Details RDE Legislation Europe

Speaker: Nikolas Kühn

June 27th 2017 - ECMA

Starter

A not to serious but quite interesting statement (quote from a German radiobroadcast show around 2010):

> *"… If, from the very beginning, exhaust gases from combustion engines would have been lead* ***into*** *the passenger cabin instead to the environment, most probably we would be way ahead of today's thinking about the effect of motorized transportation…"*

That might sound ridiculous. However, it describes the dilemma of the delayed impact on health and environment pretty well and reminds us about our responsibility towards environment and generations to come.

Content

- Introduction
- EU Emissions Legislation Roadmap
- EU Regulations Timeline
- Real Driving Emissions (RDE)
- RDE – How to Test RDE
- RDE – Boundary Conditions
- RDE – Evaluation of Tests
- RDE – Not To Exceed Limits
- RDE (HDD) – Boundary Conditions
- Discussion

Content

- Introduction
- EU Emissions Legislation Roadmap
- EU Regulations Timeline
- Real Driving Emissions (RDE)
- RDE – How to Test RDE
- RDE – Boundary Conditions
- RDE – Evaluation of Tests
- RDE – Not To Exceed Limits
- RDE (HDD) – Boundary Conditions
- Discussion

Introduction

Background

- Cycles currently used as a standard to determine emissions of vehicles do not represent realistic driving conditions. That leads to
  - **Gap between measured and real life emission – scrutinize existing law, public interest**
  - **Gap between measured and real life fuel economy (up to 40%) – public interest**

Measure

- Real Driving Emissions RDE
  - **Implementation of a testing methodology being more realistic compared to predictable test cycles (NEDC, WLTC…)**

Consequences

- RDE is going to be a part of type approval of new vehicles in future. With it a lot of challenges will come:
  - **More advanced calibration necessary. OEM have to ensure that vehicles comply with regulations on a broader range of engine map**
  - **RDE has to reflect regional aspects (traffic, driving behaviour, road conditions, climate)**

Content

- Introduction
- EU Emissions Legislation Roadmap
- EU Regulations Timeline
- Real Driving Emissions (RDE)
- RDE – How to Test RDE
- RDE – Boundary Conditions
- RDE – Evaluation of Tests
- RDE – Not To Exceed Limits
- RDE (HDD) – Boundary Conditions
- Discussion

EU Emissions Legislation Roadmap

Scenario with currently highest probability

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
CO_2 target			**130 g/km** 100% fleet					**95 g/km** 95% → 100% fleet			
Emission standards	**Euro 5**		**Euro 6b**			**Euro 6d TEMP**		**Euro 6d**			
Real Driving Emissions	**Development and monitoring phase**					$CF1_{PN}$: 1.5 $CF1_{NOx}$: 2.1		$CF2_{PN}$: 1.0+margin (0.5)* $CF2_{NOx}$: 1.0+margin (0.5)*			
Lab Cycle	**NEDC-based testing**					**WLTC-based testing**					
On Board Diagnostics	**Euro 5b**		**Euro 6-1**			**Euro 6-2**					

All dates: New type approval PC

not confirmed by final regulation.

* annual review and revision as a result of the improved quality of the PEMS procedure or technical progress

EU Emissions Legislation Roadmap

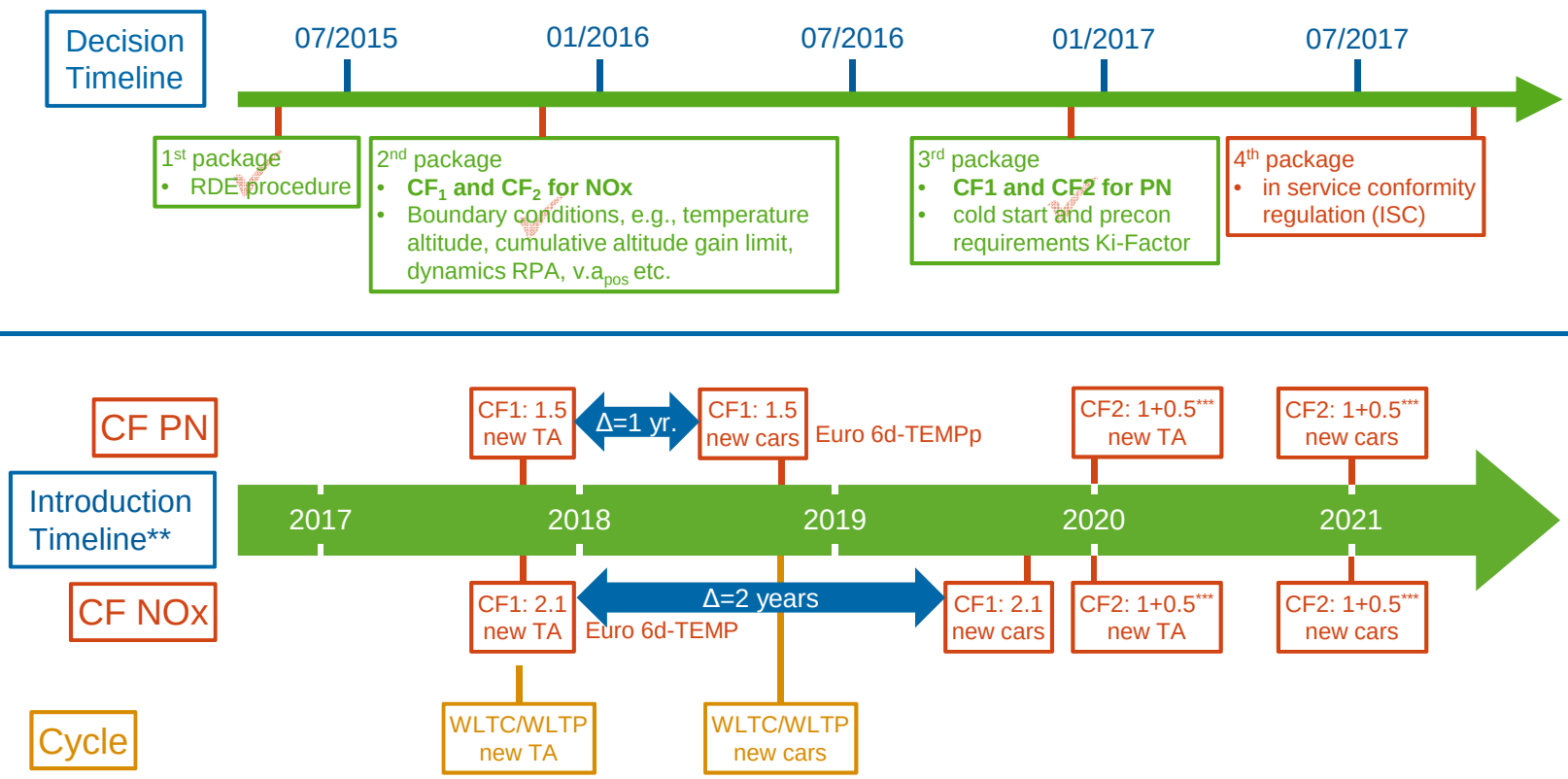
	Euro 6b		Euro 6d	
Pollutant	Gasoline	Diesel	Gasoline	Diesel
CO [mg/km]	1000	500	1000	500
HC [mg/km]	100	-	100	-
HC+NOx [mg/km]	-	170	-	170
NOx [mg/km]	60	80	60	80
PM [mg/km]	4.5*	4.5	4.5*	4.5
PN [#/km]	**$6 \cdot 10^{12}$***	$6 \cdot 10^{11}$	**$6 \cdot 10^{11}$***	$6 \cdot 10^{11}$

*applicable to gasoline direct injection engines only

Emission limits for regulated pollutants

Passenger cars (M1 and N1 class I vehicles)

EU Regulations Timeline for RDE



** Dates apply to new TA M1 and N1 class I; N1 classes II and III are one year later.
*** Subject to annual review and revision.

TA: Type Approval for new models
New cars: new registration

Content

- Introduction
- EU Emissions Legislation Roadmap
- EU Regulations Timeline
- Real Driving Emissions (RDE)
- RDE – How to Test RDE
- RDE – Boundary Conditions
- RDE – Evaluation of Tests
- RDE – Not To Exceed Limits
- RDE (HDD) – Boundary Conditions
- Discussion

Real Driving Emissions (RDE)

Definition

RDE is a measurement method using portable emission measurement systems (PEMS) for emissions determination of vehicles under realistic conditions.

- Ordinary vehicles
- Public roads
- Operated at work days
- Market fuels
- Data public available

Real Driving Emissions (RDE)

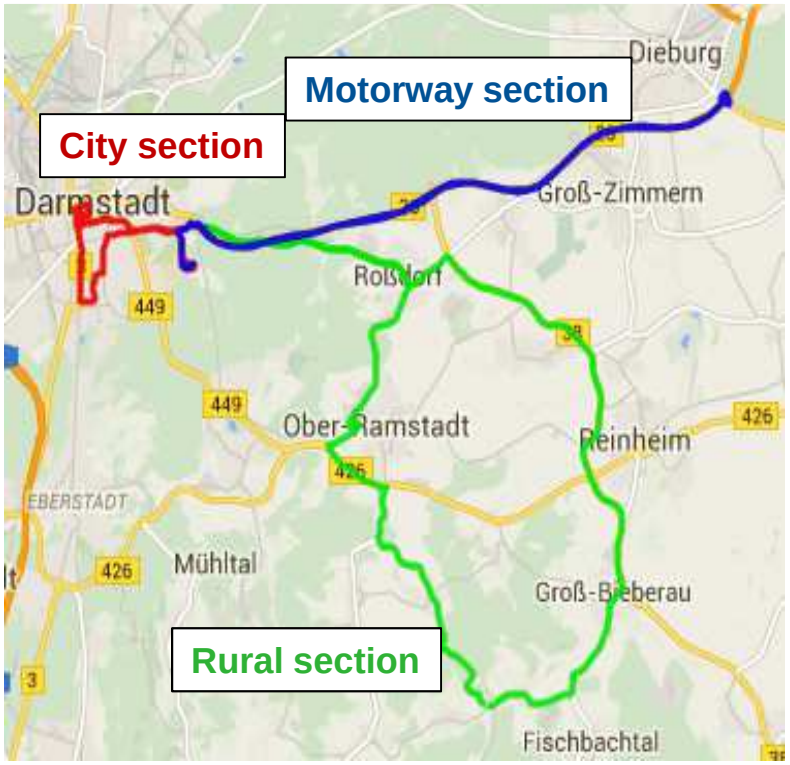
How to Test RDE

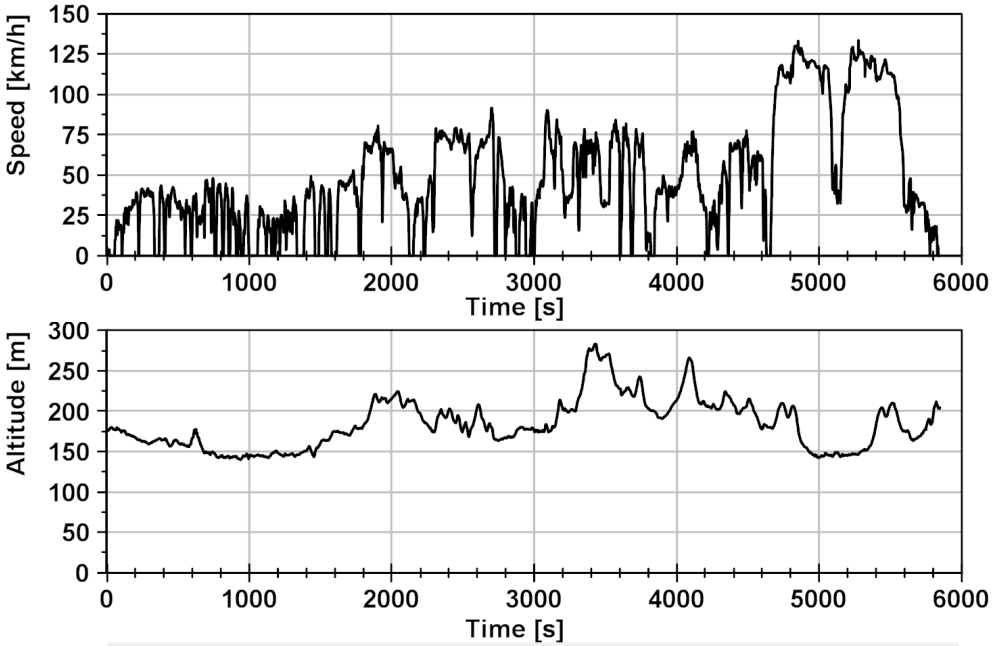
- **Phase I – Preparation**
  - **Get a vehicle**
  - **Define a compliant route – boundary conditions**
- **Phase II – Installation and Verification**
  - **Install the PEMS**
  - **Calibrate the PEMS**
  - **Run a reference WLTC at the chassis dyno**
  - **Correlate the PEMS setup vs the lab analyzers**
- **Phase III – Testing and Evaluation**
  - **Calibrate the PEMS**
  - **Run the test**
  - **Calibrate the PEMS**
  - **Check trip validity – validation of test dynamics – trip-distribution**
  - **Do the data processing and the final emission evaluation**

How to RDE – Phase I

Route Definition

Compliant RDE Route





- Rural part in hilly area with many curvy roads
- Total cumulated altitude gain 770 m/100 km

How to RDE – Phase I

Most important boundary conditions

Trip sequence (fixed):
⅓ urban-⅓ rural-⅓ motorway
min. 16km each

Altitude:
moderate < 700m
extended < 1300m

Speed: max. 145 km/h
urban: 0-60 km/h
rural: 60-90 km/h
motorway: 90-145 km/h

Temperature:
moderate: 0 – 30°C
extended: -7 – 35°C

Trip duration:
90 – 120 min.

Cold start phase:
$T_{coolant}$ < 70°C
but limited to 5 min.

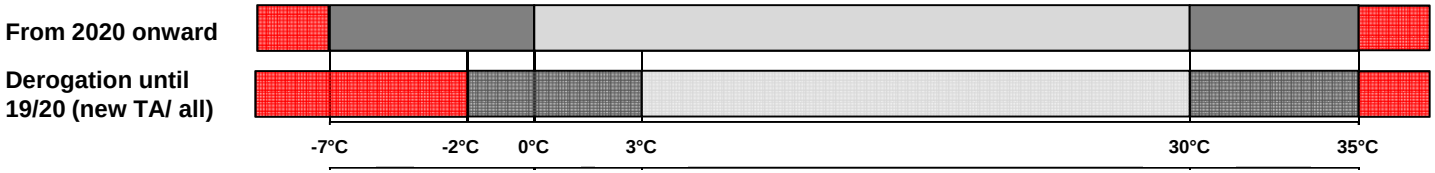
How to RDE – Phase I

Boundary conditions – Details (1)

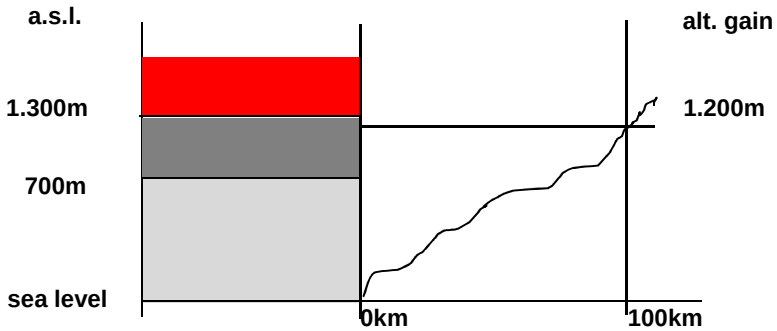
§ --'9.5. If during a particular time interval the ambient conditions are extended (…) the emissions during this particular time interval (…), shall be **divided by a value of 1,6** before being evaluated for compliance with the requirements of this Annex.';

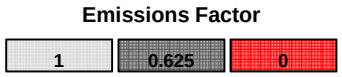
Ambient Conditions

- Temperature
  - **Moderate:** **0°C/3°C* < T < 30°C/30°C**
  - **Extended** **-7°C < T < 0°C / -2°C* < T < 0°C OR 30°C < T < 35°/35°C**



- Alltitude
  - **Moderate** **h < 700m above sea level**
  - **Extended** **700m < h < 1.300m above sea level**
  - **Gain** **max 1.200m / 100km**





How to RDE – Phase I

Boundary conditions – Details (2)

Speed

- urban: 0-60 km/h, Rural: 60-90 km/h, Motorway: 90-145 km/h (+15 km/h for max. 3% of the motorway driving)
- urban average 15-30 km/h.
- vehicle speed is limited to 60 km/h during the urban part, even if roads are included in the route, that legally allow higher speeds.
- urban shall include several stops > 10 s but not one long stop > 80% of stop time in urban (6-30%)
- motorway: properly cover a range of 90-110 km/h; above 100 km/h for at least 5 minutes

Duration

- 90 - 120 minutes

Trip sections and sequence:

- Urban > Rural > Motorway
- each section (urban 29-44% - rural 23-43% - motorway 23-43%) at least 16 km
- Altitude difference between start and end < 100m

How to RDE – Phase I

Boundary conditions – Details (3)

Vehicle payload and test mass

- $Payload_{RDE}$: test equipment, driver, witness (if applicable)
- $Payload_{RDE} < 90\% \ Payload_{max}$

Vehicle	Kerbweight [kg]	GVW [kg]	Payload [kg]	90% Payload [kg]	
A	810	1180	370	333	> 250kg
B-1	885	1145	260	234	< 250kg (incl. Witness)
B-2	885	1145	260	234	> 175kg (excl. Witness)

Weight of PEMS equipment approx. 100kg (Gas/PN PEMS, add battery, EFM, mount.) Driver 75kg, witness 75kg – TTL 250kg / 175kg payload

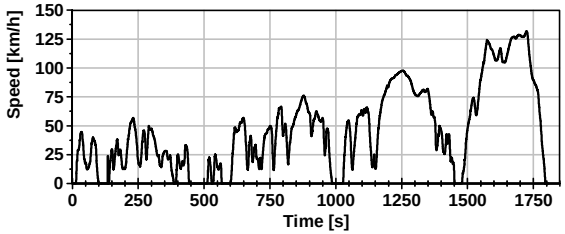
Other conditions

- Vehicles shall be operated on work days
- Market fuel to be used
- Auxiliary devices (incl. air condition) shall be operated in a way compatible with real driving on the road
- The tests shall be conducted on paved roads and streets (e.g. no off road operation)
- Preconditioning: the vehicle is driven for at least 30 min and parked between 6 and 56 hours.
- Entire cold start period (300s) is considered to be in the extended environmental conditions, if the average temperature of the last 3 hours of soaking is in the extended range (even if the driving conditions are not in the extended range)
- Idling after first engine ignition is limited to 15sec
- If regeneration occurs, test may be voided and repeated once (regen. completion to be ensured prior to 2nd test)

How to RDE – Phase II

PEMS Installation and Validation

WLTC on a Chassis Dyno to compare bag emissions and PEMS emissions for validation

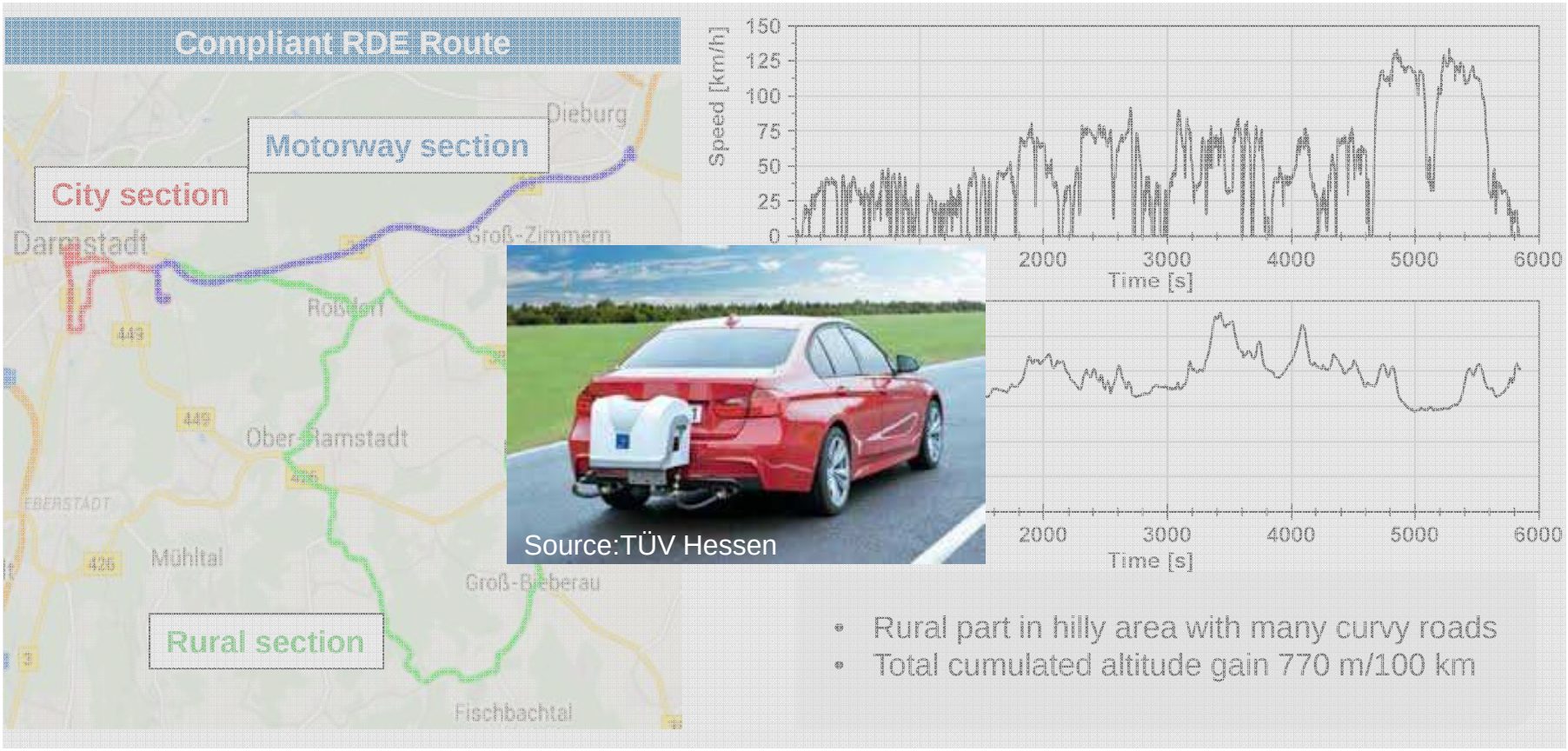


Gas-PEMS vs CVS:

Gas-PEMS/CVS	CO_2	CO	NO_x	PN
Tolerance	**10 % or 10 g/km**	**15% or 15 mg/km**	**15 % or 15 mg/km**	**50%**
Vehicle A	8 %	10 %	0 %	41%
Vehicle B	2 %	10 %	2 mg/km	37%

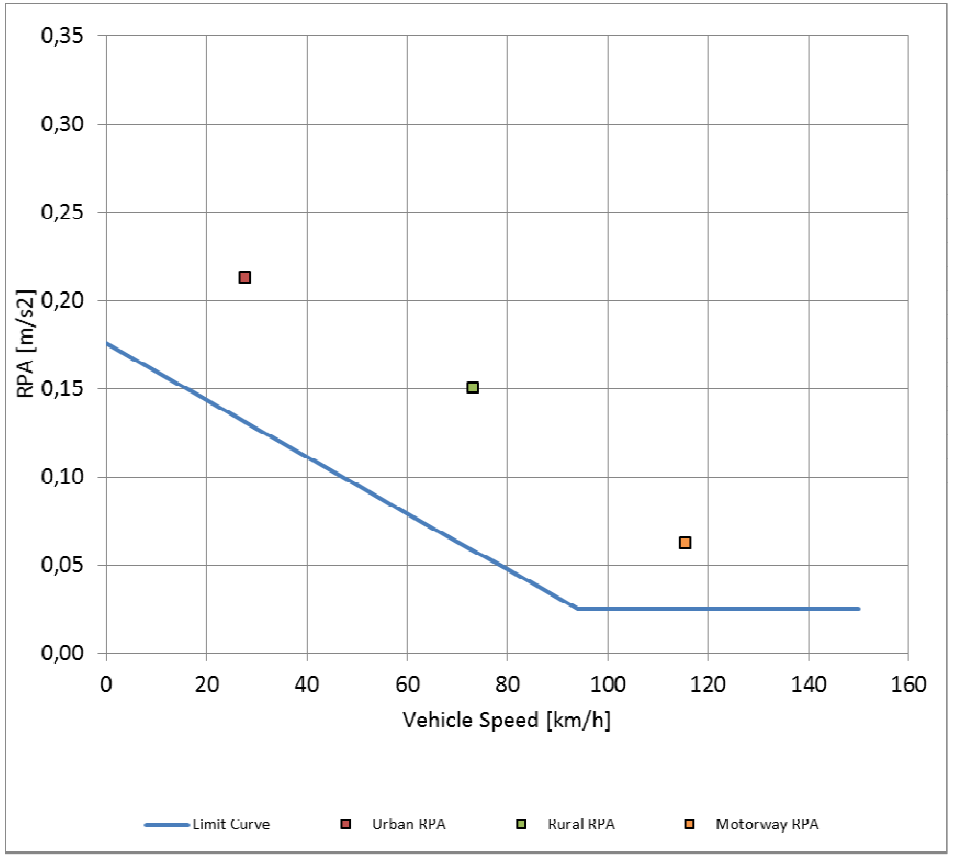
How to RDE – Phase III

Run RDE Test



How to RDE – Phase III

Relative positive acceleration (RPA) → judges softness



Calculate RPA with 1 sec time difference

Calculate average speed for each speed bin (urban, rural, MW)

→ Stay above the limit curve

Calculate Limit curve:

For average speed lower than 94.05 km/h

$RPA_{limit} = (-0.0016 \times v_{avg} + 0.1755)$

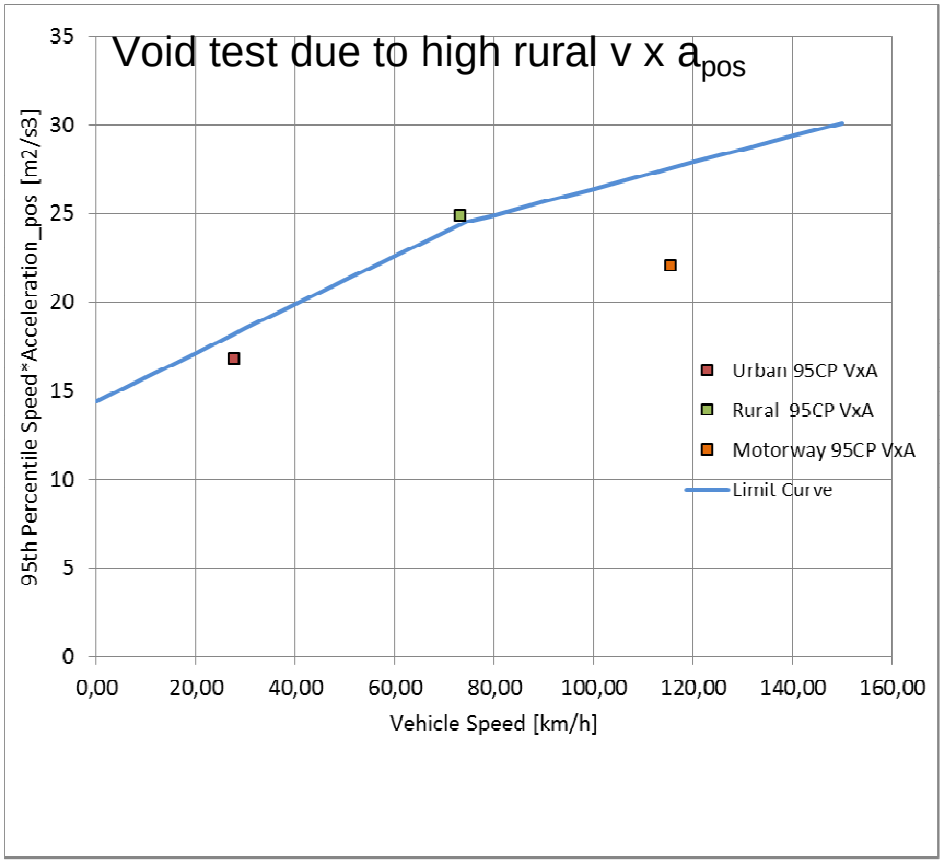
For average speed higher than 94.05 km/h

$RPA_{limit} = 0.025$

$$RPA_k = \Sigma_j(\Delta t \cdot (v \cdot a_{pos})_{j,k})/\Sigma_i d_{i,k}$$

How to RDE – Phase III

95th percentile of $a_{pos} \cdot v$ → judges severity



Calculate v x a_{pos} for each second (1 Hz data)

Calculate the 95th percentile

Calculate average speed for each speed bin (urban, rural, MW)

→ Stay below the limit curve

Calculate Limit curve:

For average speed lower than 74.6 km/h

v x a_{pos} [95] = (0.136 x v_{avg} + 14.44)

For average speed higher than 74.6 km/h

v x a_{pos} [95] = (0.0742 x v_{avg} + 18.966)

$$(v \cdot a_{pos})_{k\_}[95]$$

How to RDE – Phase III

Evaluation Tools

There exists two different evaluation tools:

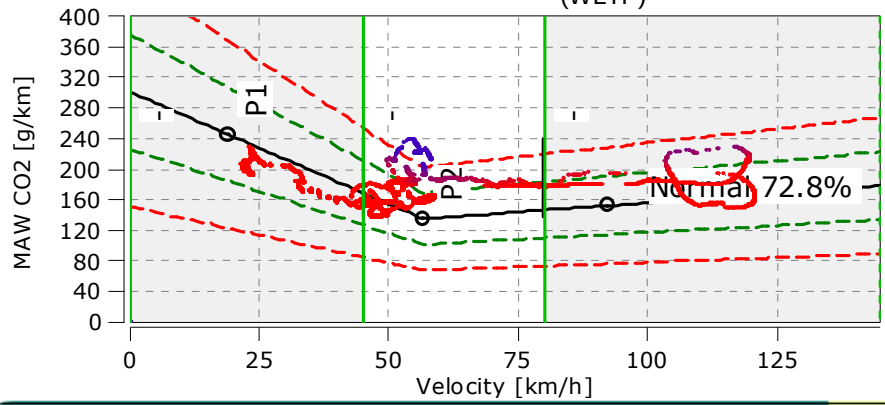
- EMROAD (developed by JRC of the EU)
- CLEAR aka power binning method (developed by car manufacturers)

→ Both are under evaluation; cancelation of both is of high probability

EMROAD:

Moving Average Window approach

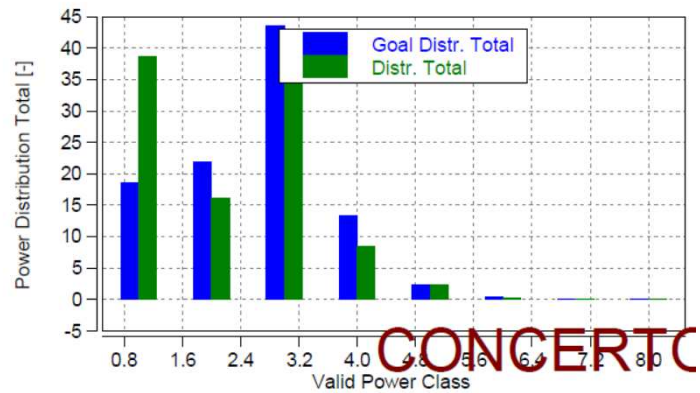
- Based on CO_2 emissions at reference WLTP
- Each window = ½ $CO2_{(WLTP)}$



CLEAR:

Power Binning approach

- Based on power at wheel
- Use of Ve-line approach



How to RDE – Phase III

Example Data Analysis

AVL

Case: TUD_Passat

Page: Conformity Factors

Start Date: 2016/01/14 08:36:35

Start Time: 20160114083635:20:20160114083635.0

DEMO

Concerto M.O.V.E, 2016

$$CF_{test} = \frac{Result}{Limit}$$

TRIP - unweighted		Limit	City	CF	Rural	CF	Motorway	CF	Total	CF
NOx	g/km	0.060	0.111	1.85	0.142	2.37	0.030	0.50	0.093	1.56
CO	g/km	1.000	0.138	0.14	1.096	1.10	0.965	0.97	0.702	0.70
CO2	g/km		184.8		133.5		168.1		162.3	
PN	#/km	6.000e+011	5.911e+011	0.99	7.109e+011	1.18	6.614e+011	1.10	6.377e+011	1.06
EMROAD										
NOx	g/km		0.057	0.95	0.144	2.39	0.029	0.48	0.076	1.27
CO	g/km		0.022	0.02	0.804	0.80	0.821	0.82	0.544	0.54
CO2	g/km		174.1		152.0		164.0		158.2	
PN	#/km		4.880e+011	0.81	6.114e+011	1.02	7.400e+011	1.23	6.119e+011	1.02
CLEAR										
NOx	g/km		0.142	2.36					0.110	1.83
CO	g/km		0.157	0.16					0.865	0.86
CO2	g/km		227.2						189.4	
PN	#/km		7.357e+011	1.23					7.690e+011	1.28

CONCERTO

CFs to be fulfilled for the complete trip and separately for the urban part

Real Driving Emissions (RDE)

Not-to-Exceed Limits NTE

NTE = Emission Limit x Conformity Factor

NTE Gasoline:

NTE_{NOx}= 60 mg/km x 2.1 = 126 mg/km

NTE_{PN} = $6x10^{11}$ #/km x 1.5 = $9x10^{11}$ #/km

Example 1: Gasoline-TDI

RDE_{NOx} = 51 mg/km → CF = 0,85 → pass!

RDE_{PN} = $4.1x10^{11}$ #/km → CF = 0,68 pass!

RDE test is **passed**

Example 2: Gasoline-TDI

RDE_{NOx} = 125 mg/km → CF = 2,08 → pass!

RDE_{PN} = $9.7x10^{11}$ #/km → CF = 1,61 → fail!

RDE test is **failed** due to PN

Real Driving Emissions (RDE)

Introduction of the K_i-factor

For periodically regenerating systems

'periodically regenerating system' means catalytic converters, particulate filters or other pollution control devices that require a periodical regeneration process in less than 4 000 km of normal vehicle operation.

The loading process and K_i determination shall be made during the Type I operating cycle, on a chassis dynamometer or on an engine test bench using an equivalent test cycle. These cycles may be run continuously (i.e. without the need to switch the engine off between cycles).

$$M_{pi} = \left\{ \frac{M_{si} \cdot D + M_{ri} \cdot d}{D + d} \right\}$$

$$K_i = \frac{M_{pi}}{M_{si}}$$

Example:

- Emissions at single test w/o regeneration (M_{si}): 50 mg/km
- Number of tests between two regenerations (D): 10
- Emissions at test w/ regeneration (M_{ri}): 150 mg/km
- Number of test until regeneration is complete (d): 1

→ M_{pi} = (50 mg/km x 10 + 150 mg/km x 1) / 11 = 59.1 mg/km → **K_i = 59.1 mg/km / 50 mg/km = 1.18**

Real Driving Emissions (RDE)

Introduction of the K_i-factor

For periodically regenerating systems

3rd RDE Package Annex II

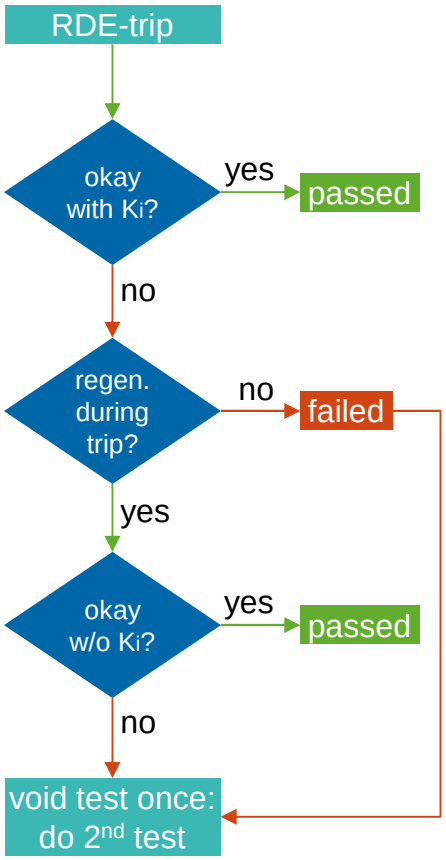
5.5.2.2 All results will be corrected with the K_i factors or with the K_i offsets developed by the procedures in sub-annex 6 of Annex XXI for type-approval of a vehicle type with a periodically regenerating system,

5.5.2.3 If the emissions do not fulfil the requirements of point 3.1.0 *[CFs]*, then the occurrence of regeneration shall be verified. The verification of a regeneration may be based on expert judgement through cross-correlation of several of the following signals, which may include exhaust temperature, PN, CO_2, O_2 measurements in combination with vehicle speed and acceleration.

If periodic regeneration occurred during the test, the result without the application of either the K_i -factor of the K_i offset shall be checked against the requirements of point 3.1.0. If the resulting emissions do not fulfil the requirements, then the test shall be voided and repeated once at the request of the manufacturer. The manufacturer may ensure the completion of the regeneration. The second test is considered valid even if regeneration occurs during it.

5.5.2.4 At the request of the manufacturer, even if the vehicle fulfils the requirements of point 3.1.0, the occurrence of regeneration may be verified as in point 5.5.2.3 above. If the presence of regeneration can be proved and with the agreement of the Type Approval, the final results will be shown without the application of either the K_i factor or the K_i offset.

$RDE_{Emission}$ x Ki



Real Driving Emissions (RDE)

Not-To-Exceed Limits and Ki-Factor

NTE Diesel:

NTE_{NOx}= 80 mg/km x 2.1 = 168 mg/km

NTE_{PN} = $6x10^{11}$ #/km x 1.5 = $9x10^{11}$ #/km

Example 1: Diesel w/ DPF: Ki = 1.25

RDE Test Results:

RDE_{NOx} = 115 mg/km → pass!

RDE_{NOx} x Ki = 144 mg/km → pass!

RDE_{PN} = $4.2x10^{11}$ #/km → pass!

RDE_{PN} x Ki = $5,312x10^{11}$ #/km → pass!

RDE test is passed (w/ or w/o)

Example 2: Diesel w/ DPF: Ki = 1.25

RDE Test Results w/ regen:

RDE_{NOx} x Ki = 175 mg/km → no

Regen? : YES

RDE_{NOx} = 140 mg/km→ ok

RDE_{PN} = $4.2x10^{11}$ #/km → pass!

RDE_{PN} x Ki = $5,312x10^{11}$ #/km → pass!

RDE test w/ regen is passed because ok w/o Ki

Example 3: Diesel w/ DPF: Ki = 1.25

RDE Test Results w/o regen:

RDE_{NOx} x Ki = 175 mg/km → no

Regen? : NO

RDE_{PN} = $4.2x10^{11}$ #/km → pass!

RDE_{PN} x Ki = $5,312x10^{11}$ #/km → pass!

RDE test w/o regen is failed because too high NOx w/o regen

Content

- Introduction
- EU Emissions Legislation Roadmap
- EU Regulations Timeline
- Real Driving Emissions (RDE)
- RDE – How to Test RDE
- RDE – Boundary Conditions
- RDE – Evaluation of Tests
- RDE – Not To Exceed Limits
- RDE (HDD) – Boundary Conditions
- Discussion

RDE HDD Europe

HDD - Real Driving Emissions (RDE)

What is RDE HDD (Europe) ?

- HDD Euro VI (Regulation 595/2009 and 582/2011) effective since 2013 for new TA and since 2014 for new vehicles PEMS/RDE is mandatory
- Conditions

Section	Vehicle Speed	N1	N2	N3
City	v < 50km/h	45%	45%	20%
Rural	50 < v < 75 km/h	25%	25%	25%
Motorway	v > 75 km/h	30%	30%	55%

  - **Test route topography (+/- 5%):**
  - **Cold start: data evaluation starts coolant temperature > 70°C, but not later than 20min after engine start**
  - **Duration: t ≥ 5 x WHTC cycle work**
  - **Ambient conditions: -7°C – 35°C (dep. on alt.) and ≥ 85kPa (approx. 1700m max)**
  - **CO, THC, NOx (Diesel), CH4 for (Gas) and CO2 – no PM/PN for now**
  - **valid windows are defined as windows having an average power P_w ≥ 20% P_{rated}. (10% for EU VI-D)**
  - **Valid windows number > 50%**
  - **If share of valid windows is < 50%, reduction of 1% steps (from 20% P_{rated} down to 15%Pmax)**
  - **90% of the valid windows must pass ISC-limit**
  - **Pay-load 50-60% (or typical loading if known)**

HDD - Real Driving Emissions (RDE)

What is RDE HDD (Europe) ?

- Thresholds and Conformity Factors

	WHTC	CF	ISC limit
• NOx	460mg/kWh	1,5	690mg/kWh
• HC	160mg/kWh	1,5	240mg/kWh
• CO	4000mg/kWh	1,5	6000mg/kWh
• PN	10mg/kWh	-	-

*in EU the evaluation is work based and have to comply with WHTS emission limit multiplied by CF

HDD - Real Driving Emissions (RDE)

What is RDE HDD (Europe) ?

- For HDD RDE in-service conformity
  - 160.000Km or 5 years - N1
  - 300.000 km or 6 years - N2 (below 16t) and M3 Class I, II, A and B (below 7,5t)
  - 700.000 km or 7years - N3 (above 16t) and M3 Class III and B (above 7,5t)

Measurement every 2 years till 5 years after end of production per engine family

Real Driving Emissions (RDE) – Backup

Conclusion

- RDE is a much more demanding methodology
- Implementation comes in phases (ambient temperatures, CFs, new TA and new vehicles)
- Boundary conditions are defined
- By RPA and $v \times a_{pos}$ limits for dynamics are defined
- Evaluation method is still subject of discussion
- Today no ISC described

Real Driving Emissions (RDE) – Backup

Conclusion for Indian RDE

- I-RDE cannot be a copy of European RDE
- Challenges for I-RDE
  - Speed – should be feasible by simply reduce the speed ranges
  - Temperature – operation-window for most devices >40 °C. For type approval that is feasible – selection of route. ISC might be difficult incase there is no adjustment
  - Traffic conditions – congestion could lead to low repeatability and positive validation
- Payload for RDE is “low enough” (< 200kg) to ensure it will not exceed max payload even of seg A. vehicles

Thank you!