

The data and insights are made available to stakeholders involved. On a regular (yearly) basis, TNO publishes reports on the performed vehicle emission measurements, disclosing the results to the public. Additionally, a vehicle emission symposium is organised every one to two years to inform all stakeholders on the status quo of vehicle emissions.

[3] Rijksdienst voor het Wegverkeer (the Dutch road vehicle authority)
[4] UNECE Working Party on Pollution and Energy (GRPE)

1.2.2 Generating emission factors

The emission measurement results provide input for the process of establishing emission factors. Those emission factors represent real-world emission values for various vehicle categories and different driving conditions. Vehicle emission factors are used for emission inventories and models for environmental impact analyses, air quality monitoring and assessment. Based on the measurements performed in the in-service testing programmes, emission factors are updated annually[5].

1.3 Scope of the in-service testing programmes

Vehicle emissions comprise a large range of chemical substances and the priority substances are regulated. Some components are regulated on an individual vehicle level, e.g. particulate matter (PM), nitrogen oxides (NO_x), hydrocarbons (HC) and carbon monoxide (CO). Carbon dioxide (CO_2) emissions are regulated in a different way: manufacturers have to comply with sales-weighted average CO_2 emission levels for all new sales in a certain target year.

Air quality policy has a strong focus on NO_x and PM_{10}. Concentration levels of these pollutants in the air are such that exceedances of the limits set by European air quality legislation cannot be excluded. Diesel vehicles are major contributors to these pollution levels. In normal use, NO_x emissions of modern diesel passenger vehicles are up to 30 times higher than those of modern petrol passenger vehicles. Without a particulate filter diesel engines also produce significantly more particulate emissions than petrol engines. It is for these reasons that the emission measurement programmes' main focus is on these two pollutant emissions and on diesel vehicles. The CO_2 emission levels are, however, also recorded during the emission tests.

Finally, the measurement programmes also leave room for specific research projects, for example to investigate unregulated emissions, specific factors that influence vehicles emissions, or the effectiveness of new emission reduction technologies. The methodologies used for these specific research projects depend on the specific research question and are not described in this report.

1.4 This report

The Dutch Ministry of Infrastructure and the Environment and TNO aspire to provide maximum transparency on the information that feeds into policy decisions regarding air quality and emission legislation. The aim of this document, therefore, is to describe the current working methodology of the light-duty and heavy-duty in-service testing programmes 'from vehicle selection to emission factors'. The report provides the necessary background information and context that is needed for the correct understanding and interpretation of measurement results presented in reports that describe the outcomes of the in-service testing programmes.

The report is structured according to Figure 1.

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[5] This is done by the Dutch GCN/GDN committee, a collaboration of the Dutch Ministry of Infrastructure and the Environment, PBL, TNO and RWS, under supervision of RIVM.

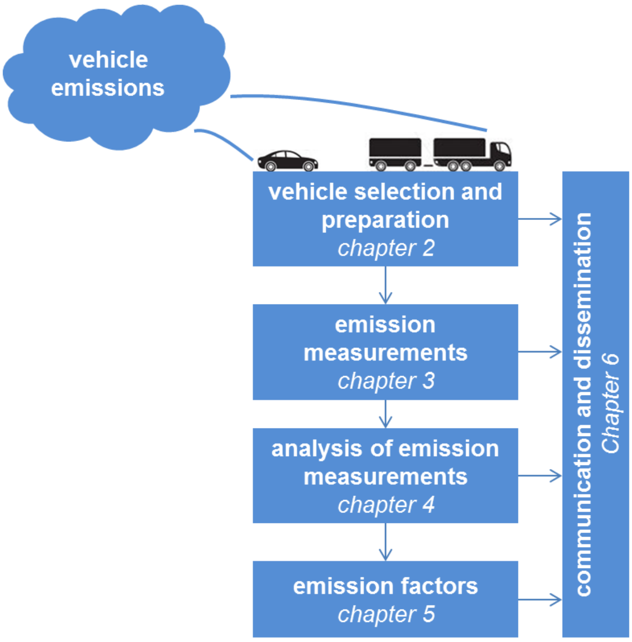

Figure 1: Methodology of the in-service testing programmes for the emissions of light-duty vehicles (passenger cars and vans) and heavy-duty vehicles (trucks and buses).

First, chapter 2 describes the process of selecting and preparing the test vehicles, after which chapter 3 presents all aspects of the emission measurements, i.e. the measuring equipment, the test trips, etc. The analysis of the emission measurements is explained in chapter 4. Chapter 5 then shows how emission factors are derived, and clearly explains what an emission factor represents and why it often differs from the emissions of an individual vehicle. As a closing remark, chapter 6 presents an overview of the ways in which results stemming from the in-service testing programmes are disseminated.

This document covers both the heavy-duty and the light-duty in-service testing programme, and many aspects are identical in both programmes. Significant differences between the two programmes are clearly indicated.

1.5 Updates of this report

This report provides background information on how emission measurements are performed at TNO. The field of vehicle emissions is continuously developing, as is illustrated in Figure 2. In case developments in e.g. vehicle emission behavior, legislation and test procedures or measurement methods call for changes in the working methodology of the emission test programmes, TNO, in close cooperation with the Ministry of Infrastructure and the Environment, will develop and implement the required adjustments and update this report accordingly.

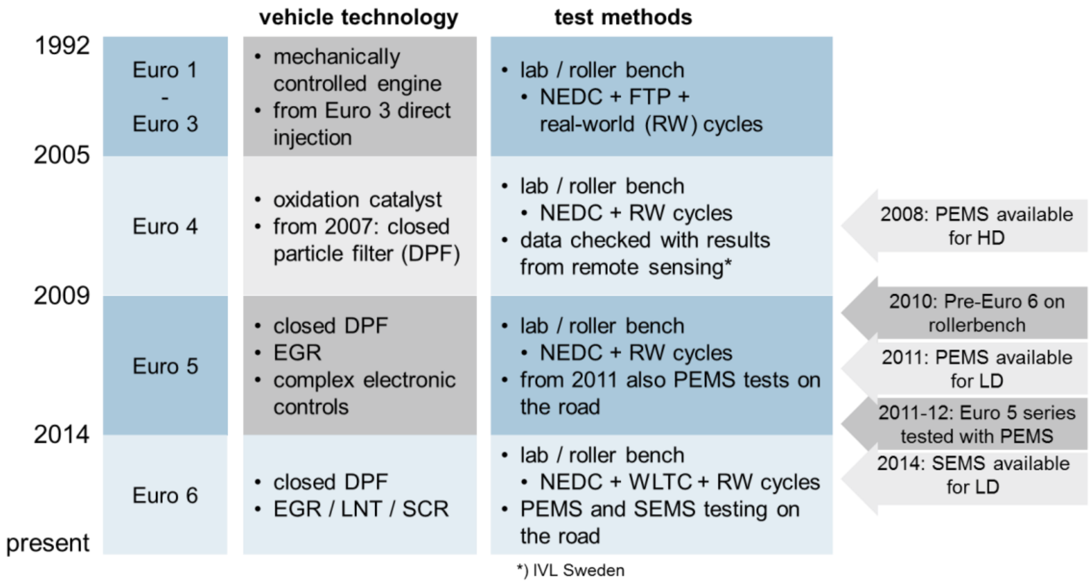

Figure 2: Overview of how the measurement program applied by TNO for testing diesel passenger cars has evolved together with the evolution of emission legislation, vehicle technology and available test methods.

2 Vehicle selection and preparation

To explain how vehicles of different categories are selected for emission tests (section 2.2), section 2.1 first gives an introduction on how vehicles are categorized. Section 2.3 then describes how vehicles are prepared for the emission test.

2.1 Vehicle categories

For EU type approval, according to 2007/46/EC, vehicles are categorized as shown in Table 1. Vehicles are generally grouped into passenger cars (M1) and buses (M2 and M3), light commercial vehicles (N1) and heavy-duty transport vehicles (N2 and N3).

Table 1: Vehicle categories in EU type approval legislation and the RDW database.

Category	Description	Category	Gross vehicle weight	Subcategory
Passenger cars and buses				Persons
M	Passenger transport with 4 wheels or more	M1	≤ 3500 kg	Up to 9
		M2	≤ 5000 kg	10 or more
		M3	> 5000 kg	
Vans and trucks				Reference mass
N	Goods transport with 4 wheels or more	N1	≤ 3500 kg	Class I: ≤ 1305 kg
				Class II: 1305 < GVW ≤ 1760 kg
				Class III: > 1760 kg
		N2	3500 < GVW ≤ 12.000 kg	NA
		N3	> 12.000 kg	

For the purpose of assessing real-world emissions of vehicles a further segregation can be made to distinguish groups of vehicles with typical emission behaviour. This more detailed categorization takes into account the following vehicle properties:

- Gross vehicle weight, which is the maximum mass of the vehicle, further specified as the technically permissible maximum laden mass.
- Fuel type (petrol, diesel, LPG, CNG, et cetera)
- Emission standard (Euro class)
- Emission reduction technology (DPF, SCR, et cetera)

Within the VERSIT+ modelling approach[6] used by TNO for determining emission factors, these properties are translated into so-called VERSIT classes, which consist of a letter coding, according to the following definitions:

- Weight class
  - L: light
  - M: medium
  - Z: heavy
  - B: bus

[6] The VERSIT+ model (Ligterink, de Lange 2009) is described in detail in section 5.1.1

- Vehicle type
  - AB: bus
  - BA: light commercial vehicle
  - BF: moped (not in Table 1)
  - MF: motorbike (not in Table 1)
  - PA: passenger car
  - PH: full-hybrid passenger car
  - PE: plug-in hybrid passenger car
  - VA: truck
  - TR: tractor
- Fuel
  - B: petrol
  - D: diesel
  - L: LPG
  - C: CNG and LNG
  - A: Ethanol (E85)
  - E: Electric
- Euro class:
  - PR82: vehicles older than 1982
  - 19** : vehicles younger than 1981 and older than 1993
  - O3WC: non-regulated 3-way catalyst
  - R3WC: regulated 3-way catalyst
  - EDE5: first generation Euro-V heavy-duty
  - EUG5: second generation Euro-V heavy-duty
  - EEV5: Euro-5 EEV, for buses only
  - Euro-0 up to Euro-6
- Extra info
  - ANH: with trailer
  - DPF: closed or wall-flow diesel particulate filter
  - HOF: retrofitted half-open DPF
  - LCH: indicating a segment of light vehicles within an overall vehicle type; distinction on the basis of gross vehicle mass for LBADs and MVAs, and for trailers combined with MVAs and ZTRs.
  - ZWA: indicating a segment of heavy vehicles within an overall vehicle type; distinction on the basis of gross vehicle mass for LBADs and MVAs, and for trailers combined with MVAs and ZTRs.
  - EGR: Exhaust Gas Recirculation
  - SCR: Selective Catalytic Reduction
  - RET: CNG retrofit category

2.1.1 Light-duty vehicles (passenger cars and vans)

For M1 passenger cars, the partitioning was chosen such that the vehicles can be distinguished by fuel type and Euro class. The difference in weight and engine size between passenger cars has a negligible systematic effect on the pollutant emissions and is therefore not used to distinguish further between vehicles.

For CO_2 vehicle size and weight and engine size are determinants. However, as the real-world CO_2 emissions scale fairly linear with the type approval emission values, in assessments of light duty vehicle CO_2 emissions vehicles are generally ranked according to their type approval value rather than by segments based on vehicle characteristics.

Light commercial vehicles, also referred to as LCVs or vans, are light-duty goods vehicles, designated “N1” in the European emission legislation. This does not fully correspond with the Dutch definition of “bedrijfswagens”, however, “bedrijfswagens” cover a similar group. LCVs exist in a variety of weight classes and cabin and chassis types.

The majority of the vans sold in the Netherlands are Class III. Light vans, class I and class II, are more similar to passenger cars, with similar weight, size, and engines. However, in almost all cases the fuel is diesel, with only a small portion of the smaller vans running on petrol, LPG and CNG fuel. The number of light-duty commercial vehicles has grown in the last decades. Only in recent years, the numbers have levelled off to a stable fraction of the light-duty fleet. Combined with the annual mileage, which is lower than that of diesel passenger cars, vans travel about 17 billion kilometres annually in the Netherlands, compared to 100 billion kilometres travelled with Dutch passenger cars.

Heavy LCVs or light heavy-duty trucks fall in a transition zone of the light-duty and heavy-duty emission legislations. In principle the legislations are distinguished by 'reference mass' (mass in running order + 25 kg). The reference mass of 2610 kg separates the two legislations (passenger cars and vans: ECE-R83 and heavy-duty engines and vehicles: ECE-R49). From each of the legislations, a type approval regarding emissions may be extended into the 'zone' of the other legislation. A truck with a light-duty Type-Approval may extend this TA to a higher reference mass, up to 2840 kg. A multi-stage vehicle (e.g. a chassis-cabin to which the bodywork is added later) with a heavy-duty type-approved engine, may extend its type-approval to a lower reference mass than 2610 kg if it can be demonstrated that the vehicle with bodywork weighs more than 2610 kg. Vehicle variants and versions for which the type-approval is extended, which have a reference mass more than 2380 kg, also need to meet the requirements for measurement of CO2 and fuel consumption.

The N1 and N2 classifications, which are distinguished by the maximum mass (gross vehicle weight below or above 3500 kg), do not fully match the emissions legislations, which are distinguished by reference mass. As a result, in the Netherlands vehicles that are registered as N1 may have a heavy-duty type-approval and vice-versa. Another reason why vehicles registered as N1 in the Netherlands may have a heavy-duty type-approval is that vehicles that are formally N2, according EU directive 2007/46, can be re-categorized and registered in the Netherlands as N1, with a maximum mass of 3500 kg. The motivation to do so is that N1 vehicles can be driven with driver’s license B.

Small LCVs (Class I and Class II) are a second group of LCVs. In many cases they are sold as a passenger car, and they are not part of the LCV fleet. However, a number of them are sold as commercial vehicles: these are typically the two-seater models with a larger cargo space. While many small van models are originally designed as Class I, the empty weight nowadays often exceeds 1205 kg, so that most small vans are in the Class II category.

The CBS[7] has its own categories of vans: vans with a gross vehicle weight below 2000 kg and vans with a gross vehicle weight above 2000 kg. This separation is

[7] Statistics Netherlands – Dutch: Het Centraal Bureau voor de Statistiek (CBS).

largely equivalent to grouping Class I and II together as light vans, and Class III as heavy vans.

The test programme for light commercial vehicles focusses on modern Class III vehicles, which comprise the majority of LCVs. Emissions of Class I and Class II vehicles are assumed to be similar to those of diesel passenger cars.

2.1.2 *Heavy-duty vehicles (trucks and buses)*

Heavy-duty vehicles can be categorized using the RDW registration as in Table 2. Different organisations that play a role in the determination and use of emission factors use different heavy-duty vehicle categories. Table 2 also lists the VERSIT classes that are used in the emission factor calculation. In this table, all special vehicles, such as e.g. concrete mixers and refuse collection vehicles, are part of the N2 and N3 categories, according to their weight. Longer Heavier Vehicles (LHV) are in the category N3 road train, but they have not been assigned a VERSIT class yet, and no separate emission factor is calculated for these vehicles. Buses are indicated separately as M2 and M3. Most buses are M3, the heavy category. Nowadays, however, smaller M2 buses are growing in numbers.

Table 2: RDW heavy-duty categories and corresponding VERSIT class for emission factors

Name	**VERSIT class**	**Description**	**Max weight**	
N2	MVALCH	Truck	3.5 - 12 ton[1]	
N3 light	MVAZWA	Truck light	≤ 19.5 ton	
N3 heavy	ZVALCH	Truck heavy	> 19.5 ton	
N3 tractor light	ZVAZWA	Tractor-semi-trailer light	≤ 19.5 ton	
N3 tractor heavy	ZTR	Tractor-semi-trailer heavy	> 19.5 ton	
N3 road train		Road train	> 50 ton	

[1]*Vehicles with a light-duty type approval may occasionally fall in the N2 category in the Netherlands, as is described in paragraph 2.1.1.*

2.2 Vehicle selection and sourcing

2.2.1 *Vehicle selection*

The combination of VERSIT+ categories results in over 300 different vehicle categories, of which the most important ones are part of the test programme. Emission factors for the remaining VERSIT+ categories are derived as described in Section 5.1.3.

As was stated in chapter 1.3, mainly diesel vehicles are currently included in the test programme. To obtain a representative sample, the vehicle selection needs to meet several requirements.

The emission data are used for modelling the vehicle emissions in the Netherlands. For this on-going work, emission data are required from vehicles in-service of models that have a large share in the Dutch vehicle fleet. After analysing the sales of vehicle models and engine types in the RDW registration database, the (engine) type and registration number of vehicles are used as the primary criteria to select representative vehicles. Additional criteria are representative engine power and vehicle type for the given engine type.

When a new emission stage enters into force, the focus of the selection shifts to that new emission stage. For example, heavy-duty Euro-VI came into force in 2014, but already in 2013 the first vehicles appeared on the market due to a tax incentive for those vehicles. The focus of the programme therefore shifted from Euro-V to Euro-VI in 2013.

The most frequently registered models often have the same engine types, such that, for example, only eleven different engines represent over 50% of all the Euro-5 diesel passenger cars sold in the Netherlands. Vehicles are first selected to cover these engine types, and then to cover a variety of models or brands. In this way, the engines of the majority of the diesel passenger cars and trucks sold in the Netherlands are covered by the test programme.

Furthermore, characteristics like ‘technology’ or ‘fuel‘ may be a reason to choose a certain vehicle on an ad-hoc basis. When new or alternative technologies enter the market, for instance using an alternative fuel, an alternative powertrain or a novel emission reduction system, the programme aims to assess the impact of these technologies on emissions under real-world driving conditions. These tests are seen as 'special tests' and are not included in the representative sample for the determination of generic emission factors.

2.2.2 Sourcing the vehicles

After selection of the representative models for an emission test programme, the test vehicles are obtained from various sources:

- <u>Vehicles of private owners or transport companies</u>: These vehicles are most probably used in normal service. The availability of those vehicles for testing depends on the willingness of the (fleet) owners to cooperate with the programme and the availability of the vehicle itself, as most vehicles are efficiently scheduled for transport operation. However, most owners are happy to provide a vehicle. The programme provides a financial compensation or a replacement vehicle for the time the vehicle is made available to TNO. In order to find the right vehicles, TNO uses its network within the transport sector and/or the RDW vehicle registration database. The database contains the light-duty vehicles (GVW ≤ 3.5 t) and heavy-duty vehicles (GVW > 3.5 t) registered in the Netherlands, vehicle specifications and information about the owner. This enables TNO to target vehicles and to start communication with vehicle owners about possible cooperation for the test programme. The database is provided under strict legal conditions preserving privacy of the owners.

- Rental vehicles: As with the group of vehicles described above, rental vehicles are expected to be subjected to normal use and conditions.
- Vehicles provided by the manufacturer: When a vehicle is hard to obtain, for instance because it is very new or recently introduced on the market, the manufacturer may be asked to supply a vehicle. These vehicles are often from the trial fleet of the importer or manufacturer. In some occasions, these vehicles are carefully inspected by the manufacturer before they take part in the test programme.

2.3 Vehicle preparation

Testing vehicle emissions requires some preparation, depending on the emission test that will be performed.

2.3.1 Obtaining vehicle information

Detailed information of the vehicle is requested from the owner. This includes information about the history of maintenance, repairs and modifications. Technical information about the vehicle itself is obtained from the OEM or the importer. The OEM is asked to provide the type-approval documents that describe the type-approval test settings of the vehicle such as reference mass, the resistance levels (“road load”) parameters, pass-fail evaluation settings and emission test results. In case of heavy-duty vehicles, engine (installation) certification is also requested. Additionally, mainly for heavy-duty vehicles, information to evaluate the results of the on-road tests using a Portable Emission Measurement System (PEMS, section 3.3.1) is often requested.

2.3.2 Technical check of the vehicle and installation of test equipment

Before every test programme a general (technical) check of the test vehicle is carried out. The presence of the main components of the exhaust after-treatment system is visually checked and an OBD[8] scan is performed. Fault codes are read and in case of emission-related fault codes the vehicle is either repaired or rejected for the test.

In some cases the manufacturer is asked to provide hardware for the installation of PEMS. With the growing number of emission reduction devices, exhaust systems have become more complex over the years, so that mounting the exhaust flow meter sometimes is a demanding task. In some cases, vehicle manufacturers provide their own PEMS connection piping.

2.3.3 Vehicle mass and payload

As chapter 3 describes in more detail, vehicles can be tested on-road as well as in the lab, depending on the prevailing research goals.

In order to test vehicle accelerations and decelerations in a realistic way during the chassis dynamometer test in the lab, the vehicle mass must be taken into account. Every regulation describes a certain definition of the vehicle test mass, which is mostly defined as the vehicle empty weight plus some additional mass (payload). On modern chassis dynamometers, the vehicle mass is partly simulated by the mass of the rollers and partly by activation of the eddy current dynamometer.

[8] On-board diagnostics

The mass of passenger cars in a road test is determined by means of a load cell and is defined as the real empty mass of the vehicle, as used in fully operational state with a 100% filled fuel tank, plus:

- the weight of the driver and technician plus 200 kg to account for the measuring equipment, battery and electric power generator (needed to run the PEMS) in case PEMS is used to measure on-road emissions;
- the weight of the driver plus about 10 kg for the measurement equipment in case TNO's Smart Emission Measurement System (SEMS, section 3.3.1) is used.

For heavy-duty vehicles and vans, additional payload (empty, half-full and full) can be added, according to the trip requirements (section 3.3.2.2). For real-world tests with SEMS, when the vehicle is used in normal operation, the payloads vary according to the normal use of the vehicle. For light commercial vehicles, two payloads are generally used in the on-road test program: the official WLTP test mass, which includes 28% payload, and the 100% payload, or gross vehicle weight.

The vehicle is weighed with a full fuel tank to see if it does not differ too much from the registered weight. For heavy-duty vehicles, the weight (including payload) is taken into account when determining the emission factors.

2.3.4 *Tyre pressure*

On the chassis dynamometer, the pressure of the tyres is set according to the manufacturer's instructions. Due to the chassis dynamometer's single rollers per axle, no increase of the tyre pressure is needed. For on-road tests, the payload determines the tyre pressure. Generally, higher payloads require a higher tyre pressure.

2.3.5 *Test fuel*

For the light-duty tests, regular market EN590 (diesel) and EN280 (petrol) fuel is used instead of the reference fuel prescribed by the type approval test procedure. Also, heavy-duty PEMS and SEMS measurements are performed with regular market EN590 fuel. The use of normal fuel better represents real-world conditions. Moreover, reference fuel is expected to have only a minor effect on the vehicle emissions, as the parameters of the applied Dutch trade fuel are within or very near the specifications of reference fuels.

For tests on a roller bench according to the formal type-approval test procedures, a CEC[9] reference fuel is used. Reference fuel is within the specification of market fuels, but has a more narrow specification bandwidth. Using a reference fuel ensures reproducibility of the type-approval test and reduces the test flexibilities with respect to fuel choice.

For PEMS tests on heavy-duty vehicles that are equipped with an SCR, a sample is taken from the reagent (AdBlue) and the fuel that are present in the respective tanks before the test, as this is required for the execution of a formal ISC test using PEMS. In case of high measured NO_x emissions, the sample may be needed after the test to investigate whether or not a reagent with the right quality was present during the test.

[9] http://www.cectests.org/

2.3.6 Battery State of Charge

For a chassis dynamometer test, the battery of passenger cars and vans is charged until the test starts. This ensures a full battery so that no extraordinary generator work is included in the test. Generally, no battery charging is applied before on-road tests. Tests are often carried out consecutively, and the vehicle and battery state are thus the result of the vehicle operation in the prior test.

For on-road tests with heavy-duty vehicles, no additional charging is performed if the vehicle that is to be tested was used normally in the days before the tests.

3 Emission measurements

3.1 Introduction

TNO has been carrying out the in-service testing programmes for the Dutch government since 1987. Over time, the testing procedures and the test programme have evolved with the developments in the type approval test procedures as well as available measurement technologies, with developments in the understanding of real-world emissions and with advances in vehicle technology.

As stated in the introduction, the vehicle emission measurements serve as a basis for establishing emission factors. Emission factors (chapter 5) reflect *real-world* vehicle emissions. Given the complex emission behaviour of modern vehicles, these emission factors must be derived from measurements conducted under representative, real-world conditions. These measurements can, of course, be on-road emission tests, but can also be measurements that are performed on a chassis dynamometer in a laboratory, e.g. using a driving cycle (speed-time profile) derived from real-world driving. Whether or not a measurement on a dynamometer produces emission results that well represent real-world emissions, depends on the emission behaviour of the tested vehicle. In case the vehicle's emission behaviour is mainly determined by factors that are well simulated in the laboratory, dynamometer measurements will provide representative, real-world emission results.

For light-duty vehicles up to and including Euro-4 the emissions depend mainly on engine load, which in the lab depends almost entirely on the driving cycle. By letting the Euro 4 vehicle drive a driving cycle that well represents real-world driving behaviour, real-world emissions can be reliably determined in the lab.

On the other hand, Euro 5 and 6 light-duty vehicles show a much more complex emission behaviour. Specifically for the NO_x emissions of these vehicles, research has shown that other (external) circumstances, such as the ambient temperature, to a greater extent influence the vehicle emissions. As a consequence, the reliable determination of real-world emission factors for Euro 5 and Euro 6 vehicles requires on-road emission measurements. In addition chassis dynamometer tests of these vehicles have become more complicated as modern vehicles require a special chassis dynamometer test mode, in order to prevent fault codes in the engine control from contradictory sensor readings. On-road emission tests using portable emission measurement systems were therefore introduced in the light-duty test programme as of Euro 5. For heavy-duty vehicles, on-road testing was also started with Euro V vehicles, in 2008.

As a result, from 2014 onwards, on-road tests have become increasingly important for determining Dutch generic emission factors. The equipment and test routes and conditions used for on-road measurements are described in section 3.3.

Still, laboratory measurements provide valuable information on vehicle emission performance and are needed to check whether vehicles comply with the type approval procedure. Also up to now PM-emissions could not be measured on the road. At the same time the operation of closed particulate filters applied to modern diesel vehicles is such that emissions measured in the lab can be considered representative for real-world driving. Laboratory measurements therefore continue to form an important part of the emission testing programmes. They are described in further detail in section 3.2.

3.2 Measurements in the laboratory

When testing a vehicle in the laboratory, the vehicle is made to drive a specified speed-time pattern (driving cycle) and its emissions are measured. This section describes the test equipment, procedures and driving cycles used during measurements in the laboratory. The subsections discern equipment and cycles for light-duty vehicles and heavy-duty vehicles.

3.2.1 Test equipment

3.2.1.1 Chassis dynamometer (roller bench) equipment for light-duty vehicles

A chassis dynamometer, also called roller bench, simulates the inertia (mass) and driving resistances (rolling resistance and air drag) of the vehicle. Chassis dynamometer tests as part of the Dutch in-service testing programme for light duty vehicles are performed at the facilities of Horiba in Oberursel, Germany (Figure 3), under supervision of TNO. Horiba is the manufacturer of certified laboratory test equipment and operates facilities that are certified to perform tests according to official protocols to the highest industry standards (ISO 17025).

In the laboratory, emission measurements on light-duty vehicles are carried out in two different ways:

1 For the overall emission results, the emissions are measured in accordance with UNECE R83; the test protocol of the NEDC test (section 3.2.2.1), which requires the emissions accumulated over the complete tests to be determined by sampling the diluted exhaust gases collected in large bags. With this method, emission behaviour cannot be linked to specific events during driving (such as accelerations or gear shifting).
2 For determining emission factor models, which are used to predict average real-world emissions of vehicles in a wide range of traffic circumstances, a measurement device is used that records emissions on a second-by-second basis (“modal mass”).

Both test results are frequently compared and only minor deviations were found in recent years. In the past, with the introduction of direct sampling around 2008, large deviations were found, and the second-by-second results had to be recalibrated from time to time to make them suitable for emission predictions.

The mass and driving resistance (road load), which are simulated by the roller bench, can be set in different ways. For replicating the type approval test the applied roller bench settings are the values used by the manufacturer for the type approval. These are obtained by TNO from the vehicle’s type approval certificate or information supplied by the importer or manufacturer. The determination of these road loads is in accordance with UNECE R83. In other cases e.g. road load setting are used which are derived from down tests performed by TNO, or vehicle mass and road load settings may be adapted to simulate specific use conditions such as driving with a high payload.

The vehicle test mass varies between tests and depends on the applied test procedure.

The NEDC test mass, based on prescribed weight classes, is usually the lowest mass at which a vehicle is tested. The WLTP “test mass high”, which includes the additional weight of the vehicle model options and a limited payload, is usually the highest mass at which a vehicle is tested. The differences between these two extremes is about 150 kg for a normal passenger car. LCVs may have a larger optional weight, up to 500 kg. However, the testing of LCVs according to the WLTP requires the use of a 28% payload, which yields a higher additional weight still. For LCVs, a coast-down test is commonly not performed. Instead, chassis dynamometer settings are generally determined from table values or rules based on weight.

As a vehicle tested by TNO is not exactly the same as the vehicle submitted for type approval by the manufacturer, the type approval road load setting may not adequately reflect the actual road load of the tested vehicle. The road load of a vehicle can be independently determined by carrying out a coast-down test on a test track.

In general, in recent years, the road load values for the chassis dynamometer settings obtained from the importer or manufacturer are low compared to the findings obtained in a coast-down test programme in which these values were determined independently by TNO, carried out in accordance with the official test procedure as described in Regulation 83. In a number of cases the official road-load values, used for type approval, were found to be too low to be realistic. In some cases the tyres mounted on the production vehicle had a higher driving resistance, as declared in the tyre energy label, than the value specified for the vehicle as a whole.

Figure 3: A passenger car tested in the laboratory on a two-wheel chassis dynamometer (roller bench).

Higher road load values yield higher fuel consumption and CO_2 emission values, but may affect also the NO_x emissions of the vehicle in two ways: The higher required engine power for the actual production vehicle will lead to an increase in emissions by the basic combustion process. In addition, if a vehicle’s engine control system is optimized for the engine powers and speeds associated with a low road load, the engine may have a poor emission calibration for the engine loads occurring in independent tests with production vehicles. Even higher road loads may occur during on road testing, in part due to the added weight of equipment and operator, but largely related to e.g. different road surfaces, steering and ambient conditions.

The Worldwide harmonized Light vehicles Test Procedures (WLTP) has a different test procedure for determination of the road load curve, which results in higher values to be used when the WLTC is driven on a chassis dynamometer.

Table 3 lists the regulated emissions that are measured with the corresponding measurement techniques. An additional NO/NO_2 analyser is connected for determination of the emission rates of these constituents of NO_x.

Table 3: Techniques for emission measurements on the chassis dynamometer.

Component	**Analysis**
CO	Non Dispersive Infrared (NDIR)
HC	Heated Flame Ionization Detection HFID
NO_x	Chemo Luminescence (CLA)
CO_2	NDIR
PM	Gravimetric
PN	Condensation Particle Counter (CPC) with Volatile Particle Remover(VPR)

3.2.1.2 Lab equipment for heavy-duty engines

Emissions of heavy-duty vehicles are mostly and preferably measured in on-road tests. In some cases, however, a laboratory test may still be required. One may think of checking type-approval compliance over the engine test cycles and in-depth investigations under well-controlled conditions. To this end, three types of laboratory heavy-duty testing methods exist:

1 engine tests bed
2 powertrain test bed
3 chassis dynamometer (not available at TNO)

Engine test bed

The conventional tool to test HD engines is the engine test bed (Figure 4). On an engine test bed, an engine’s crankshaft/flywheel is mounted to a dynamometer which is able to brake (or accelerate) the engine directly. Normalised torque and engine speed cycles, either steady-state or transient, are applied to the engine.

Figure 4: Test bed for heavy-duty engines at TNO.

The main advantage of the engine test bed is that the load and speed can be applied and measured very accurately and the other conditions, like intake air temperature, engine cooling can be controlled within narrow margins. Therefore, in general the repeatability, reproducibility and accuracy are very good.

A test on an engine test bed is, however, not representative for real-world operation and preparation of a test is very time-consuming. Moreover, modern engines are controlled by highly advanced, complex engine control software, which makes getting an engine to run without the help of a manufacturer a demanding task. The engine test bed, therefore, is mainly suitable to perform in-depth research on an engine, its controls and the aftertreatment system.

Power train test bed
The power train test bed (Figure 5) is a rather new tool for testing HD power trains. The complete vehicle is mounted to the test bed. The wheels of the powered axle are taken off and the load is applied by dyno’s to the hubs of the wheels over the drive line to the engine. Any torque-engine speed cycle can be applied. Engine torque-engine speed cycles or wheel torque-engine speed cycles can be derived from vehicle speed cycles if the gear shifting points, transmission ratios and road load are determined. Additionally, it is possible to drive a vehicle speed-time cycle.

Figure 5: Power train test bed at TNO.

The power train test bed set up at TNO in Helmond is situated in a climate chamber. This allows for testing under controlled and extreme ambient conditions. The ambient temperature can be varied between -40° C and +55° C, and altitudes up to 4000m above sea level can be simulated.

This makes the power train test bed suitable for:
1 type approval test checking over approximated engine test cycles;
2 research and development projects;
3 comparative assessments at the whole-vehicle level, and;
4 investigating emission behaviour under a wide range of environmental conditions.

3.2.2 Test cycles

In case of testing light-duty vehicles, the vehicle at hand is placed on the roller bench (section 3.2.1.1) and is made to drive a specified velocity-time pattern: the 'driving cycle' or 'test cycle'. Many different driving cycles exist, as will be explained in section 3.2.2.1. In case of heavy-duty testing, most of the times the engine rather than the complete vehicle is tested. The engine is subjected to an engine load cycle, which is described in section 3.2.2.2.

3.2.2.1 Light-duty vehicles (passenger cars and vans)

NEDC

The New European Driving Cycle (NEDC[4,10]) is the test cycle (speed-time profile) that is prescribed to be used for European type approval testing of vehicle emissions and fuel consumption. The test procedure as a whole is prescribed by regulation UNECE R83 [4].

[10] See: *Reference book of driving cycles for the use in measurement of road vehicle emissions*, Barlow, T.J., Latham, I.S., McCrae, I.S., Boulter, P.G., (2009), TRL report PPR 354

The “NEDC cold start” test, as carried out by TNO, is an independent reproduction of the type approval test (the so-called Type 1 test). The roller bench settings (vehicle mass and driving resistance) are the values used by the manufacturer, and are obtained by TNO from the vehicle’s type approval certificate or information supplied by the manufacturer.

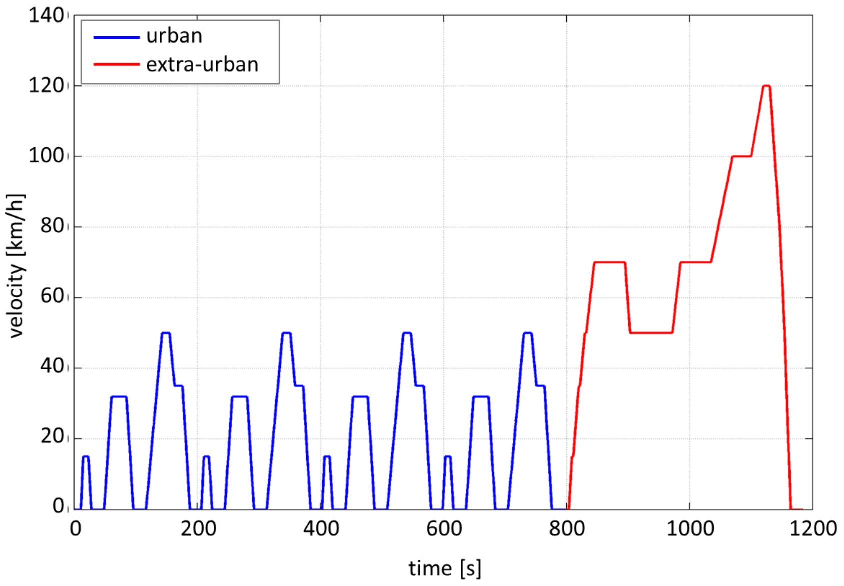

Figure 6: NEDC (New European Driving Cycle).

In the type approval test procedure the emission test is started with a cold engine, a condition obtained by “soaking” the vehicle for at least 6 hours at a temperature between 20 and 30°C. The NEDC test can also be started with a warm engine, i.e. an engine that is at its nominal operating temperature. The test is executed at an ambient temperature between 20 and 30°C. Based on scientific principles, emissions at cold start are expected to be higher than when a vehicle starts a trip with a warm engine and warm exhaust aftertreatment system. Until 2009 (up to “halfway” the Euro 4 timeframe) the effect of a cold start on real-world emissions could be determined by subtracting the emissions measured on an NEDC test starting with a warm engine from those measured on an NEDC test with a cold start. This approach was abandoned when Euro 5 diesel vehicles started to exhibit higher emissions on the NEDC with hot start than on the NEDC with cold start.

CADC

The Common Artemis Driving Cycle (CADC[10]) has been derived from speed patterns recorded on the road for vehicles operated in normal traffic. It consists of three different parts representing urban, rural and highway driving. The CADC is used as a de facto standard for simulating real-world driving on a roller bench by many research organisation throughout Europe, although its speed distribution and dynamics are somewhat more aggressive than would be representative for average real-world driving in the Netherlands and many other countries.

In the period that Euro 5 and Euro 6 vehicles were tested, roller bench tests using the CADC were performed on almost all vehicles that were tested in the laboratory. Over time the CADC was applied in different manners. Initially, a variant of the

CADC with a maximum speed of 130 km/h was used. In order to include possible effects of the introduction of the 130 km/h speed limit in the Netherlands in 2011, in the emission testing the low velocity variant of the CADC was replaced by a variant with a maximum speed of 150 km/h from 2013 onwards. The urban and rural part of both CADC variants are the same. Also the road load settings were changed over time. Up to the last quarter of 2014 the same road load as for the NEDC was applied. From the last quarter of 2014 onwards the WLTP road load is used when testing cars on the CADC.

For Euro 5 vehicles laboratory testing on the CADC is found to produce emission results that are representative for the actual emissions occurring in real-world driving on the road, as observed from the limited PEMS testing by TNO of Euro 5 vehicles. This has also been verified by comparing our test results with accurate remote sensing measurements carried out by IVL in Sweden[11].

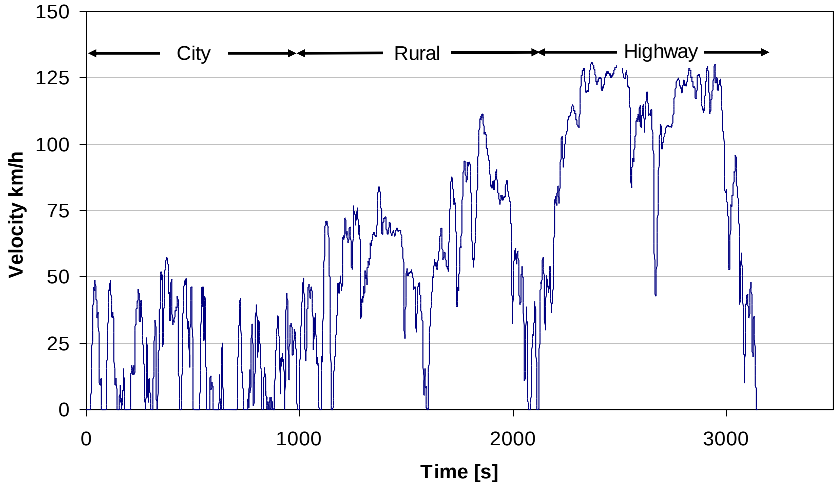

Figure 7: The 130 km/h variant of the CADC (Common Artemis Driving Cycle).

The CADC test is performed under the same temperature conditions as the NEDC-test. Between 2009 and 2012 (starting “halfway” the Euro 5 timeframe) the effect of cold start on vehicle emissions was assessed by performing a CADC with a cold start, immediately followed by driving an additional urban part of the cycle, and comparing the results for the cold and warm urban sub-cycle. Around 2012 also on this test vehicles started to exhibit higher emissions on the warm test than on the test starting with a cold engine, and the method of comparing cold and warm tests was abandoned altogether. As a consequence for modern diesel vehicles it is difficult to assess the real-world cold start effect from either laboratory tests or PEMS tests.

TNO-Dynacycle

In 2008 TNO concluded that the driving cycles commonly used in the laboratory do not cover strong and prolonged accelerations that are sometimes observed in real-world driving. In order to also collect emission data for this type of driving in the

[11] See *Evaluation of European Road transport emission models against on-road emission data as measured by optical remote sensing*, Sjödin, Å., Jerksjö, M. (IVL), (2008) 17th International Transport and Air Pollution Conference, Graz

laboratory the artificial TNO-Dynacycle was developed. Not all cars have enough power to follow this driving pattern: in that case full throttle driving is used. High emissions on the TNO-Dynacycle are typically associated with shortcomings of the emission control for strong accelerations and their associated high power demand.

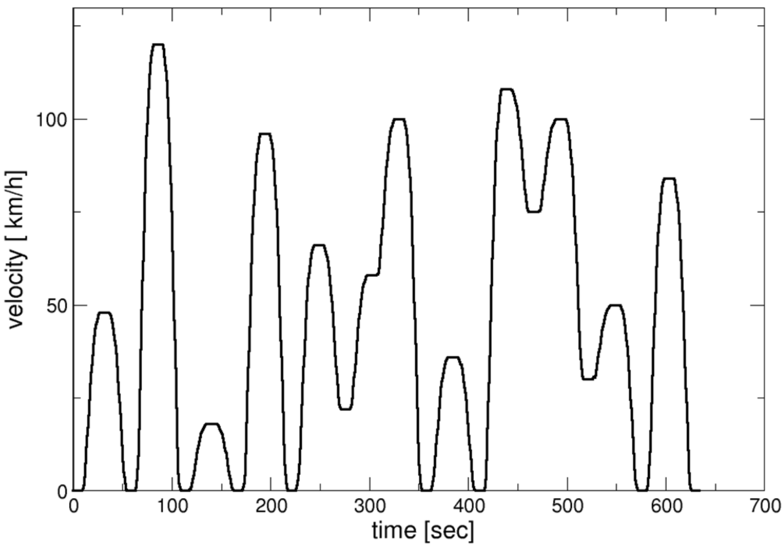

Figure 8: The artificial TNO-Dynacycle, developed for assessing emissions at strong and prolonged accelerations.

WLTC

Over the last years the world harmonized light-duty test cycle WLTC has been developed as part of the WLTP. From 2013 onwards draft versions of the WLTC have been used by TNO and other institutes in specialized test programs, executed at the request of the European Commission for the evaluation of the protocol and the comparison of the different type-approval tests. TNO has also used the WLTC for its test programme for the Ministry of Infrastructure and the Environment. The validation tests were part of a larger test programme and generally had a slightly different test protocol compared to the tests which were executed for the Dutch Ministry. In almost all of these tests the road load settings for the roller bench were in accordance with the (draft) procedures prescribed by the WLTP.

The WLTC driving cycle was developed over a number of years, and earlier versions were slightly more aggressive, in terms e.g. accelerations and decelerations, than the final test cycle as defined in the UNECE Global Technical Regulation 15.

Apart from the speed-time profile, four important aspects have to be taken into account, in order to yield a fair comparison of the results and the bandwidth in testing on the NEDC and WLTC. First of all, the vehicle test mass in the WLTP test procedure is higher than in the NEDC test, and therefore closer to that of production vehicles in actual use. Secondly, the road load is generally higher, in part because of the higher vehicle test mass, but also due to the improved determination of the road load. Thirdly, the testing of a vehicle model on the WLTC occurs in a bandwidth: Given a family of vehicle models, a “low road load” and a “high road load" version has to be tested to establish the bandwidth, within which all vehicle models from the "vehicle interpolation family" should find a place. In many cases in the validation programme appropriate data on weight and road load for the laboratory settings were not available so rough estimates had to be used to allow for testing. In particular, the new table values for road loads, as part of the new regulation, are an extreme worst case setting for the test, corresponding to the worst 3% vehicles. This estimate is meant to be an incentive for determining road loads through measurement, rather than relying on table values. Testing with these table values may increase the emissions significantly.

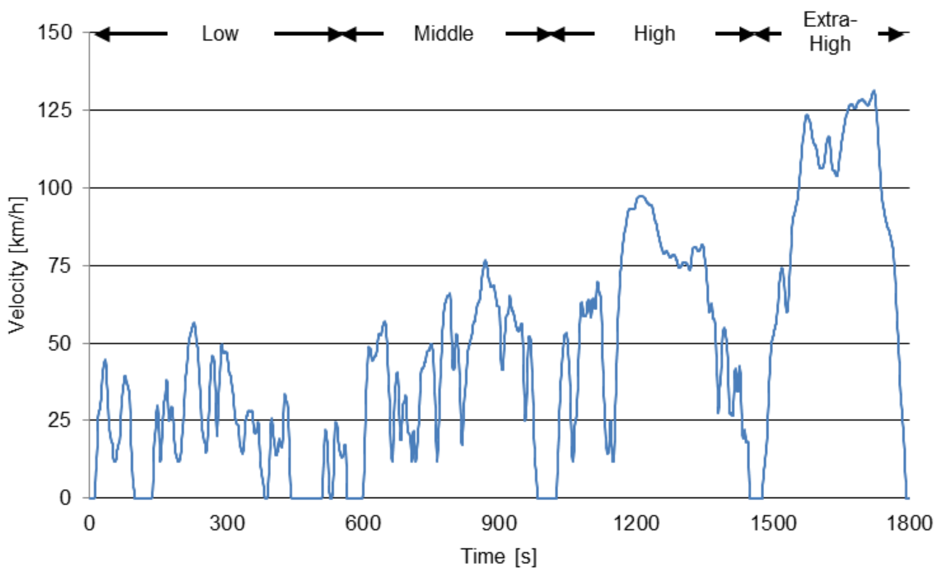

Figure 9: The Worldwide harmonized Light-duty driving Test Cycle (WLTC_v5).

In an early stage of the WLTP development, measurements by TNO have been done using both mass and road load definitions. Later on only the high test mass and road load values were used.

Gear shift strategies
The gear shift points vary from test protocol to test protocol. The NEDC and the TNO Dynacycle have fixed velocities for gear shifts. The CADC also has gear shifts at fixed velocities, but unlike the NEDC these velocities depend on vehicle characteristics such as the rated power. For the WLTP the gear shift strategy to be applied is, within some limitations, determined by the manufacturer. For our measurements, the WLTP tests were executed with gear shift points that were determined using generic tools, developed for and supplied by the European Commission, based on the vehicle and transmission characteristics.

3.2.2.2 *Heavy-duty vehicles (trucks and buses)*
For heavy-duty engines, the most important test cycle is the World-harmonized Heavy-duty Transient Cycle (WHTC), which was introduced for type approval at Euro-VI. The test cycle generally has a lower and more representative engine load (torque) compared to its predecessor, the ETC. According to the type approval procedure, the WHTC is performed twice, the first cycle is started with a cold engine and the second cycle is started with a hot engine after a short hot soak period. The

results of both tests are weighted before they are compared with the applicable emission limit.

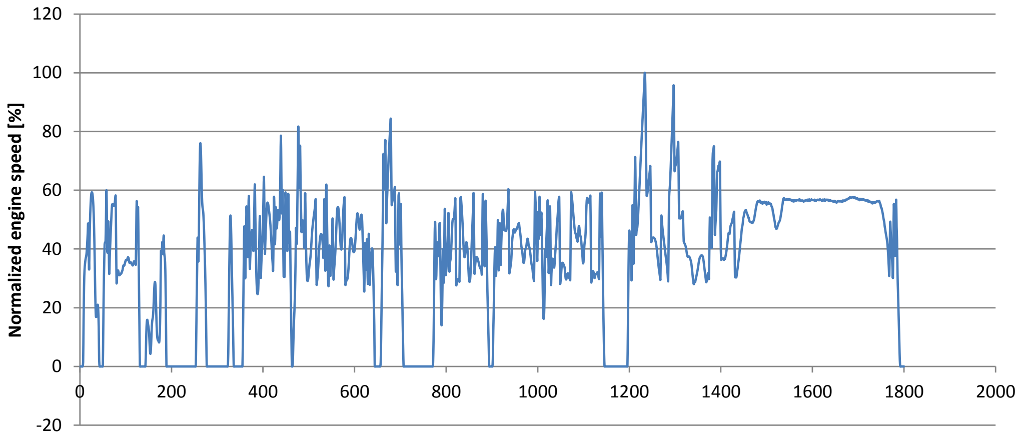

Figure 10: WHTC test cycle, second by second sequences of normalized engine speed.

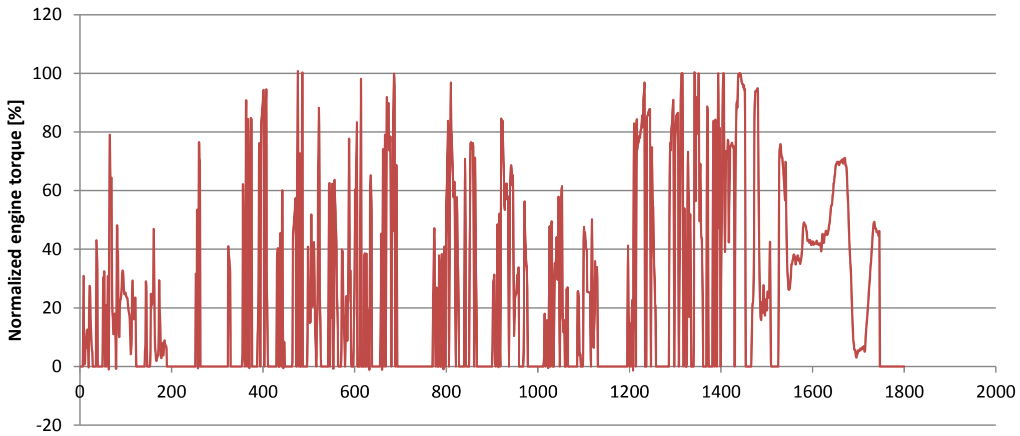

Figure 11: WHTC test cycle, second by second sequences of normalized engine torque.

3.3 Measurements on the road

This section elaborates on the measurement equipment and test trips for on-road measurements and gives more details on test conditions that have to be accounted for in real-world emission measurements.

On-road tests generate real-world emission results, but as these emissions are strongly influenced by various test conditions the results of a single test generally deviate from the average real-world emission behavior of a vehicle. In on-road testing, there are a large number of widely varying test conditions such as temperature, road type and traffic situations (e.g. congestion), payload, the use of auxiliaries and warming up effects of the engine and exhaust aftertreatment system. These conditions are therefore monitored.

Light-duty vehicles
On-road tests with a Smart Emissions Measurement System (SEMS) and a Portable Emissions Measurement System (PEMS) are performed in various test trips. TNO uses the PEMS and SEMS measurement method as the basis for determining emission factors for Euro 5 and Euro 6 light commercial vehicles and Euro 6 passenger cars from 2014 onwards.

Heavy-duty vehicles
For heavy-duty engines, since 2009 mainly PEMS measurements have been performed by TNO, testing EEV, Euro V and Euro VI vehicles. Since the beginning of 2015, SEMS was added to the heavy-duty in-service testing programme and since then SEMS and PEMS are used in conjunction with each other in a special scheme to screen the emission performance and to determine the real world emissions.

3.3.1 Emission measurement equipment

PEMS
With the regulatory developments for on-road testing of heavy-duty vehicles in the USA and Europe, certified mobile measurement equipment, also known as portable emissions measurement system (PEMS), became available from 2008 onwards. In 2010 the European Commission decided that the use of PEMS equipment was also the way forward for the RDE legislation, currently under development, which prescribes on-road testing as part of the type approval test protocol for light-duty vehicles. In response to that, TNO started to gain experience with emission testing of light-duty vehicles on the road. TNO's previous experience with PEMS-testing of heavy-duty vehicles was helpful to arrive at a pragmatic test protocol quickly. As part of the test protocol a reference test cycle was developed with an appropriate coverage of all relevant driving behaviour and road types.

Until 2015, TNO performed its measurements with a Semtech DS-version, a first generation of PEMS equipment. In 2015, TNO acquired a new PEMS system, the Horiba PEMS OBS-ONE. The specifications of both aforementioned PEMS systems can be found in appendix C.1. Figure 12 and Figure 13 show the way PEMS is mounted in and on light-duty vehicles and heavy-duty vehicles respectively.

Figure 12: The PEMS system mounted on vehicles to be tested on the road

PEMS equipment is relatively bulky and heavy, and as a consequence affects the total weight of a light-duty vehicle, tested on the road. The set-up used by TNO weighs around 170 kg, including analysers, battery and generator-set[12], and its operation also requires the presence of a technician in the car besides the driver. The air-resistance and exhaust back pressure are also somewhat affected due to the fixture of a flow tube on the exhaust pipe. Especially for light-duty vehicles the higher mass and resistance affect the fuel consumption and emissions of the vehicle while driving with the PEMS on-board.

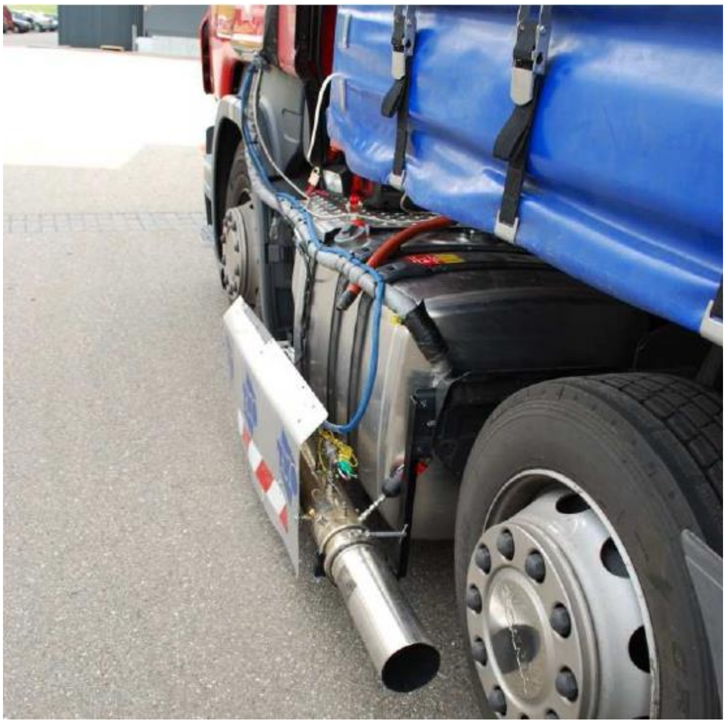

Figure 13: PEMS equipment installed on a heavy-duty vehicle.

TNO always installs the PEMS system inside the vehicle, either in the trunk, in the passenger compartment or in the cargo area (trucks), dependent on available space. Compared to the alternative of installation on a rack outside the vehicle, this provides a more stable operating environment for the PEMS and thus more stable measurement results.

Validation of the PEMS equipment
The Sensor Semtech DS PEMS, which was in-service from 2009 to 2015, has been evaluated, and extensive correlations tests against laboratory standards have been performed and were reported in [TNO 2012a].

The new Horiba OBD-ONE (in-service since 2015) was evaluated in a test set-up in which engine test bed and PEMS results could be compared because test were executed simultaneously sampling the same exhaust gas.

[12] Through the use of a generator-set the PEMS' electrical power supply is independent from the vehicle and therefore does not affect the engine load during driving.

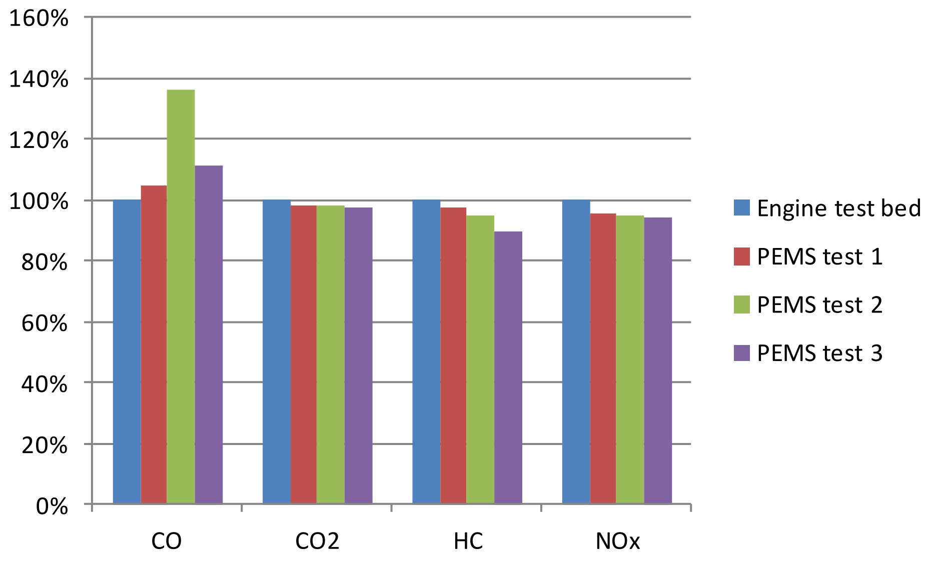

Figure 14: Comparison of the emissions results of engine test bed P2 in Helmond power train test center (Horiba STARS, MEXA raw emission measurement according ECE R49) and PEMS OBS-ONE test in g/kWh. The differences between the two test methods are caused by variability of the emissions test equipment (analysers and flow measurement). The work used to determine work specific emissions is the same for both the engine test bed results and the PEMS results and is a quantity that is calculated from engine torque and speed.

SEMS

The size, weight, and complexity of the certified PEMS equipment are prohibitive for large monitoring programs. Therefore, soon after starting PEMS testing of heavy-duty vehicles, TNO initiated the development of a simpler measurement technique, tuned towards monitoring NO_x emissions: the Smart Emissions Measurement System (SEMS[13]). This method uses automotive NO_x and oxygen sensors to estimate the emission performance. Combining measurements of the NO_x and oxygen concentrations with the MAF signal (Mass Air Flow) on the OBD (On Board Diagnostics) allows for an accurate, robust, and fast way of measuring absolute emissions on light-duty diesel and heavy-duty vehicles. The weight of the system is around 10 kg.

Since this method is not certified, and relies on signals of (in principle) unknown accuracy and origin, the results and sensors are continuously calibrated and compared with results of laboratory testing in cross-validation experiments. The accuracy and reproducibility of measurements with our current generation of SEMS equipment is in most cases within a bandwidth of 10%, and in many cases even within a much smaller bandwidth of a few percent.

[13] For more details on the TNO SEMS system see e.g.:
SEMS operating as a proven system for screening real-world NO_x emissions, R.J. Vermeulen, H.L. Baarbé, L.W.M. Zuidgeest, J.S. Spreen, W.A. Vonk, S. van Goethem (2014),TAP conference Graz.
A smart and robust NO_x emission evaluation tool for the environmental screening of heavy-duty vehicles, R.J. Vermeulen, N.E. Ligterink, W.A. Vonk, H.L. Baarbé (2012), TAP conference Thessaloniki.

Figure 15: The SEMS system, developed by TNO, mounted on vehicles to be tested on the road (prototype version 2015).

Figure 16: The SEMS sensors (NO_x-O_2, NH_3 and temperature) mounted in the exhaust.

For SEMS testing, the vehicles are modified slightly to insert sensors in the tailpipe and connect equipment to the vehicle electronics. Special care is always taken not to interfere with the normal operation of the vehicle. In one case a manufacturer argued, in response to test results that were sent for evaluation, that the location of an additional sensor may have affected the exhaust gas flow and the readings for emission control from the car’s own sensor downstream.

TNO is aware of the variation in quality of automotive NO_x sensors and the possible cross-sensitivity for NH_3. We take account of that in the design and manufacturing of our SEMS devices, and by regular calibration of the systems before and after tests. For vehicles equipped with SCR systems part of the NO_x values, recorded by SEMS, could be attributable to NH_3 slip. The approach used by TNO aims to minimize that share.

TNO uses the PEMS and SEMS measurement method as the basis for determining emission factors for Euro 5 and Euro 6 light commercial vehicles and Euro 6 passenger cars and Euro VI trucks and buses from 2014 onwards.

Signals and calibration of the SEMS equipment
First of all, several velocity signals are registered by the SEMS equipment: ABS (velocity from wheel rotation), VSS (vehicle speed sensor) and GPS, of which the ABS is the most accurate. The ABS and VSS vehicle speed signals are calibrated to match the GPS vehicle distance.

The SEMS equipment does not provide the overall flow or absolute emissions in mg/s. Therefore the mass air flow (MAF) signal from the On-Board Diagnostic system is used, along with the carbon and hydrogen content of the fuel and the oxygen concentration in the exhaust gas, to calculate the flow rates of CO_2 and NO_x. This procedure contains the following steps [TNO 2015b]:

1. The CO_2 concentration is determined from the remaining O_2 concentration compared to the ambient O_2 concentration;
2. The CO_2 flow is determined from the MAF and oxygen concentration;
3. The inlet mass flow is the sum of the MAF and fuel consumption. The fuel consumption is calculated from the CO_2 flow by carbon balance. The exhaust rate flow [kg/s] is equal to the inlet mass flow;
4. The NO_x and NH_3 concentrations are converted to flow rates using the exhaust mass flow and molecular mass ratios.

Figure 17: Left: Load packages (black box) and data logger of the SEMS (blue cradle) used in on-road testing of a light commercial vehicle.
Right: The laptop used to monitor and control the SEMS equipment.

This analysis requires two input parameters:

- the C:H ratio of the fuel, which is assumed to be $CH_{1.95}$ for modern market-fuel diesel;
- the ambient oxygen content of air at 20.8% for on-road conditions. However, for several tests, the maximal oxygen percentage observed in data when ambient air is flowing through the exhaust, was lower than 20.8%. A lower maximum oxygen percentage results in a lower NO_x mass per second, so the conservative approach is to use the lower O_2 percentage (when it does not reach 20.8% in the data) for calculating the mass flow.

The NO_x and O_2 signals are calibrated for each different sensor and vehicle, and also in between measurements. These calibrations are performed under laboratory conditions using bottled calibration gas at different concentrations. The offset and gain of the calibration tests are used to correct the NO_x signal. Since the quality of the OBD air-flow signal is not known, independent verifications with fueling data are used to determine the quality of the air flow signal of the different vehicles. The total CO_2 between fueling, as determined from the fuel and from the air flow signal, was equal for all light-duty vehicles, within a 5% range. No systematic deviation for this 5% variation was found. The accuracy of the SEMS measurements is validated in previous projects [TNO 2012d, TNO 2014a] and is further discussed in the next paragraph.

It is noted that at very low concentrations of NO_x, the SEMS sensor is less accurate for transient signals. However, in the range of concentrations of the current measurements on Euro-5 and 6 diesel vehicles the correlation and calibration tests carried out in the last four years provide a good evidence for accurate measurements.

Validation of the SEMS equipment: comparison to PEMS and dynamometer results

For light-duty vehicles, in order to validate the SEMS test results, tests were performed on a chassis dynamometer for one vehicle comparing SEMS results with the reading of the laboratory emission measurement equipment. The CO_2 and NO_x test results are shown in Figure 18 and Figure 19. The SEMS test results are well in line with the chassis dynamometer test results. SEMS test results are partly based on Mass Air Flow data of the CAN-bus of the vehicle, the accuracy of which is unknown. In all emission tests the CO_2 deviation is 8% and the NO_x deviation is -14% to +12%.

Although SEMS is less accurate than PEMS, the system is well suited for a quick screening of NO_x emissions of a vehicle. Its error margins are sufficiently low to identify emissions that are well beyond emission limits. Furthermore, the NO_x and CO_2 volume concentrations of SEMS and the raw analyser of the chassis dynamometer are compared. Both measuring signals are in line, especially at lower volume concentrations. At higher NO_x concentrations, i.e. around 300 ppm, some deviation occurs.

The results show that SEMS is a screening tool which yields reproducible results. One should keep in mind that the accuracy of these test results is directly related to the accuracy of the mass air flow signal of this vehicle type. Other vehicle types may gain different accuracies.

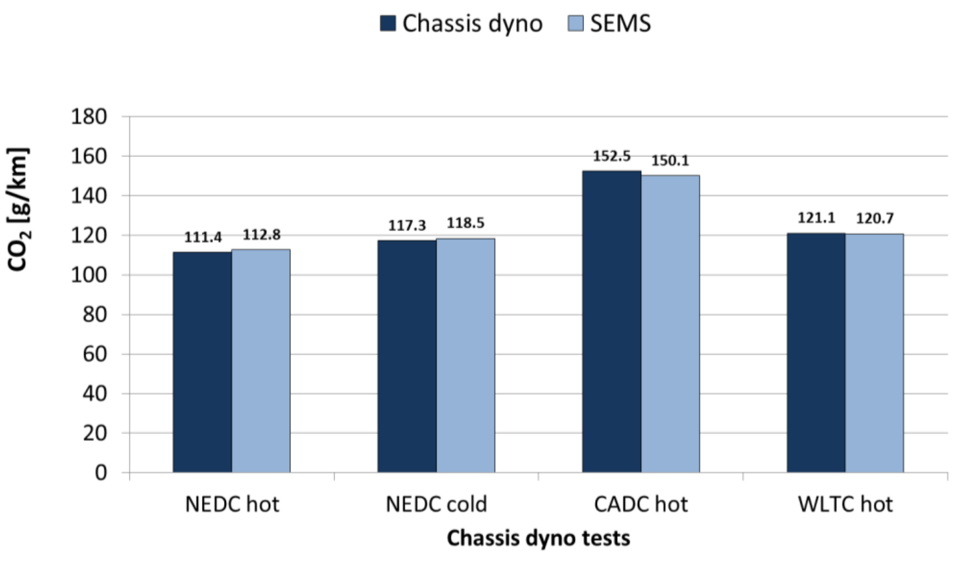

Figure 18: CO_2 emissions of a Euro 6 diesel passenger car (chassis dyno bag and SEMS results).

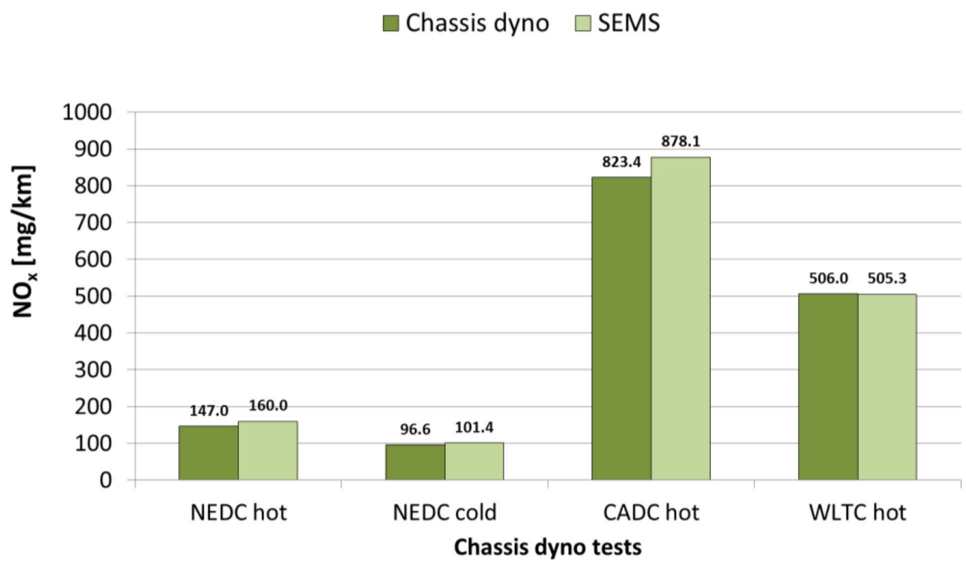

Figure 19: NO_x emissions of a Euro 6 diesel passenger car (chassis dyno bag and SEMS results).

For heavy-duty vehicles SEMS results have been compared to PEMS results. [TNO 2012d] reported a correlation exercise between PEMS and SEMS results.

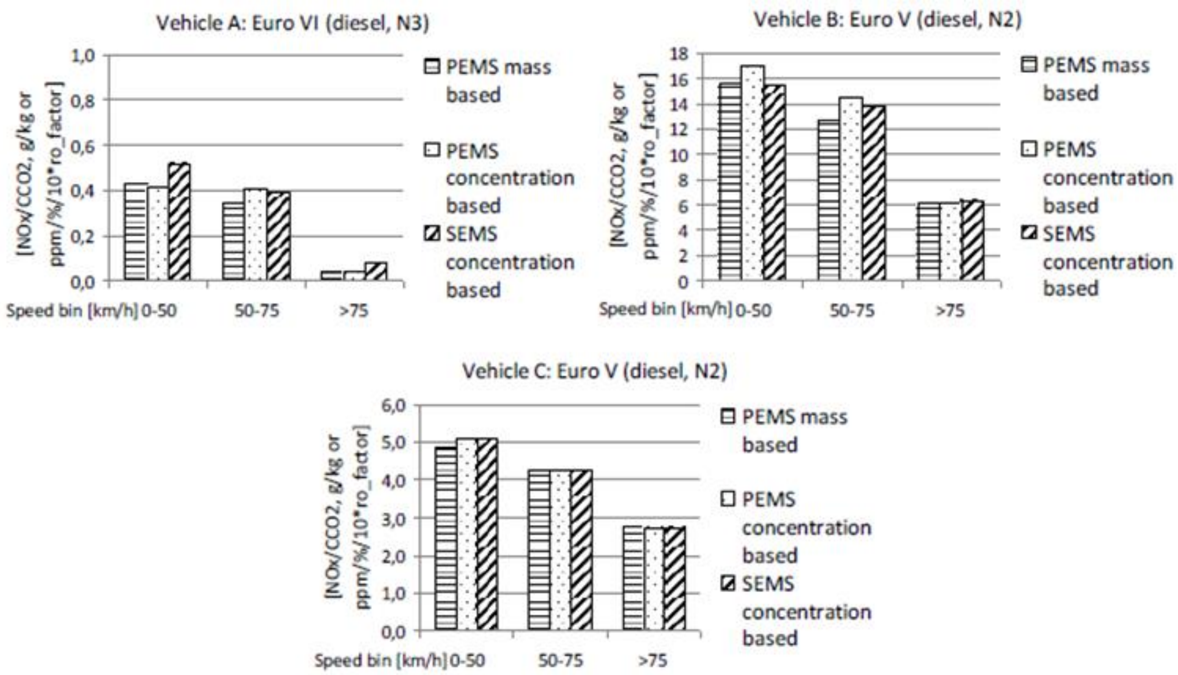

Figure 20: In the three figures the PEMS and SEMS results for different Euro V and VI trucks are compared using speed bins. For PEMS both the mass emissions and the concentration of the emissions were used for the evaluation. For SEMS the evaluation is purely based on the raw sensor output (and a separate GPS system). The outcome of the data-evaluation with PEMS and SEMS differs from a few to a maximum of about 20%. In general, the trends over the large speed bins are very well comparable.

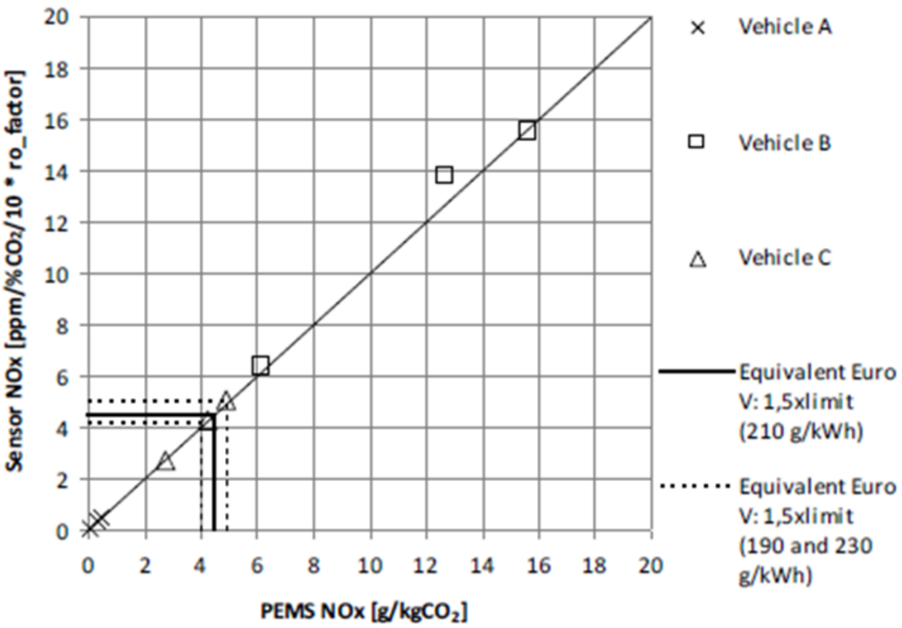

Figure 21: The data as evaluated in large speed bins of SEMS and PEMS are shown to depict the correlation between the two measurement methods. Vehicle B and C represent a regular and a bad performing Euro V heavy-duty vehicle. Vehicle A represents a Euro VI vehicle. Emissions levels can be clearly distinguished with both methods.

3.3.2 Trips used for on-road testing

The on-road data is recorded for a variety of routes. Besides a reference trip on a fixed trajectory, which is used for each vehicle, a number of random trips and specific trips can be driven with different driving styles (dynamic, economic) on different Dutch road types (city roads, motorways and rural roads).

The specified trips are designed to meet one or more of the following requirements:
- represent typical Dutch urban, rural and motorway conditions and applicable for testing with different payloads;
- allow assessment of the effectiveness and robustness of the procedures currently being used for checking in-service conformity of heavy-duty vehicles with PEMS (EC/582/2011 and amendments) and being developed for the future Real Driving Emissions legislation;
- allow assessment of the relation of in-service conformity legislation and Real-Driving Emissions legislation with real-world emissions for typical Dutch driving conditions;
- allow evaluation of vehicles with respect to the current and future regulatory standards for RDE (LD) and ISC (HD).

3.3.2.1 Trips for light-duty vehicles

The following routes are available for the test programme for light-duty vehicles, as Table 4 shows.

Table 4: Specifications of on-road test routes of the Dutch In-Service testing programme.

	RDE route Helmond/Delft	**TNO City route Helmond**	**TNO Reference route Helmond**	**Constant velocity route (Germany)**
Type	City, rural and highway	City	City, rural and highway	Highway
Distance [km]	77/83 km	25.6. km	73.5 km	189 km
Duration [min]	100-110 min	57 min	89 min	119 min*
Average velocity [km/h]	46-50 km/h (including idle time)	32 km/h (excluding idle time)	55 km/h (excluding idle time)	93 km/h (total route)*
Load [-]	Driver** + test equipment	Driver** + test equipment	Driver** + test equipment	Driver** + test equipment

*Constant velocity measurements are part of this route; constant velocity tests have duration of approximately 300 to 600 seconds.
**For PEMS trips a driver and a test engineer run the test.

RDE routes

RDE routes are based on the Euro 6 RDE legislation. TNO defined RDE routes in the Helmond area (suffix ‘A’, Figure 22) as well as in the Delft area (suffix ‘D’, Figure 23). RDE routes are driven with cold starts (suffix ‘C’) and hot (warm) starts (suffix ‘W’) starts. As an example, an RDE route with a hot start in the Delft area is designated ‘RDE_D_W’.

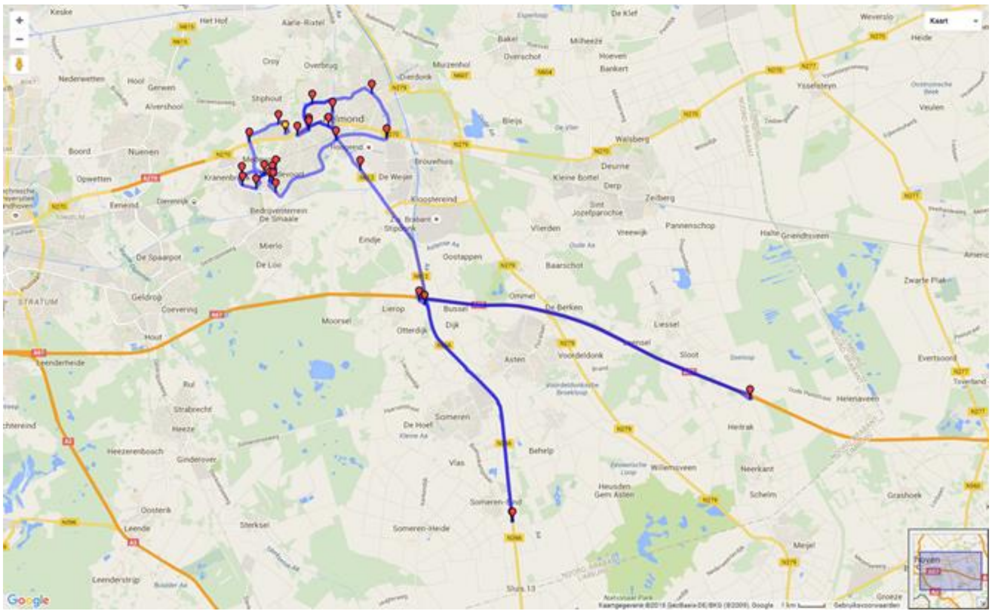

Figure 22: Plot of TNO's RDE_A route, in the Helmond area.

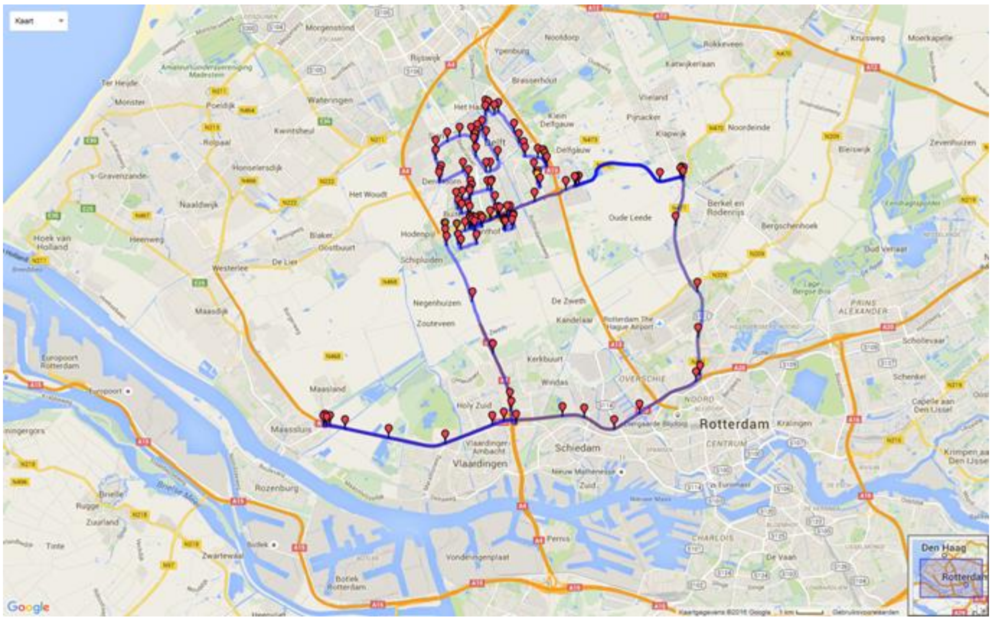

Figure 23: Plot of TNO's RDE_D route, in the Delft area.

TNO Reference route

Prior to the RDE-compatible routes TNO has developed a reference route (designated 'TNO Reference route Helmond', Figure 24) for on-road testing in the Helmond area. This enables the comparison of all test vehicles. The route contains roughly equal parts of urban roads, rural roads and highways. The trip is started both with a cold engine and with a warm engine and after-treatment system. The warming-up consists of a trip over the same route as the reference trip, until stable engine oil and coolant temperature is reached.

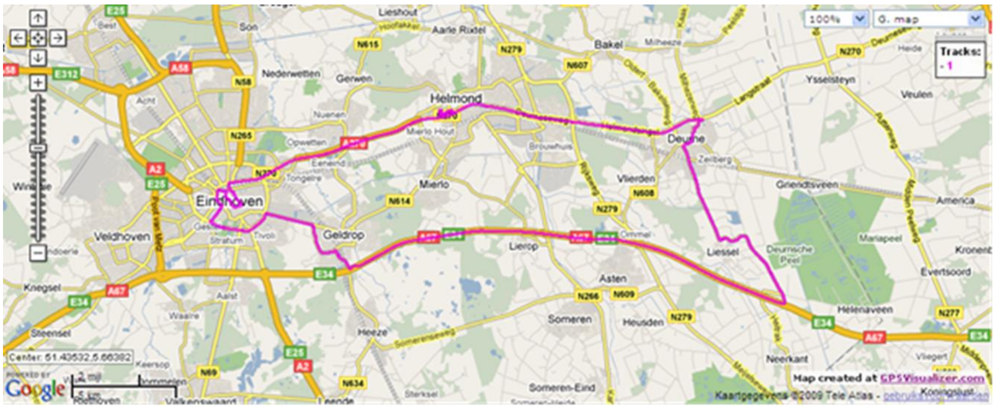

Figure 24: Light-duty reference trip in Helmond, the Netherlands.

Specialized routes
The programme often also includes specialized tests such as typical commuting trips, city trips (TNO City route Helmond in Table 4), constant velocity driving (Table 4) and monitoring data from trips to the test laboratory in Germany.

Random routes
Dependent on whether specific research questions exist, random trips may be driven. One may think of routes covering a variety of road types (such as CITY, RURAL and MOTORWAY in Table 6), traffic conditions (e.g. CONGEST in Table 6), velocities and distances.

Comparing TNO's Reference route with the current RDE routes
The TNO on-road reference route, which is further detailed in Table 5, predates any trip requirement proposal for RDE legislation[14]. Legal trip requirements for the RDE test have been under development since 2013. However, only from October 2015 the RDE trip requirements were solid enough to develop a TNO RDE-compliant test trip. This new test trip is still considered within the bounds of typical Dutch driving behaviour. However, some special provisions were taken to ensure a generally valid trip according to the RDE requirements (for the variant "moderate"). Up to the middle of 2015, however, there has been limited testing with this RDE-compliant trip.

Aspects of the RDE legislation which deviate from the original on-road reference trip used by TNO are:

- The order of road type prescribed for the RDE test is urban→ rural→ motorway. This is unlike the reference trip, which is a round trip starting and finishing in an urban area, with rural and motorway sections in between.
- The driving dynamics in the TNO reference trip, which for urban driving is on the high end of the allowed bandwidth and for the rural driving at the low end of the bandwidth allowed by the RDE.
- The evaluation of the emission data: typically no data is excluded from the measurement on the reference trip and the data is not normalized to a particular standard.

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[14] Real Driving Emissions, see e.g.:
http://europa.eu/rapid/press-release_IP-15-5945_en.htm, or
http://ec.europa.eu/growth/sectors/automotive/environment-protection/emissions/index_en.htm

- The fractions of urban, rural and motorway driving in the RDE cover the same distance yielding a long time of urban driving and a short time of motorway driving. In the reference trip the distribution is more skewed distance-wise to achieve a more even sampling in time over the different road types.
- The duration of successive urban, rural and motorway parts of the reference trip is approximately 90 minutes while the duration of an RDE-trip must be 90 to 120 minutes.

With respect to payload, the RDE requirements are not very specific. It is specified that the vehicle's basic payload shall comprise the driver, a witness of the test (if applicable) and the test equipment, including the mounting and the power supply devices. Furthermore, for the purpose of testing, some artificial payload may be added as long as the total mass of the basic and artificial payload does not exceed 90% of the sum of the “mass of the passengers” and the “pay-mass” defined in points 19 and 21 of Article 2 of Commission Regulation (EU) No 1230/2012.

Table 5: Characteristics of light-duty reference trip in Helmond, the Netherlands.

Test route Helmond						
		Stop	**Urban**	**Rural**	**Motorway**	**Total**
Speed	[km/h]	0-1	0-60	60-90	90-145	0-145
Time	[s]	*693*	*3766*	*1114*	*715*	5593
Time percentage	%	*12%*	*67%*	*20%*	*13%*	*100%*
Average speed	[km/h]	*0*	29,43	*77,08*	*113,44*	*49,64*
Distance travelled	[km]	*0*	30,8	23,9	22,5	*77,1*
Percentage distance travelled	%	*0%*	40%	31%	29%	*100%*

2016 standardized light-duty test programme

As of 2016, light duty vehicles are tested according to a fixed trip schedule with a total length of approximately 579 km, that covers different road types and congestion levels, and three trips that fulfill the RDE trip requirements. The test trips of this two-day test programme are specified in Table 6. Trips 2 and 8 are equal and meant to get a view on the reproducibility of this trip. In order to test vehicles in traffic with congestion, trips 4 and 5 are started during evening and morning traffic on motorways.

Table 6: Standardized light-duty test programme in Delft in 2016.

No.	**Trip**	**Type**	**Start condition**	**Distance [km]**
1	RDE_D_C	Urban / rural / motorway	Cold start	78
2	RDE_D_W	Urban / rural / motorway	Hot start	78
3	MOTORWAY	Motorway	Hot start	87
4	CONGEST_W	Motorway	Hot start	66
5	CONGEST_C	Motorway	Cold start	84
6	CITY	Urban	Hot start	22
7	RURAL	Rural	Hot start	85
8	RDE_D_W	Urban / rural / motorway	Hot start	78
	TOTAL			**579**

Figure 25 shows the routes that are covered. The CITY trip, for example, is performed in Amsterdam, and most of the motorway trips are driven between Delft and Amsterdam.

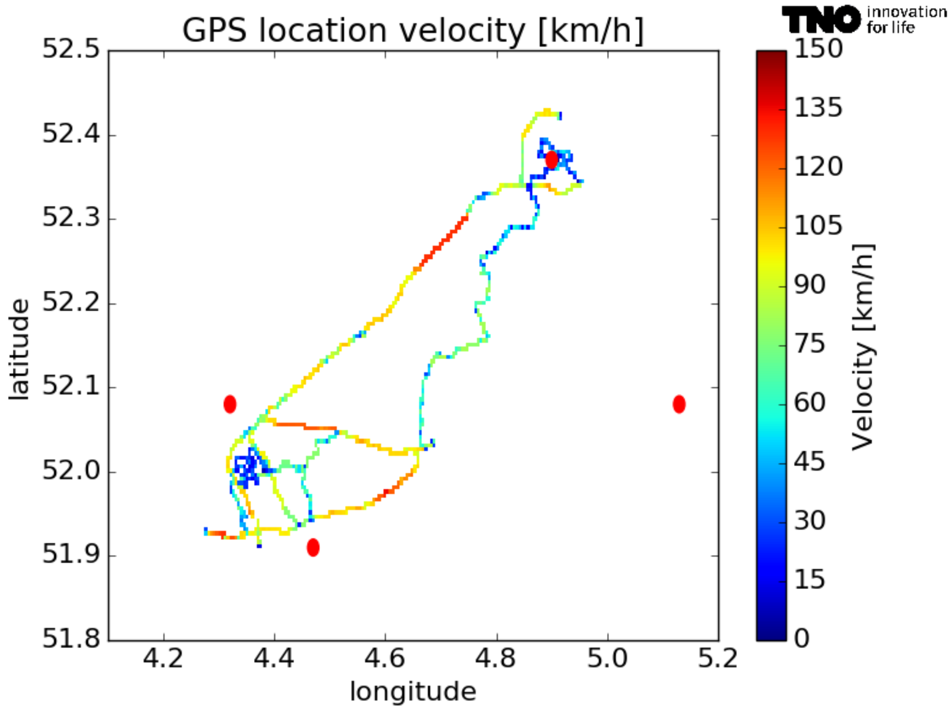


Figure 25: GPS location of the nine trips. The color indicates the average velocity, and the red dots represent the cities of Amsterdam, Den Haag, Utrecht and Rotterdam.

3.3.2.2 *Trips for heavy-duty vehicles*

Based on the requirements defined under section 3.3.2, the following trips are used in the heavy-duty test programme:

- Reference trip: a fixed trip used for each test vehicle. This enables comparison of all test vehicles. The trip is started with a warm engine and aftertreatment systems. Warming-up is done by driving a trip over the same route as the reference trip, until stable engine oil and coolant temperature is reached.
- EU trips: The trips are designed and chosen according the trip requirements of EC/582/2011 (see Table 7), and are used to check the in-service conformity and to collect data for emission factors.
- Alternative trips: In addition to the trips above, for specific goals or questions alternative trips are available, such as:
  - bus trips: Chasing city busses in real operation with actual bus stops and door openings to simulate boarding (without people actually boarding).
  - a trip with a 15 minute idle period and a 15 minute period with the engine shut off to investigate the effects of the cooling down of the aftertreatment systems on the emissions. Occasionally, a longer idling period may be used;
  - in some cases, a few trial runs are performed with shorter trips for the N2 truck class.

– Real-world trips: these trips are the result of everyday operation of the vehicle by the user. Payload may vary, depending on the actual use. An indication of the use and payload is obtained from the user/owner. These trips are used for collecting data for emissions factors and for the screening the emissions performance.

The Reference trip and the EU trip are normally driven with 55% of the maximum payload. Maximum payload is defined as the difference between the maximum technically permissible laden mass taking account of an eventual trailer and maximum axle loads and the weighted empty vehicle mass in running order. To investigate the possible effect of payload, and as an effect higher or lower engine load during driving, in some occasions trips are also driven with 10% or 100% of the maximum payload.

Table 7: Overview of trip requirements according to the in-service conformity legislation [582/2001/EC] for vehicles with a heavy-duty type-approved engine.

Vehicle category	**Trip duration percentage (± 5%)**		
	Urban	**Rural**	**Motorway**
M1 and N1	45	25	30
N2	45	25	30
N3	20	25	55
M2 / M3	45	25	30
M2 / M3 M3 of Class I, II or Class A	70	30	0

Figure 26: Example of a speed trace of the N3 trip which has shares of urban, rural and motorway according to Euro VI specifications.

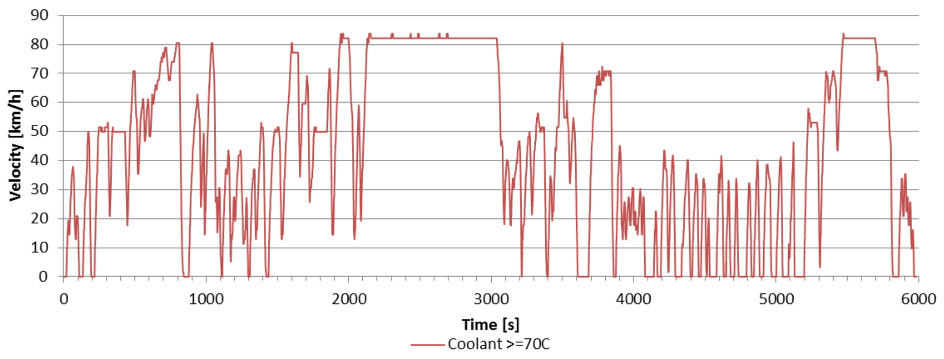


Figure 27: Example of a speed trace of the reference trip, a mixed trip with shares of urban, rural and motorway. This trip is started with a warm engine, i.e. with a coolant temperature higher than 70 °C.

3.3.3 Test conditions for on-road testing

In on-road measurements, it is impossible to control all the circumstances as well as can be done in the laboratory. Some of the main influencing parameters are ambient temperature and wind, the use of auxiliaries, and the driving pattern (influenced by traffic and driving style).

Ambient temperature
Testing on the road is performed all year round, from warm summer days to cold winter days. Temperatures typically range between 0 and 30 °C. This variation in ambient conditions is known to affect the emissions of modern vehicles. Extreme weather is typically excluded: snow and sub-zero temperatures are not common in the test data.

The on-road temperature, which for average Dutch daytime weather is around 11 °C, is much lower than the NEDC test conditions (between 20 and 30 °C) and the WLTP target temperature of 23 °C. In the laboratory, it is generally possible to test at temperatures between 14 and 30 °C. Hence it is generally possible in laboratory testing to separate the effects of slightly deviating ambient conditions from the effects of other aspects of laboratory tests.

Auxiliaries
During the tests on the road the air conditioning (A/C) is switched on or off depending on the comfort requirements of the driver, as part of testing under realistic real-world conditions. The A/C use is not recorded. During on-road testing with PEMS, however, the A/C may be used more than what would be representative for daily use of the vehicle due to the heat load of the PEMS and its generator-set[15] that are sometimes installed in the passenger compartment. The use of A/C generally increases the load on the engine and therefore can increase emissions.

Preconditioning and soaking
For a test trip with PEMS or SEMS the preconditioning of the vehicle in principle consists of the previous trip, a soak period (if applied), plus a limited amount of idling before start of the trip. As previous trips may have different characteristics, this leads to some variation in the starting conditions of the vehicle, its engine and aftertreatment system (e.g. temperature or ammonia storage of the SCR system). Such variations, however, are representative of real-world driving. The use of a more standardised preconditioning procedure before every trip could reduce the variability of on-road test results, but would also lead to a bias in the test results compared to average real-world driving.

The starting temperature of the engine has a large effect on its emissions. To quantify this effect, a number of tests is started with a cold engine and a number of tests is started with a warm engine. A cold engine in this case means an engine that has completely cooled down to ambient temperature after having been shut down. The test equipment starts measuring before the engine is started, so all cold engine data are collected. A warm engine is an engine with a lubricant temperature of 80 °C.

Cold started on-road tests of heavy-duty vehicles are started outside and after an overnight soak at the occurring ambient temperature. The reference trip is started cold, driven until the engine is at its normal operating temperature, driven back to the starting location of the tests and then started with a warm engine, so that cold and warm start emissions can be determined.

[15] A generator-set is used to provide electric power to the PEMS system so that it operates independent of the vehicle's electric system. In this way the energy use of the PEMS does not affect the engine load during driving.

Driving style

For light-duty vehicles, both eco-driving and sportive driving styles are included in the test programme. In order to have a common understanding of the driving style some guidelines are defined. The main parameters are:

- dynamics and position of the accelerator pedal;
- activation of the brake pedal and duration of braking;
- gear shift pattern, and;
- anticipation to traffic situations.

Table 8 shows an example of the variation of the driving style parameters with the different styles. Every vehicle has a specific engine speed range and engine performance and, as a result, the parameters of the driving styles might vary somewhat.

Table 8: Specification of driving styles (example).

	Driving style		
	Economic	**Normal**	**Sportive**
Activation accelerator pedal	Slow	Medium	Fast
Activation brake pedal	Soft	Normal	Prompt
Activation time brake pedal	Early	Normal	Late
Gear shift speed [rpm]	1500 - 2000	2000 - 2500	2500 – 3000
Anticipation to traffic	Early	Normal	Late
Start-stop system	Activated	Activated	Not activated

For PEMS tests with heavy-duty vehicles, the driving style is a normal defensive driving style. This means that, as trucks are heavy vehicles, a professional truck driver is expected to maintain a safe driving style, with enough distance to the preceding vehicle, which gives room to anticipate to unexpected vehicle movements in front of the truck and allows the traffic situation to be overseen. Shifting often occurs by an automated transmission. In the case a manual transmission is present, the driver shifts up in the high torque range of the engine. Throttle is used to keep up with regular traffic, which for loaded vehicles means that accelerations are performed full throttle. Motorways are driven at a representative speed of just above the speed limit (85 km/h) or using the speed limiter of the vehicle.

SEMS tests with heavy-duty vehicles are mostly driven by the daily operator of the vehicle without driving style instructions. In this way the SEMS measurement data represent everyday driving. In case the SEMS tests are driven by a TNO driver, the PEMS-test driving style is applied as explained above.

4 Analysis of emission measurements

Before the collected data is fed into a model for the calculation of emission factors, or for the screening of emission performance, it first needs to be validated and analysed.

For that purpose several assessments are performed to analyse the emission behaviour, and the dependency on external factors. These assessments are needed to make sure that the measurements are representative for real-world conditions, to assess the uncertainties in the data, and to assure that the parameterisation used in the emission factor model is valid for the vehicles that are tested.

For the screening of the emission performance of vehicles and engines against formal requirements under formalised test conditions, such as the RDE requirements for light-duty vehicles and ISC requirements for heavy duty vehicles, dedicated pass-fail evaluation methods are available (EMROAD (light-duty and heavy-duty vehicles), CLEAR (light-duty vehicles). In addition, for heavy-duty vehicles, TNO uses an alternative method for the screening of emissions in a dedicated test schedule: the TNO SEMS emission performance screening.

4.1 Light-duty vehicles

4.1.1 Data processing

Once the signals are collected and calibrated, the results of various trips can be combined. To give an impression of the type of signals that are registered, Figure 28 shows the time series of several signals during a single trip.

Several checks are performed to clean the measurement sample from noise and invalid data:

- if the engine speed (RPM) is zero, the signals for the concentrations of NO_x, NH_3 and O_2 as well as the mass air flow are set to zero;
- remove unrealistic velocity jumps by smoothing the velocity signal using a Velleman filter, also used in RDE legislation;
- the signal for cooling water temperature is linearly interpolated to fill the empty data points that occur because of the different sampling frequency of this signal;
- use the most accurate velocity signal. If available, this is the ABS signal, calibrated using the GPS information. If the ABS velocity is unavailable, use the ‘ground velocity’ GPS signal, and if that is also missing, use the vehicle velocity as supplied by the CAN/OBD system (VSS);
- negative NO_x values are set to zero;
- for light-duty vehicles, idling times longer than three minutes are removed from the dataset in order to remove the bias for idling. If idling occurs at the start of the trip, the data is removed until 3 minutes before the vehicle starts driving. If idling occurs during or at the end of the trip, the data is removed after 3 minutes after the vehicle comes to a halt. During the trip, only periods of standstill longer than three minutes without interruption are shortened;
- In order to be able to model the emissions as function of the velocity, the emission signals are aligned with the velocity signal, by optimizing the cross-correlation of the CO_2 signal with the work-related quantity w = a + v/70 (see

section 5.1.1). The shift that needs to be applied is typically between 1 and 3 seconds.

After performing these checks, the data are ready to be analysed. The following paragraphs describe which (data-driven) methods are used to get a better insight in the emission behaviour of vehicles.

Figure 28: Time series signals of NO_x [mg/s], CO_2 [g/s], exhaust gas temperature [°C], engine coolant temperature [°C], velocity [km/h] and engine speed [RPM] for one trip, measured with SEMS equipment.

4.1.2 *Assessment of emission measurements*

4.1.2.1 *EMROAD and CLEAR evaluation*

EU RDE legislation [EU 2015, EU 2016] requires evaluation of RDE test data to be performed in one of two accurately prescribed ways. Core of the associated processing is the so-called data normalisation, which in fact converts the trip dynamics to that of a type approval test. Currently, two software tools exist which do this as prescribed in the EU RDE legislation, these are EMROAD and CLEAR. For a more comprehensive discussion on the EMROAD and CLEAR algorithms as well as their implications see [TNO 2016c]. The normalization methods of EMROAD and CLEAR are summarized below.

The EMROAD and CLEAR tools are used for generating normalized results that are compatible with RDE legislation. These tools are not used in the processing of emission data to determine generic emission factors for the Netherlands. The tools give a single value to be compared with the applicable emission limit. Due to the complexity of the EMROAD and CLEAR tools the results of the formal normalisation with these tools do not directly correlate with the results of normalisations of the same measurement data to derive (inputs for) emission factors for average traffic situations in the Netherlands (see chapter 5).

The normalisation process applied in EMROAD is known as the *'Moving Average Window'* or MAW normalisation method and is described in detail in [EU 2016], see *"Appendix 5 Verification of trip dynamic conditions with method 1 (Moving Averaging Window)"* on page 48 and thereafter. There it is summarised as:

> *"The Moving Averaging Window method provides an insight on the real-driving emissions (RDE) occurring during the test at a given scale. The test is divided in sub-sections (windows) and the subsequent statistical treatment aims at identifying which windows are suitable to assess the vehicle RDE performance.*
> *The "normality" of the windows is conducted by comparing their CO_2 distance-specific emissions (1) with a reference curve. The test is complete when the test includes a sufficient number of normal windows, covering different speed areas (urban, rural, motorway)."*

The normalisation process applied in CLEAR is known as the *'Power Binning'* normalisation method and is also described in detail in [EU 2016], see *"Appendix 6 Verification of trip dynamic conditions with method 2 (Power Binning)"*, on page 62 and thereafter. There it is summarised as:

> *"This Appendix describes the data evaluation according to the power binning method, named in this appendix "evaluation by normalisation to a standardised power frequency (SPF) distribution"."*

The version and settings that are used when evaluating TNO RDE tests with CLEAR and EMROAD are described in appendix D.

4.1.2.2 *Dependence of emissions on velocity and acceleration*

The most straightforward way to derive an emission estimate per vehicle is to average all the emission measurements (one measurement per second), and divide it by the total distance, which gives a number in g/km. This number indicates whether the vehicle is overall 'clean' or 'polluting', but not under which conditions it performs better or worse. To get more insight in the causes of emission behaviour, one can look at the second-by-second data in more detail instead of only at the total results of a trip. The largest deviations in instantaneous emissions are caused by changes in velocity and acceleration. These two variables can be used to model the emissions, and to obtain emission factors. The dependence of emissions on velocity and acceleration is therefore discussed in detail in this section. Other factors that do affect vehicle emissions but are of less importance are discussed afterwards.

Figure 28 implies that the emissions are higher for higher velocities. Indeed, the most important variables influencing the variation in relative emissions per vehicle are velocity and acceleration. This becomes clear when plotting the NO_x emission in g/s in bins of velocity and acceleration, as in Figure 29. The highest emissions occur at high velocity and high acceleration. Those so-called 'v-a plots' provide insight into the details for different emission performance between different vehicles. The vehicle shown on the left performs bad at very high velocity and high acceleration, but it performs much better at low velocities. When this vehicle drives mostly at low velocity (30 - 100 km/h) and low acceleration (0 - 1 m/s), its emissions are relatively low. The vehicle on the right, however, has lower maximum emissions, but the emissions are at about the same level over a large part of the whole velocity-acceleration range. When this vehicle drives at low velocities and accelerations, its emission are relatively high.

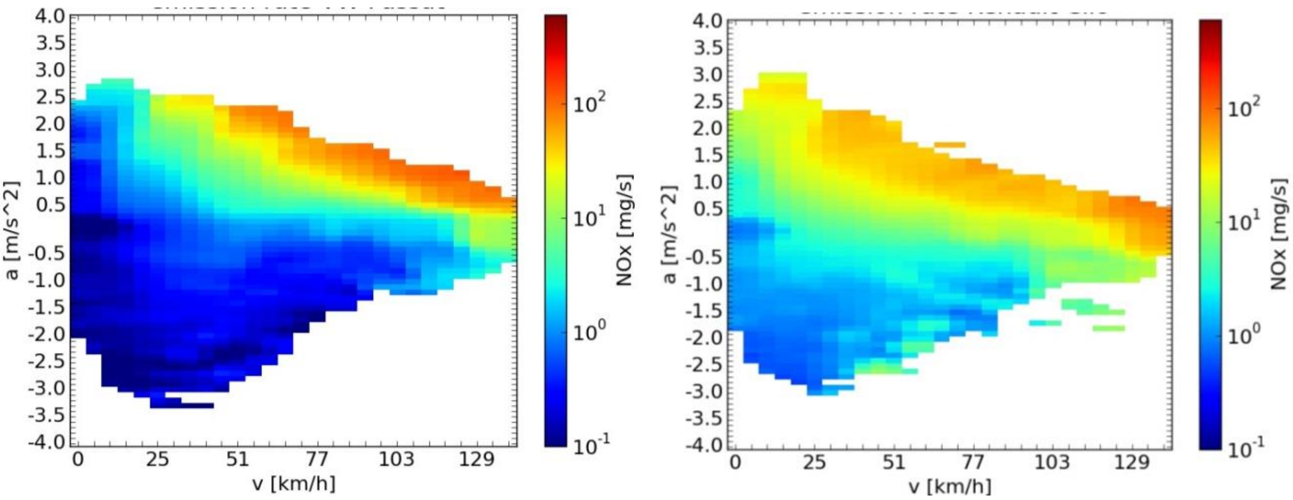


Figure 29: Emission rate for each velocity-acceleration point, for two different Euro 6 vehicles. The vehicle shown on the left performs bad at very high velocity and high acceleration, but it performs much better at low velocities. The vehicle on the right has lower maximum emissions, but the emissions are at about the same level over the whole velocity-acceleration range.

The spread between high and low emissions for the same vehicle can be quite large, especially for more recent vehicles. The v-a plots in section 4.1.2 (Figure 29) indicate that emissions can either be produced in a short period of time when the velocity or acceleration is high (left plot), or in more equal amounts during the whole trip (right plot). This is confirmed when the time is counted in which the most emissions occurs. For the left vehicle, at velocities between 60 and 90 km/h, analysis showed that 64% of the total emissions are emitted in only 5% of the time. For the vehicle on the right, only 25% of the emissions are emitted in 5% of the time.

This large spread of the amount of emissions per time unit was also seen in earlier tests, although it was less prominent. The spread also depends on the pollutant in question. More details can be found in [TNO 2012c].

4.1.2.3 *Other factors affecting vehicle emissions: residual analysis*

Even though the emissions of a vehicle are low in most circumstances, other factors can have a large effect on its total emissions. To adequately assess these effects, sufficiently long tests under varying circumstances are necessary to get a full picture of the typical emission behaviour of vehicles.

The v-a plots shown in Figure 29 are also used to study secondary effects on the emissions, such as the cold start, catalyst temperature and ambient temperature. In order to study the secondary effects, the average emission at a certain v-a value is subtracted from the total emission at that moment, such that only the extra emissions, that do not depend on velocity and acceleration, remain. Some examples of the analysis of secondary effects using this residual analysis method are given below.

Cold start

The cold start in the laboratory does not provide useful information for the real-world performance of - especially diesel - cars. The control strategy for cold starts is special, and it is unclear whether on-road behaviour is similar. However, cold start effects are expected to be smaller in modern cars than in the past. Up to Euro 4 cold start emissions are determined from comparing a warm and a cold test, typically a UDC test. Given the lower weighing of cold starts in the new test procedure of the WLTP, higher cold start emissions may be a risk. For Euro 6 light-duty vehicles, the residual method is used to extract the dependence of emissions on time, and therefore on engine coolant temperature. Figure 30 shows the residual NO_x emissions for a vehicle with SCR, indicating a clear contribution from the cold start at the beginning of this trip. The contribution is quantified as the extra NO_x per kilometre that is emitted on the city part of this trip, after subtracting the expected emissions that are typically produced at these velocities and accelerations.

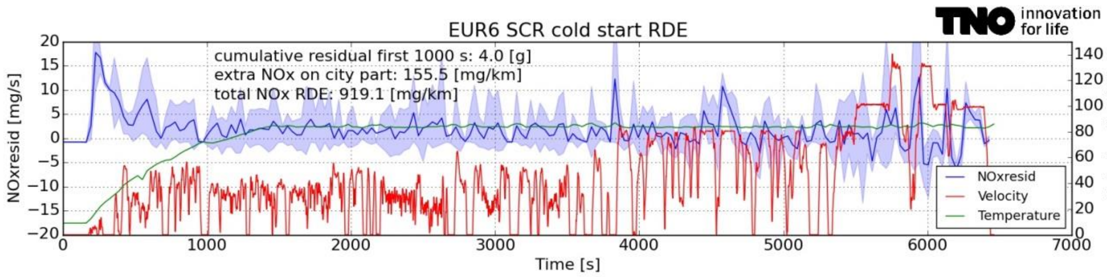


Figure 30: Cold start effect: residual NO_x emission (blue) per second, velocity (red) and engine coolant temperature (green) versus time, for an RDE trip of a Euro-6 passenger car with SCR.

DPF -regenerations

DPF regenerations occur usually at velocities above 80 km/h, i.e. motorway driving. In on-road tests, regenerations are included in the data sample when they occur, since they are part of real-world driving. Vehicles with a large test programme on the chassis dynamometer (six or more tests) are likely to experience a regeneration event of the DPF. The number of regeneration events on the total distance, combined with the PM emissions with and without regenerations provides a proper real-world PM emission factor including these regenerations. In the case of on-road test programmes, the inclusion of all the emission data over the total distance should ensure that the effect of regenerations is properly represented in the emission factors. No special analysis is applied for emission factors based on on-road testing.

Ambient temperature

For EGR the ambient temperature may affect the control strategy, probably to avoid clogging. Currently, such effects are not taken into account, and the test programme is assumed to be representative also for ambient conditions. In the future, more attention has to be given to correlate test results with ambient conditions, to compensate for possible bias. Dedicated tests can be performed with a single vehicle over a large variety of temperatures to investigate the effect of ambient temperature on vehicle on-road emissions.

Control strategies

Control strategies for emission reduction technologies are an important factor in the emission behaviour of vehicles. By monitoring for example the EGR or SCR temperature, these complex control strategies can be studied, although they cannot be determined exactly. There is often not only a synchronous dependency on the catalyst temperature, but also a dependency over a longer period of time. For example, it typically takes five minutes of slow driving to cool down the system of a truck. The question then remains whether the SCR of a truck cools down in heavy congestion on the motorway. It is therefore essential to measure enough and representatively, such that all situations, in which different aspects of the control strategy might apply, are included in the tests.

4.2 Heavy-duty vehicles

4.2.1 Stepped approach using SEMS and PEMS

In the heavy-duty vehicle test programme the instruments SEMS and PEMS are both used according a standard schedule in which the data required for emissions factors, emission performance screening and in-service conformity assessment is obtained. The processing of measurement data for each of these goals and for both PEMS and SEMS data is described below.

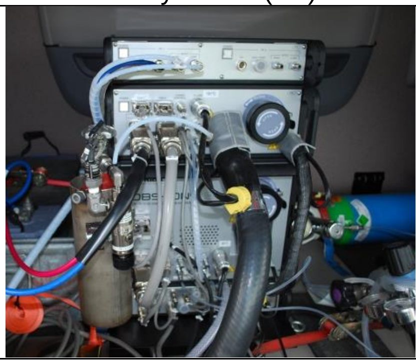
Emission factors

Both PEMS and SEMS measurement data of heavy-duty vehicles are included in the data analysis that leads to emission factors. The merit of the SEMS is that it can measure NO_x emissions and NH_3 emissions over longer periods of time during everyday operation of a vehicle. For the determination of emission factors for both NO_x and NH_3 this way of testing is preferred over shorter testing with PEMS, because the emissions of these compounds can be quite variable over time. Emissions excursions depend on specific driving conditions and history and may not occur in a shorter test of a few hours, or at least not in a representative amount. During longer testing these excursions may be expected to determine the overall emissions in a representative manner.

Emissions performance screening

To check the in-service conformity, normally the formal PEMS test (EU 582/2011: Portable Emission Measurement System) would be carried out. This is a time-consuming and expensive activity. To increase the number of vehicles that can be checked in the measurement programme, TNO has developed a smart screening method which utilizes a novel screening instrument, called SEMS. The measurement data of this instrument is fed to a data-evaluation method that simulates the formally prescribed method for in-service conformity testing with PEMS to calculate the ‘SEMS Factor’. The SEMS Factor is compared to a threshold (1.5 [-]). If the threshold is exceeded, it is decided that the vehicle needs further screening tests on another vehicle of the same type, but now applying the formal test routes as used for in-service conformity testing. More details on this decision-based test scheme is shown in appendix A.2. The SEMS factor indicates a certain likelihood that a vehicle might pass or fail a formal PEMS test. During the process the results are shared with the respective vehicles importers and manufacturers and finally sent to the national type-approval authority. The major goal of the programme is to measure the real world emissions and use them for the determination of the national emission factors for heavy-duty vehicles.

Table 9: Overview of SEMS and PEMS for the heavy-duty emissions testing programme.

	SEMS	**PEMS**
	Smart Emissions Measurement System	Portable Emissions Measurements System
Used for	– Real-world emissions – Emissions performance screening	– Real-world emissions – Emissions performance screening – EU in-service Conformity testing
Gases	NO_x, O_2, NH_3, measured with automotive sensors	CO, CO_2, HC, NO, NO_2, NO_x measured with gas analysers
Emissions	Absolute emissions estimated using CAN signals, e.g. fuel rate, manifold air flow CO_2 emission estimated from O_2 (diesel)	Absolute emissions determined with aligned exhaust gas flow measurement
Status	Alternative method/instrument developed by TNO for screening tail-pipe emissions levels and determination of real world emissions =>SEMS Factor (SF)	Formal instrument for on-road testing of the EU in-service conformity => Conformity Factor (CF)
		

The real-world emissions as obtained with both SEMS and PEMS are also used to monitor the effectiveness of the current emission legislation for heavy-duty vehicles.

4.2.2 SEMS data-evaluation

To make the SEMS measurement data applicable in view of the individual goals of the testing programme, the collected raw emission data with SEMS is evaluated in four ways:

1. For the in-service conformity assessment a ‘SEMS factor’ is calculated. This SEMS factor indicates a certain likelihood that a vehicle might pass or fail a formal in-service conformity PEMS test. This SF is used for the emission performance screening test, to make a decision whether a follow-up test will be performed or not. When the SF is higher than 1.5, a SEMS test will be executed with a vehicle of the same type, but now over the formal trip that meets the EU requirements for PEMS testing. If for that SEMS test over a PEMS trip, the SF is higher than 1.5 a full PEMS test will be performed, according to the formal in-service conformity procedure (EU 582/2011 and amendments) with the same vehicle.

2. For the purpose of gaining insight in the emission performance of the test vehicles in different types of operation, the NO_x emissions are calculated for different operational speeds to determine the real world NO_x emissions over the entire speed range with the Binning method (called VESBIN).
3. The emissions of ammonia are calculated as average concentrations over 30 minute-windows, and compared with the Euro VI limit of 10 ppm that applies for the WHTC test cycle.
4. The raw emission data with SEMS is fed to the VERSIT+ emission model to calculate vehicle emission factors, this is explained in chapter 5

The first three evaluation methods are further explained in this section:

SEMS Factor 'SF'
According to the EU regulation 582/2011/EC on type approval of heavy-duty vehicles, special data evaluation rules need to be applied to calculate a so-called Conformity Factor which indicates if a vehicle in-service complies with the regulation or not. The evaluation is based on PEMS data.

However, using all available information from real driving, SEMS measurements and a methodology developed by TNO, a similar evaluation for NO_x emissions can be made with SEMS data. The inherent drawback of a simpler measurement with less parameters available, is overcome by algorithms, using insight in properties of turbo-diesel engines and combinations of measured parameters. The data evaluation leads to a SEMS Factor that correlates well with the formal PEMS Conformity Factor and approximates the formal pass/fail calculation method. The alternative conformity factor is a first indication if more thorough measurements with SEMS or PEMS are necessary to establish the vehicle's in-service conformity.

In the text box 1 the principle is explained. TNO works on a publication in which the method is explained and its robustness is evaluated.

Box 1: TNO SEMS Factor calculation method

This method results in an approximation of the formal Conformity Factor and is therefore called the 'SEMS Factor'. The method is used to determine whether or not further tests are necessary. It approximates the formal pass-fail calculation method that is used for the PEMS measurements [582/2011/EC] and is based on the same principles, using moving averaging windows (MAW) over which emissions are evaluated. The alternative method uses the data from the SEMS instrument. Like in the formal pass-fail evaluation method, windows which meet certain criteria are excluded from the evaluation.

The SEMS Factor is calculated in three steps, in analogy with 582/2011/EC:
1. Including data from operation with a warm engine only (coolant temperature is higher than 70 °C);
2. Including only windows with sufficiently high engine power (higher than the threshold of 20% and decreasing to 15% if not enough valid windows are obtained from the data);
3. 90-percentile of the remaining windows (the 10% windows with the highest emissions are excluded).

The SEMS Factor threshold of 1 g NO_x/kg CO_2 approximates the in-service conformity factor of 1.5.

Speed range binning method (VESBIN)
A special data-evaluation method (VESBIN) is used to determine the emission performance over the entire operational speed range of a vehicle. The VESBIN method is based on collecting (binning) emissions of NO_x and CO_2 in speed intervals and calculates the CO_2 specific NO_x emissions for each interval.

The measurement system proved to correlate well with the portable emission measurement system PEMS [TNO 2012b], which can be seen as an accurate reference. The SEMS method is less accurate than PEMS, but its merit is that more vehicles can be measured, for a longer period of time, at lower costs. This increases the amount of vehicles to be screened, the amount of data and therewith the overall accuracy, because more of the often variable emission behaviour of modern diesel heavy-duty vehicles is captured.

Box 2: Example binning method calculation:

$$gNOx\ per\ kgCO2 = \frac{\sum_{v=vi}^{v=vi+5} NOx[g/s]}{\sum_{v=vi}^{v=vi+5} CO2[kg/s]}$$

Data points in a bin: 1 g/s NO_x, 10 kg/s CO_2
1 g/s NO_x, 0.1 kg/s CO_2
(In reality many more data points are needed)

Weighing of the contribution to the total emission in a bin:
Sum of the emissions / sum of the CO_2
=> (1+1) / (10+0.1) = 0.2 [gNO_x/kg CO_2]

And not: Arithmetic average of the specific emissions
(1/10+1/0.1) / 2 = (0.1+10)/2 = 5.1 [g/kg CO_2]

With these units, the emission is related to a parameter which indicates a certain amount of engine output, either work or CO_2 emission. Engine work and CO_2 emission are strongly related through engine efficiency.

Box 3: From work-specific emissions to CO_2-specific emissions

Engines with a Euro VI type approval have a limited maximum NO_x emission of 460 mg/kWh over the WHTC engine test. For in-service conformity (ISC) a conformity factor (CF) of 1.5 is used on top of the WHTC engine test limit when vehicles are tested on the road according to the regulation 582/2011/EC. Special data evaluation rules and test conditions apply to perform the ISC test and to calculate the CF.

To make the SEMS results in g NO_x/kg CO_2 comparable with work specific emissions an estimate of the brake specific fuel consumption (CO_2 emission) can be used to convert the work specific emission to comparable CO_2 specific emissions.

When a brake specific fuel consumption (BSFC) of 210 g/kWh is assumed, this corresponds with a work specific CO_2 emission of 3.17[1] * 210 g/kWh = 667 gCO_2/kWh for regular diesel fuel.

For the Euro VI emission limit of 460 mg/kWh: 460 / 667 = 0.69 g NO_x/kg CO_2. With a conformity factor of 1.5 for EU in-service conformity the CO_2 specific NO_x emission limit becomes 0.69 x 1.5 ≈ 1 g NO_x/kg CO_2.

[1]Approximate amount of CO_2 produced by the combustion of regular diesel fuel, in kg CO_2 per kg fuel

Evaluation of ammonia (NH_3) emissions
The NH_3 concentrations measured in the tailpipe are averaged over a moving time window of 30 minutes. The averaged window values are compared to a value of 10 ppm, which is the limit value for the WHTC test cycle (annex 1 of EC 595/2009). Although the present measurements have taken place under real driving conditions, the 10 ppm limit can be considered as a benchmark.

4.2.3 PEMS data-evaluation for checking the in-service conformity of heavy-duty engines and vehicles

This paragraph presents an overview of the procedure for checking the conformity of engines and vehicles in-service, applying the in-service conformity testing procedure and the pass-fail method to determine the Conformity Factor (EC/582/2011 and amendments), using PEMS.

The method is introduced in the EURO V and Euro VI heavy-duty engine emission legislation for determination of in-service conformity. ‘In-service conformity’ in this matter can be explained as: does the engine in-service comply with the emission standards under comparable conditions as if its engine would be tested on an engine test bed. The ‘in-service conformity’ method was originally designed to check if engines in-service are in conformity with their original type approval over the engine test. For Euro VI the check of ‘in-service conformity’ is done with a real-world test on the road using PEMS and is mandatory.

PEMS Pass-fail evaluation
The pass-fail evaluation method is applied, using the EMROAD tool or a comparable tool that applies the EMROAD data evaluation equations. Both software tools have been compared to check whether all the calculation rules are applied correctly. The exercise showed minor deviation between the two results, which can probably be attributed to rounding of numbers.

The evaluation tool is fed with emission data from PEMS and CAN data from the vehicle and calculates the conformity factors (CF) according to the in-service conformity rules. The Conformity Factor (CF) is the ratio of the calculated emission value according to the given data-evaluation method and the WHTC limit value in case of Euro VI engines. A CF of 1.5 for NO_x means for Euro VI that the result of the evaluation of the test results equals 1.5 times the limit applicable for the WHTC test cycle (1.5 x 0.46 g/kWh = 0.69 g/kWh). Vehicles are not allowed to emit more than 1.5 times the emission limit value under the prescribed conditions and data-evaluation rules for the in-service conformity procedure. Generally for in-service conformity testing, more than one vehicle should be analysed to determine whether the vehicle type is compliant with the in-service conformity requirements. In this programme only one vehicle per type is tested and therefore the results are indicative only.

The table below shows the basic settings as used for the pass-fail data evaluation with EMROAD. The CO_2 averaging window method is always used for the data-evaluation. The work window method is used whenever a reliable CAN data stream is available with data from engine torque an speed. The method calculates the average emissions over windows as large as the CO_2 mass that would have been emitted during a WHTC test (Euro VI) or over windows as large as the work that would have been produced by the engine over the WHTC test cycle. In the EU legislation criteria are defined to exclude windows from the evaluation, see also the table below.

Table 10: Data evaluation settings for the calculation of the Conformity Factor according to the pass- fail method for PEMS tests to be used in the data-evaluation tool EMROAD or in a similar tool in which the same evaluation is offered by PEMS manufacturers.

EMROAD version	Until 2016: 5.1 build 8 As of 2016: 5.9 beta 5
Horiba PEMS pass-fail evaluation scripts	2.4.0 r 74763
Reference quantity	Work or CO_2, depending on the availability and quality of the broadcasted ECU signals needed for the calculation of work.
Reference torque	As provided by the manufacturer or ECU
Torque calculation method	Method 3 (using % torque, reference torque and friction torque)
Reference cycle	ETC (Euro V) or WHTC (Euro VI), which is applicable
CO_2 estimation	CO_2 and work provided by OEM or work or CO_2 estimated from brake specific fuel consumption (EMROAD): 210 g/kWh used
Data exclusion	Engine coolant temperature < 70 ºC, Altitudes > 1500 m, 10^{th} percentile of the maximum values of the valid windows Power threshold: on (15-20%)
Time-alignment	On
Fuel density	0.84 kg/litre, (EN590 market fuel)
Vehicle speed	GPS vehicle speed

Cold engine operation and high altitudes are excluded from the pass-fail analysis. Furthermore, windows with a very long duration or low power are excluded. A power threshold excludes windows where the average power in a window is below a certain percentage of the rated power. A maximum for the window duration also excludes windows with a very low average power because at a low average power it takes a long time before the CO_2 reference mass is reached.

What remains after exclusion of ‘invalid’ data is a set of ‘valid windows’ of which the single window with the largest value of 90percentile of the data is taken to calculate the CF for each regulated emission compound.

4.2.4 PEMS data evaluation: real-world emissions

To gain insight into the real-world emission performance of heavy duty vehicles, the PEMS raw and instantaneous mass emissions of the emission compounds are converted in:

- gram/second with the instantaneous exhaust gas concentrations and exhaust gas flow. The gram per second data is used for the determination of the emissions factors with the dedicated emissions model Versit+ HD;
- gram/kilometre with the vehicle speed measured by the GPS;
- gram/kilowatt-hour when the data stream of the ECU provides accurate signals for engine torque and engine speed;
- g/kgCO_2 which is convenient when engine work isn't available.

Both g/kWh and g/kgCO_2 allow the comparison of the often very different engine sizes of heavy-duty vehicles. With these units, the emission is related to a parameter which indicates a certain amount of engine output, either work or CO_2 emission. Engine work and CO_2 emission are strongly related through engine efficiency.

Box 4: Relation between CO_2 specific emission results and brake specific emission

The CO_2 specific emission results can be related to brake specific emission results assuming a constant average engine efficiency and fuel consumption. With an average engine efficiency of 40% (BSFC = ~210 g/kWh), the g/kg CO_2 results can be divided by 1.5 to get a corresponding g/kWh result. Lower average engine efficiencies would lower this factor and would thus increase the brake specific results accordingly.

For Euro V the NO_x emission limit of 2.0 g/kWh would amount to 3.0 g/kg CO_2. When the ISC conformity factor of 1.5 is taken into account, this would amount to 4.5 g/kg CO_2.
For Euro VI the NO_x emission limit of 0.46 g/kWh would amount to 0.69 g/kg CO_2. When the ISC conformity factor of 1.5 is taken into account, this would amount to about 1.0 g/kg CO_2.

Because PEMS trips deliver a lot of data and insight is needed in the emissions over the speed range of the vehicle, TNO developed the vehicle speed binning method VESBIN.

Box 5: VESBIN

The primary purpose of the VESBIN method is to facilitate the use of large amounts of PEMS data as input to calculate emission factors for urban, rural and motorway conditions and to gain insight into the emission behaviour over the speed range of a vehicle. The method collects all emission data belonging to a defined speed interval and determines the average emissions for every interval over the complete speed range of a truck.

As preparation for the binning method, PEMS data of the trips are pre-processed with EMROAD and for the new Horiba PEMS with the DiaDEM software. EMROAD and the Horiba software perform a data quality check and align the test signals. Data with a cold engine, i.e. coolant temperatures below 70 °C are excluded from the evaluation.

Vehicle speed bins with a width of 5 km per hour are selected to distinguish emission data for low, intermediate and high vehicle speeds easily. In each bin of vehicle speed, the emissions [g/s] and CO_2 [kg/s] or engine power [kW] from the data points belonging to that speed bin are collected. In the end the average speed within a bin, the average emissions in [g/kg CO_2] or [g/kWh] and the amount of data points within a bin are calculated. The method of calculating average NO_x emissions per unit of CO_2 emissions within a bin is the same as explained in Box 2 above for the evaluation of SEMS data (section 4.2.2).

The binning method can also be used to estimate brake specific emissions in gram per kilowatt-hour.

5 Emission factors

The results of vehicle emission measurements are used to derive emission factors that represent the real-world emissions of vehicles of different categories under overall average or specific traffic conditions.

Emission factors are the input to air-quality models and emission inventories. The environmental impact of traffic is assessed through these numbers. The two main applications for emission factors are:

1. The emission inventory: the contribution of traffic in the total emissions of the Netherlands. National emission totals for past years are derived annually in the Dutch Pollutant Release and Transfer Register (Emissieregistratie), whereas projections of future national emissions are made by PBL Netherlands Environmental Assessment Agency.
2. The national air-quality models SRM1 and SRM2. The average emission per vehicle category and traffic situation are determined. This data is used as line sources in dispersion models at different length and time scales in order to calculate current and future air quality at roadsides in the Netherlands.

The uncertainties in emission factors, including those related to uncertainties in the test results, the estimation of average driving behaviour and the extrapolation to the Dutch traffic situation, are evaluated in [TNO 2012b].

5.1 Emission factors per vehicle category

In a vehicle test, emission values are registered every second and evaluated as a function of the vehicle velocity and acceleration. Some quality checks are performed to remove incorrect data, as described in section 4.1.1. The resulting data serve as input to the VERSIT+ model, which is subsequently used to calculate emission factors for different vehicle categories, ranging from light-duty passenger cars to heavy-duty trucks and buses, and for different driving conditions. A more detailed description of the processing of the data can be found in the document *VERSIT+ process chain* [Ligterink 2012b].

5.1.1 VERSIT+ for light-duty vehicles

VERSIT+ is a statistical emission model which calculates real-world HC, CO, NO_x, NO_2, PM_{10} and CO_2 emissions of road vehicles. The VERSIT+ model is described in detail in [Ligterink, de Lange 2009], and the implementation is described in *VERSIT+: theory and fitting routines* [Ligterink 2012a]. In short, first all data collected during the different test trips are accumulated for each vehicle separately. Next, the emission factor of each individual test vehicle is calculated using the method described below. The average of the emission factors of all tested vehicles belonging to the same VERSIT+ category is the representative emission factor for this category. This procedure is repeatedly performed to obtain the emission factors of different road type categories (WT1 urban, WT2 rural, WT3 motorway, etc.).

Emissions typically increase with both acceleration and velocity. A dynamic variable *w* is defined to describe the combined dependency of emissions on those two measured quantities:

$$w = a + v/70,$$

with the velocity v in km/h and the acceleration a in m/s^2. This variable defines the lines along which the emissions are expected to vary only slowly. Besides this, the emissions also depend more generally on velocity, and three categories are defined to describe this dependency: urban, rural and motorway driving ($v \leq 50$ km/h, $50 < v \leq 80$ km/h, $v > 80$ km/h). Idling is defined as a separate hot map area. Figure 31 shows the distribution of the hot maps over the velocity-acceleration space. The areas in the map are typically labelled 1 (idling) until 10 (high velocity and high acceleration).

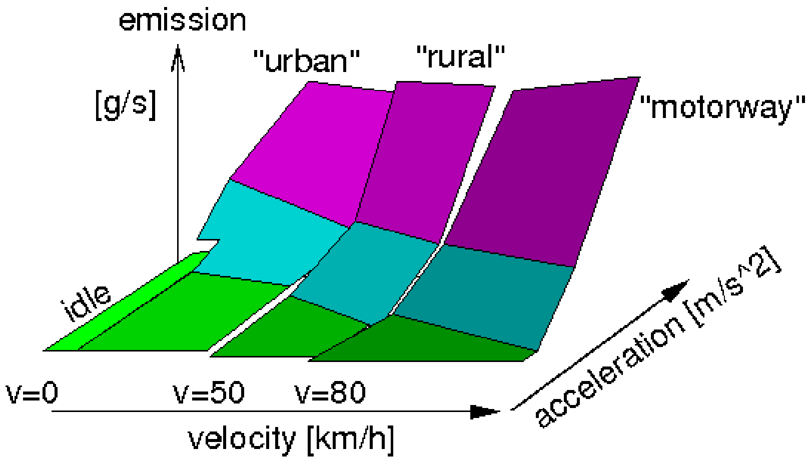


Figure 31: Emission hot maps as a function of velocity and acceleration in VERSIT+.

The three coloured areas per velocity bin contribute in a similar amount to the total emissions: a large share (~65%) of smooth driving, a smaller share (~30%) of mild accelerations and a small share (~5%) of high acceleration. This indicates that driving behaviour (combination of velocity and acceleration) has a significant effect on the total emissions. In particular, high accelerations that only take place in 5% of the time and amount to about a third of the total emissions.

For each of the hot map areas, the emissions are defined as a function of w and some coefficients **u**, where **u** is a vector of ten emission rates with the unit [g/s]. The driving behaviour for a particular trip can be described by a vector of ten variables **q**, which determine the weight of the coefficients **u**. This weight is simply expressed as the time 'spent' in a particular hot map area. For example, for urban driving, q1 until q4 are high, while q5 until q10 are low, since most of the driving occurs at low velocities. For motorway driving, on the other hand, only the variables q8 until q10 contribute significantly. Section 5.2.2 explains the derivation of **q** in more detail. Consequently, the total emission from a test can be expressed as the dot-product of **u** and **q**:

$$EM\,[g] = \mathbf{q}[s] \cdot \mathbf{u}[g/s] = q1{*}u1 + q2{*}u2 + ... + q9{*}u9 + q10{*}u10.$$

To determine the values of the emission rate vector **u**, a least-squares error fit is performed on the measured 1 Hz emission data per vehicle using the **q** of the trips in the test. Once the vector **u** is determined, the emissions can be normalised to a common driving behaviour, using a fixed vector **q** that is equal for all vehicles, This results in a normalised emission EM in [g] for each vehicle.

The emission factors, normalised to unit distance, can subsequently be calculated by dividing EM by the total distance travelled in the test:

$$EF\ [g/km] = EM[g]\ /\ dist\ [km]$$

The total emission factor of a certain VERSIT+ category is determined by averaging the emission factors of all the tested vehicles of this category. To get an indication of the statistical uncertainty of the results, a bandwidth is calculated by taking the average after removing the vehicle with either the highest or the lowest value.

5.1.2 VERSIT+ for heavy duty vehicles (power and payload dependency)

The method for the calculation of emission factors per tested heavy-duty vehicle is the same as for light-duty vehicles. The translation from the results per vehicle to the VERSIT+ categories does, however, differ. A detailed description of the implementation of VERSIT+ for heavy-duty vehicles can be found in *VERSIT+ for heavy-duty vehicles* [Kraan and Ligterink 2012].

The TNO vehicle emission model VERSIT+ for heavy-duty works in two steps. Firstly, from the measurements a VERSIT+ specific vehicle group model is derived from the performed on-road-test measurements. Secondly, the VERSIT+ Euro VI diesel truck model is used to calculate road-type specific emission factors. These are calculated for seven ‘standard’ classes of Euro VI trucks, which differ in total mass and rated power.

For Euro VI diesel trucks the seven VERSIT+ standard classes are as indicated in Table 11.

Table 11: The seven VERSIT+ standard classes for Euro-VI diesel trucks.

VERSIT+ Standard Class	Description	Mass (tonne)	Power (kW)
MVADEUR6LCH	Rigid Truck Light	5.210	126
MVADEUR6ZWA	Rigid Truck Heavy	11.820	239
ZVADEUR6	Heavy Rigid Truck	19.500	302
ZVADEUR6ANHLCH	Heavy Rigid Truck with Trailer Light	23.220	239
ZVADEUR6ANHZWA	Heavy Rigid Truck with Trailer Heavy	35.940	302
ZTRDEUR6LCH	Tractor Semi-Trailer Light	19.000	300
ZTRDEUR6ZWA	Tractor Semi-Trailer Heavy	42.750	300

For these seven Euro-VI vehicle classes, road type specific emission factors are calculated with VERSIT+ for emissions CO, CO_2, HC, NO_2 and NO_x and road types WT1 (urban), WT2 (rural), WT3 (motorway), WS1 (urban, congested), WM1 (= WT1 or urban normal), WF1 (urban, free flow) and WS3 (motorway, congested).

5.1.3 Emission factors for VERSIT+ categories for which no vehicle test results are available

About 350 VERSIT+ vehicle categories are defined, to describe all variations of vehicle types, weights, emission classes and fuel types (see Section 2.1). Due to the introduction of new vehicles (e.g. electric and hybrid plug-in vehicles), more categories are added regularly. Many categories are less relevant for air-quality modelling, because the number of vehicles in the category is small, the vehicles travel little distance per year, or the emissions are expected to be low. For these vehicles, no dedicated test programme is carried out, and emission factors are derived in different ways:

- Copied from a similar technology: For example, LPG, CNG, and petrol vehicles all have three-way catalyst and spark-ignition engines. In case an LPG or CNG vehicle has not been tested, the test results from the same type of petrol vehicles are used.
- Adaptation from given technology: For example the PHEV (Plug-in Hybrid Electric Vehicles) are expected to behave as their hybrid counterpart when driving on the combustion engine. To account for off-vehicle charging, the emissions are lowered by the fraction of the distance in which the vehicle drives electrically.
- Forward extrapolation based on tightening of the legislation: For future technologies or Euro classes, usually no representative measurements are available yet. The only predictors for the emission results are the legislative values that will apply at the moment of introduction, and the deviation of real-world emissions from the current limits. Extrapolation using the current deviation from legislative values introduces a large uncertainty for future predictions. For example, before Euro 5 diesel cars entered the market it was assumed that since Euro 4 vehicles had NO_x emissions two to three times higher than the emission limit, the Euro 5 vehicles would have real-world emissions exceeding the Euro-5 emission limit by the same factor. This turned out to be an underestimation, and measured NO_x emissions were much higher than the estimate based on Euro 4.
- Emission legislation: In the case of robust emission control technology, the emission factors are occasionally based on the emission limits. For example, many heavy-duty trucks have been tested exclusively on-road from 2008, and therefore only a limited number of PM emission measurements are available. These tests are combined with the situations of high engine load, when PM emission occur, and the emission limits, to generate a representative PM emission number across all Euro V heavy-duty vehicles.

Studies to estimate emission factors for vehicles categories for which no measurement results are available are often carried out in projects for the Dutch Taakgroep Verkeer and Vervoer. This group evaluates if the approximation is sound, or if additional measurements are needed to generate a more reliable result. This assessment is based on the impact of specific vehicle categories on national emission levels. Hence, it is possible that minor categories have emission factors whose uncertainty can significantly affect local results or the effectiveness of detailed policies, even though in the overall assessment of transport emissions the effects are negligible.

5.1.4 The effect of the vehicle state on emissions

The vehicles are tested in a proper maintenance state, but two elements that affect vehicle emissions remain.

The first one is deterioration with age and mileage. The tested vehicles are mostly relatively new, and typically have a mileage below 30,000 kilometres. For older vehicles, some deterioration with regard to the emissions is expected. The aging or the state of maintenance of vehicles has effects on the functioning of hardware such as a DPF, the tyre pressure, etc., and therefore influences the emissions.

The second element is technology failure and tampering with the vehicle. EGR valves may be fixed and after-treatment components may be removed. Even though this might only occur in a limited number of cases, the consequences may still be significant due to much higher emissions associated with such malfunctioning emission control.

The ageing of the vehicle is taken into account when applying the emission factors to the Dutch vehicle fleet. In the past, the legislative durability requirements of vehicles were used to estimate the deterioration of vehicles in real-world. The increase in emissions due to deterioration is set to stop at nine years in the Dutch emission inventory. The measured emissions are translated back to points on the deterioration curve, based on the mileage of the vehicles. Recently, this assumption and the corresponding testing have shown some flaws. First, deterioration is generally higher and especially does not stop at nine years [TNO 2015a]. Secondly, the malfunctioning and tampering of emission control technology has to be recognized as a major risk that contributes to the emissions of modern vehicles. In particular, the recent study on the performance of diesel particulate filters shows higher emissions than expected from the general rules [TNO 2015c, TNO 2015d].

5.2 SRM: Normalization and road types

The resulting emission factors are used in the Netherlands Pollutant Release & Transfer Register (PRTR) to calculate national emission totals for road transport. The PBL Netherlands Environmental Assessment Agency uses the emission factors to estimate future emissions of road transport.

Also, aggregated emission factors are used by national and local governments to calculate the air pollution in different locations in the Netherlands, in order to construct air quality maps. The so-called ‘Standaard Rekenmethode’ (SRM) is used to calculate the effect of traffic emissions on local concentrations of air pollutants. For these different purposes, two sets of emission factors are provided:

1. Three main emission factors for urban driving, rural driving and for motorways. These emission factors are provided for all 300+ different vehicle categories to the PRTR and PBL to calculate national emission totals.
2. SRM emission factors for motorways that distinguish between different velocity regimes, and three additional factors for different types of urban driving. These emission factors are aggregated to four different vehicle categories and are used for calculating current and future air quality alongside roads in the Netherlands.

The description of the different road types, according to the type of road, the velocity and the congestion, is given in section 5.2.1. This section describes how these road types are incorporated into the VERSIT+ model using additional driving behaviour data.

5.2.1 Road types

The emission measurements are reweighted for different road and congestion types, as defined in Table 12. Every road location in the Netherlands gets assigned to one of these categories, depending on the speed limit and the degree of congestion. However, these theoretical definitions still need to be linked to the actual driving behaviour (per-second velocity and acceleration of individual cars) on this specific road type.

Table 12: Road type definitions. The three bold lines are the main three road categories.

Name	Description
WS1	Urban congested
WM1	Urban normal
WF1	Urban free-flow
WT1	**Urban average**
WT2	**Rural**
W80MSH (W83)	Motorway 80 km/h with enforcement
WS3	Motorway congested
WT3	**Motorway average**
W100MSH (W03)	Motorway 100 km/h with enforcement
W100ZSH (W13)	Motorway 100 km/h
W120ZSH (W23)	Motorway 120 km/h
W130 (W33)	Motorway 130 km/h
W93	Motorway 80 km/h without enforcement)

A test programme was set up to determine average Dutch driving behaviour by randomly following vehicles across the Netherlands over several weeks, corresponding to 108 hours of driving time [TNO 2016a].

A high-powered passenger car with automatic transmission randomly followed other cars for a certain time. The velocity signal and latitude and longitude information were recorded at 1 Hz. An appropriate large headway distance was used, such that the actions, i.e., braking and acceleration, of the car in front were not enhanced by the car follower.

This resulted in a distance of 6640 km travelled, in which all different road types in the Netherlands are covered, as illustrated in Table 13. Data was collected throughout the day and night, on all week days and outside holidays to get a representative sample of congestion levels.

Table 13: Total distance covered in the car-following programme, categorized by road type.

trip	**distance covered (km)**	**driving time (h)**	**average speed (km/h)**
urban	835	32	26
rural	1179	22	53
motorway	4625	53	87
total	**6640**	**108**	**62**

The data need to be divided at two different levels:

- Road type (urban, rural, motorway) determined from mapping the GPS location to the so-called Nationaal Wegen Bestand map with road segments per road authority: communal (urban), provincial (rural) and national (motorway).
- Congestion level and speed limit: The speed limit is determined from maps of the Dutch national road authority (Rijkswaterstaat) and the congestion level is determined from the recorded velocities at a certain road type.

Figure 32 shows the distribution of velocities over the three main road types. Across all traffic conditions, the driving dynamics in the test were higher than previously assumed. This means that emission factors are more influenced by acceleration and deceleration, and less by average velocities. On motorways for example, effects from different speed limits are smaller than effects from driving dynamics.

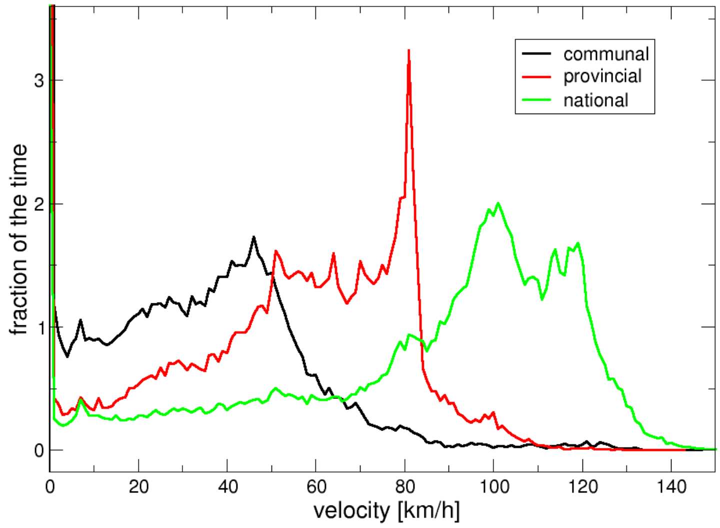


Figure 32: Velocity distribution of the three main road types (WT1 communal, WT2 provincial and WT3 national).

Urban

The emission factors for urban roads are divided into congestion, normal and free-flow driving. The distinction between these categories is made based on the average velocity and number of stops per kilometre. Average velocities below 20 km/h are categorized as congestion, between 20 and 30 km/h as normal, and above 30 km/h as free-flow. Driving behaviour associated with congestion may also include low average velocities due to traffic lights, sharp bends, 30 km/h zones or speed bumps. The velocity distributions of the three categories are shown in Figure 33.

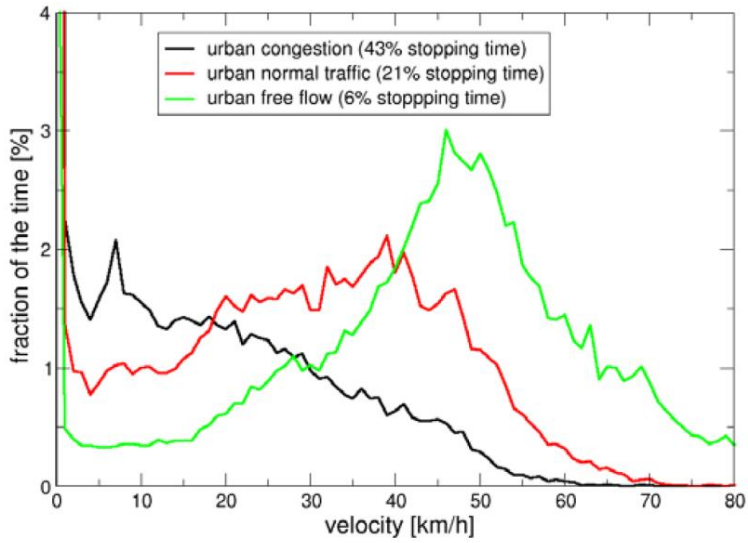


Figure 33: Velocity distribution of the three urban situations.

Rural
Rural driving is associated with provincial roads with a speed limit of 80 km/h, occasionally including 60 km/h and 100 km/h speed limits. The rural roads mainly contain free-flow situations, as can be concluded from the peak at 80 km/h in Figure 32.

Motorway
Figure 34 illustrates the velocity distribution at motorways with different speed limits. It is remarkable that the distributions for 120 and 130 km/h both peak at roughly 120 km/h. The second peak at 100 km/h at the 120 km/h speed limit may be partly due to congestion lanes ('spitsstroken') with a reduced dynamic speed limit.

Currently, congestion at the motorway is defined as all velocities under 50 km/h. This excludes driving behaviour between 50 and 70 km/h, which turns out from the test programme to be very dynamic. The high emissions associated with large driving dynamics at these velocities are therefore not taken into account in the congested motorway road type definition. Instead, they are included as high-dynamic periods in the free-flow motorway categories. Setting the congestion definition at velocities up to 70 km/h would give a more representative picture of congestion-effects on motorways. The definition of congestion can be adapted by shifting, or reweighing the driving behaviour for the different traffic situations.

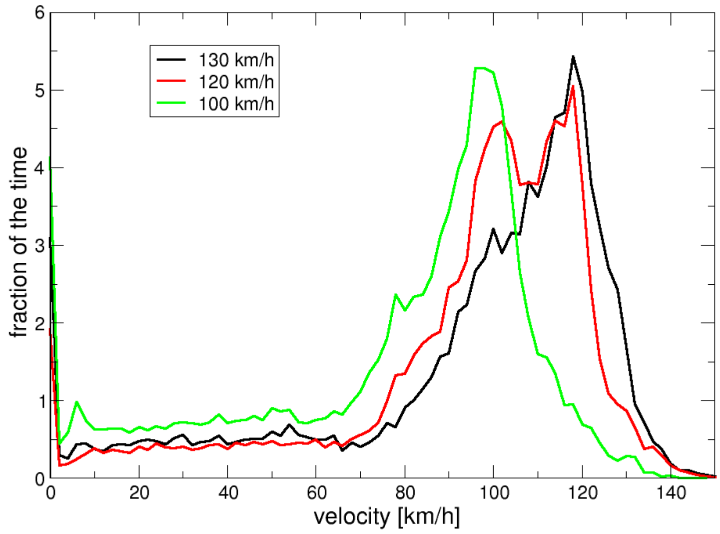


Figure 34: Fraction of time spent at a certain velocity, for motorway segments with different speed limits.

5.2.2 *Trip profiles*

The different road types are implemented in the VERSIT+ emission model. For this, one first needs to determine to which extent a velocity-acceleration hot-map area is contributing to the specific road type. For example, an urban road type (WT1) will contain higher values for the first hot maps (at low velocity), whereas a motorway profile (WT3) will have relatively high values for the last hot maps at high velocity.

For each road type, a driving vector **q** (q1,q2,... q9,q10) is determined which is implemented in the VERSIT+ model to normalize the emission factors. The vector **q** consists of 10 values, analogously to the vector of hot maps **u**, and it indicates the number of seconds spent in a certain velocity-acceleration regime (hot map).

Sometimes a value q0 is added to account for the fraction of cold starts per kilometre. The following properties can be deduced from the driving vector:

- Total idling time per kilometre in seconds: q1
- Percentage of idling time: q1 / (q1 + q2 + q5 + q8)
- Average velocity in km/h: v = 3600 / (q1 + q2 + q5 + q8)
- Fraction of time of congestion on the motorway: (q1 + q2) / (q1 + q2 + q5 + q8)

The driving behaviour vectors allow for different emissions in the case of hard accelerations in the different road type categories. In urban situations for example, accelerations are short and hard, while accelerations on the motorway are generally longer and slower. The actual effect of hard accelerations in both situations is determined by emission measurements.

To determine what the distribution of **q** is for each road type, the average driving behaviour on such a road is determined from the programme described in the previous section. The test programme covers the driving behaviour of both passenger cars and vans.

Every velocity-acceleration point in the resulting 1 Hz dataset gets assigned a certain road type. First the data are divided into the three main categories WT1, WT2 and WT3, and subsequently these are divided into all the different road type definitions in Table 12. The same procedure that determined the VERSIT+ hot map area for a given velocity and acceleration is used to count the time spent in a certain hot map for each road type. The q values are normalized to get the number of seconds per kilometre.

The resulting driving behaviour vectors for all eleven different road types are given in Table 14 and Table 15. More detailed information on these results can be found in the report on *On-road determination of average Dutch driving behaviour for vehicle emissions* [TNO 2016a].

Table 14: The driving behaviour vectors q [s/km] for urban driving based on the average velocities.

q	**urban congestion**	**urban normal**	**urban free flow**	**urban average**
q_1	147.95	36.10	6.21	39.93
q_2	148.29	97.46	43.54	76.37
q_3	73.64	57.88	28.89	44.39
q_4	12.67	11.22	6.05	8.56
q_5	4.51	13.01	30.41	21.28
q_6	3.84	11.13	26.77	18.63
q_7	0.49	1.50	3.28	2.32
q_8	0.00	0.06	2.41	1.38
q_9	0.00	0.04	1.80	1.03
q_{10}	0.00	0.00	0.12	0.07

Table 15: The driving behaviour vectors q[s/km] for different speed limits on the motorway.

q	congestion	80 km/h MSH	80 km/h ZSH	100 km/h MSH	100 km/h ZSH	120 km/h	130 km/h
q_1	36.49	0.00	0.00	0.00	0.00	0.00	0.00
q_2	125.55	3.31	3.31	3.31	3.31	3.31	3.31
q_3	69.53	1.88	1.88	1.88	1.88	1.88	1.88
q_4	14.23	0.40	0.40	0.40	0.40	0.40	0.40
q_5	0.00	31.83	18.71	9.89	7.59	3.33	3.07
q_6	0.00	31.38	18.45	9.62	7.39	3.28	2.98
q_7	0.00	4.21	2.48	1.51	1.16	0.60	0.59
q_8	0.00	9.39	21.48	28.17	28.98	30.58	29.58
q_9	0.00	6.22	16.59	23.28	26.02	30.74	31.37
q_{10}	0.00	0.21	0.83	1.08	2.05	3.82	4.73

Information on the driving behaviour parameters of heavy duty vehicles is currently limited and outdated. Ideally, a similar study as for passenger cars and vans is carried out for trucks.

5.3 Reweighting using mileage

TNO delivers detailed emission factors for more than 300 vehicle types, an example of which is shown in Table 16. The resulting emission factors are grouped by vehicle VERSIT+ category and sampling year. These numbers, along with mileage figures (from Statistics Netherlands and PBL) are used to calculate national emission totals for road transport in the Netherlands. This calculation is performed by PBL and described in more detail below.

Table 16: Example of reported emission factors.

INVOER EMISSIEFACTOREN WEGVERKEER TNO-EST											zichtjaar	2010
	CO	CO	CO	HC	HC	HC	NOx	NOx	NOx	PM	PM	PM
	WT1	*WT2*	*WT3*	*WT1*	*WT2*	*WT3*	*WT1*	*WT2*	*WT3*	*WT1*	*WT2*	*WT3*
	gram /km			alleen uitlaat, geen verdamping						alleen uitlaat, geen slijtage		
LBABEUR1	4,762	10,236	2,184	0,253	0,199	0,046	0,384	0,781	0,404	0,007	0,001	0,001
LBABEUR2	3,881	1,741	1,975	0,240	0,069	0,058	0,294	0,206	0,080	0,007	0,005	0,005
LBABEUR3	1,778	0,936	0,627	0,218	0,017	0,015	0,099	0,025	0,039	0,004	0,001	0,001
LBABEUR4	1,372	0,245	0,456	0,204	0,012	0,009	0,066	0,040	0,024	0,004	0,002	0,002
LBABEUR5	1,098	0,196	0,365	0,163	0,010	0,007	0,053	0,032	0,020	0,003	0,001	0,001
LBABEUR6	1,098	0,196	0,365	0,163	0,010	0,007	0,053	0,032	0,020	0,003	0,001	0,001
LBADEUR0LCH	0,995	0,483	0,389	0,442	0,147	0,155	0,733	0,696	1,395	0,272	0,161	0,214
LBADEUR0ZWA	1,216	0,604	0,389	0,538	0,183	0,155	0,912	0,870	1,395	0,272	0,161	0,214
LBADEUR1LCH	2,806	0,434	0,417	0,165	0,117	0,110	1,231	0,689	0,782	0,214	0,103	0,156
LBADEUR1ZWA	3,662	0,577	0,557	0,190	0,142	0,134	1,506	0,837	0,949	0,267	0,135	0,205
LBADEUR2LCH	0,846	0,117	0,107	0,175	0,062	0,033	1,340	0,665	0,902	0,129	0,070	0,100
LBADEUR2ZWA	0,989	0,139	0,128	0,206	0,075	0,040	1,617	0,809	1,097	0,175	0,099	0,143
LBADEUR3HOFLCH	0,483	0,023	0,043	0,045	0,008	0,014	1,156	0,714	0,706	0,055	0,023	0,053
LBADEUR3HOFZWA	0,544	0,026	0,051	0,050	0,009	0,016	1,387	0,857	0,847	0,078	0,033	0,076
LBADEUR3LCH	0,483	0,023	0,043	0,045	0,008	0,014	1,156	0,714	0,706	0,084	0,036	0,082
LBADEUR3ZWA	0,544	0,026	0,051	0,050	0,009	0,016	1,387	0,857	0,847	0,120	0,051	0,117
LBADEUR4DPFLCH	0,150	0,017	0,065	0,021	0,004	0,007	0,671	0,496	0,519	0,006	0,003	0,008
LBADEUR4DPFZWA	0,149	0,017	0,065	0,021	0,004	0,007	0,793	0,586	0,613	0,008	0,005	0,012
LBADEUR4LCH	0,150	0,017	0,065	0,021	0,004	0,007	0,671	0,496	0,519	0,056	0,032	0,079

5.3.1 *Statistics Netherlands mileage data*

In order to determine emission totals from road transport, Statistics Netherlands provides annual mileage data for the different vehicle categories. This is listed in the 'basislijst' as MKM: million kilometers travelled per year. These values are also used for reweighting the detailed VERSIT+ emission factors to emission factors for the aggregated SRM vehicle categories.

The mileages (MKM) represent the number of kilometers driven by all vehicles of a certain vehicle type on Dutch roads in a given year. This number is determined by using information on:

1. The size and composition of the Dutch fleet;
2. The average annual mileages of different types of Dutch vehicles;
3. The number of kilometers driven by foreign vehicles in the Netherlands.

The fleet composition (1) is determined by Statistics Netherlands using registration data from RDW of all vehicles with a Dutch license plate. The fleet is decomposed using vehicle type and mass, fuel type and year of manufacture. The average annual mileages for Dutch vehicles (2) are calculated by Statistics Netherlands using odometer readings collected by RDW. All RDW-acknowledged garages and companies are obliged by law to register the odometer readings of all passenger cars and trucks that come in for maintenance of repairs. Every year, Statistics Netherlands uses this data combined with data on vehicle characteristics to derive average annual mileages for different vehicles types (age classes and fuel types). This methodology is applied to derive average annual mileages for passenger cars, light-duty and heavy-duty trucks and buses. By multiplying the annual mileages by the number of vehicles of a certain category, Statistics Netherlands calculates the number of kilometers driven by Dutch vehicles. This is corrected for the distance driven abroad using different statistics, as described in [Klein et al. 2016].

The vehicle kilometres driven in the Netherlands by foreign passenger cars (3) are estimated by Statistics Netherlands using different tourism related data, as described in [Klein et al. 2016]. Vehicle kilometres driven by foreign trucks were derived from statistics on-road transportation in the Netherlands and in other EU countries, collected by Eurostat. The vehicle kilometres driven by foreign buses in the Netherlands were estimated by different national and international statistics on buses and tourism, such as the Dutch Accommodations Survey, the UK Travel Trends and the Belgian Travel Research (Reisonderzoek), as described in [Molnár-in ‘t Veld and Dohmen-Kampert 2010].

Combined, this results in the so-called ‘MKM’ values, the number of kilometers covered per vehicle type per year in The Netherlands. The results of these calculations are available in StatLine, the online database of Statistics Netherlands.

For the calculation of emission factors, the mileages are weighted to the vehicle categories used in VERSIT+ and divided over the three road types: urban roads, rural roads and motorways. The emission categories are based on the Euro classes, which coincide with the year of manufacture. Sometimes new technologies are introduced before they are mandatory (e.g. DPFs for passenger cars). This is taken into account in the division of the mileages into emission categories.

The distinction between road types is made specifically for each vehicle category (based on vehicle type, fuel type and vehicle age), using research by Goudappel Coffeng [2010]. In this study, a national transport model was used to estimate the overall road type distribution for passenger cars and light and heavy-duty trucks. Subsequently, data from license plate registrations throughout The Netherlands were used to differentiate these distributions according to fuel type and vehicle age. In general, it was concluded that the share of gasoline passenger cars on urban roads is higher than on motorways. Also, the fleet on motorways on average is younger than on urban roads. These differences can mainly be attributed to differences in average annual mileages: higher mileages in general result in higher shares of motorway driving in total mileages. For public transport buses and tour buses, the road type distribution was determined by CE Delft [2015].

5.3.2 *Projections of future mileages*

In order to estimate future emissions of road transport and SRM emission factors for future years, PBL estimates the mileages for the different VERSIT+ vehicle categories in the years 2020 and 2030 using different transport and fleet related models. Projections of passenger transport volumes are made using the Dutch national transport model LMS, which includes passenger cars and buses. LMS takes into account the expected economic and demographic growth, changes in fuel prices and the road network, impacts of government policies and changes in car ownership. Projections of the size and composition of the Dutch passenger car fleet are derived by PBL using the Dynamo model [MuConsult 2015], taking into account (among other things) the impact of EU and Dutch policies and incentive programmes that influence the composition of the vehicle fleet, such as:

- EU CO_2 emission standards, influencing the cost of car ownership and car use and also the fuel mix of the future fleet.
- The Euro standards for air pollutants, including the introduction of RDE legislation for light duty vehicles from 2017 onwards.
- The fiscal regime for passenger cars, including changes in coming years. This influences (among other things) the renewal rate of the fleet, the fuel mix and the introduction of new vehicle technologies such as plug-in hybrid electric cars and full electric cars.

Projections of freight transport in the Netherlands are derived from the Dutch national freight model BasGoed, taking into account (among other things) the impact of economic growth in different sector of the economy, expected improvements in transport efficiency and impacts of government policies on freight volumes and modal split. Projections of the size and composition of the heavy-duty truck fleet in the Netherlands are derived by PBL using the Treva model (Traa 2015). Treva projects the renewal rate of the truck fleet and the resulting (on-road) composition of truck fleet in future years. Projections of the future bus fleet are derived from a model developed by CE Delft [2015].

The latest projections of the future vehicle fleet in the Netherlands were made for the Dutch National Energy Outlook 2015 [Schoots and Hammingh 2015] and are described in [Geilenkirchen et al. 2016]. All projections are made on a national level. Total mileages per vehicle type are subsequently divided over the three road types using the study from [Goudappel Coffeng 2010]. This results in projections of the composition of the average traffic flow on urban roads, rural roads and motorways in the Netherlands in 2020 and 2030.

It should be noted that the composition of the traffic flow can vary substantially from road to road, as can be seen from different licence plate registrations throughout the Netherlands. Differences in, for example, the age composition and fuel mix can substantially influence the resulting emissions of different substances of the traffic flow. These differences do not influence the calculation of emission totals at the national level, but are important when using the SRM emission factors to calculate air pollution along specific roads.

6 Communication and dissemination

The in-service testing programmes generate a wealth of emission data and insights into the real-world emission performance of road vehicles. Apart from using this for the derivation of emission factors, the Ministry and TNO disseminate the results stemming from the in-service testing programmes in many ways and in many platforms, political bodies and/or working groups.

6.1 Vehicle emission measurement reports

Test results are discussed in regular project meetings between the Ministry of Infrastructure and the Environment. Data per tested vehicle is kept confidential until TNO has informed the vehicle manufacturer and received and processed its feedback.

6.1.1 Feedback of emission results to the vehicle manufacturer

As the very first step in the external dissemination process of a vehicle emission measurement, the results of a vehicle emission test are shared with the vehicle importer and manufacturer. The manufacturer is the first party to receive a presentation (light-duty vehicles) or memo (heavy-duty vehicles) on the emission performance of the vehicle. An example of the most important information that is provided to the manufacturer can be found in appendix A.

The manufacturer is always invited to reflect on the results and to discuss them with TNO.

6.1.2 Vehicle emission report to the Dutch road vehicle authority

After having finalized discussions with the manufacturer concerned, TNO sends a vehicle emission report to the Netherlands Vehicle Authority (RDW). This emission report, an example of which can be found in appendix B, is a concise report of the information shared with the manufacturer.

Heavy-duty vehicles are tested according a scheme in which testing is gradually intensified from screening towards formal testing. The results are only reported to RDW once all test of the scheme have been concluded and discussed with the importer and/or manufacturer.

In Europe, a vehicle type must be type-approved in one of the EU Member States. After having obtained the Type Approval Certificate, the vehicle may then be sold in all EU countries. Therefore, RDW forwards the vehicle emission report to the Type Approval Authority that type-approved the vehicle if the RDW was not the responsible Type Approval Authority. This way, emission results will always be fed back to the Type Approval Authority that type-approved the vehicle at hand.

6.1.3 Overview report of all emission measurements

On a regular, and mostly annual basis, TNO publishes a report covering all emission measurements performed in the last year. As part of TNO's constructive contribution to the on-going public debate about the real-world NO_x emissions of diesel vehicles, TNO as of 2016 presents emission results with reference to makes and models. This decision also meets a desire expressed by the Dutch Ministry of

Infrastructure and the Environment. By presenting results from the complete sample of vehicle models tested, covering a wide range of makes and models in the vehicle emission measurement reports, and by providing the necessary background information on test procedures and test conditions as well as caveats with respect to what can be concluded from these data in this methodology report, the test results on individual vehicle models are presented in a context that allows a well-balanced interpretation of the meaning of the results.

6.1.4 Stakeholder meetings on vehicle emissions

About every two years, the Ministry and TNO organize a stakeholder meeting on vehicle emissions, for which all relevant players in the field are invited. TNO presents the results of the emission measurements performed over the last years and analyses trends. In case other parties did perform relevant studies on vehicle emission performance, they may be invited to contribute to the symposium. Mostly also here pollutant emissions play a central role, but the symposium may have a specific theme, depending on the then-current events.Input for knowledge platforms on real-world emission performance

6.1.5 Task force on Transportation

The Dutch national Task force on Transportation (Taakgroep Verkeer en Vervoer) covers the emissions to soil, water and air from the transportation sector. It supervises research efforts to keep the national emission factors up to date and ensures the latest emission measurements are incorporated in the emission inventories. The group identifies lacunas in the understanding and information, for which new research projects are initiated. The data on the emissions of the transportation sector collected by the Task force on Transportation is fed into the Dutch Pollutant Release and Transfer Register. The information supplied by the Task Force in its annual methodology report and data sheets on emission factors are the starting point for international audits.

6.1.6 National concentration and deposition maps

The national concentration and deposition maps of the Netherlands (GCN/GDN) are updated annually and the results are used in air quality models and prognoses. These updates are core to the effort to make the best predictions of the improvements in air quality, based on the policy measures combined with the economic trends.

6.1.7 Low-emission zones for heavy-duty traffic

For a number of years the effects of low emission zones for heavy-duty traffic are accounted for in the national air quality models. The effects of a cleaner vehicle fleet are added to the urban heavy-duty emission factors for cities which implement and enforce this low emission zone. The effects are presented as scaling factors on the emission factors which are input to the air quality models.

6.1.8 Emission factors for bus fleets

Since, as a result of the public transport concession system, the bus fleet of a given city can vary greatly from the national average, a tool is maintained which gives the average emission factors of a given bus fleet for a particular city. Not only Euro-class information but also fuel and technologies affect the actual emissions of busses. The *bussenknop* (‘bus switch’) tool in air quality models accounts for the large effects on NO_x, NO_2, and PM.

6.1.9 ERMES

The insights of the programme are shared within the international ERMES group (European Research on Mobile Emissions Sources). This group consists of experts on vehicle emissions who share data and knowledge about the emissions of mobile sources with a purpose to make national and international emission models more reliable and accurate in an efficient way.

6.2 Input for legislative processes at the European and UN level

6.2.1 European working groups

On behalf of the Ministry of Infrastructure and the Environment, TNO participates in working groups in Brussels in which the foundations for new emission legislation are made. Data of the test programme is used to support the discussion making process within the working groups to develop effective and efficient procedures to be used for type approval of light- and heavy-duty engines and vehicles. In the HD-PEMS working group the improvement of the PEMS test procedures were discussed. In the RDE-LDV group and the RDE expert group the emission testing is used to assess the proposals for RDE legislation.

6.2.2 UNECE working groups

The UNECE is establishing the technical regulations which can be implemented in national and European legislation. The working groups do not determine the emission limits, but the test protocol to measure the emissions to be compared against the emission limits. Emission measurements are occasionally used to establish the feasibility of certain regulation and the effects of a change in test protocol.

6.3 TNO policy with respect to publication of data

TNO takes the utmost care in generating data and in communication on the findings of its studies, taking into account the interests of the various stakeholders. As described above, in the testing programmes, importers and manufacturers of tested vehicles are informed of the test results of their vehicles, and are given the opportunity to reflect on them.

> In the evaluation and interpretation of test results on individual vehicles the following considerations need to be taken into account:
>
> - The tests performed by TNO are not intended for enforcement purposes and are not suitable for identifying or claiming fraud or other vehicle-related irregularities in a scientifically and legally watertight way.
> - For each make or model, only a single vehicle or a small number of vehicles is/are tested a limited number of times. This means that it cannot be ruled out that the results correlate to the specific condition of the tested vehicles or to specific test conditions. The latter is especially the case in real-world testing on the road in which a large number of conditions, that have a strong influence on test results, vary from trip to trip.

Finally, we would like to emphasize that as an independent knowledge institute, TNO is, has been and will be open to constructive dialogue with industry and governments. This is part of TNO’s efforts to work together with relevant stakeholders in finding and supporting the implementation of effective solutions to reduce real-world emissions of harmful substances from vehicles, as well to determine and demonstrate the effects of implemented measures in an objective way.

6.4 TNO webpage on vehicle emissions

All emission reports are made available on TNO's website, through:

www.tno.nl/vehicle-emissions

www.tno.nl/voertuigemissies

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8 Signature

Delft, 20 October 2016

TNO

Nico Zornig
Head of department

Jordy S. Spreen
Author

A In-service testing programme procedure - summary

A.1 Light-duty vehicles

A.1.1 Scheme of test procedure

For the light-duty programme, the complete process, i.e. from selection of the test vehicle towards the determination of emission factors, consists of the following subsequent steps:

1 Vehicle selection (section 2.2)
2 Notification to vehicle importer/manufacturer and request for type approval documents
3 Execution of the standardized test programme using SEMS for screening of NOx-emissions (section 3.3.2.1)
4 PEMS measurement and/or chassis dynamometer measurement (optional; dependent on results of standardized test programme) (section 3.3.1)
5 Data analysis (chapter 4)
6 Feedback of test results to vehicle importer/manufacturer (section 6.1.1)
7 Vehicle emission report to Dutch Road Vehicle Authority (section 6.1.2)
8 Overview report of all emission measurements (section 6.1.3)
9 Update of emission factors (annually)

A.1.2 Example report of main results per vehicle

To be able to compare the emission results of different vehicles, it is convenient to produce standard output for each of the tested vehicles. An example of this output is given here for one vehicle.

In Table 17 the CO_2 and NO_x test results of the vehicle are reported. Additionally, special conditions during the trips are noted:

- Number of times and trips in which regeneration took place
- Congestion conditions during the different trips

Table 17: Emission results per trip (example)

Trip	Date	Start time	Duration [s]	Distance [km]	Average velocity [km/h]	Ambient temp min/max/avg [°C]			CO2 [g/km]	NOx [mg/km]
RDE_D_C	2016-3-9	8:19	6935	78.6	40.8	1	8	5.4		
RDE_D_W	2016-3-9	10:37	6471	79.1	44	6	10	7.9		
MOTORWAY	2016-3-9	13:27	6494	143.1	79.3	7	13	10.4		
CONGEST_W	2016-3-9	15:24	2926	49.6	61	8	12	10.4		
CONGEST_C	2016-3-11	8:41	3852	84	78.5	0	8	3.8		
CITY	2016-3-11	9:47	4876	23	16.9	3	9	4		
RURAL	2016-3-11	11:16	6055	86.9	51.7	2	13	7.2		
RDE_D_W	2016-3-13	16:32	6484	88.2	49	8	11	9.5		
TOTAL				632.5	51.6	0	13	7.4		

In order to better compare the different vehicles, the data of all trips is grouped into velocity bins of 10 km/h each. Figure 35 for example shows the binned NO_x emissions in mg/km. An important quantity is the spread of the emission results.

This is indicated by the error bars, which represent +/- one standard deviation from the median NO_x value. If both very high and very low emissions occur, the spread is large and so are the error bars. If the NO_x emissions in one velocity bin are all close together, the spread is small. For example, the bin at 110-120 km/h in Figure 35 has a large spread, so both very high and very low emissions occurred at this velocity.

Furthermore, it is important to keep in mind that not all velocity bins are filled with the same amount of data. For some bins in Figure 35, for example at velocities over 120 km/h, a limited amount of data is available. This is illustrated by the blue bars in Figure 36, which represent the number of seconds the vehicle is driving in that specific velocity regime. In this figure, most data is collected in the bin 100-110 km/h. The amount of data is an indication of the reliability of the average NO_x emission value.

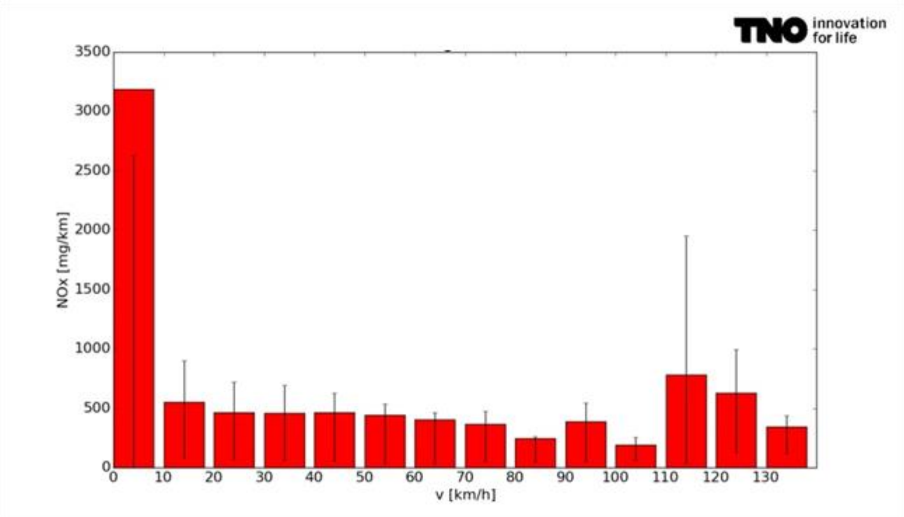


Figure 35: Average NO_x emissions per velocity bin for all trips (example). The error bars represent +/- one standard deviation from the median. Idling is excluded.

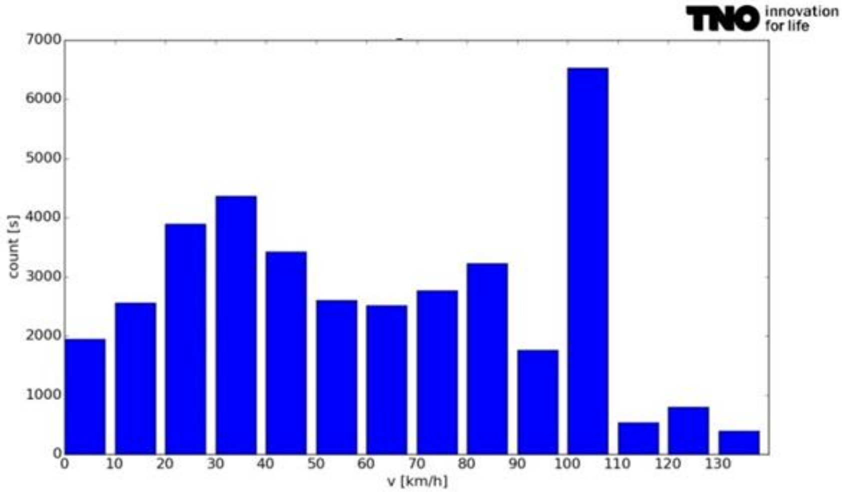


Figure 36: Number of seconds per velocity bin, over all trips (example). Idling is excluded.

An even better illustration of the emission behaviour of the vehicle can be given by not only grouping the data in bins of velocity, but also in bins of acceleration, as shown in Figure 37. The emissions increase for higher velocities, and they increase for higher accelerations. The combination of both high velocity and high acceleration yields the largest increase in emissions. By comparing these figures for different vehicles, the emission behaviour of the vehicles can be compared.

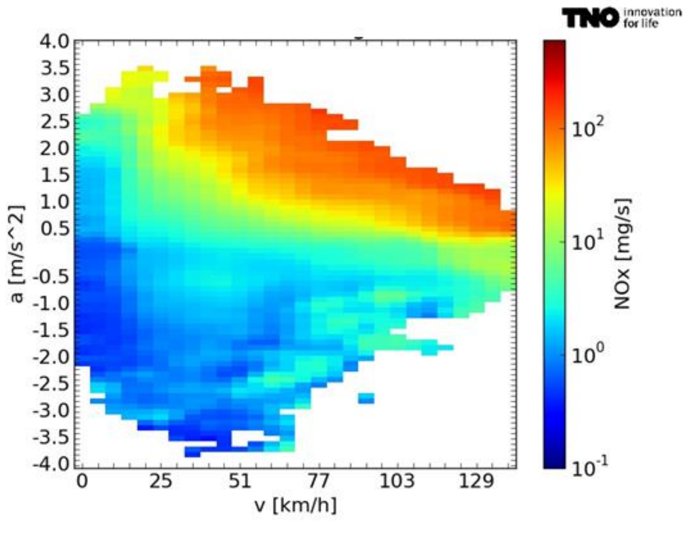


Figure 37: NO_x emission rate [mg/s] in bins of velocity and acceleration (example).

A.2 Heavy-duty vehicles

The decision-based flow-chart in which the SEMS and PEMS tests and the evaluation criteria are shown, is depicted below.

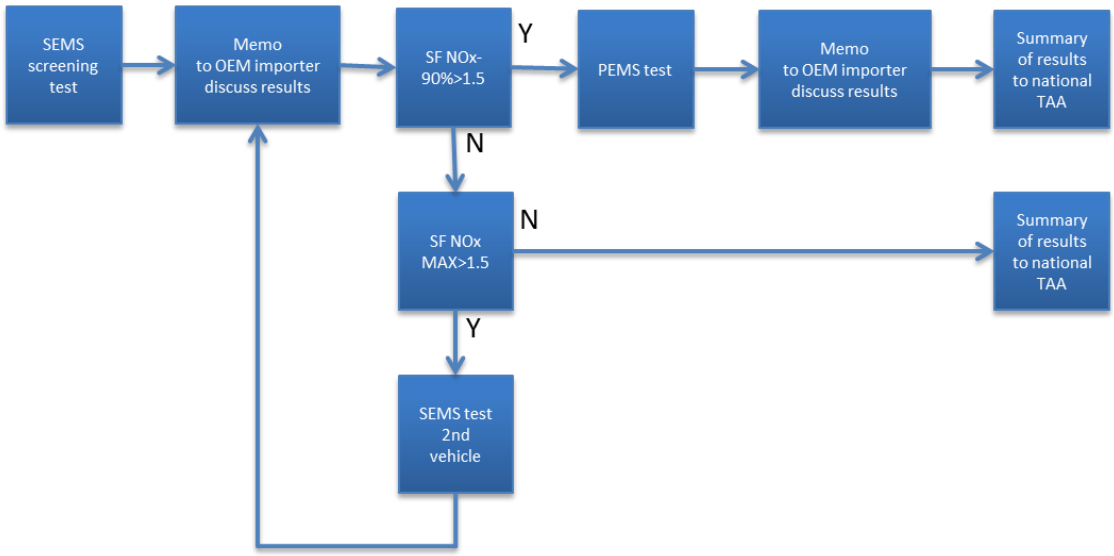


Figure 38: Flow chart with decision moments for emission performance screening, using SEMS as screening instrument and PEMS as the formal confirmatory testing instrument.

For vehicle selection, tests, follow-up actions and dissemination of the results the following scheme is used:

1. Vehicle selection based on RDW registrations in the Netherlands;
2. Step 1 test with SEMS (screening) emissions performance during every days use of the vehicle;
3. Test NO_x emissions with the SEMS Factor (SF <1.5?);
4. Concept memo to the importer. Possibility to discuss results;
5. If NO_x SF >1.5, perform a step 2 test with SEMS over the applicable Euro VI compliant in-service conformity test trip with the same or another vehicle with the same engine type;
6. Concept memo to the importer. Possibility to discuss results;
7. If NO_x SF >1.5, perform a formal PEMS-test (step 3) over the applicable Euro VI compliant in-service conformity test trip with the same vehicle;
8. Disseminate a summary of all test results to the national type-approval authority;
9. Archive the data;
10. Annual report with specification of brand and model of the tested vehicles together with an explanation of the method and context;
11. Update of the emission factors (annual).

B Vehicle emission report to RDW

B.1 Light-duty

TNO innovation for life

TNO Vehicle Emission Report

COMMERCIAL RESTRICTED

date	
version	1.0

Vehicle Characteristics

Trade Mark	[-]	
Type	[-]	
Body	[-]	
Vehicle Class	[-]	
Fuel	[-]	
Vehicle Registration Number	[-]	
Vehicle Identification Number	[-]	
Engine Code	[-]	
Swept Volume	[cm^3]	
Max. Power	[kW]	
Euro Class	[-]	
Type Approval Authority	[-]	
Type Approval Number	[-]	
Vehicle Empty Mass	[kg]	
Odometer	[km]	
Registration Date	[dd-mm-yy]	

Vehicle Emissions

TNO		Euro 6 Emission Limits	Emissions on Chassis Dynamometer	On-road Emissions Measured with SEMS
Test Cylce / Test Trip	[-]	NEDC		
Cold Start / Hot Start	[-]	cold		
Start of Test Programme	[-]	n/a		
Road Load Setting	[-]			
CO	[mg/km]	500		
CO_2	[g/km]	152*		
NO_x	[mg/km]	80		
$THC+NO_x$***	[mg/km]	170		
PM	[mg/km]	4.5		
PN	[#/km]	6.0E+11		
Fuel Consumption	[l/100 km]	5.80*		
Conformity Factor****	[-]	n/a		

*Type Approval Value

**A hot urban part of the CADC is driven directly after the CADC cold test trip.

***THC only for PEMS tests.

**** The Conformity Factor will be part of future emission legislation.

TNO is commissioned by the Dutch Ministry of Infrastructure and the Environment to perform emission measurements on light-duty vehicles.

B.2 Heavy-duty

TNO innovation for life

TNO Heavy-Duty Vehicle Emission Report
COMMERCIALLY RESTRICTED

TNO vehicle code	**XXYYY**	
Date	[dd-mm-yyyy]	
Version	1.0	

Vehicle characteristics

Vehicle manufacturer			
Type			
Body			
Vehicle Class [2007/46]			
Fuel			
Vehicle Identification Number			
Vehicle Registration Number			
Registration Date	[dd-mm-yyyy]		
Registration Country			
Euro Class			
Type Approval Authority			
Type Approval Number			
Vehicle empty mass in running order	[kg]		
Semi-trailer empty mass in running order	[kg]		
Vehicle combination empty mass in running order	[kg]		
Vehicle combination max technical permissible mass	[kg]		
Odometer at test start	[km]		
Configuration vehicle			rigid, rigid and trailer, tractor semi-trailer, bus, coach,
Configuration axles			4x2, etc

Engine characteristics

Engine manufacturer					
Type Approval Authority					
Type Approval Number					
Engine Code					
Engine displacement	[cm^3]				
Max. Power	[kW]		@		[rpm]

Test results in-service conformity with PEMS

TNO test code								
Date	[dd-mm-yyyy]							
Test type	PEMS / SEMS							
Test trip	Name							
Start	[cold, hot]							
T ambient	[Celcius]							
p baro	[kPa]							
Vehicle combination test mass weighted	[kg]							
Trip share urban	[%]							
Trip share rural	[%]							
Trip share motorway	[%]							
Minimum work window average power	[%]							
Maximum CO2 mass window duration	[s]							
Work window: percentage of valid windows	[%]							
CO2 mass window: percentage of valid windows	[%]							
Fuel consumption consistency ratio	[-]							
work window conformity factor CO	**[-]**							
work window conformity factor THC	**[-]**							
work window conformity factor NMHC	**[-]**							

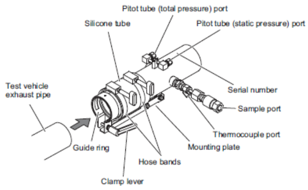
C Equipment specifications

C.1 PEMS

C.1.1 SEMTECH

Make, type	Semtech DS  
Measured gaseous components	CO 0-8% (heated NDIR) +/- 50 ppm or +/-3.0 reading repeatability +/-2.0% reading or 20 ppm T90 < 3s
	CO_2 0-20 vol-% (heated NDIR) +/- 0.1% or +/3.0% reading repeatability +/- 2.0% reading or +/-0.05% T90 < 3s
	NO (0-2500ppm) NO2 (0-500ppm) (NDUV) +/- 3% of reading or 15 ppm repeatability +/-2.0% reading or 5ppm T90 < 2s
	THC 0-100 ppm, 0-1000 ppm, 0-100000 ppm , 0-40000 ppm (heated FID) 0-1000 ppm (used) +/- 2.0% erading or 5 ppmC repeatability +/-1.0% reading or +/- 10ppmC T90 < 2s
Measured parameters	Exhaust flow rate: 0-2.0 to 0-65.0 m^3/min (pitot tube flow meter + module) +/-0.5% FS or +/-2.0% reading, repeatability +/-2.0% reading. Atmospheric pressure: +/-1.5 % Ambient temperature: +/-0.2°C Ambient humidity: +/-2% (0-90%) +/-3% >90% GPS (lat, lon, alt, velocity): +/- 10m Battery voltage
Data rate analysers / sampling rate	0.8333 to 4Hz / configurable
Calculated by post processing software	Mass emissions (ECE-R49) Fuel consumption (carbon balance) Work specific emissions from ECU signals
Sampling line	Heated 5m sampling line
Masses	Gaseous analysers approx. 35 kg
ECU data	Dearborneinterface unit J1939
Power supply	12 Vdc Batteries or external power supply
Operating environment	0-45 °C

C.1.2 HORIBA

Make, type	Horiba OBS ONE GS11  
	582/2011/EC, ECE-R49, EPA 40 CFR subpart J
Measured gaseous components	CO 0-0.5, 0-10 vol-% (heated NDIR) +/- 0.3% FS or +/-2.0 reading Zero repeatability +/-1.0% FS, span repeatability +/-1.0% FS
	CO_2 0-5, 0-20 vol-% (heated NDIR) +/- 0.3% FS or +/-2.0 reading Zero repeatability +/-1.0% FS, span repeatability +/-1.0% FS
	NO, NOx, NO_2 0-100, 0-3000 ppm, (heated dual CLD) +/- 0.3% FS or +/-2.0 reading Zero repeatability +/-1.0% FS, span repeatability +/-1.0% FS
	THC 0-100, 0-100000 ppm (heated FID) +/- 0.3% FS or +/-2.0 reading Zero repeatability +/-1.0% FS, span repeatability +/-1.0% FS
Sample gas	Direct wet, 2.5 l/min
Measured parameters	Exhaust flow rate: 0-2.0 to 0-65.0 m^3/min (pitot tube flow meter + module) +/-0.5% FS or +/-2.0% reading, repeatability +/-2.0% reading. Atmospheric pressure: +/-2.0% FS Ambient temperature: +/-0.5°C at 23°C Ambient humidity: +/-1.5% at 23°C GPS (lat, lon, alt, velocity): +/- 10m Battery voltage
Data sampling	10Hz
Calculated by post processing software	Mass emissions (ECE-R49) Fuel consumption (carbon balance) Work specific emissions from ECU signals
Sampling line	Heated 3 or 5m sampling line
Masses	Gaseous analysers approx. 45 kg
ECU data	OBS interface unit OBD I/F: ISO15765-4, J1939
Power supply	12 V Batteries or external power supply for heating up
Operating environment	-10-40 °C <80% RH <2000m

C.2 SEMS

SEMS	Smart Emissions Measurement System
SEMS type	SEMS 2.0
NO_x-O_2	Continental UniNOX gen 2.8
NH_3	Delphi NH3 sensor
Exhaust gas temperature	k-type thermocouple
CAN data	HDV protocol CAN - module
GPS	Standard protocol GPS - module

C.3 Chassis Dynamometer

To give the reader an impression on chassis dynamometer testing, the following movies are a valuable illustration:

- https://www.youtube.com/watch?v=PyZA-wQJ87I
- https://www.youtube.com/watch?v=0gjnaKr932Y

The following measuring equipment is installed on the chassis dynamo test bench and is certified according to ISO 17025:

Emission test equipment:
- Horiba MEXA ONE D1-EGR, Exhaust Gas Analysing System for direct measurement (1-line) with following analysers: O_2, CO, CO_2, NO_x/NO, THC, CH_4 and separate EGR-Analyser
- Horiba MEXA ONE C2-OV, Exhaust Gas Analysing System for dilute bag & continuous measurement with following analysers: O_2, CO, CO_2, NO_x/NO, THC, CH_4
- Horiba MEXA 2100 SPCS, Solid Particle Counting System
- Horiba MEXA ONE CVS, Constant Volume Sampler System, 6 m³/min to 18 m³/h
- Horiba DLS 7000, Particulate Measuring System with Dilution Tunnel DLT 18 Different temperature and pressure regulators (according to the test application), max. 16 temperature inputs (Type K) and 8 voltage- and current analog inputs
- Horiba VETS One,Host Computer and evaluation of measuring data with DIVA
- Horiba PWS-ONE, Particle measurement and conditioning chamber with micro balance and robot

Chassis Test Cell Air conditioning
Weiss Umwelttechnik
- cooling performance 150 kW
- air circulation 30.000 m³/h
- fresh air 2.000 m³/h
- CVS-dilution air 1.200 m³/h
- waist air 2.000 – 4.000 m³/h

Chassis Dynamometer
VULCAN II EMS-CD48L 4WD
- max. speed 200 km/h
- max. capacity/power 2 x 155 kW

- wheel base 1800 – 3400 mm
- max. axle load 2.500 kg
- Fan LTG VQF 500/1250

Exhaust Measurement Equipment

- **MEXA ONE D1-EGR**
  Exhaust gas analyser, Undiluted (direct) for: O_2, CO, CO_2, NO_x/NO, THC and CH_4, separate EGR-Analyser
- **MEXA ONE C2-OV**
  Exhaust gas analyser, dilute bag & continuous measurement for: O_2, CO, CO_2, NO_x/NO, THC, CH_4
- **Heated Bag Cabinet**
  with 3 x 4 emission bags for ambient air-, gasoline– and diesel measuring
- **MEXA 2100 SPCS**
  Measures solid particle number concentration in raw engine exhaust gas in real time, within a specified particle size range (UN/ECE Regulation No.83, Rev.3, Amend.2).

D Version and settings for EMROAD and CLEAR evaluations

The version and settings as used when evaluating TNO RDE tests with CLEAR and EMROAD are described in the next sections.

D.1 CLEAR

- Version: 1.8.6
- Executable: CLEAR.exe (dd. 14-11-2014 13:48)
- Settings: All settings set to default values with exception of minor changes in the CLEAR configuration files 'Config.xml' (switch on of 'Use Willans Power') and 'Vehicle.xml' (as appropriate for vehicles tested).
- Input: The RDE test data and the following vehicle characteristic data:
  - CO_2 emission factors in g/km for phases of WLTC test of vehicle;
  - road load factors (F0, F1, F2) and test mass as used for WLTC test of vehicle;
  - when this data is unavailable for the vehicle, the above mentioned default settings and estimated average vehicle characteristics are used to still get an indication of the CLEAR results for the RDE test.
- Output: Main outputs are the raw and normalized emission factors in g/km for the RDE test.

D.2 EMROAD

- Version: EMROAD_5_90B5_BETA
- MS Add-In: EMROAD_V5_90_B5.xla (dd. 15-3-2016 18:08 (in EMROAD_5_90B5_BETA.zip)
- Template: LDV Real Driving Emissions
- Settings: All settings set to default values with exceptions for the tab 'EXCLUSIONS' in the 'ADVANCED SETTINGS' menu of the EMROAD Excel Add-In, where all 'exclusions' are switched off. Note that the latter implies that all data in a trip, including a certain time of cold start or standstill, if (still) present in the data, is included in the evaluation.
- Input: The RDE test data and the following vehicle characteristic data:
  - CO_2 emission factors in g/km for phases of WLTC test of vehicle;
  - total mass of emitted CO_2 in kg for WLTC test of vehicle
  - when this data is unavailable for the vehicle, the above mentioned default settings are used to still get an indication of the EMROAD results for the RDE test.
- Output: Main output are the raw and normalized emission factors in g/km for the RDE test.