RDE Plus – Frontloading Powertrain and Vehicle Development utilising Engine-in-the-Loop and Virtual Tools

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A HORIBA COMPANY MIRA

Presentation Outline

- Introduction
- RDE+ Applications
  - RDE+ Road: On-road RDE Testing
  - RDE+ Chassis: Road-to-Chassis
  - RDE+ Power: Road-to-Engine
  - RDE+ Virtual: Engine-in-the-Loop and Virtual Tools
- Conclusions

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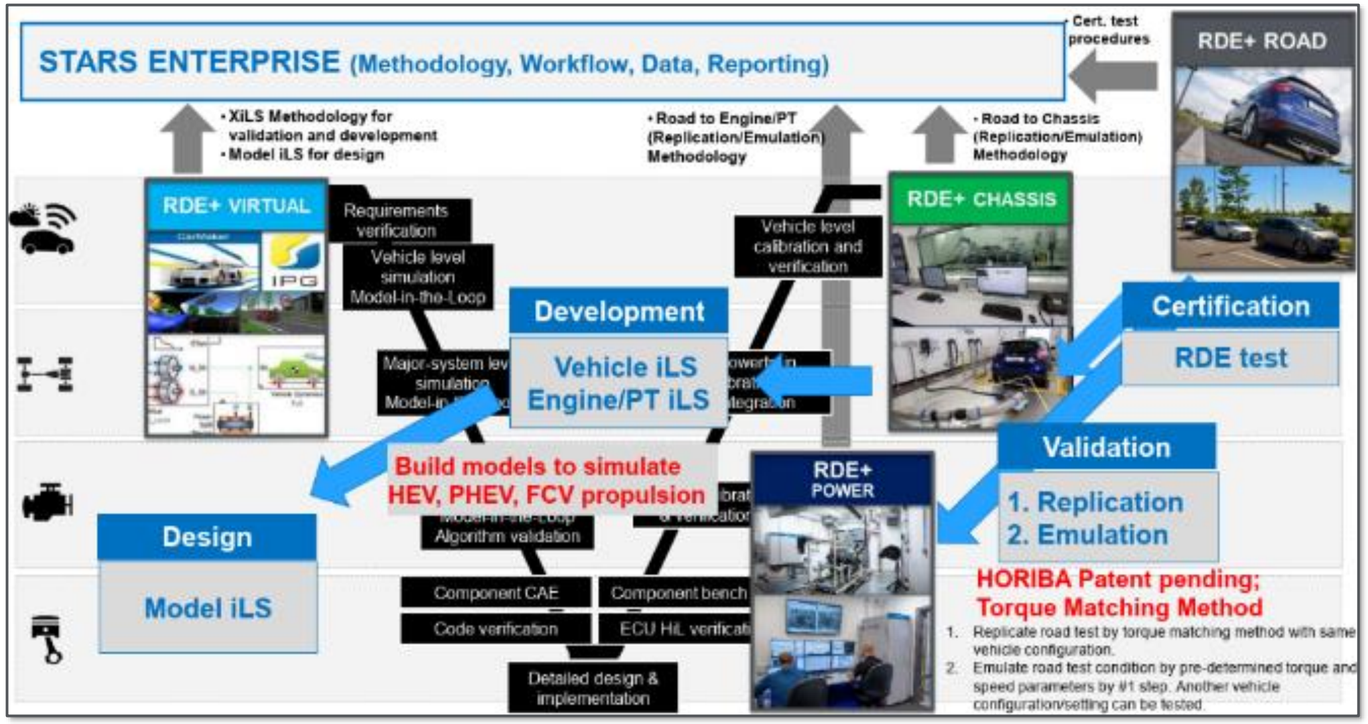
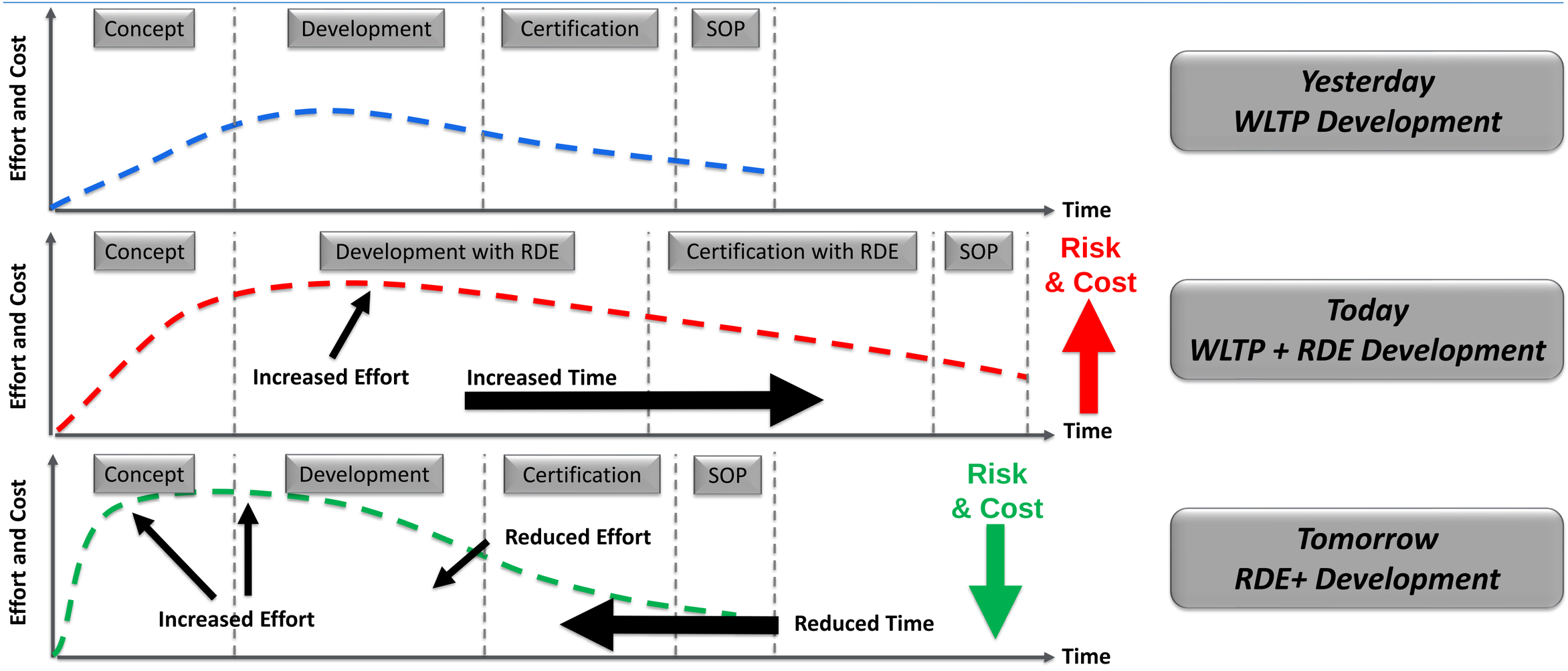
Introduction
What is RDE+

- **RDE+ is a development and validation methodology that reduces cost, time & risk**
  - RDE+ is a development toolset and new development process for emissions compliance development
  - RDE+ integrates virtual tools with HORIBA's advanced real-world testing methodologies, hardware and software
  - RDE+ reduces the number of prototype vehicles required – saving up to $19M in a vehicle programme
- **RDE+ is a SOLUTION for emissions development and validation:**
  - Enhanced productive road testing
  - "Road-to-Rig" and "RDE in the Lab"
  - Simulation and hardware-in-the-loop (HiL)
- **RDE+ is a MODULAR solution comprising HORIBA hardware & software with process applications in STARS Enterprise**
- **RDE+ is offered as a solution product or a testing/development service**



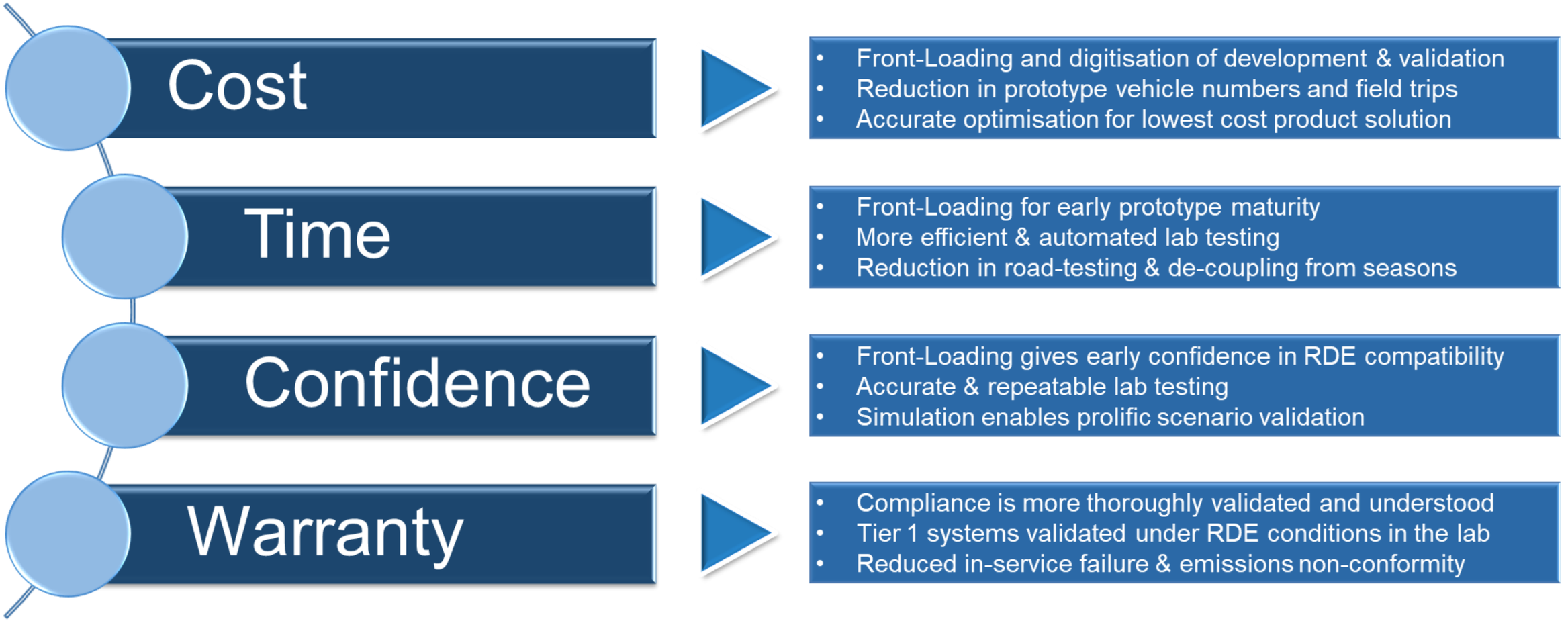
Introduction

Why the need for Frontloading?



Introduction

Benefits of Frontloading



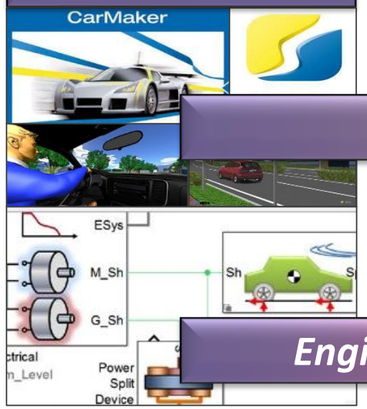
Introduction

RDE+ Application Portfolio

RDE+

STARS ENTERPRISE

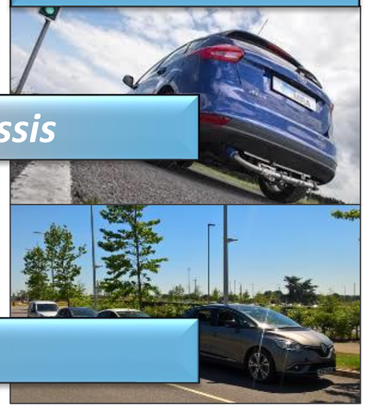
RDE+ VIRTUAL



RDE+ POWER

RDE+ CHASSIS

RDE+ ROAD



Vehicle-in-the-Loop

Road to Chassis

Engine-in-the-Loop

Road to Engine

DESIGN & SPECIFICATION

DEVELOPMENT

VALIDATION

VERIFICATION & CERTIFICATION

Introduction

Replication, Emulation, Simulation & Automation

REPLICATION

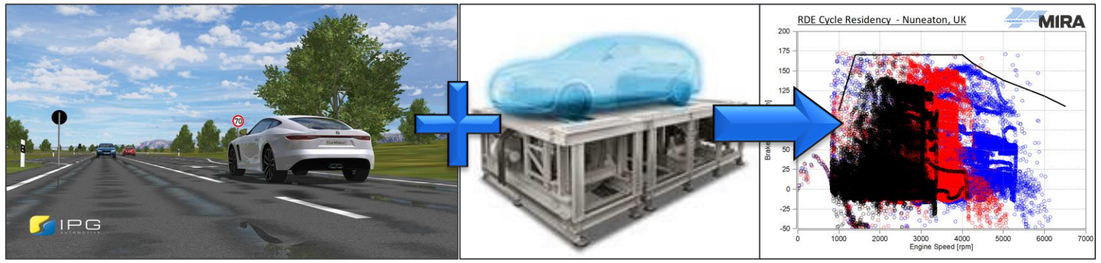
Reproduction of the on-road drives on chassis, powertrain and engine dynos

EMULATION

Ability to repeatedly reproduce realistic scenarios for calibration, development and validation

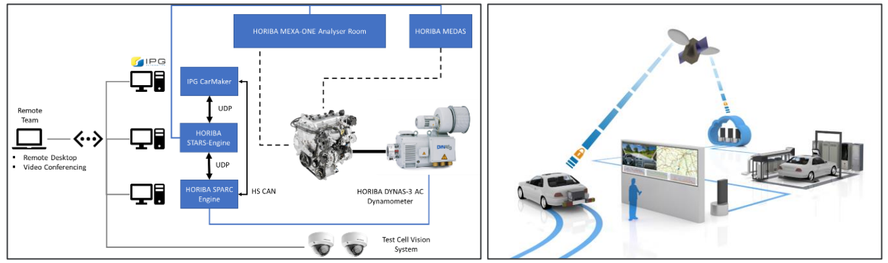
SIMULATION

Simulation of real-world driving connected to chassis, powertrain and engine dynos (HiL)



AUTOMATION

Automated laboratory and dyno control systems integrated with remote connectivity



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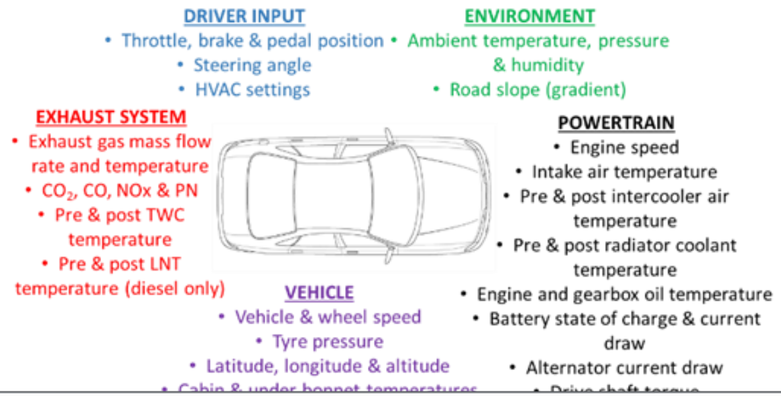
RDE ROAD – The Story So far…

RDE Testing Phase	Location	Target Temperature [°C]	Average Altitude [m]	Total/Urban Cumulative Positive Elevation (CPE) [m/100km]	Distance Split [%] (Urban/Rural/MWay)
1	Innsbruck, Austria	-7-0	623.2	498.1/579	32.5/31.2/36.3
2 3	Nuneaton, UK	0-10 10-20	105.1	491.0/611.6	37.0/33.8/29.2
4	Vera, Spain	30-35	103.9	837.1/950.4	39.0/30.4/30.6
5	Avila, Spain	30-35	1137.9	953.1/1022.4	33.3/30.3/36.4



For further information, please take a look atSAE Paper 2019-01-0756

Significant spread in emissions and fuel consumption between test locations with vehicles tested within the moderate and extended RDE boundary conditions.

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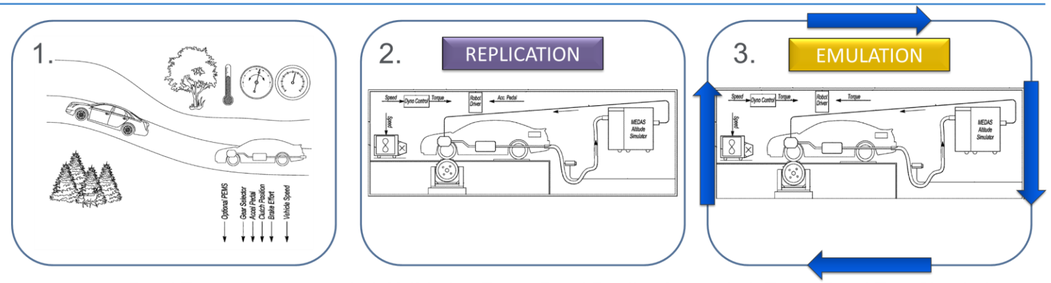
RDE CHASSIS – The Story So far…

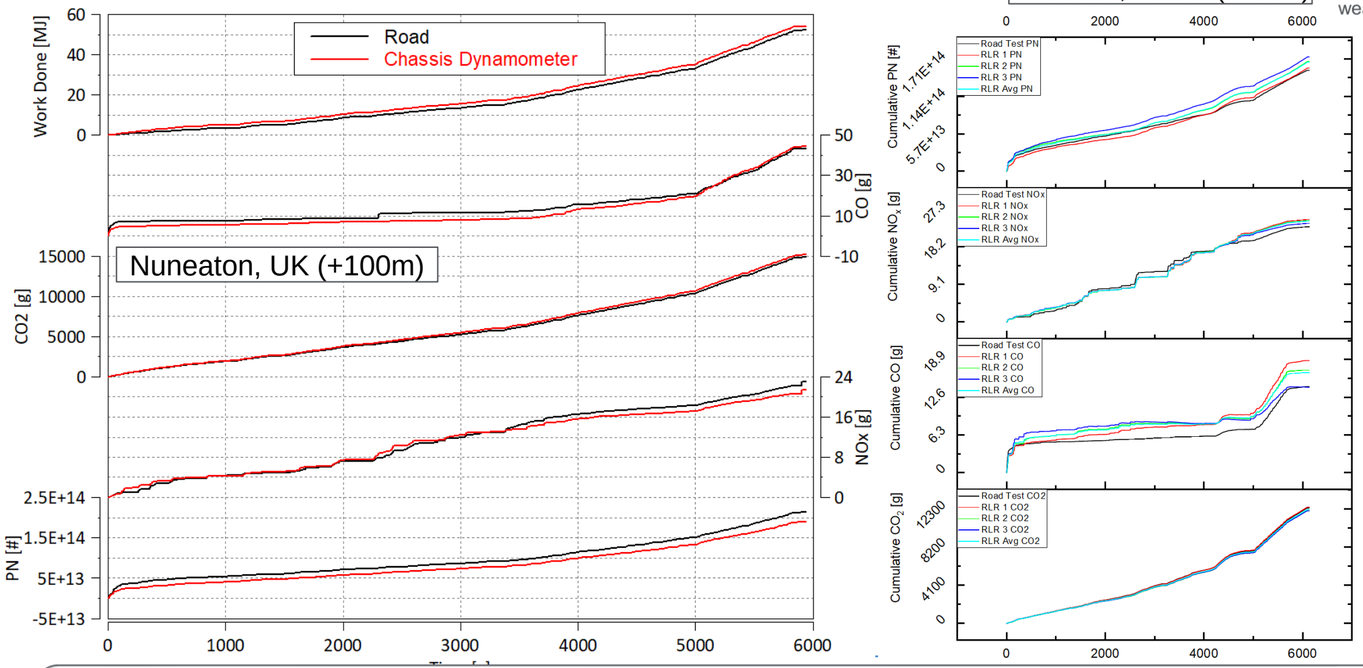
- **Sea Level and Moderate Altitude RDE Replication**
  - Successful replication of road drives from Nuneaton, UK and Innsbruck, Austria
  - Successful integration of a robot driver and the HORIBA MEDAS
  - Development of an elegant method for transferring road tests to the chassis dyno – Torque Matching



Road Test
- Record velocity, pedal and weather conditions
- Any road gradient, surface, weather, altitude and cornering

Lab Validation Test – Road Replication
- MEDAS matches ambient
- Dyno matches velocity
- Robot driver matches acc pedal
- Dyno torque recorded

Lab Test – Road Test Simulation
- MEDAS matches ambient
- Dyno matches velocity
- Robot driver controls acc pedal to match recorded dyno torque
- Change vehicle calibration and repeat



- **HORIBA Torque Matching – Bringing Road Tests to the Laboratory**
  - Record all aspects of road drive – match road drive using chassis dyno and record dyno torque – closed loop control on dyno torque using robot driver
  - Vary calibration and rerun to the same recorded torque
  - Minimal instrumentation required on test vehicle
  - Minimal test to test variability

For further information, please take a look at
SAE Paper 2020-01-0367

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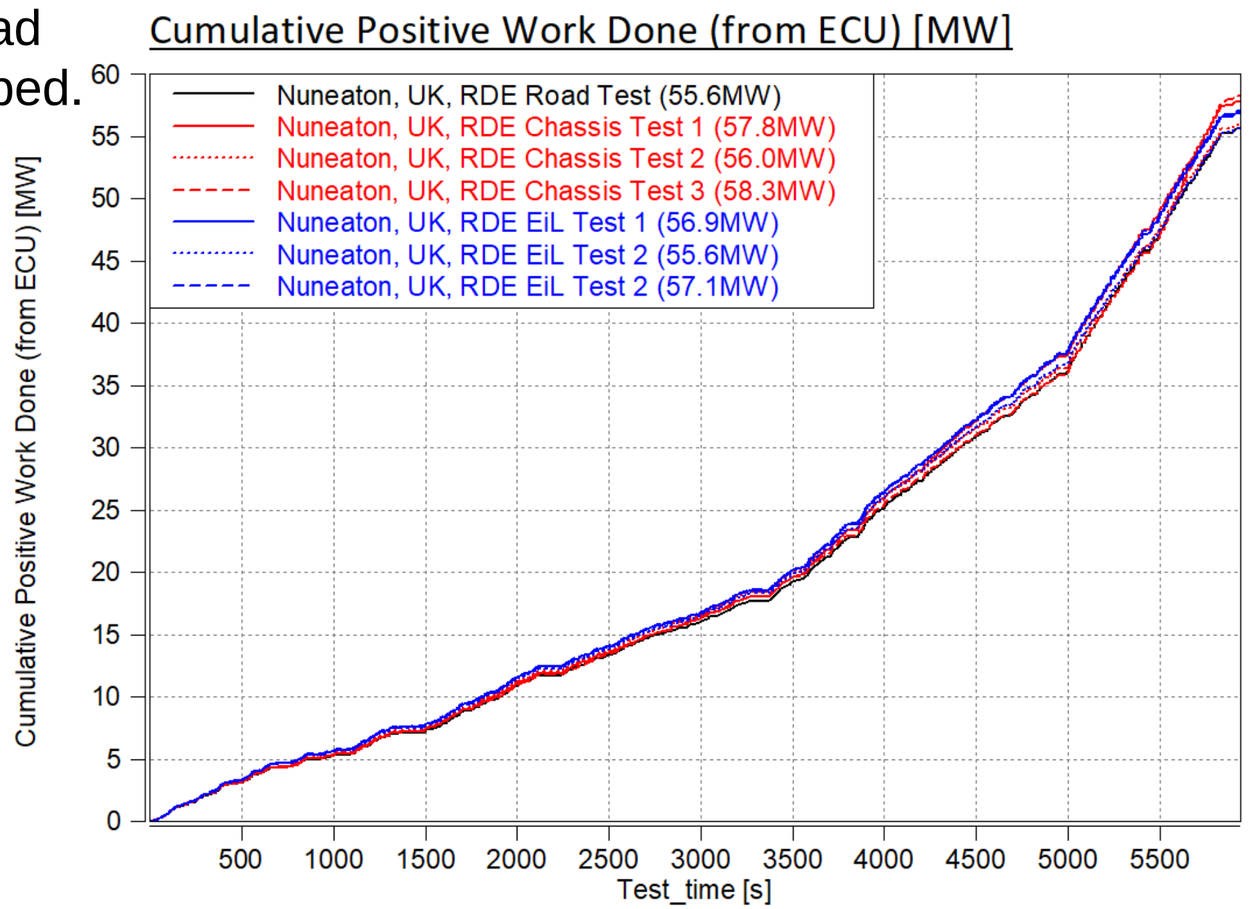
- RDE+ Application for Non-Road Mobile Machinery
- Conclusions

RDE POWER – The Story So far…

- Currently ongoing.
- Engine removed from vehicle tested on the road and chassis dyno and installed on engine testbed.
- Playback engine speed and accelerator pedal position for 3 real RDE routes (Nuneaton, UK, Innsbruck, Austria and Avila Spain).
  - Match all temperatures (coolant, oil, charge air, under-bonnet)
  - Match all environmental conditions (pressure, temperature, relative humidity)
- Initial results show an excellent match with cumulative positive work done across the Nuneaton, UK cycle for road, chassis and EiL.
- Further work required to improve emissions correlation.



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RDE VIRTUAL – The Story So far…

	Equipment
Analysers	MEXA ONE D2 EGR exhaust gas analysis system OBS ONE PEMS GS12 kit (gaseous and particle) MEXA-2100SPCS Real Time Particle Counter MEXA ONE QL NX Quantum cascade laser system (NOx speciation)
Test Cell	HORIBA DYNASPM LI 470 AC Dyno Hot and cold box (engine containment) -30°C to HORIBA MEDAS, MTM and MHM
Misc	AVL Indicom X-Ion high-speed data acquisition ETAS INCA HORIBA STARS SPARC HORIBA STARS Calibrate IPG CarMaker

RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

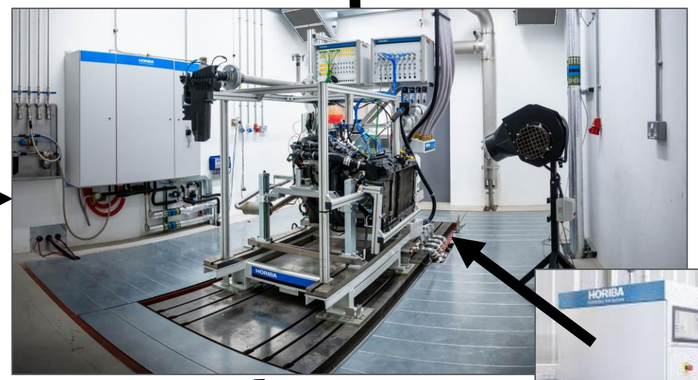
EiL Setup (1)

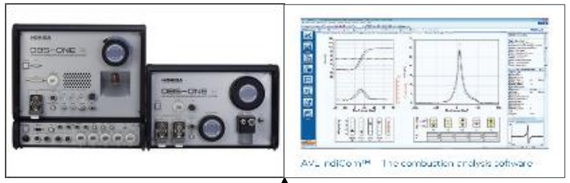
Screening of real-world driving scenarios without the need for prototype vehicles

Vehicle, Road, Driver and Environmental Information

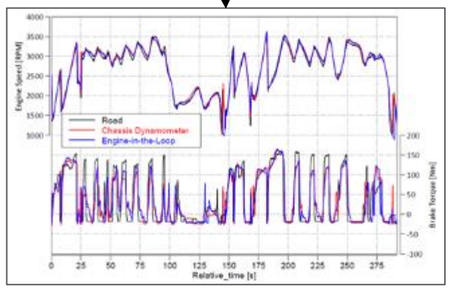
Creation of the Virtual Environment

Engine Speed and Torque/Pedal Closed Loop Control





Environmental Emulation



RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

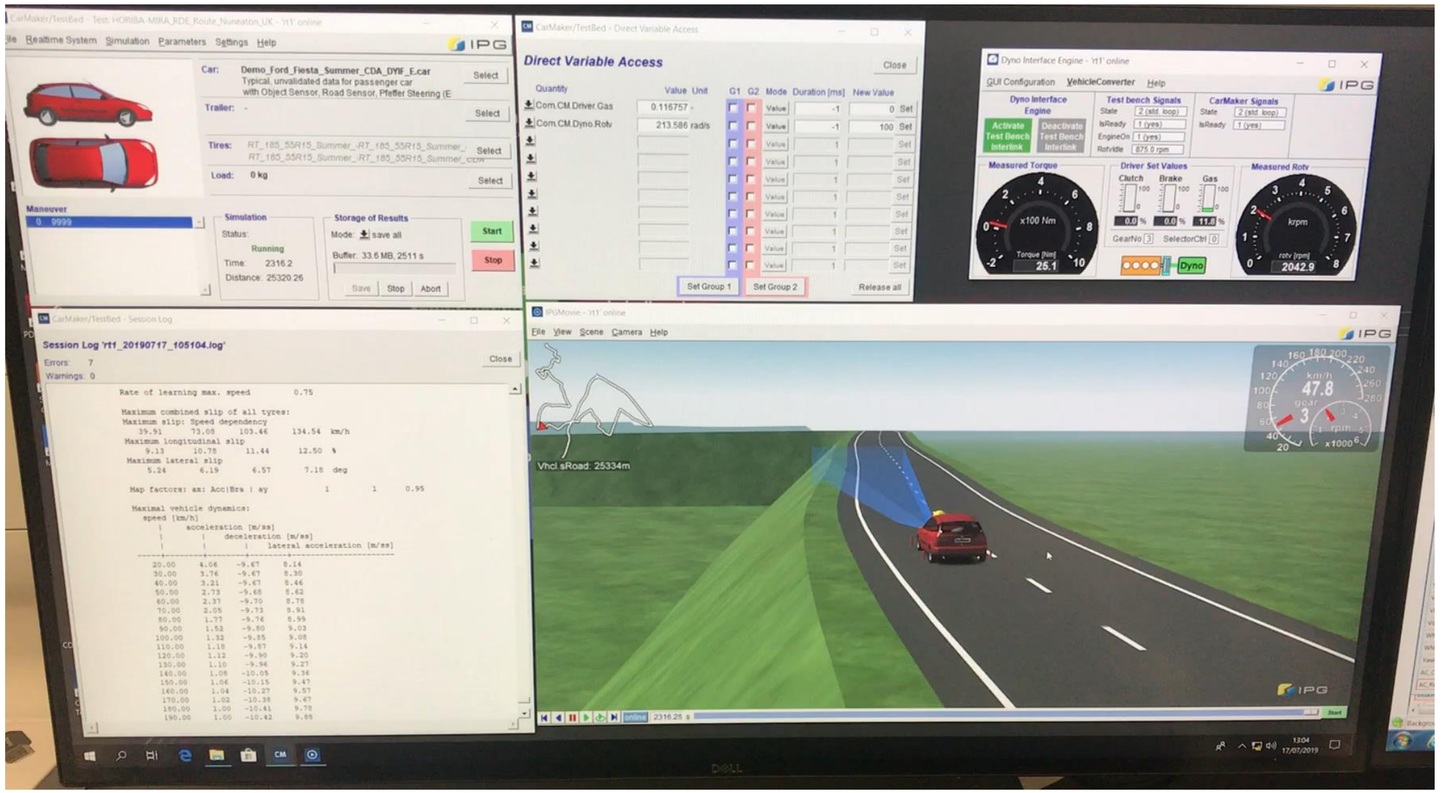
EiL Setup (3)

- IPG CarMaker to STARS interface – purchased vehicle, engine removed, no OEM support.
- Engine can be operated across any scenario that can be programmed (RDE, traffic, weather etc)

Closed-loop engine speed and load control through IPG CarMaker

Torque Demand

Speed Demand



RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

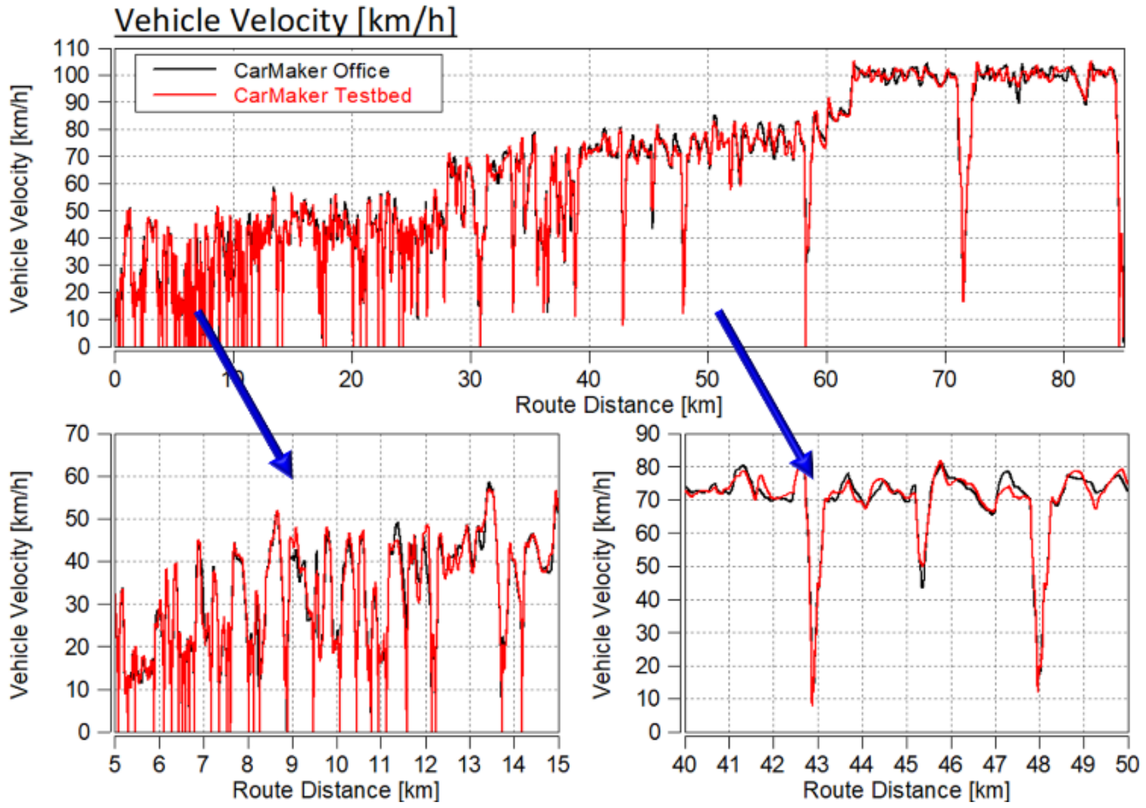
Virtual Aspects (1)

- IPG CarMaker is used as the virtual toolset.
- Flexible approach allowing:
  - Configurable driver
  - Virtual routes and traffic scenarios
  - Environments
  - Model interfaces (Simulink, GT-SUITE etc)
- Used in two formats currently:
  - CarMaker Office (simulation)
  - CarMaker Testbed (simulation + hardware)
- Importantly, Office and Testbed simulation environments are equivalent.
- Results in equal Office and Testbed cycle metrics.

RDE+ Virtual: Engine-in-the-Loop and Virtual Tools
Virtual Aspects (2)

- CarMaker Office (simulation only) vs. CarMaker Testbed (simulation + hardware)
- Identical RDE route (Nuneaton, UK), vehicle (B-segment) and driver models
- Addition of engine with CarMaker Testbed runs.

RDE Cycle Metric	CarMaker Office	CarMaker Testbed
Urban distance [km]	35.6	35.9
Urban distance share [%]	41.9	42.2
Urban va_pos[95] [m²/s³]	11.6	11.5
Rural distance [km]	28.5	28.1
Rural distance share [%]	33.5	33.0
Rural va_pos[95] [m²/s³]	16.4	17.5
M'way distance [km]	21.0	21.1
M'way distance share [%]	24.7	24.8
M'way va_pos[95] [m²/s³]	12.1	12.4
Cycle va_pos[95] [m²/s³]	12.4	12.6
Cycle va_pos[95] % limit [%]	60	61
Test time [mins]	114.6	115.1
Urban stop time share [%]	8.2	8.3
Urban average velocity [km/h]	27.2	27.1
Time > 100km/h M'way [mins]	6.5	7.0



RDE+ Virtual: Engine-in-the-Loop and Virtual Tools
Virtual Aspects (3)

Allows driving scenarios to be screened at faster than real-time and cycle metrics calculated without the need for physical hardware.

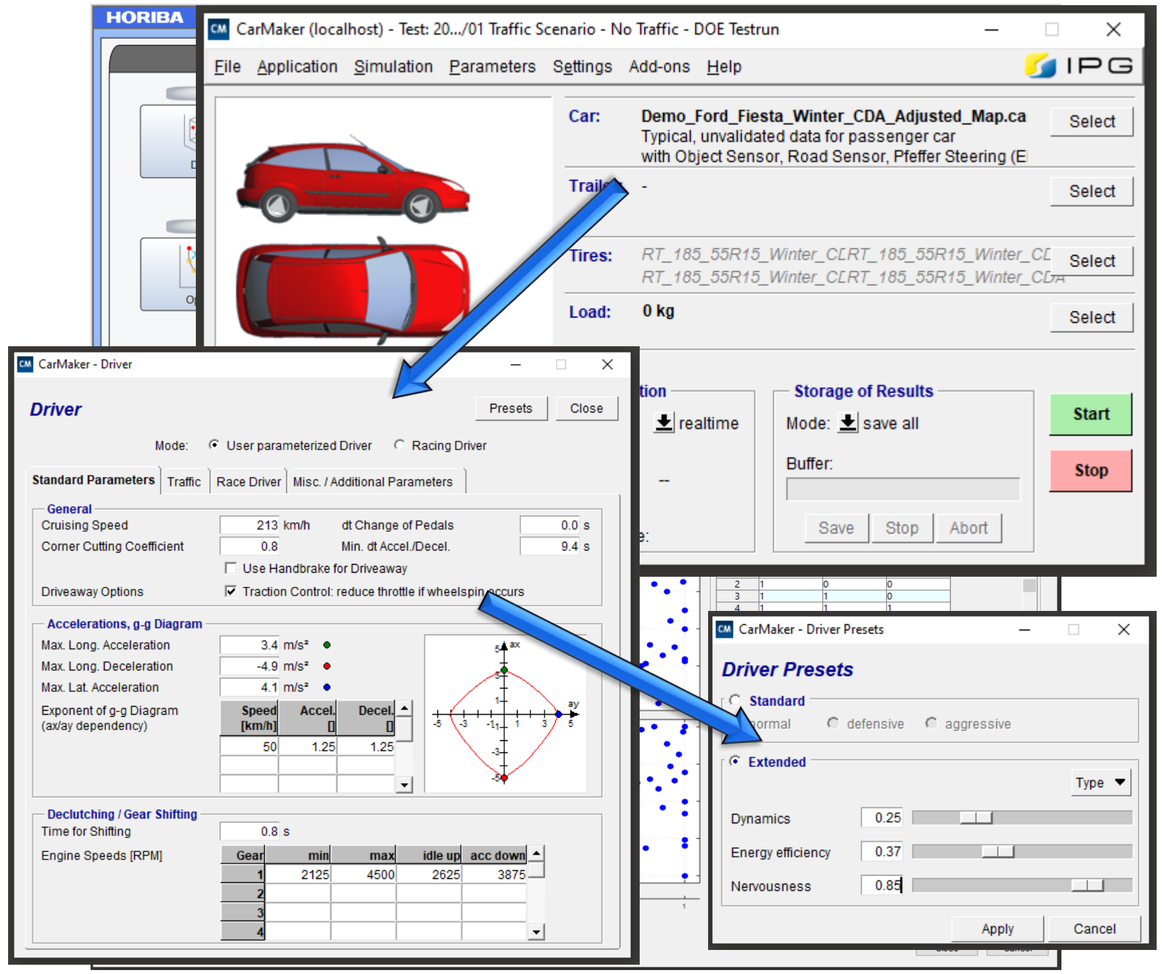
Ensures scenarios (RDE or other) are “compliant” with regulations without the need for physical testing.

The powertrain and/or vehicle is physically tested to resolve performance and emissions using completely compliant scenarios.

RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

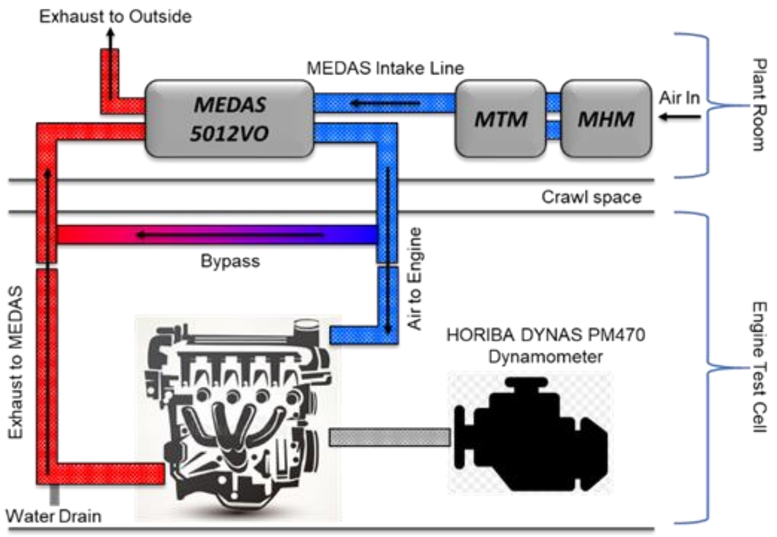
Driver Parameterisation

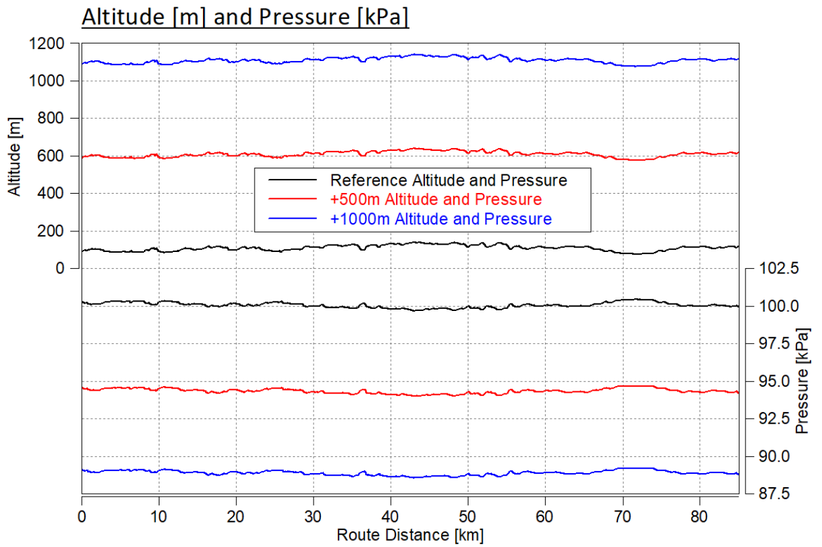
- CarMaker Office and Testbed equivalency allows the driver model to be parameterised within the Office environment.
- Current default CarMaker driver models do not adhere to HORIBA's definition of driving style.
- To parameterise the model to HORIBA's standard, HORIBA STARS Calibrate DoE toolset was used.
- Extended Driver Presets within CarMaker were varied according to the DoE test points generated.
- 100 different combinations of Extended Driver Presets run within CarMaker Office (per route).
- 5 hours computational run-time time.
- Minimum of 150 hours physical engine runtime would otherwise be required.



RDE+ Virtual: Engine-in-the-Loop and Virtual Tools
Environmental Emulation (1)

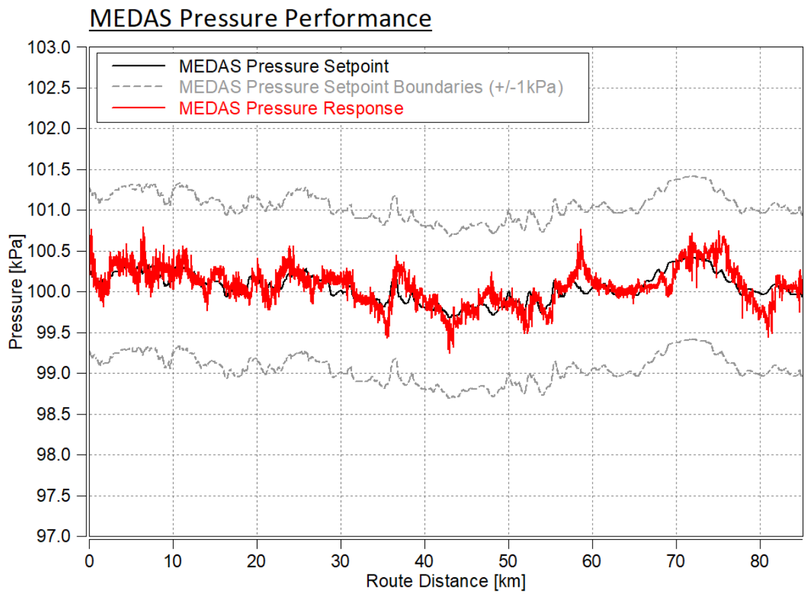
- Environmental emulation hardware (MEDAS, MTM and MHM) control is linked to pressure, temperature and relative humidity profiles vs. route distance within CarMaker.
- Allows different dynamic pressure, temperature and humidity to be scheduled for the same route.
- For example, the sea-level Nuneaton, UK RDE route has been offset by 500 and 1000m with the corresponding pressure delivered to the engine (ongoing investigation).
- Hot/cold thermal encapsulation will be used in the near future for emulating under-bonnet conditions.

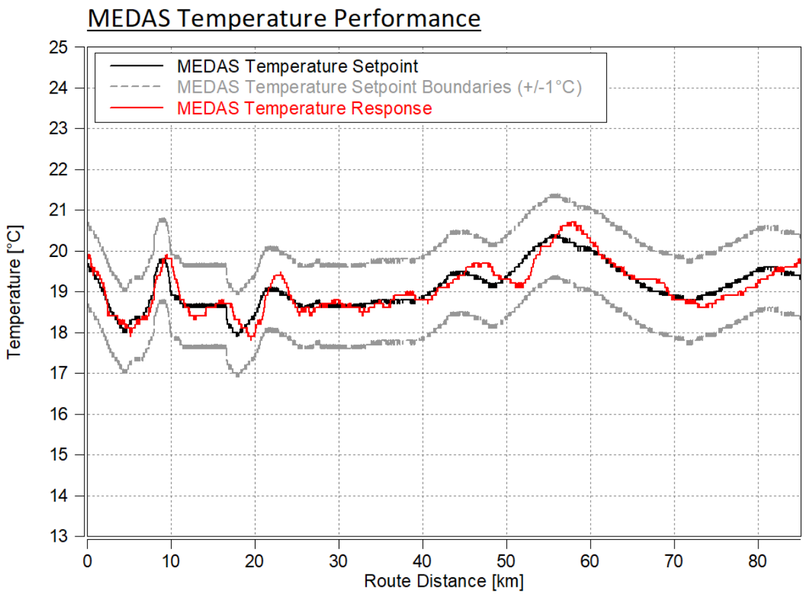


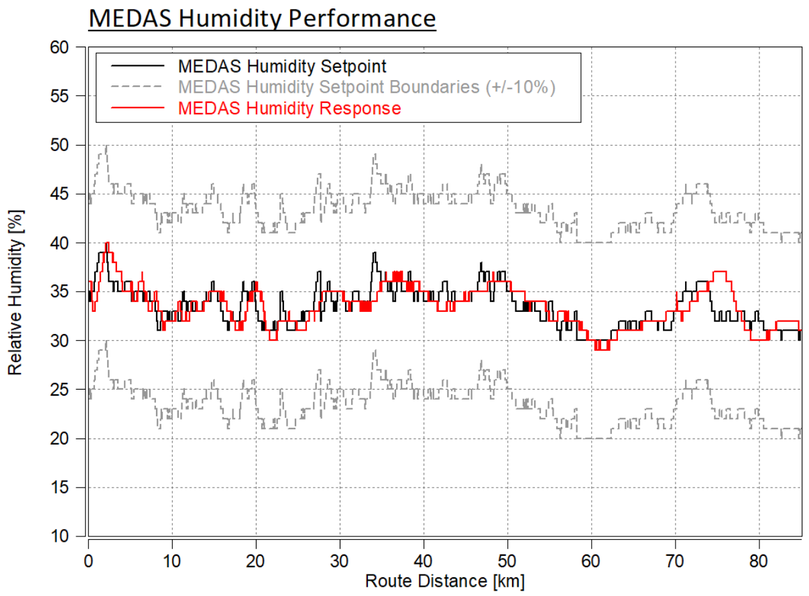


RDE+ Virtual: Engine-in-the-Loop and Virtual Tools
Environmental Emulation (2)

- Very good control of pressure, temperature and relative humidity for the Nuneaton, UK profiles.
- These environmental profiles were used throughout the investigation into the effects of driving style and traffic density on engine performance and emissions.



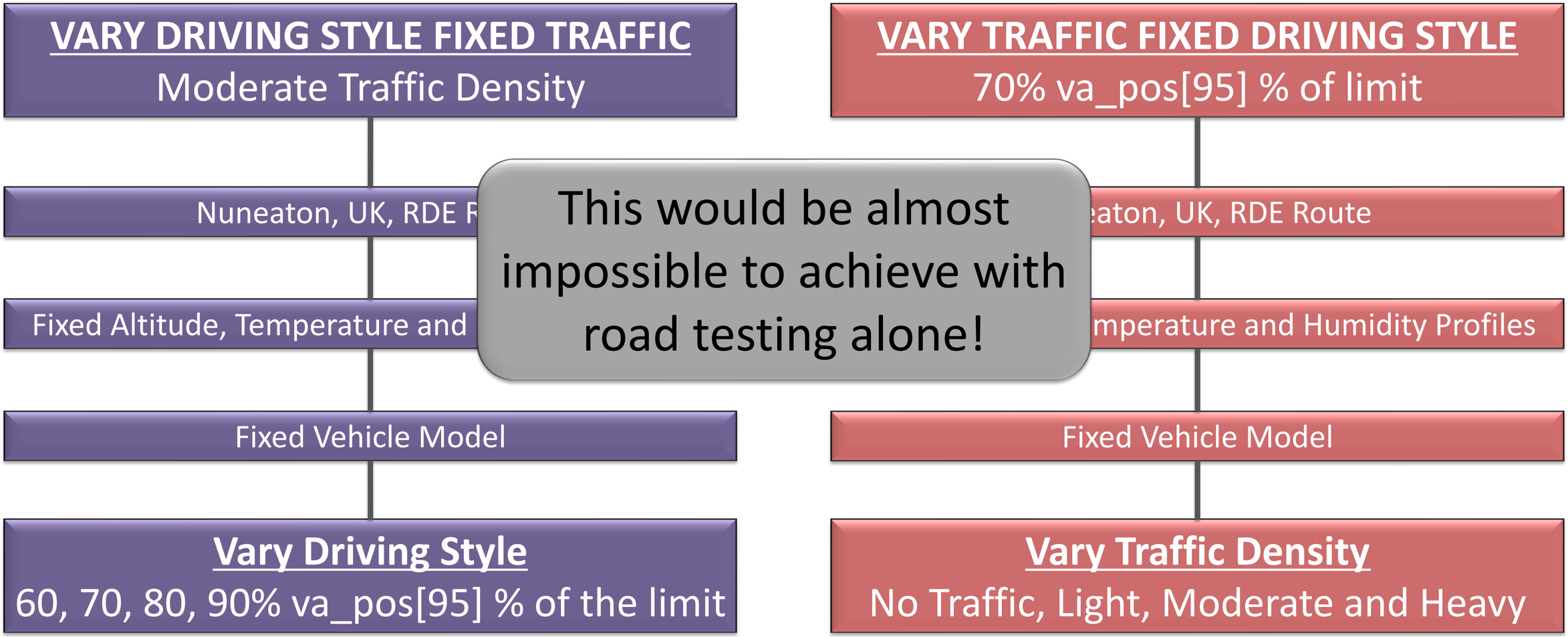




Nuneaton, UK, Environmental Emulation using MEDAS

RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

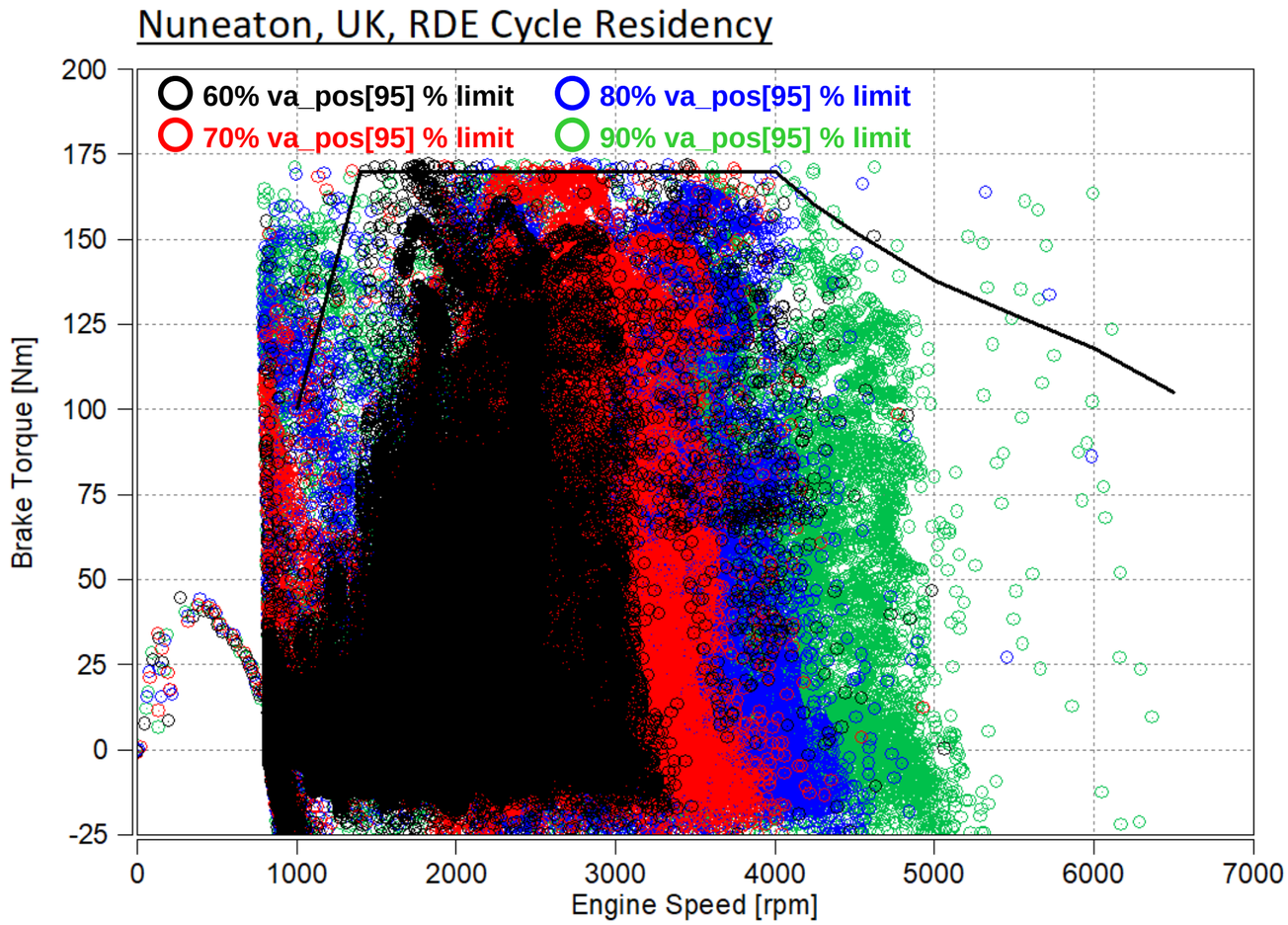
Results – Decoupling Driver and Traffic Effects



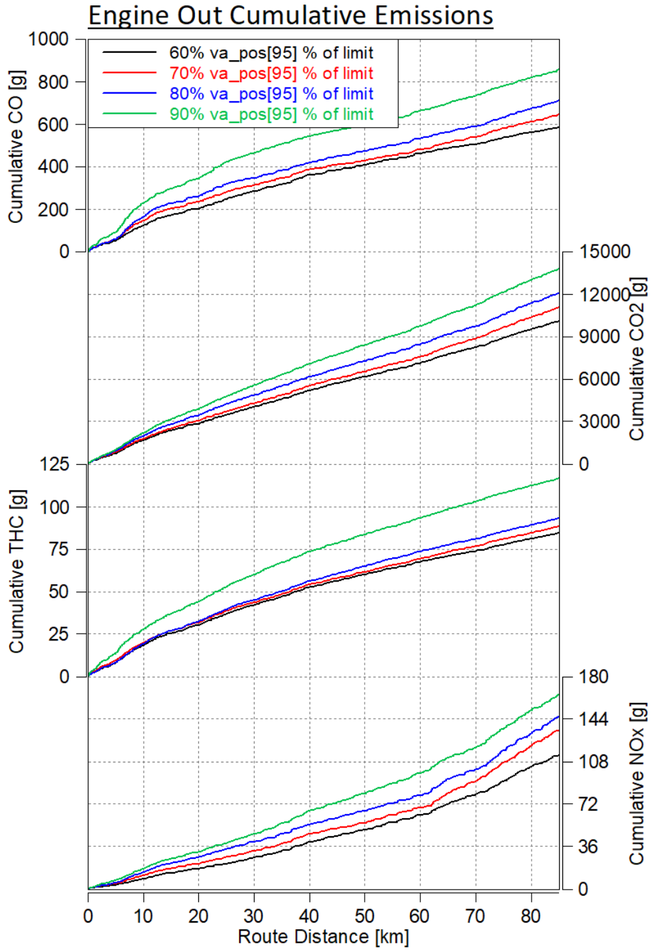
RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

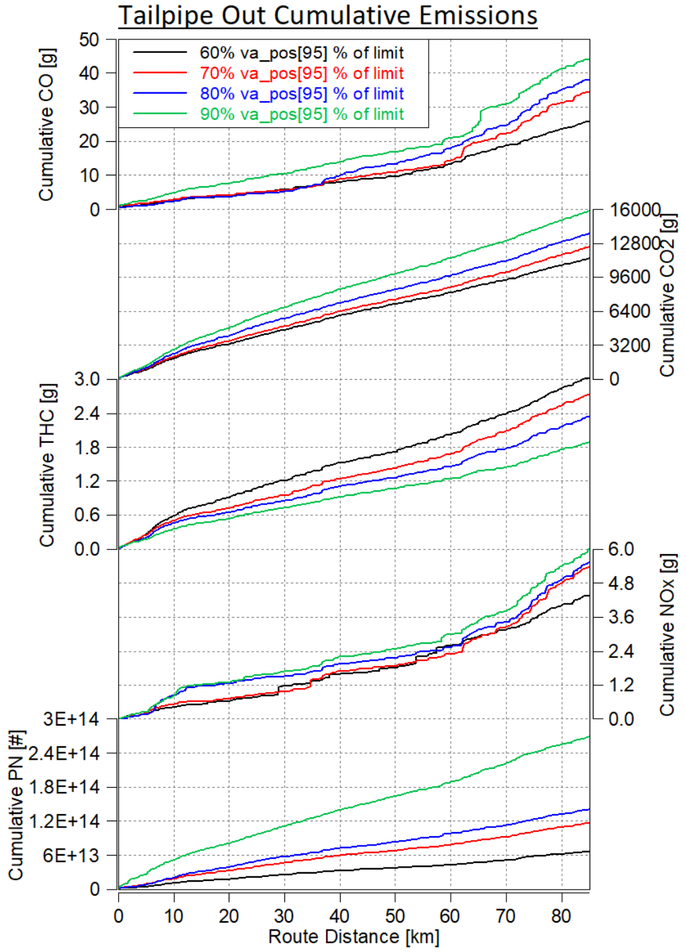
Results – Fixed Traffic Density, Altered Driver Dynamics (1)

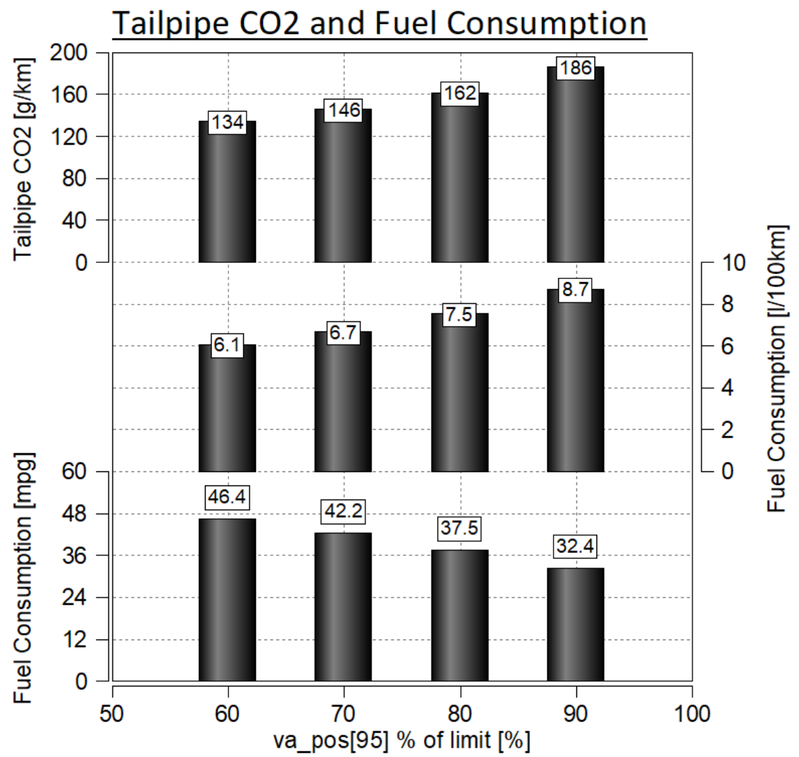
- Engine speed and load range is extended with more aggressive driving.
- Average cycle power increased as driver aggressivity increased: 8.7, 10.8, 13.2 and 15.1kW.
- Engine starts to operate within areas that require Auxiliary Emissions Systems (AES); these systems will likely have to be declared.
- The most aggressive driving here is non-typical. Importantly though, it is within the RDE regulations.
- Non-typical, but completely compliant scenarios, still need to be addressed during engine development however.



RDE+ Virtual: Engine-in-the-Loop and Virtual Tools
Results – Fixed Traffic Density, Altered Driver Dynamics (2)



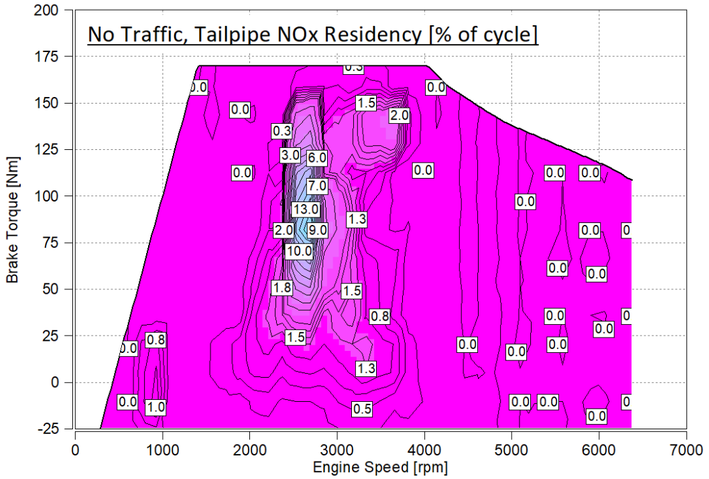


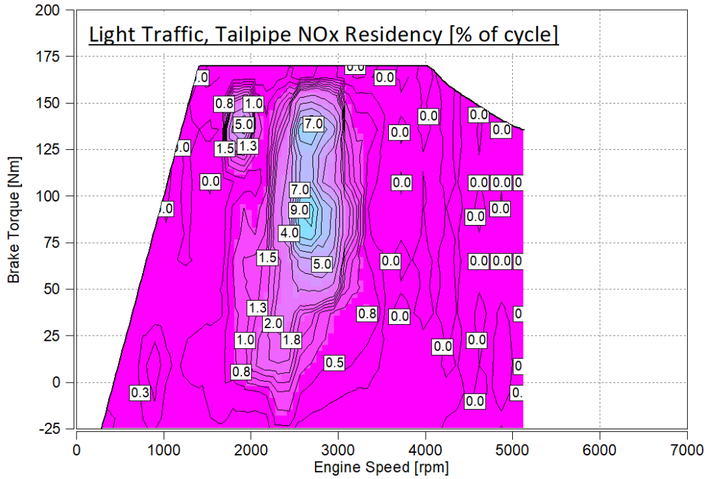


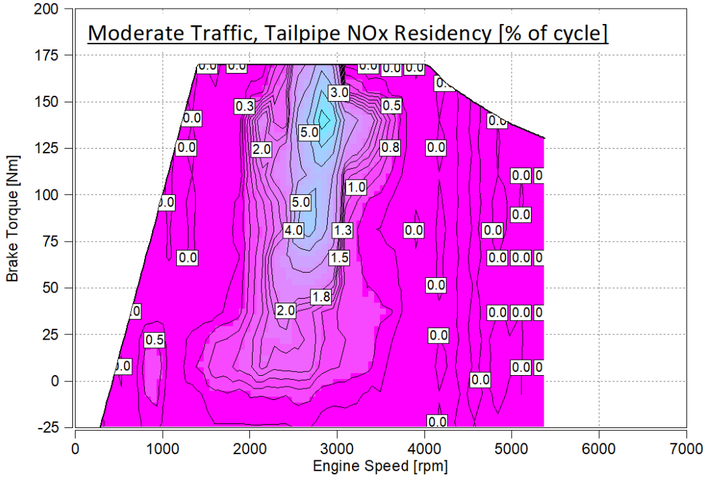
RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

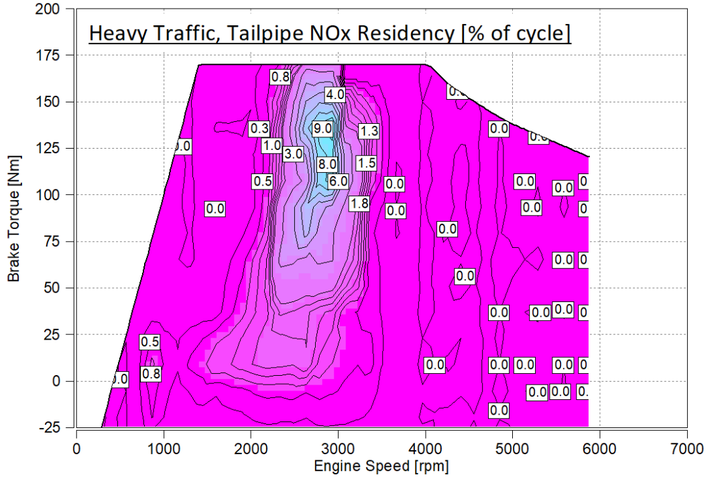
Results – Fixed Driver Dynamics, Varied Traffic Density (1)

- Fixed driving style, varying traffic – **NOx Residency.**
- Overall metric used to define cycle driving style (va_pos[95] % of limit) was equal for each traffic density tested.
- However, urban, rural and motorway dynamics were very different; thereby very difficult to decouple driving style and traffic effects in this case.
- Nevertheless, all cycles were still RDE compliant and highlight spread in tailpipe out emissions for different traffic densities.









RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

Results – Fixed Driver Dynamics, Varied Traffic Density (2)

- Fixed driving style, varying traffic – **PN Residency.**
- Overall metric used to define cycle driving style (va_pos[95] % of limit) was equal for each traffic density tested.
- However, urban, rural and motorway dynamics were very different; thereby very difficult to decouple driving style and traffic effects in this case.
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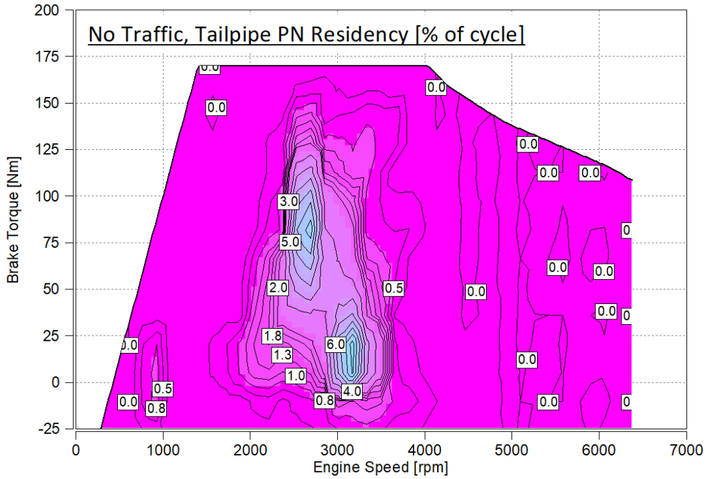
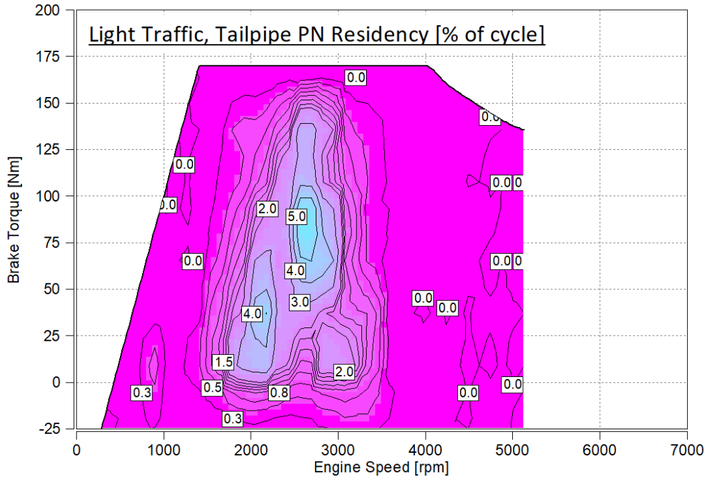
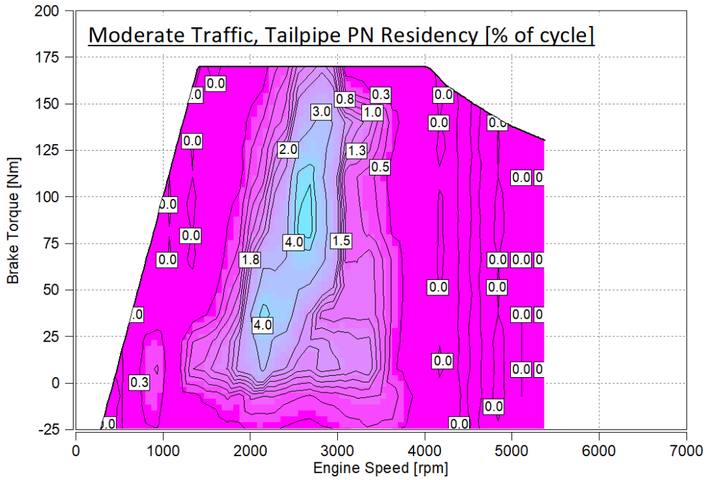
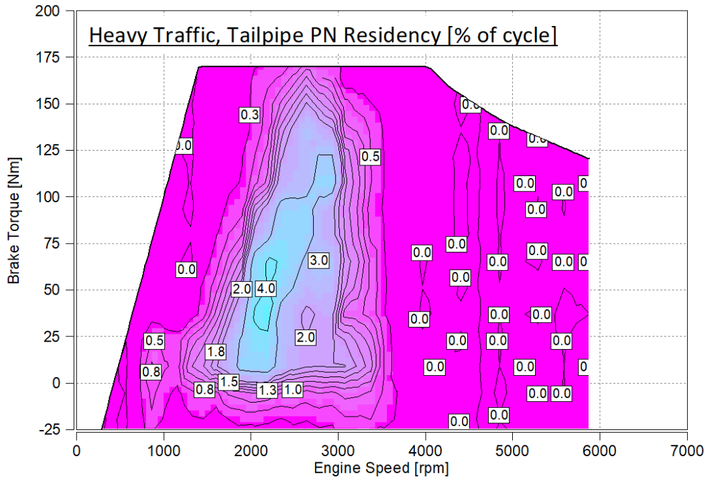




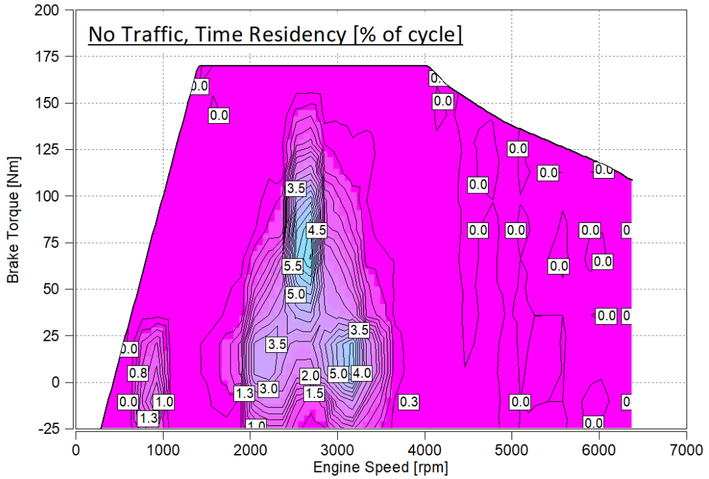


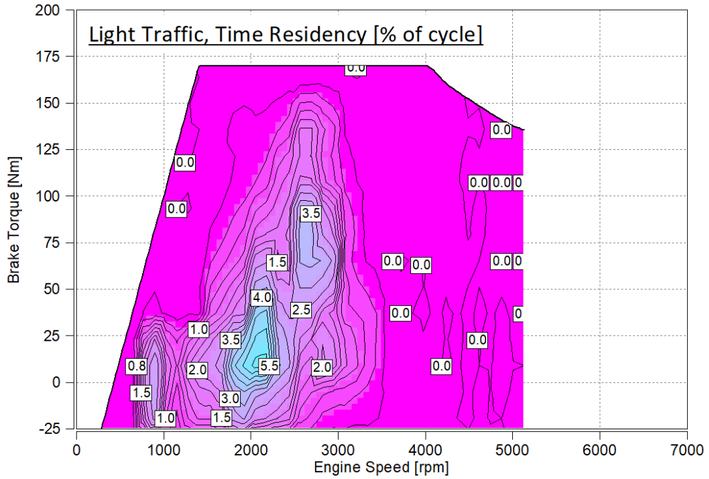


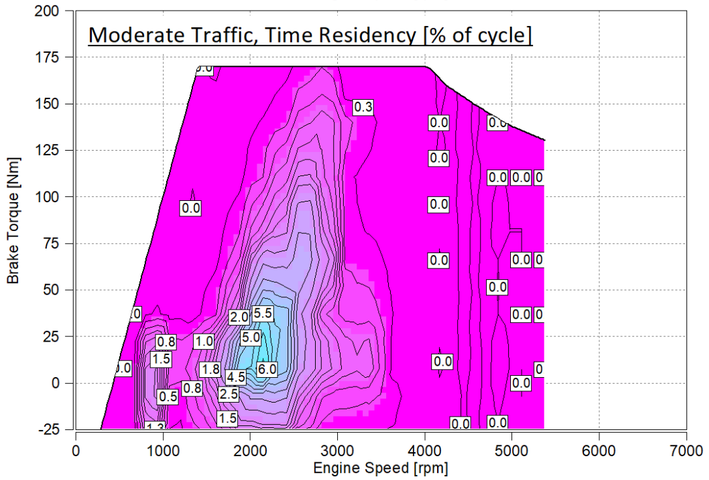
RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

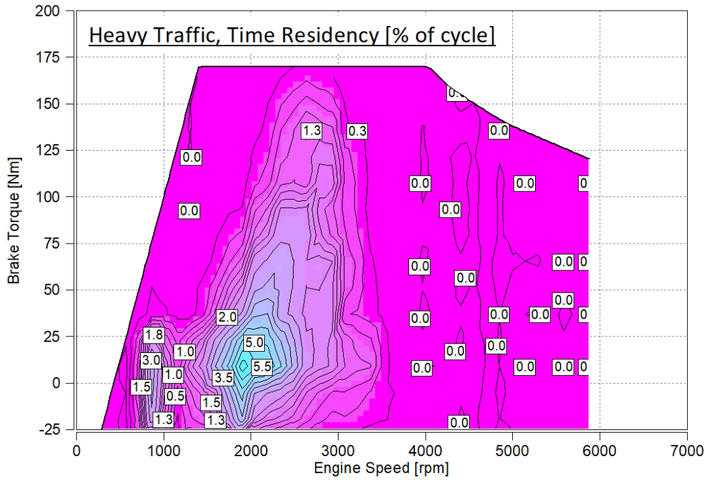
Results – Fixed Driver Dynamics, Varied Traffic Density (3)

- Fixed driving style, varying traffic – **Time Residency.**
- Overall metric used to define cycle driving style (va_pos[95] % of limit) was equal for each traffic density tested.
- However, urban, rural and motorway dynamics were very different; thereby very difficult to decouple driving style and traffic effects in this case.
- Nevertheless, all cycles were still RDE compliant and highlight spread in tailpipe out emissions for different traffic densities.





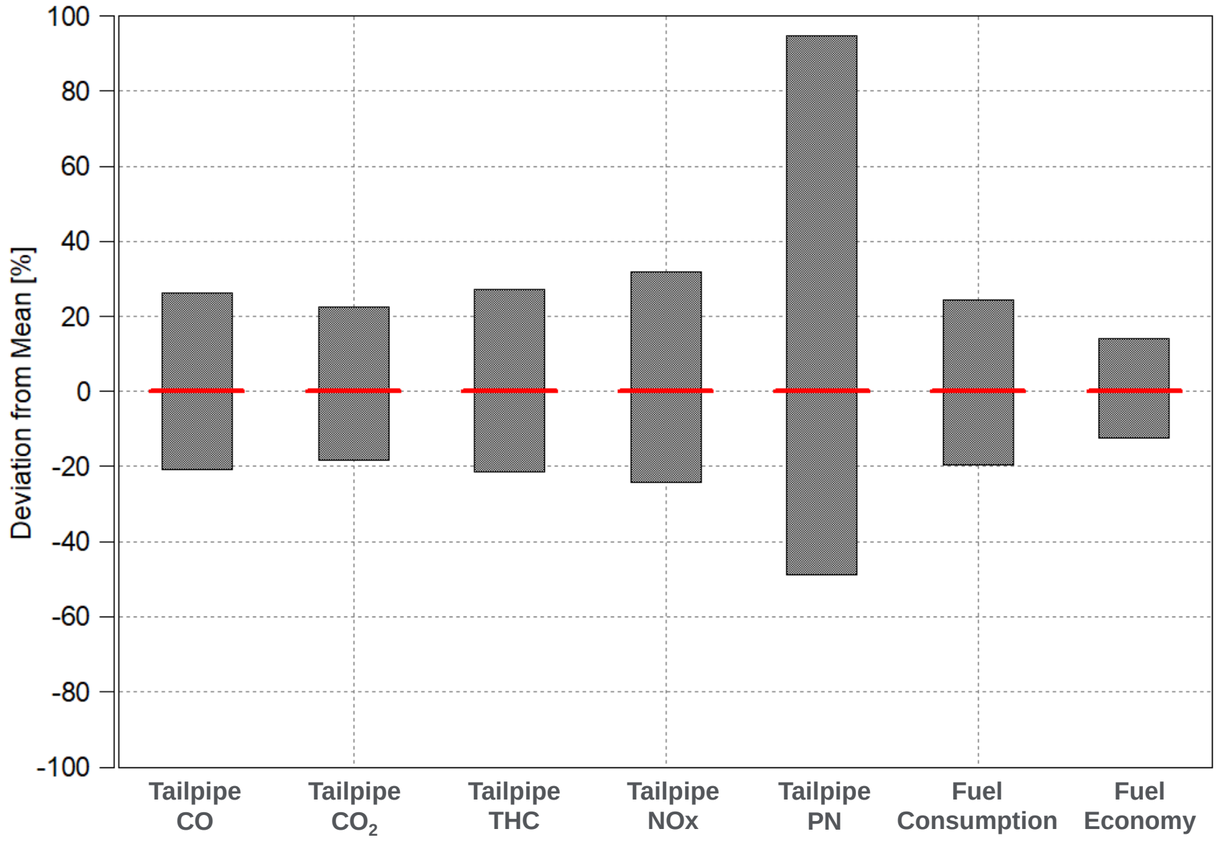




RDE+ Virtual: Engine-in-the-Loop and Virtual Tools

Results – Overview

- Emissions spread from mean tailpipe emissions for all test concluded thus far.
- All cycles tested adhere to RDE regulation criteria.
- Significant spread in emissions for one RDE route; this spread is likely to increase when other routes are tested with the same powertrain and vehicle.
- OEMs will need robust calibrations to ensure emissions limits are not compromised when the vehicle is tested at the moderate and extended boundary conditions.
- Similar testing is taking place using the Innsbruck, Austria RDE route and MEDAS for environmental emulation.



Methodology – Engine-in-the-Loop
DOE Testing and Rapid Calibration Techniques

Run test scenarios to identify areas of concern

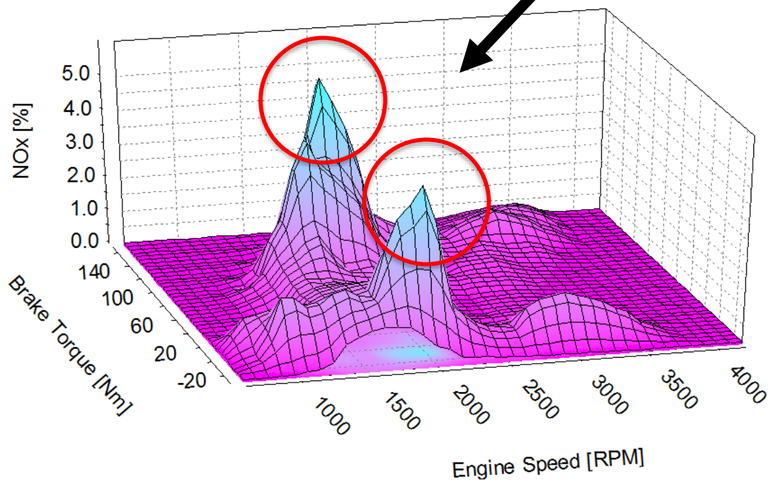
DOE optimisation of: ignition timing, cam phasers, boost pressure etc

Apply optimised setpoints and rerun scenarios

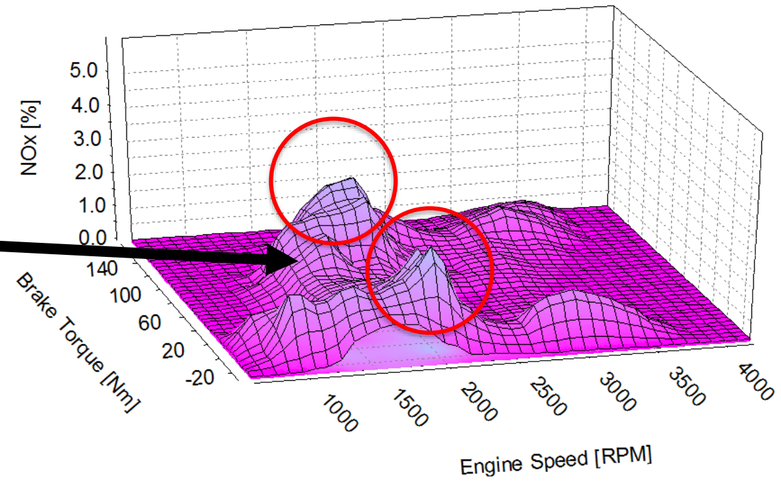
Removal of problematic areas of the operating map

Improved cycle result

Cycle Residency across RDE
Baseline Calibration



Cycle Residency across RDE
Optimised Calibration



Presentation Outline

- Introduction
- RDE+ Applications
  - RDE+ Road: On-road RDE Testing
  - RDE+ Chassis: Road-to-Chassis
  - RDE+ Power: Road-to-Engine
  - RDE+ Virtual: Engine-in-the-Loop and Virtual Tools
- Conclusions

Conclusions

- HORIBA MIRA's R2R RDE+ test methodology has been described.
- The road and chassis dynamometer parts of the programme is complete with work underway on the EiL replication and virtual tools segments.
- Sea-level and high altitude, cold temperature RDE routes have been successfully correlated with the vehicle driven on the chassis dynamometer utilising a robot driver and HORIBA MEDAS environmental emulation device.
- The effects of driving style and traffic on engine performance and emissions for a fixed "virtualised" RDE route have been presented using an EiL toolchain.
- The EiL methodology will allow OEMs to front-load powertrain design, development and calibration activities thus resulting in fewer prototype vehicles and physical climatic testing to achieve RDE compliance.
- By adopting road, chassis, EiL and virtual testing (RDE+), many of the unknown scenarios that arise through real testing can be mitigated much further upstream; thus reducing time, effort, money and pollution.

Thank you

감사합니다

Cảm ơn

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

நன்ற

ขอบคุณครับ

Obrigado

Σας ευχαριστούμε

شُكْرًا

Tack ska ni ha

Большое спасибо

Danke

Gracias