INTELLIGENT LAB DEVELOPMENT SOLUTIONS

ECMA CONFERENCE
DELHI
10TH & 11TH NOVEMBER 2022

EMISSIONS
ELECTRIFICATION
CAV
DATA

HORIBA Intelligent Lab

Intelligent Development Methodologies to Meet the Challenges of RDE and Future Emissions Targets for Net Zero

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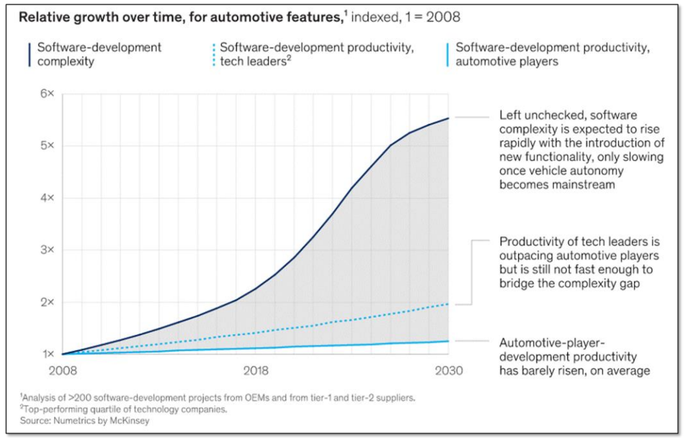
Automotive

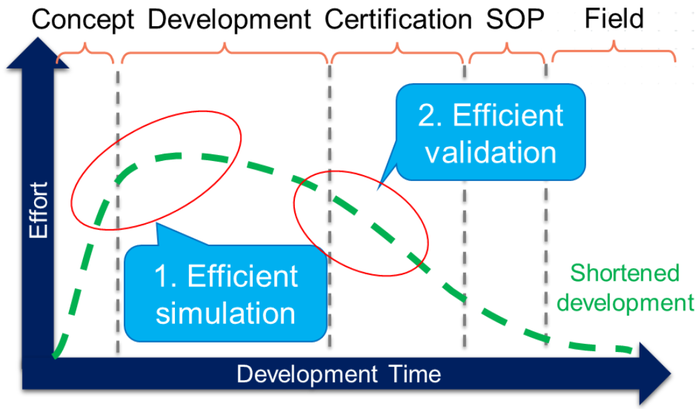
Agenda

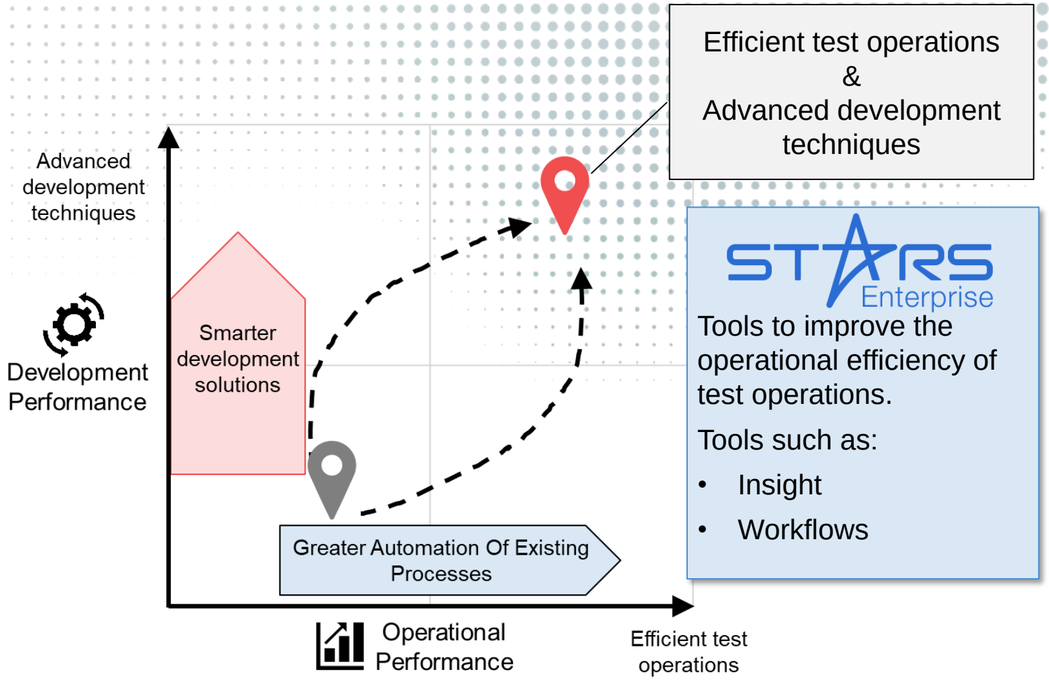
- Introduction & Motivation
- HORIBA Intelligent Lab & Torque MatchingTM
- Conclusions

Introduction & Motivation

Operate Better + Develop Smarter







- Net-Zero automotive products are getting more complex
- Software complexity is dominating
- Productively is not keeping pace with complexity

- Development time, cost and carbon footprint must be reduced
- "*Front-Loading*" using efficient and accurate simulations
- More efficient V&V processes using digital engineering

- Operate Better
- Develop Smarter

Intelligent Lab

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Road tests need to be accurately replicated and emulated in the laboratory to allow efficient problem resolution, development and model sign-off.

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Connecting the real-world and simulation to the laboratory

Accelerate front-loading, development, validation, verification & sign-off

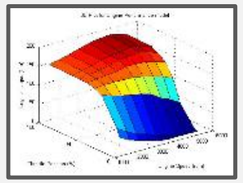
Intelligent Lab

- **Minimize cost & man-hours**
- **Highly repeatable environment & scenarios**
- **Use existing equipment**

Virtual World

Simulation & Scenario
(Road / Environment / Driver)

+



Digital Twin
(Empirical Model)

=

Range / Emissions / Performance Prediction

Example Use Cases

Design Explore more of the regulatory design space faster then real time.

Design Early validation before on-road testing

Quality Re-run road tests to validate changes or replicate failure modes

Development , Quality/Warranty Use cases, Regulatory Compliance Testing, Competitor Bench marking

Import / Create Scenarios

Drive the lab from simulation

Create Empirical Digital Twins

XiL

Validate Results Quickly

Real World

STARS ENTERPRISE

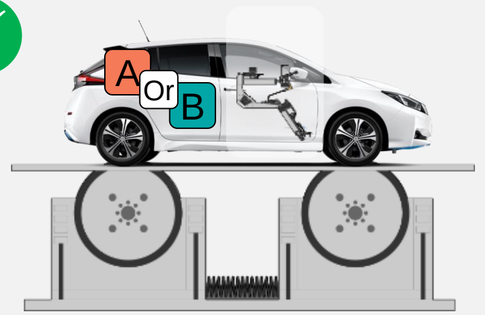
Cloud based data management and applications

Replay the real-world in the lab

R2R

Test Labs

Engine / E-Motor / Powertrain / Chassis Dynos



- **Replicate** the real-world
- **Emulate** changes
- Create **Digital Twins**
- Enable **X-in-the-Loop**

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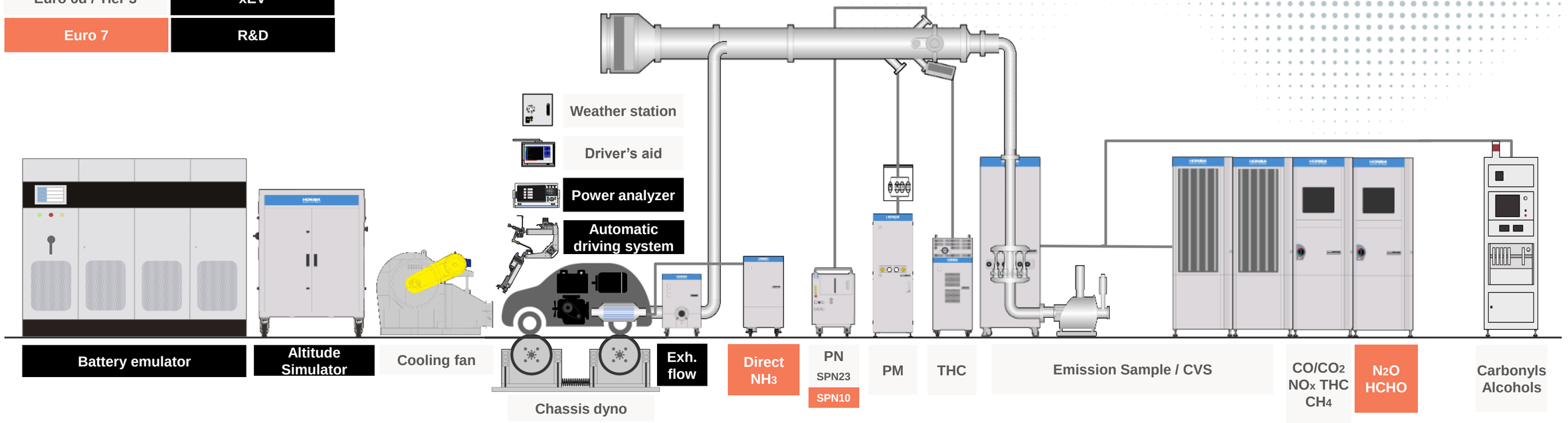
Upgrade existing labs. Optimise development processes. Reduce development times by over 70%. Eliminate prototypes. Reduce expensive test trips

RDE Road-to-Rig Laboratory

RDE Road-to-Rig Replication, Emulation and WLTC

Euro 6d / Tier 3	xEV
Euro 7	R&D



Soak area

Soak vehicle management system

Power analyzer

Operation area

Test cell management Automation, Mass emission calculation

Weighing area

PM filter management system

Real road

On-board emission measurement system

CO/CO2 NOx CH4 SPN10 NH3, etc.

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Accurate replication and emulation of road tests in the lab

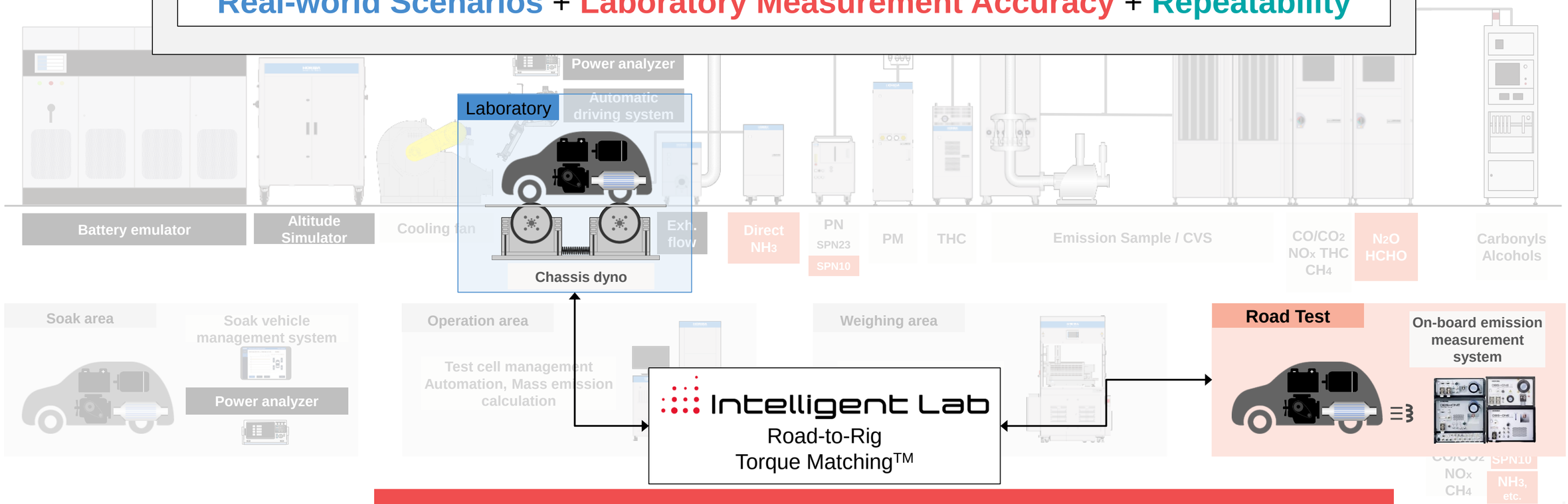
HORIBA's Torque Matching brings development back to the lab for more efficient workflows

Euro 6d / Tier 3

Euro 7

Vehicle manufacturers and suppliers need a way to measure the response of a vehicle's powertrain to real-world scenarios with the accuracy of a test lab.

Real-world Scenarios + **Laboratory Measurement Accuracy** + **Repeatability**



Repeat the road test <u>exactly</u>, time after time in the lab until problems are resolved.

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RLS is inaccurate! Multiple measurements and assumptions

Extensive measurements are required to achieve a laboratory replication with RLS

Real-world Driving

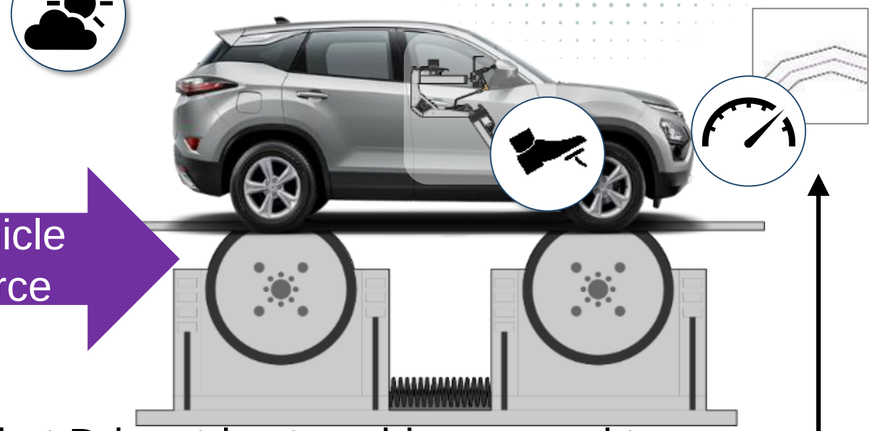
Resistive Forces

- Rolling
- Aerodynamic
- Gradient

Vehicle Force

Dyno Replication using Traditional Road Load Simulation

Dyno in **Road Load Simulation** Control Mode



Vehicle Force

Resultant force provides acceleration and speed

1. **Measure** Speed, Throttle position, GPS, roll, pitch and yaw, ambient weather conditions.
2. **Measure or estimate** Rolling resistance,, Aerodynamic drag, Road gradient or Coastdown.
3. **Approximate** Road Load via simplistic model

Drver / Robot Driver tries to achieve speed trace

Dyno models road load using traditional chassis dyno Road Load Model

$$Road\ Load\ R(t) = \left(A + B.v_x + C.(v_{rel})^2\right) + m.g.\sin\theta$$

The laboratory result contains multiple assumptions therefore leading to a poor R^2 coefficient.

Traditional RLS method requires a lot of extra measurements and assumptions which makes the accuracy low

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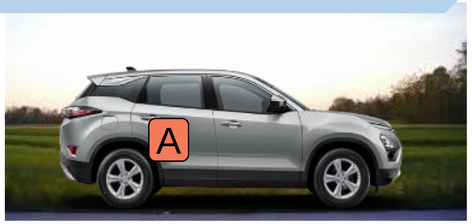
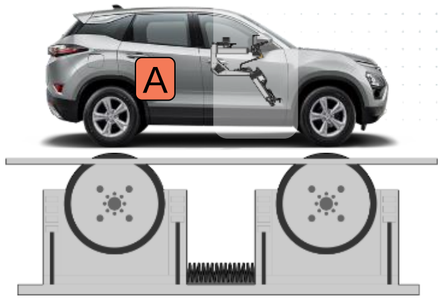
HORIBA Torque Matching Replication & Emulation Overview

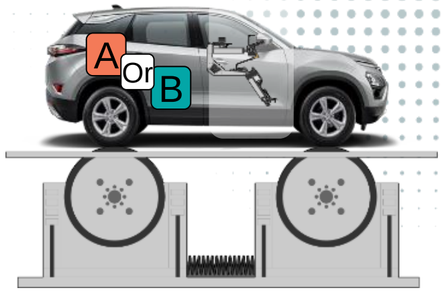


Recorded Road Test



HTM Replication Cycle

Dyno in **Speed** Control Mode



HTM Emulation Cycle

Dyno in **Road Load Simulation** Mode

Inputs

Input Changes
- Driver Aggressivity
- Environmental

Vehicle Changes
- Vehicle components
- Calibration

Outputs

Driver robot replicates throttle & brake position

MEDAS replicates Temperature, Humidity, Pressure

Dyno targets vehicle speed during replication. Resultant torque recorded

Target Speed

Road Load & Gradient derived from resultant HTM dyno torque

T_{RL} → [A B C] Coefs → m.a

Or

Or

Resultant Dyno Torque is a perfect 'match' to loads seen during the r

T_{HTM}

Output: Resultant dyno torque = Highly Accurate Road Load

Record the benchmark road test. Only throttl… Ambient co…

Replay throttle and brake positions and …

Replace original vehicle with similar model by subtracting …ter torque. … environmental

Superior accuracy between measured outputs over traditional RLS chassis replication method

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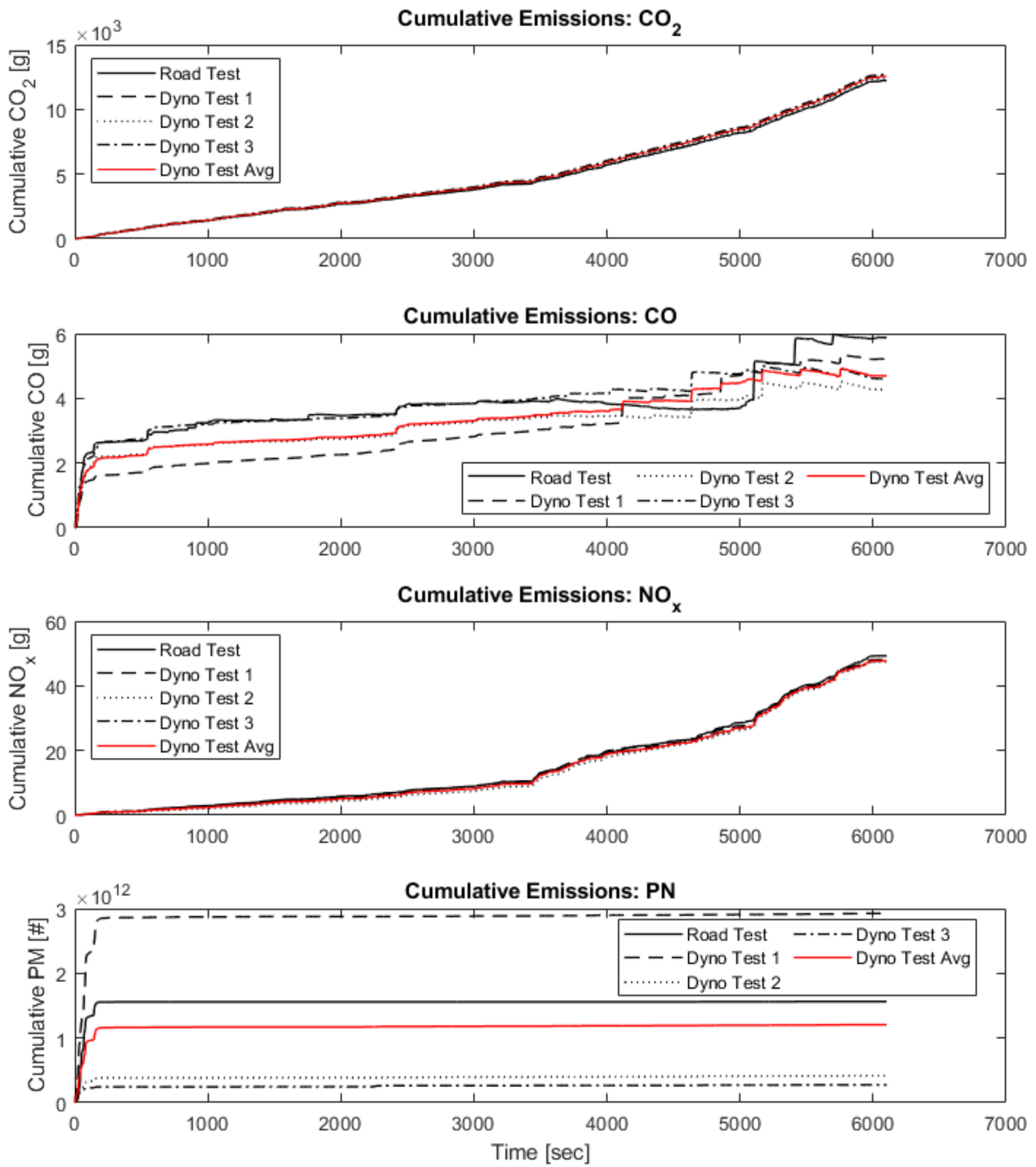
RDE Replication

EU6 DI Diesel Example (Speed, Acc, Gear)

Sea Level (Road vs Lab : PEMS)	CO2 [kg]	CO [g]	NOx [g]	PN [#]	Work [MJ]
Road Test	12.23	5.88	49.28	1.56e12	49.96
Replication Test	12.55	4.83	47.79	1.2e12	49.09
Difference	2.67%	-17.8%	-3.01%	-23%	-1.7%
Variance	0.88%	8.4%	0.5%	100%	1.2%
Diff as % of EU6	-	2.4%	21%	0.7%	

- ❑ **High degree of replication:**
  - ✓ Mass emissions
  - ✓ Instantaneous emissions
  - ✓ RPM & Torque
  - ✓ Pedal inputs
  - ✓ Temperatures
  - ✓ High repeatability



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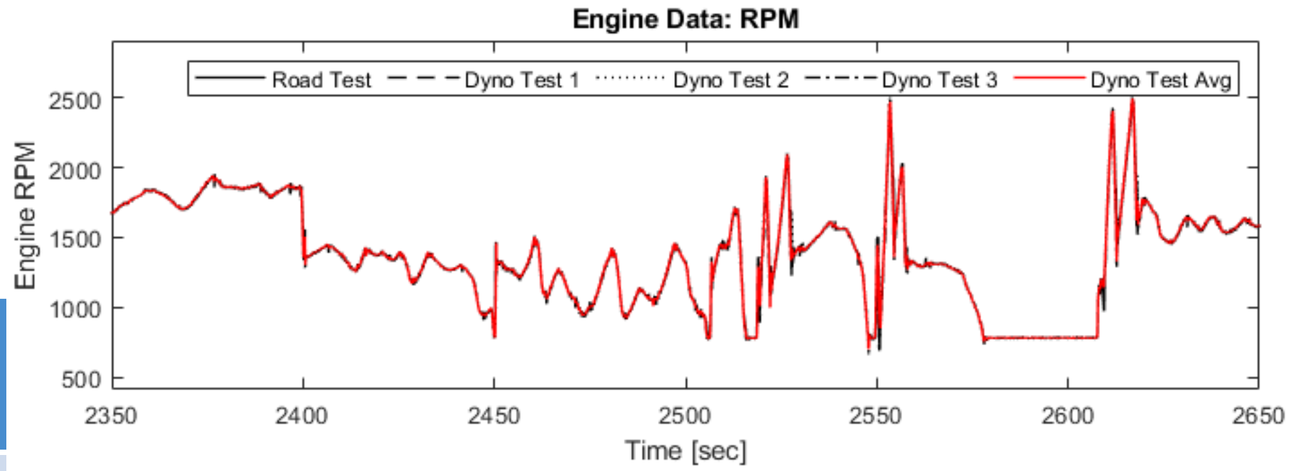

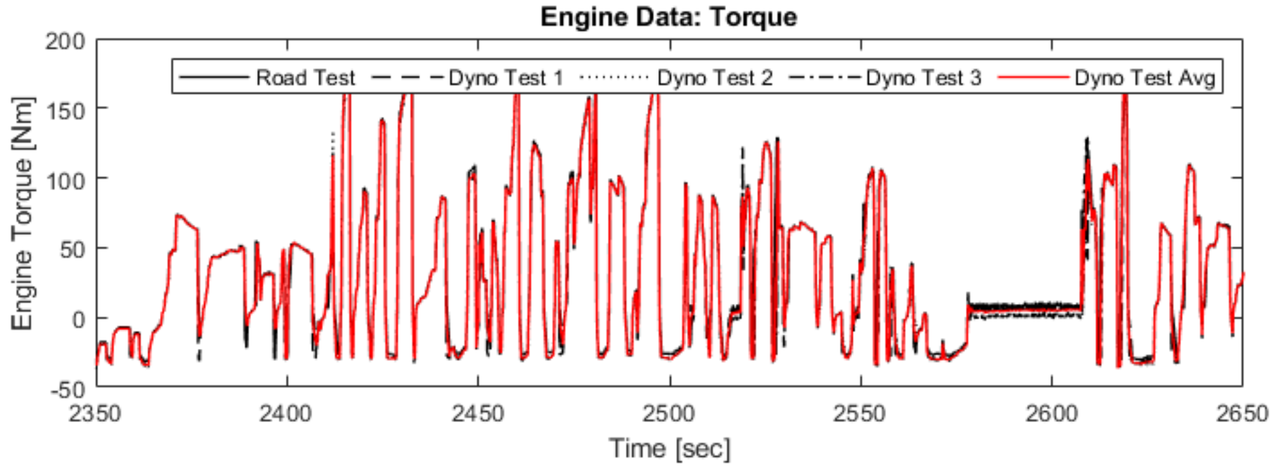

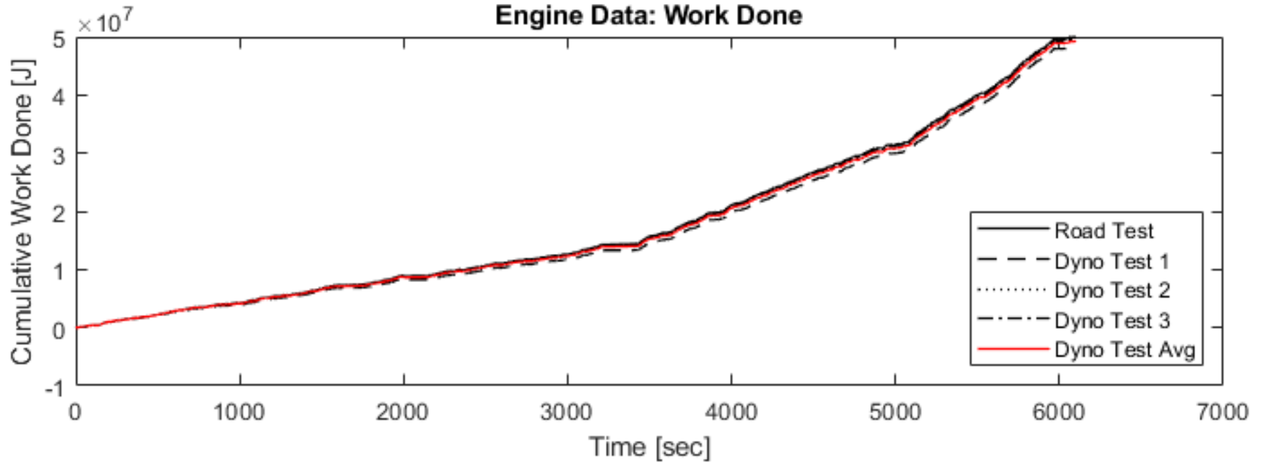

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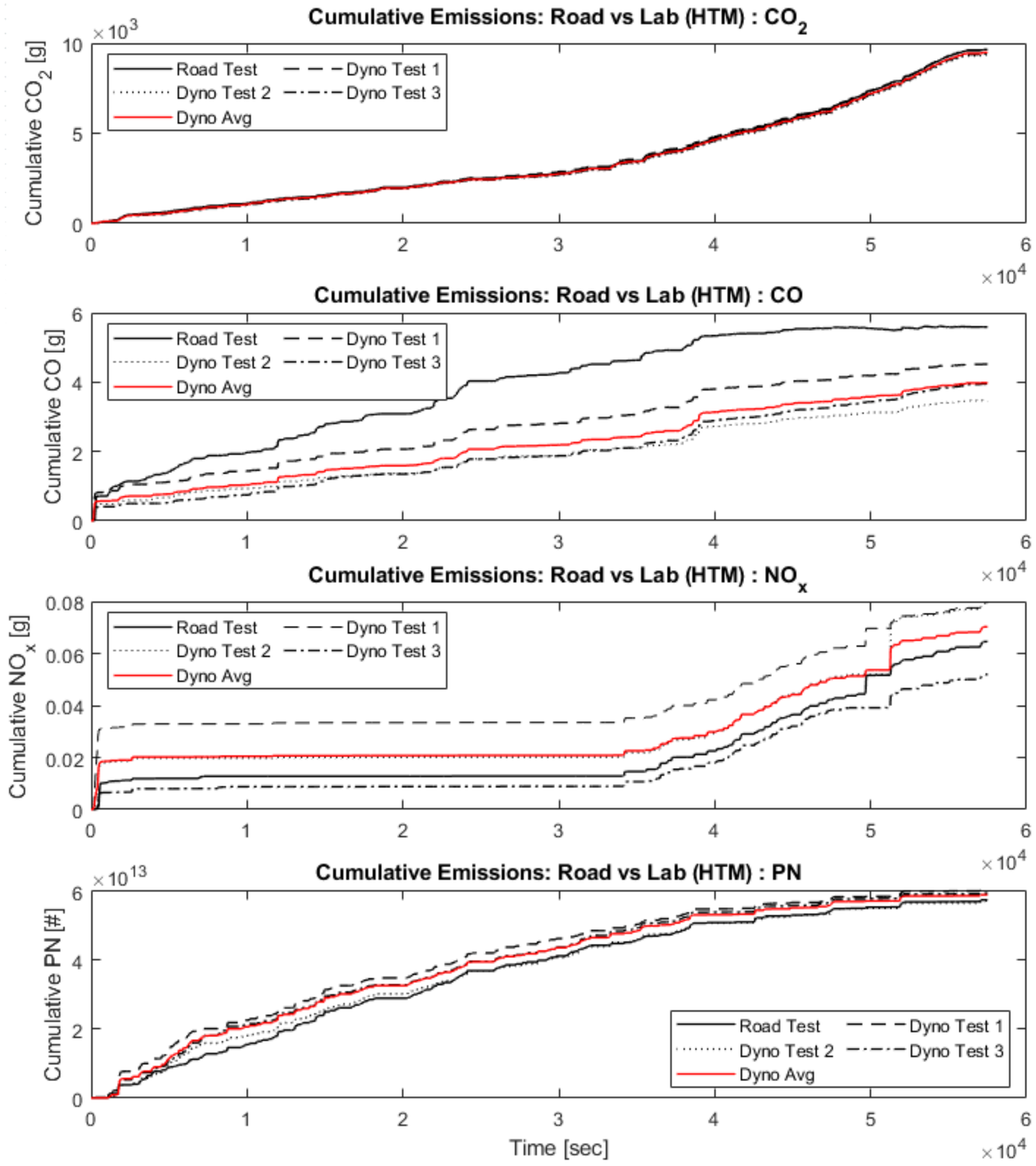
RDE Replication

PHEV Example (Speed, Acc, Brk, Gear)

Sea Level (Road vs Lab : PEMS)	CO2 [kg]	CO [g]	NOx [g]	PN [#]
Road Test	9.64	5.58	0.064	5.75e13
Replication Test	9.48	3.93	0.063	5.90e13
Difference	-1.66%	-29.7%	-1.73%	-2.67%
Variance	3.1%	10.0%	58%	2.3%
Diff as % of EU6	-	4.01%	0.02%	3.09%

Sea Level (Road vs Lab : PEMS)	System Energy [kWh]	Battery Energy (-ve) [kWh]	Battery Energy (+ve) [kWh]
Road Test	14.93	2.78	2.2
Replication Test	14.75	2.75	1.87
Difference	1.5%	0.79%	1.34%



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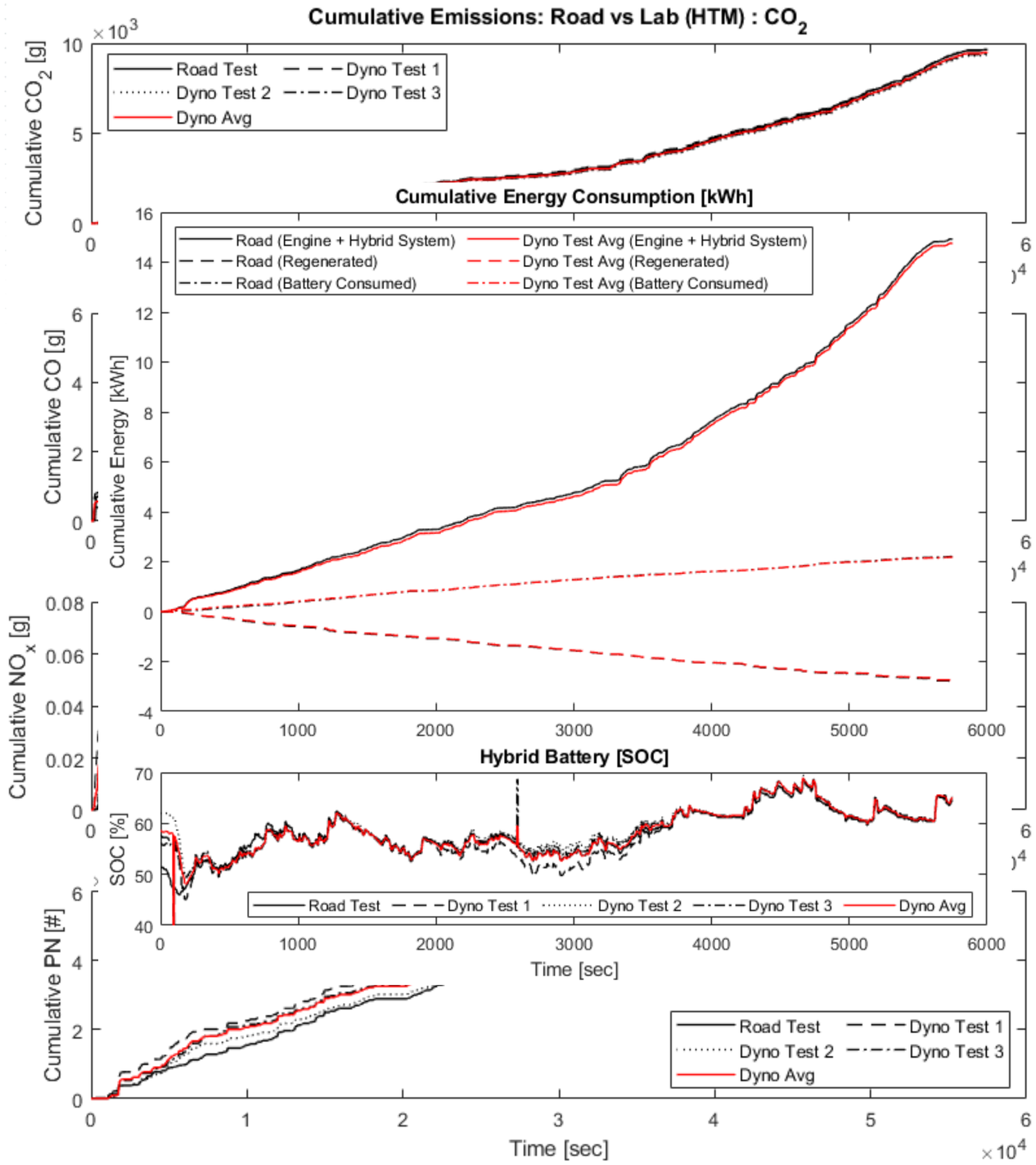

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Comparison of results (ICE)

HTM RLS **Emulation has greater accuracy**

- **Result:** HTM RLS approximately similar to the original replication test. Maintains higher replication performance than traditional RLS method
- **Robot Driver:** Existing robot speed controller and gradient adaption method is used to control vehicle accelerator
- **Accelerator:** Better pedal input replication compared to “RLS” method. Leads to closer emissions match.
- **Benefits of HTM RLS Gradient Extraction:**
  - Convert to Distance-Road Gradient Look-Up to enable different vehicles to be evaluated over same gradient
  - Import real gradient to virtual test route (e.g.IPG CarMaker vehicle simulation) for Simulation and Vehicle-in-Loop testing

RLS vs HTM RLS **Emulation**		**Linear Fit Model**		
		Gradient	Intercept	R^2
Vehicle Speed	Replication	0.99	0.09	0.99
	Traditional RLS	0.99	0.18	0.99
	HTM RLS	0.99	0.21	0.99
APedal	Replication	0.98	0.16	0.99
	Traditional RLS	0.85	0.67	0.87
	HTM RLS	0.91	0.70	0.94
CO2 Rate	Replication	1.00	-0.03	0.95
	Traditional RLS	0.88	0.07	0.87
	HTM RLS	0.92	0.10	0.91

CO2 Error Against Original Road Test		
HTM (Replication)	HTM RLS Emulation	RLS + GPS Method
~ 1.8%	**~ -1.8%**	**~ -10.5%**

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HORIBA Torque Matching has superior accuracy to replicate the original road test and then produces a better Road Load Simulation for a more trustworthy development environment

HTM RLS = HORIBA Torque Matching Derived RLS method

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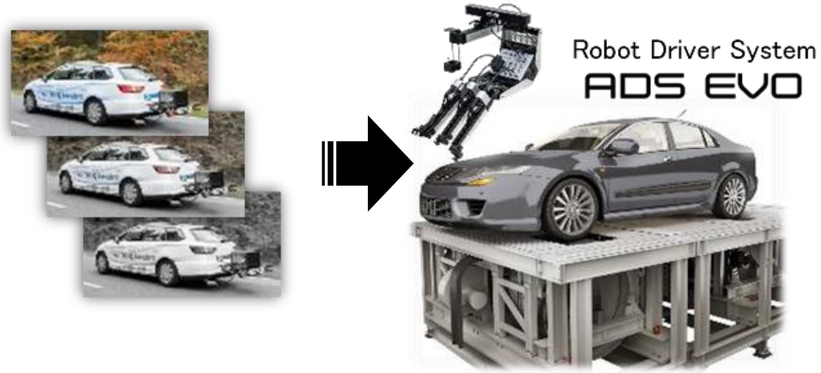
Torque Matching Method Gives Unrivalled Accuracy

Seamless transition from Road to Rig

HORIBA STARS ENTERPRISE

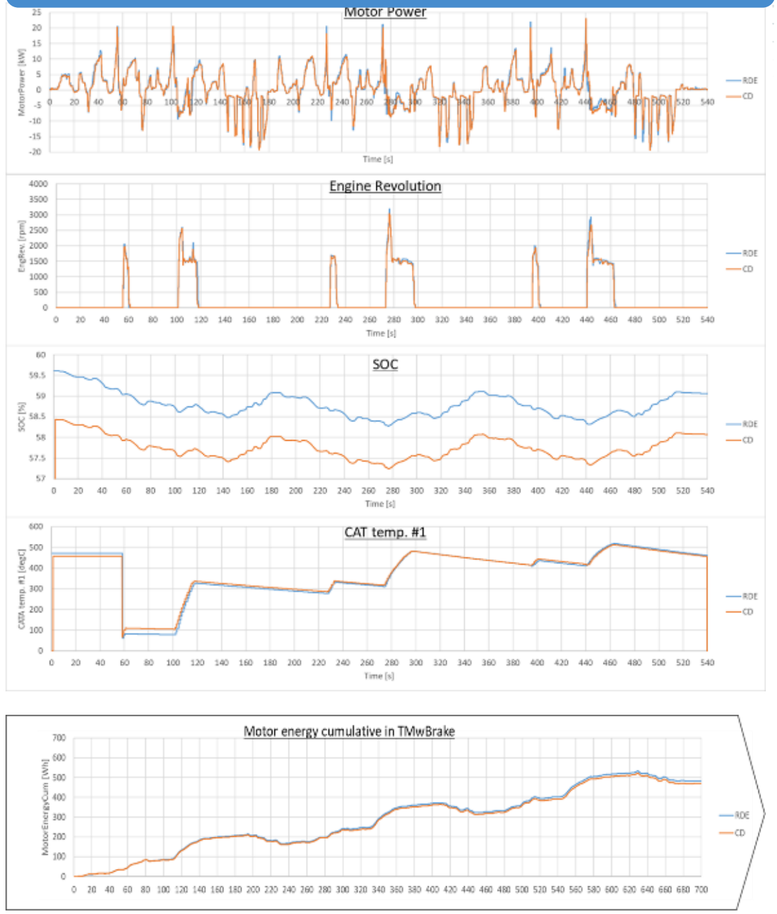


Automated vehicle data transfer

Real-world drive is perfectly **Replicated**

Road Load is accurately derived to **Emulate** the real-world for vehicle attribute development

Superior Accuracy and Flexibility



Left-shift Verification & Validation

- Verify and validate more designs in the lab, not on the road.
- Use the same high accuracy equipment in development as in certification
- Save time & cost by eliminating road testing and expensive prototypes

Reduce Chassis Lab correlation time by 50%	€5-15M reduction in prototypes per programme

Fully automated road-test replication with superior corelation

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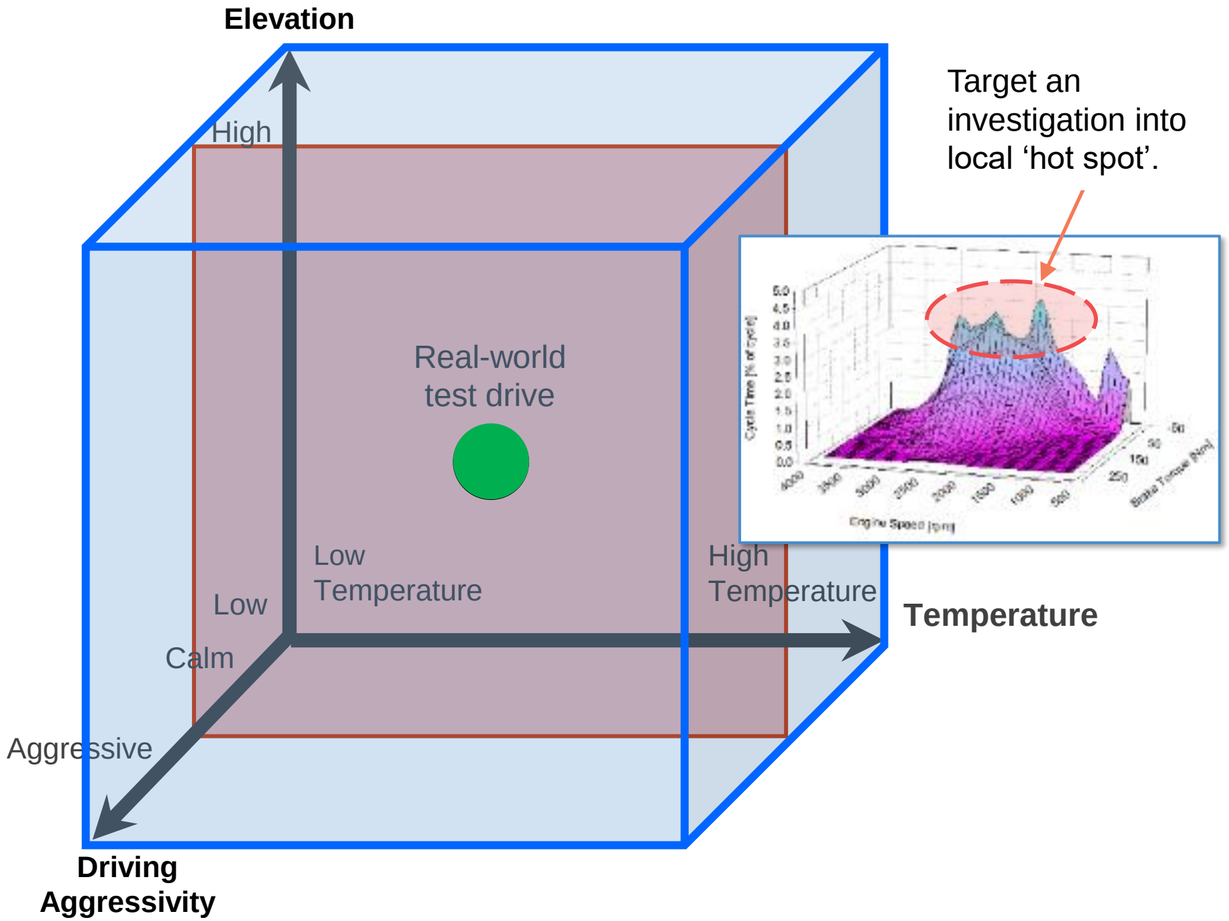
Smart lab-based development: Torque Matching + Simulation

Replication >> Simulation >> Emulation



Replication

- Reproduce the real-world test accurately on the chassis dyno
- Record the road load to use in simulation and emulation
- Validate the lab is able to accurately replicate the real-road test
- Use the same vehicle coefficients in the lab and in simulation

Simulation

- Create a digital twin of a sub-system or complete vehicle
- Simulate over the entire regulatory window to highlight ‘hot spots’ (areas of concern)
- Validate designs in simulation faster than real-time
- Check areas of concern on the real vehicle in the lab
- Prioritise areas for investigation and further development

Emulation

- Validate simulation results are real to focus development effort
- Change variables to emulate a particular scenario of concern
- Change 1 or more vehicle or environmental conditions to explore the impact of design changes on real hardware
  - **Environment:** Aggressivity / Elevation / Temperature
  - **Vehicle/ DUT:** Change components or calibrations

Torque Matching + Simulation provides a powerful development combination

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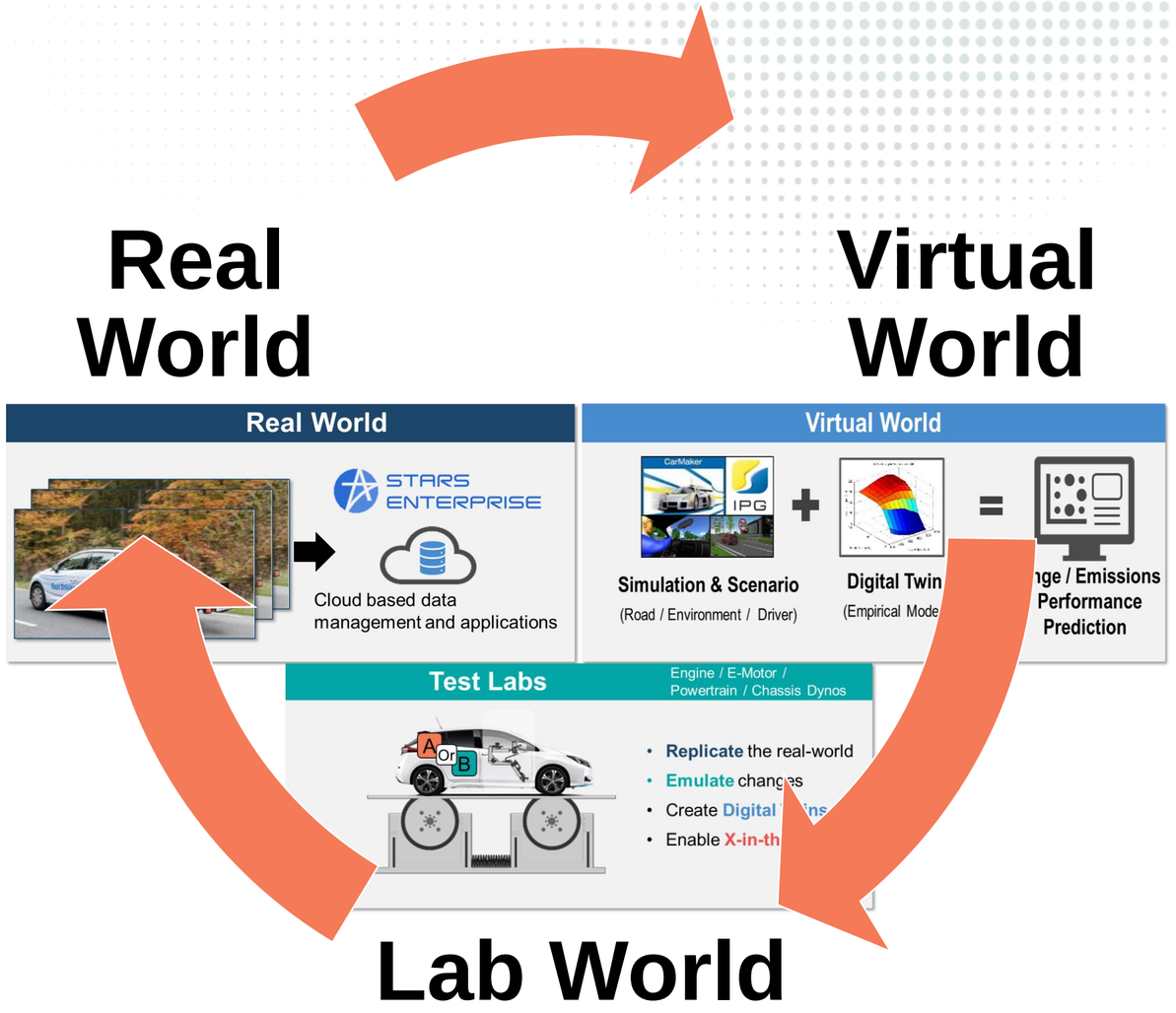
Intelligent Lab

- New Road-to-Rig, HiL and Digital Twin methodologies have been developed and demonstrated
- Significant programme time (>70%) and cost (>€5M)savings can be realized by the adoption of Intelligent Lab
- We must “Develop Smarter” now and in the future to meet the challenges of RDE in the shortest timeframe



Thank you

Cảm ơn

감사합니다

ありがとうございました

Dziękuję

धन्यवाद

Grazie

Merci

谢谢

நன்றி

ขอบคุณครับ

Gracias

Obrigado

Σας ευχαριστούμε

Děkuji

Teşekkürler

شكرا

Tack ska ni ha

Danke

Большое спасибо

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