Reducing BEV and xHEV Development Times with Highly Efficient System Testing

Vaughan Morton, Christian Weiss and Andreas Haspl
June 15, 2022 | 4:00 PM CEST

Today‘s Presenters

Vaughan Morton

Chief Engineering Testing, AVL

Christian Weiss

Lead Engineering Powertrain Methodology, AVL

Andreas Haspl

Senior Simulation Engineer, AVL

Today‘s Agenda

1

Testing Approach

Efficient testing

2

Optimization of PTCE/HTOE Testing Duration

Based on real road load profiles

3

AVL Powertrain Testbed

Reduce time-to-market and system robustness validation for complex powertrain systems

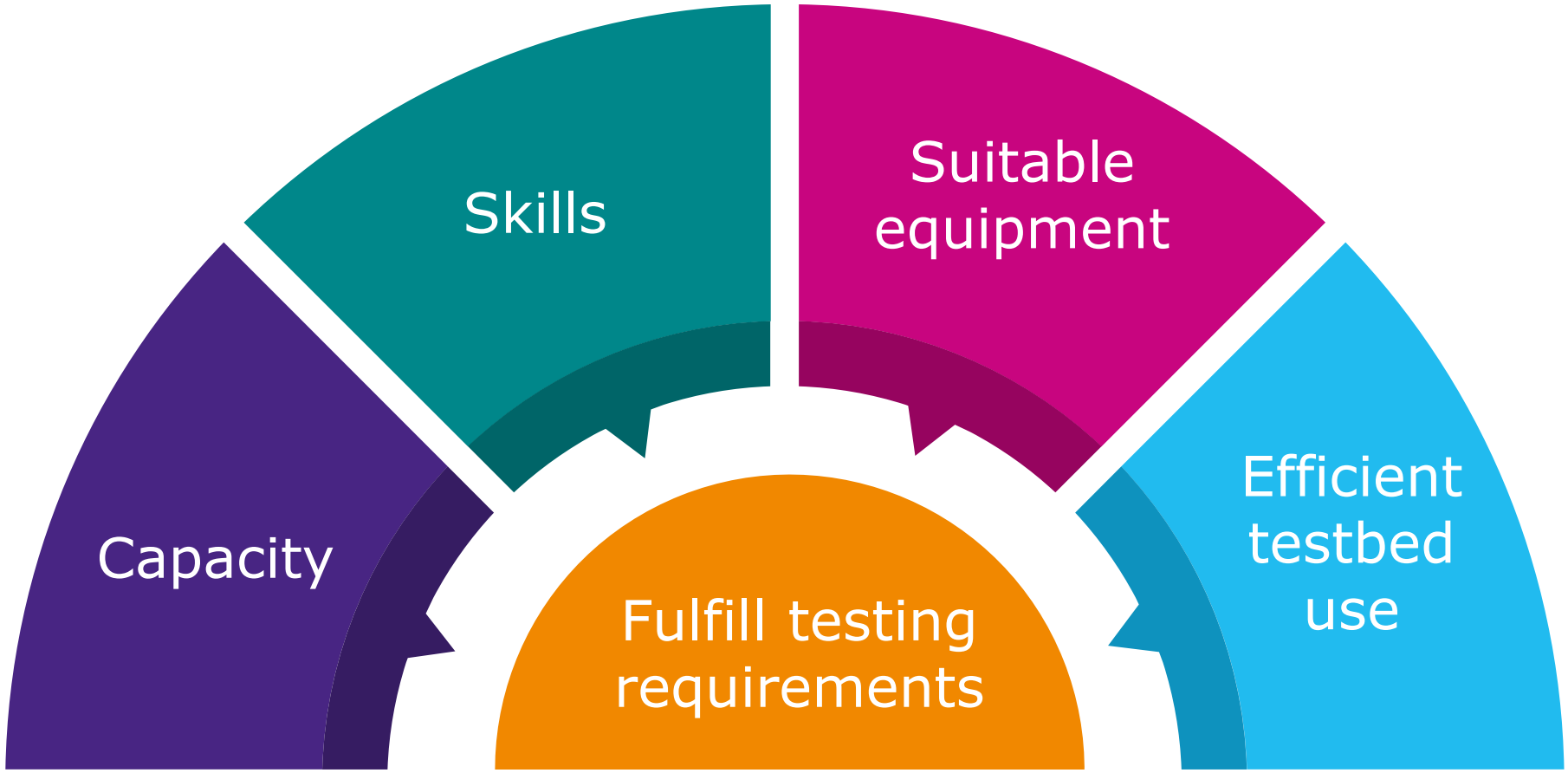
Efficient Testing

Testing AVL Approach

AVL Test Factory – A One-Stop-Shop

- > 70 years experience in automotive testing
- > 1,250 experienced and skilled team
- > 300 testbeds of different types
- Cutting-edge measurement technologies
- Best in class test management and execution systems

Building Blocks to Fulfill Project Requirments



Electrified Drivetrains – AVL Main Test Facilities

Capacity

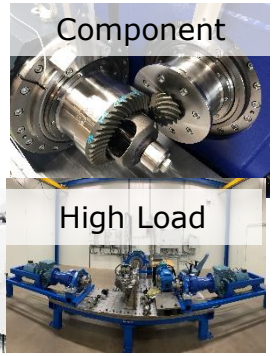
EDU system

Europe Graz (HQ AUT)
Remscheid (GER)
Trollhaettan (SWE)
Budapest (HUN)

Asia Shanghai (CHN)
Tianjin (CHN)
Gurgaon (IND)
Kanagawa (JPN)

N-America Ann Arbor (US)
Lake Forest (US)

Transmission



Europe Graz (HQ AUT)
Remscheid (GER)
Trollhaettan (SWE)

Electrified Drivetrains – AVL Main Test Facilities

Capacity

E-motor

Europe	Graz (HQ AUT)
	Stockholm (SWE)
	Trollhaettan (SWE)
	Remscheid (GER)
	Regensburg (GER)
Asia	Shanghai (CHN)
N-America	Lake Forest (US)

Power electronics

Europe	Graz (HQ AUT)
	Regensburg (GER)

Ensure the Safety and Skills of the Employees

Skills

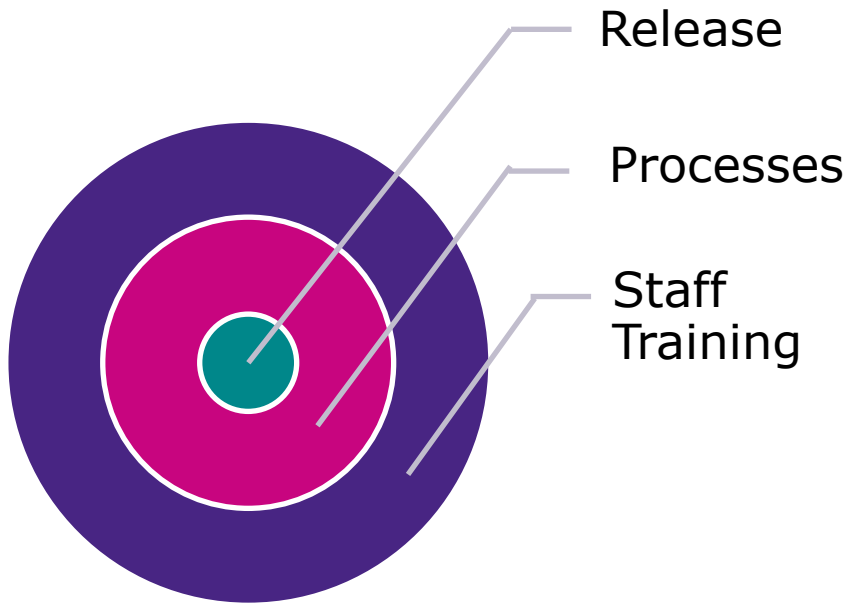
Ensure the Safety and Skills of the Employees

Skills

Procedural instructions
Safety standards HV responsibilities

Procedural instructions
- Module based training
- HV handling (training on the job)
- Data handling
- Technical skill and product knowledge

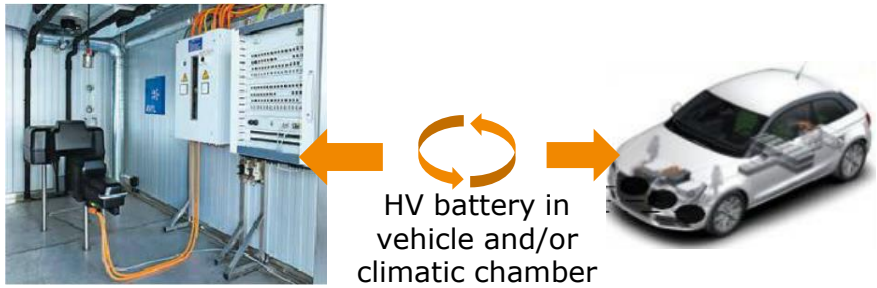
Safety check and management (HV release)



Capacity and Suitable Testing Environments

Suitable equipment

HV Powertrain TS E-Integration
Four dyno configuration → EV powertrain setup



- Development close to reality in early phases, where high voltage components are not fully available
- Automated switching between battery (in container), battery simulation and battery only possible**
- High voltage safety tests in a virtual environment
- Development in a highly reproducible testing environment

Capacity and Suitable Testing Environments

Suitable equipment

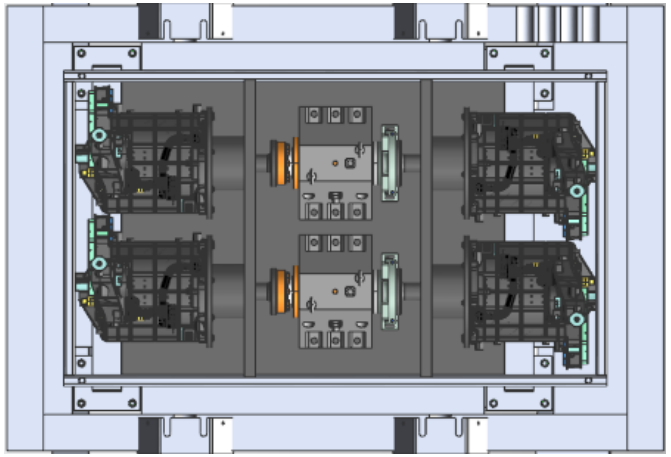
E-axle/E-motor back-to-back
Thermal Endurance Testing (Standards L-02 / L-03)

E-axle B2B

E-axle vs. E-axle

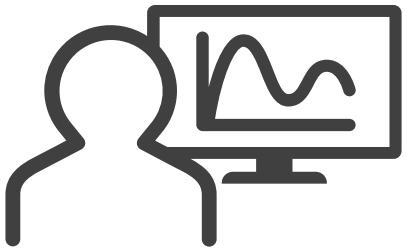
Alternatively:
E-motor vs. E-motor

E-motor B2B



Efficient Use of the “Night Shift” Challenge

Efficient testbed use



0:01 am — No engineer available — Testbed not utilized ☹

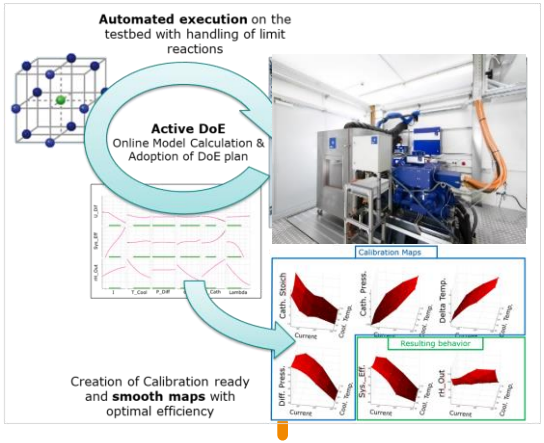
8:00 am — Manual calibration activities — Testbed utilized ☺

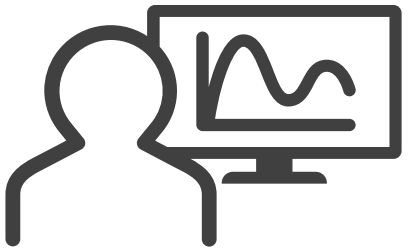
5:00 pm — No engineer available — Testbed not utilized ☹

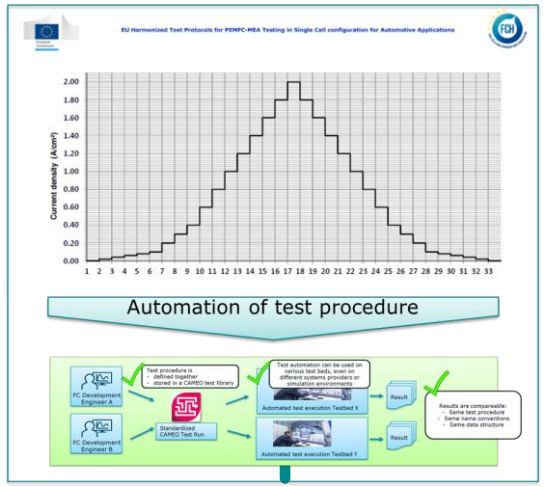
11:59 pm

Efficient Use of the “Night Shift” Solution

Efficient testbed use







0:01 am — Automatic execution of active DoE — Testbed utilized ☺

8:00 am — Manual calibration activities — Testbed utilized ☺

5:00 pm — Prepare and start automatic test procedure — Testbed utilized ☺

11:59 pm

Improve the Value of Testing and Development Environments Challenge

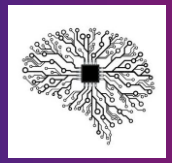
Efficient testbed use

Task: BEV / xHEV development optimisation (range, calibration, validation…)

- Charging infrastructure
- Robotic driver
- High degree of automation DOE
- Multiple vehicle variants - models
- Remote testbed access
- Residual bus simulation
- Safety
- Charging infrastructure

Manual calibration: ~4 weeks

Is there a quicker way?



Is there a smarter way?

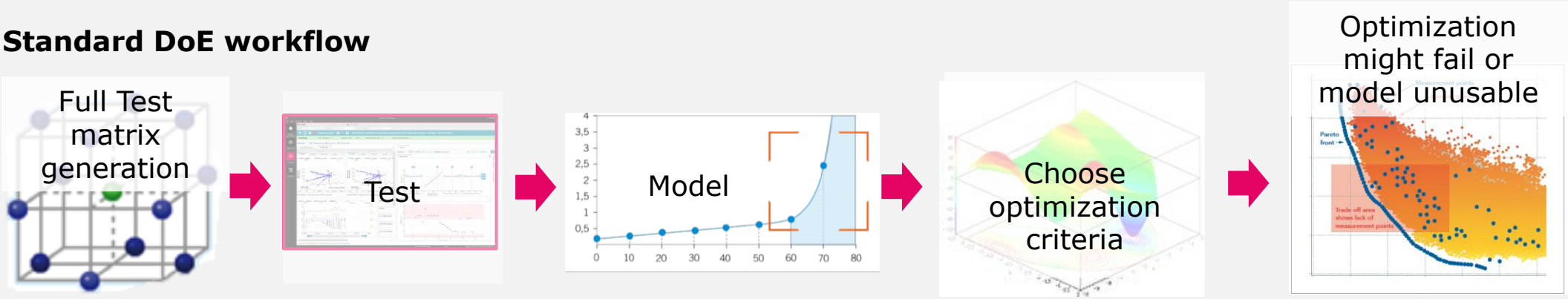
Improve the Value of Individual Tests – Solution

Efficient testbed use

Traditional DoE

Test – Model – Predict – Optimize: Too late for knowledge gained after testing to improve the testing phase

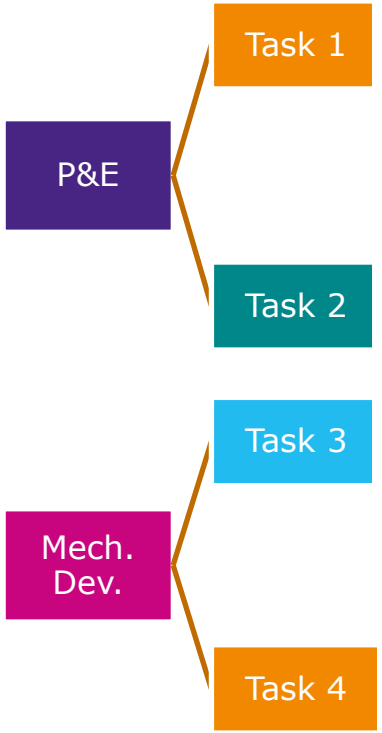
Standard DoE workflow



However, for high numbers of input dimensions or highly non-linear systems, even standard DoE has its limits.

Smart Evaluation of Generated Test Data via "Event-driven Big Data Analytics"

Efficient testbed use

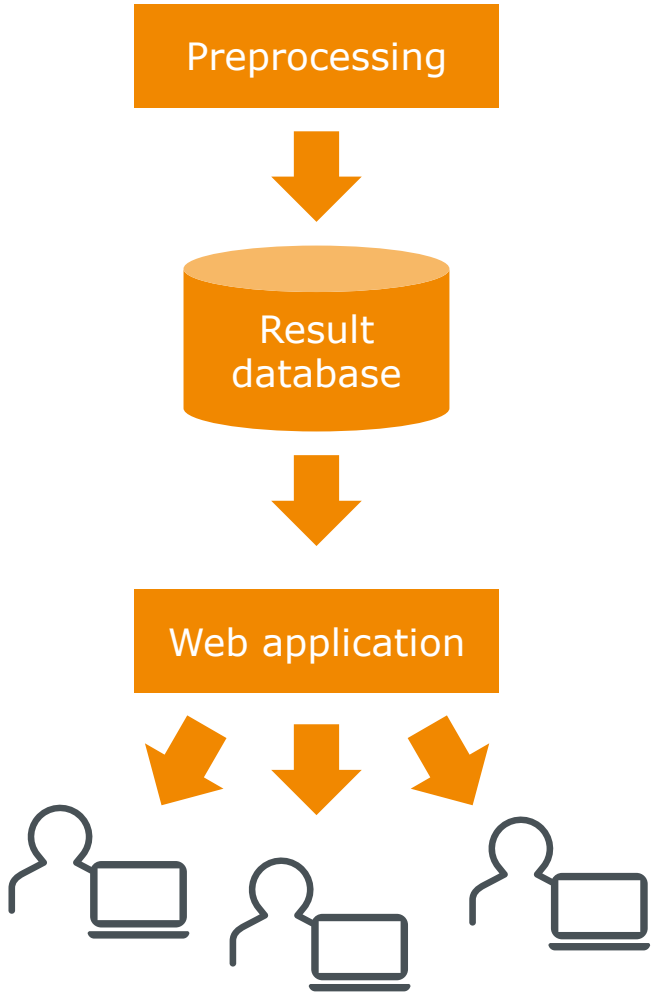


Missing content information

Low trust

Missing computational power

How to compare?



Example
669 measurements
196GB/176h

Extracting …
… 14.825 events
… 2.591 aggregates
… ~38 Mio. results

in 20 mins!

- Fast
- Automated
- Ability to handle large amount of data
- Flexible
- Coverage

Key Topics and Takeaways

Optimize testbed efficiency, performance and safety

Maximize the value of individual tests

Establish flexible testing infrastructure

Based on Real Road Load Profiles

Optimization of PTCE/HTOE Testing Duration

Optimization of PTCE/HTOE Testing Duration

Task description

Target:

- **Optimization of testing time**
- Based on LV 124 standard

Development potentials

Identified development potential:

Introduce EDU **specific temperature distribution**

Solutions

Solutions:

- **Simulation** of EDU compartment and coolant temp.
- Real track data
- Usage space

Development results

Conclusions:

- Reduction of testing time **by ~50 %**
- **Simulated** and **weighted** EDU temperatures

LV124
L-02/L-03 Test Specification

HTOE
High Temperature Operation Endurance Test

Test Target:

- Test simulates the **thermal exposure** of the component **during vehicle service life**.
- Intended to **verify the quality and reliability** of the component with respect to faults that occur due to thermal exposure such as **diffusion, migration and oxidation**.
- HTOE test corresponds to the L-02 test from LV124-2 corresponding to DIN EN 60068-2-2:2008-05;VDE 0468-2-2:2008-05

PTCE
Powered Thermal Cycle Endurance Test

Test Target:

- Test simulates the **thermomechanical exposure of the component** as a result of temperature changes that occur **during vehicle service life.**
- Intended to **verify the quality and reliability** of the component with respect to faults that occur due to thermomechanical exposure such as **aging and cracking** in soldered joints, adhesive joints and welded joints, in bond connections as well as in seals or housings.
- PTCE test corresponds to the L-03 test from LV124-2, corresponding to DIN EN 60068-2-14:2010-04.

LV124
L-02/L-03 Test Specification

Approach according LV 124

- The LV 124 standard **does not cover** the effect of external **air temperature**
- **No influence** of specific **vehicle application** or market **specific environmental conditions**
- **Actual EDU temperatures** from usage space are **neglected**

Why does this lead to a long testing time for HTOE and PTCE tests?

How can the AVL approach reduce the testing time by using CRUISETM M?

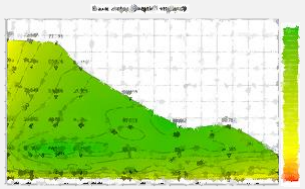
Workflow with AVL CRUISE™ M

EDU components modeled in CRUISE™ M

EDU

- E-motor
- Inverter
- Transmission

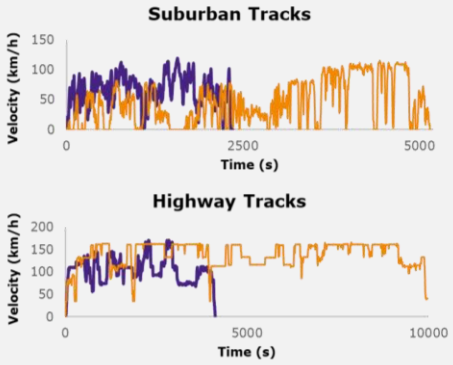
considering **cooling circuit** and **under-hood** flow **thermal losses** based on efficiency Maps



Real drive data or simulated **track data**

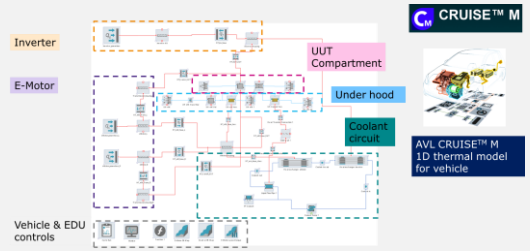
Vehicle track data as load boundary condition for EDU

- vehicle speed
- e-motor speed and torque

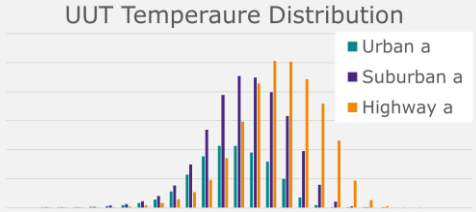


Combined in thermal EDU/vehicle model

Evaluation of actual losses in the EDU with **CRUISE™ M**

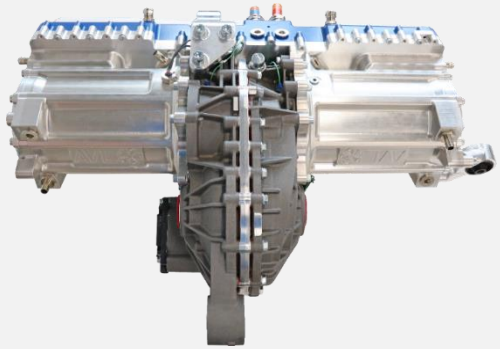


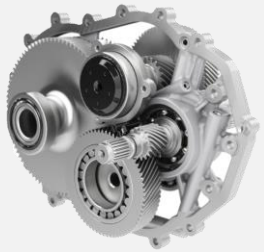
Result: **thermal profiles**

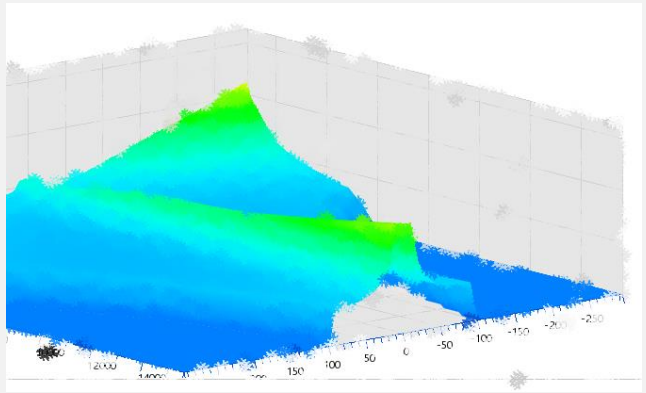


Vehicle/EDU Model in AVL CRUISE™ M

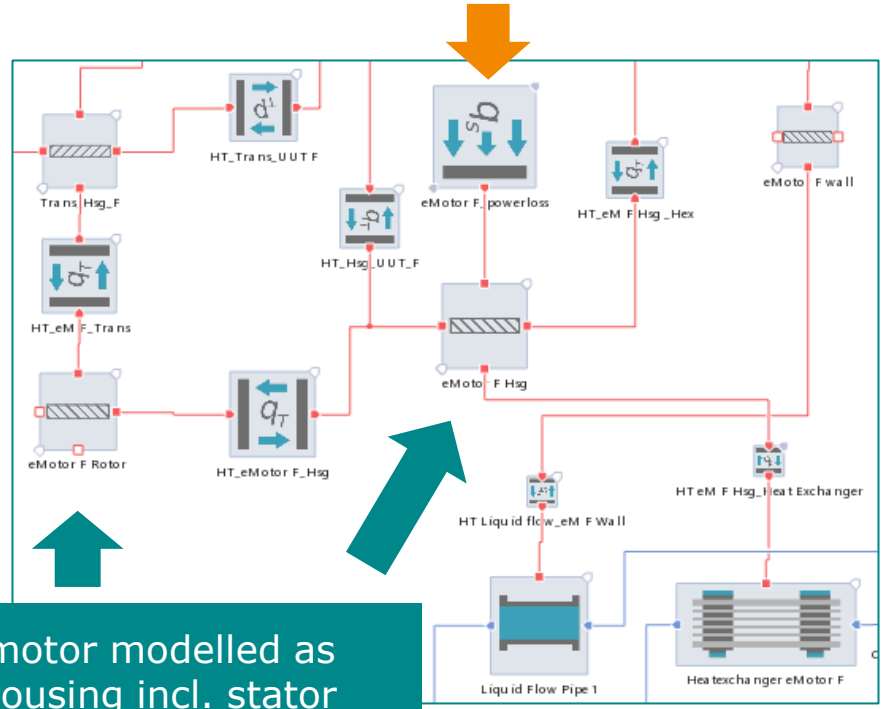
Example for Thermal Modelling







Power loss of e-motor according efficiency map



E-motor modelled as
- Housing incl. stator
- E-motor rotor

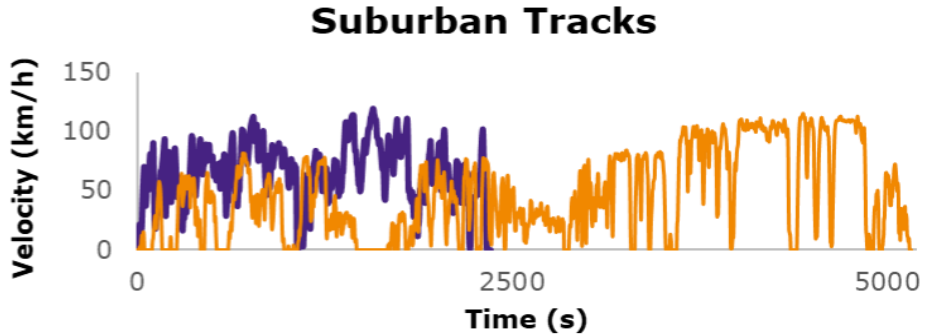
Cooling circuit

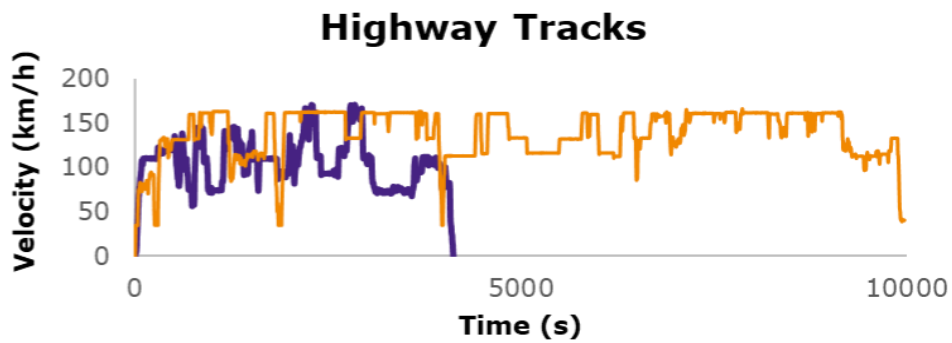
Road Load Profiles in AVL Smart Mobile Solutions

Example route in Detroit:

- 100km mixed route containing
- 42.0km of urban,
- 27.2km of rural and
- 29.9km of motorway track

Road profiles

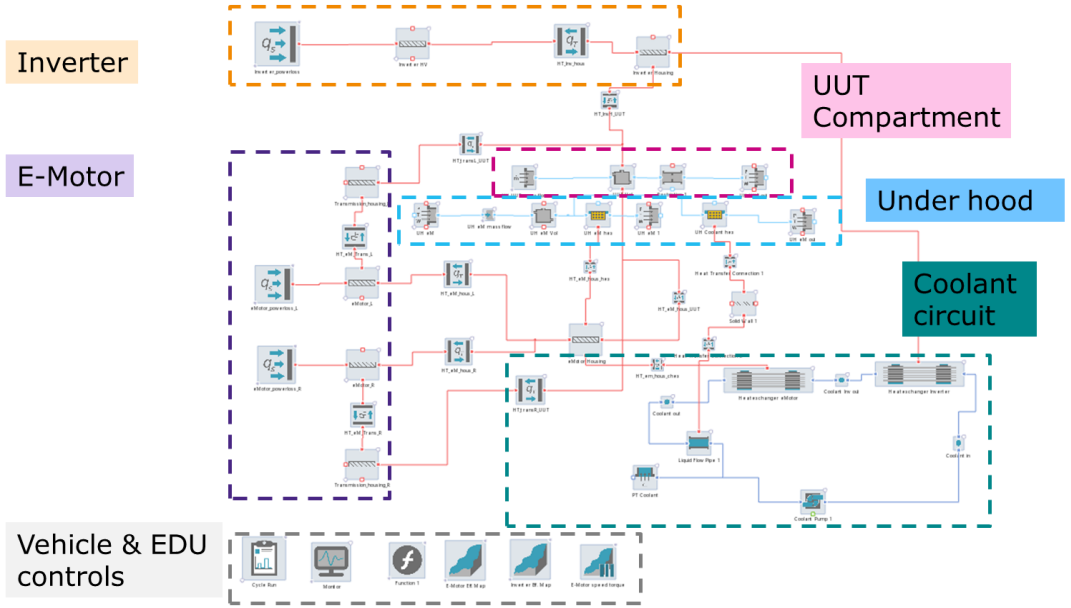




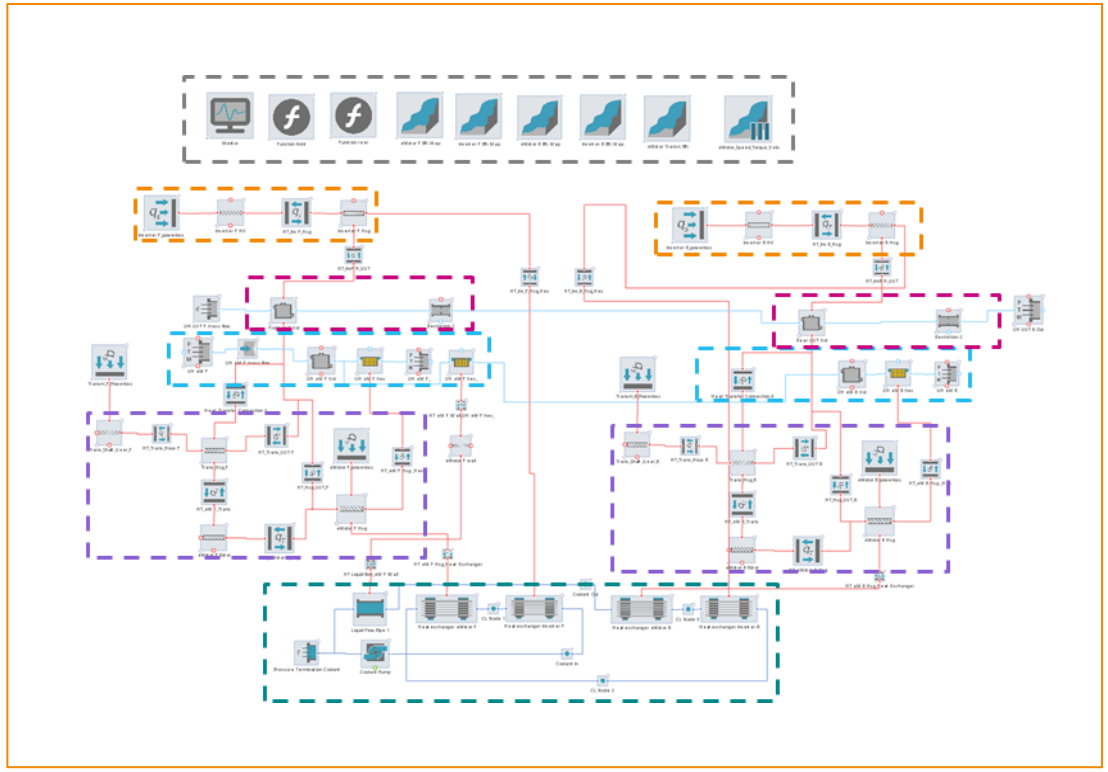
Workflow: Vehicle/EDU Model in AVL CRUISE™ M

Example models where the AVL approach has been applied

Rear e-axle with dual e-motor

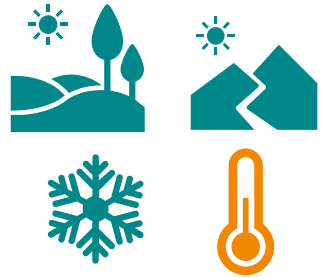


Vehicle with front and rear e-axle



Vehicle/EDU Model – Model Setup
Variations according usage space

- Calculation of **several track profiles** with CRUISE™ M
  - e.g. highway, rural, urban, sub-urban or mountain tracks
  - Simulation of entire usage space **temperature range** (e.g. -40°C / +50°C)



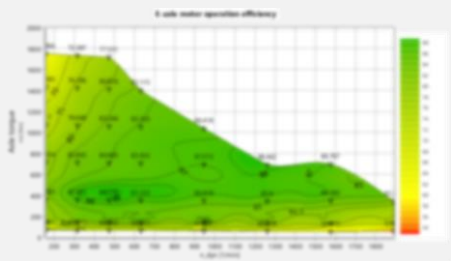
- Model variation across track profiles
  - Consideration of different **vehicle loads**
    e.g. curb weight +2 passengers, max towing load
  - Different **driver profiles**: aggressive, normal or peaceful driver

- Evaluation of EDU **compartment and coolant temperature** for all variations

Thermal Model
Simulation Results

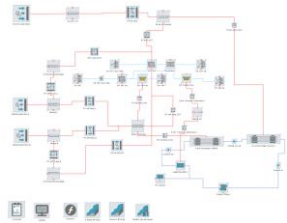
P=f(M,n)

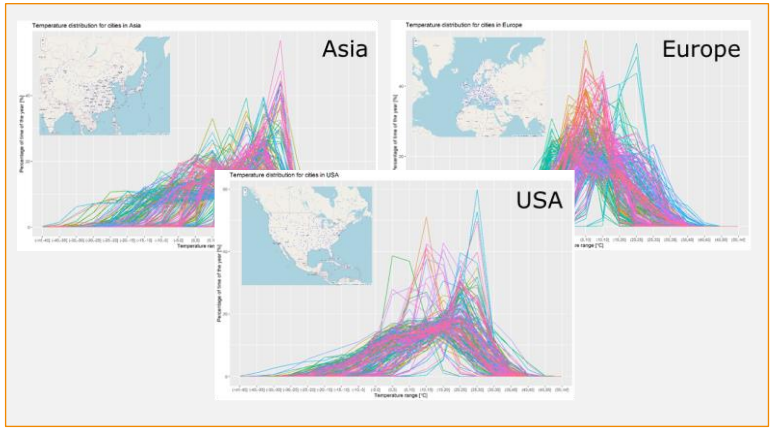
Variations:
- driving tracks
- air temperature
- vehicle load
- driver behavior

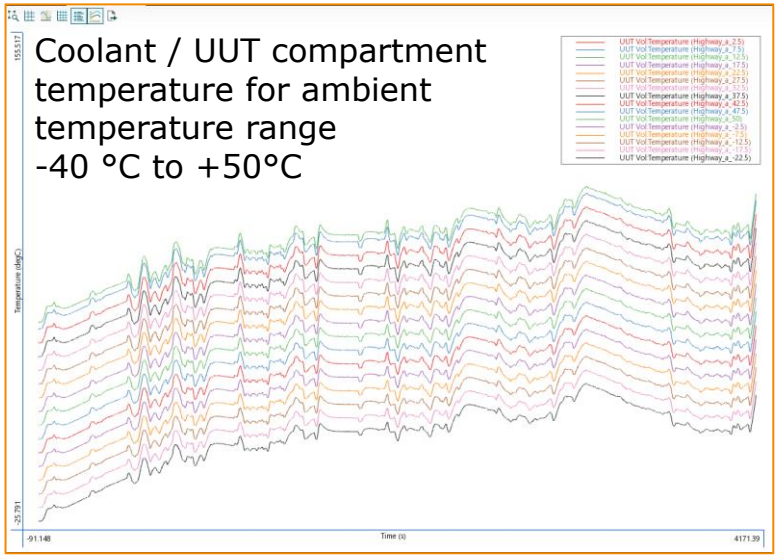


E-motor
Inverter

CRUISE™ M





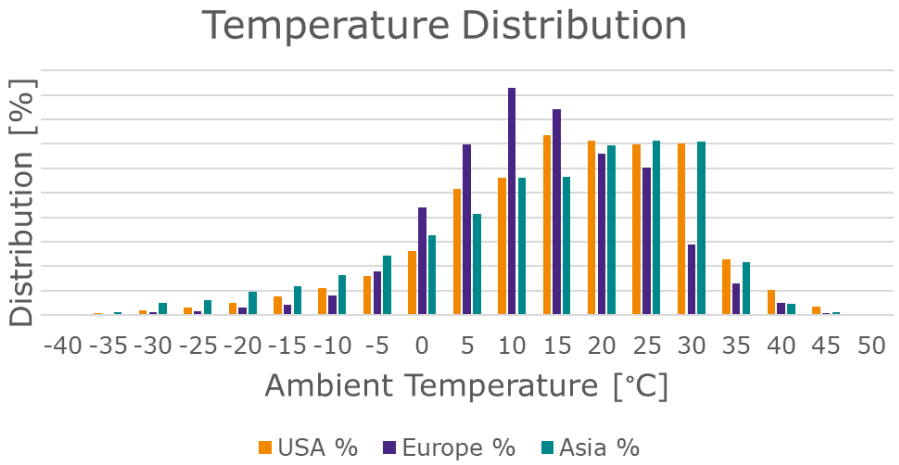


Evaluation of UUT compartment and coolant temprature based on entire range of ambient temperature

e.g. -40°C ... +50°C

LV 124 – L-02/L-03

Market Specific Environmental Conditions

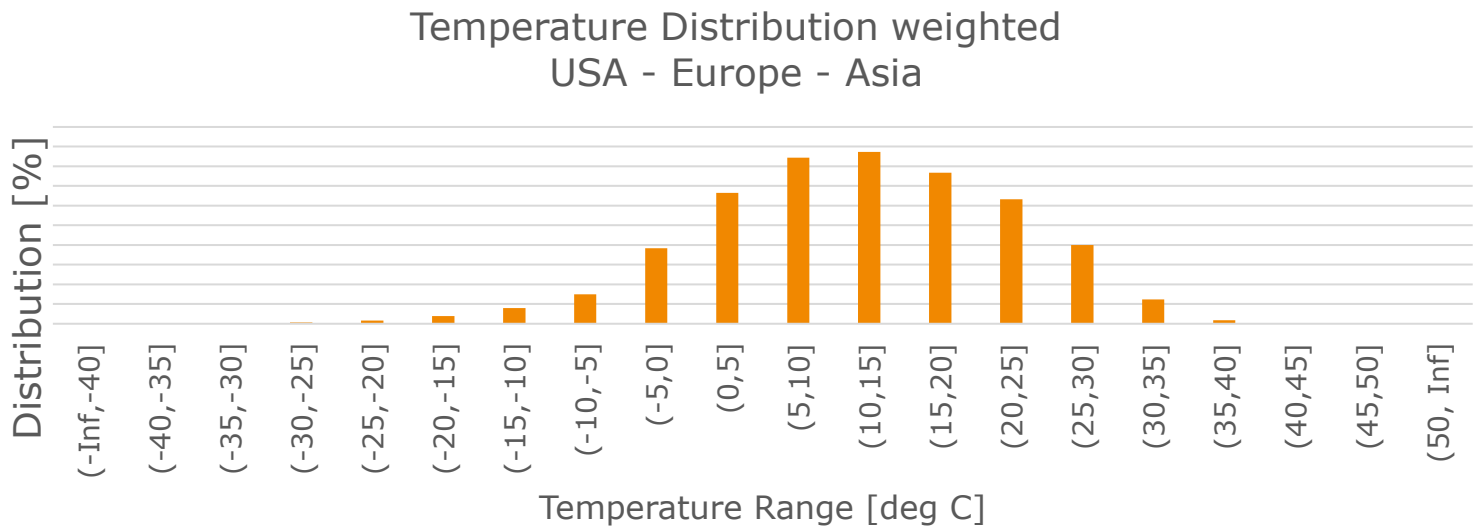


x

market distribution weighting

Market temperature distribution weighting e.g.

- 50 % Europe
- 25 % Asia
- 25 % USA



LV 124 – L-02/L-03
Temperature Weighting

Calculated **Temperature Profile** with CRUISE™ M according **track profile** for **coolant** and **UUT compartment**

x

Ambient temperature distribution over the year as weighting factor

x

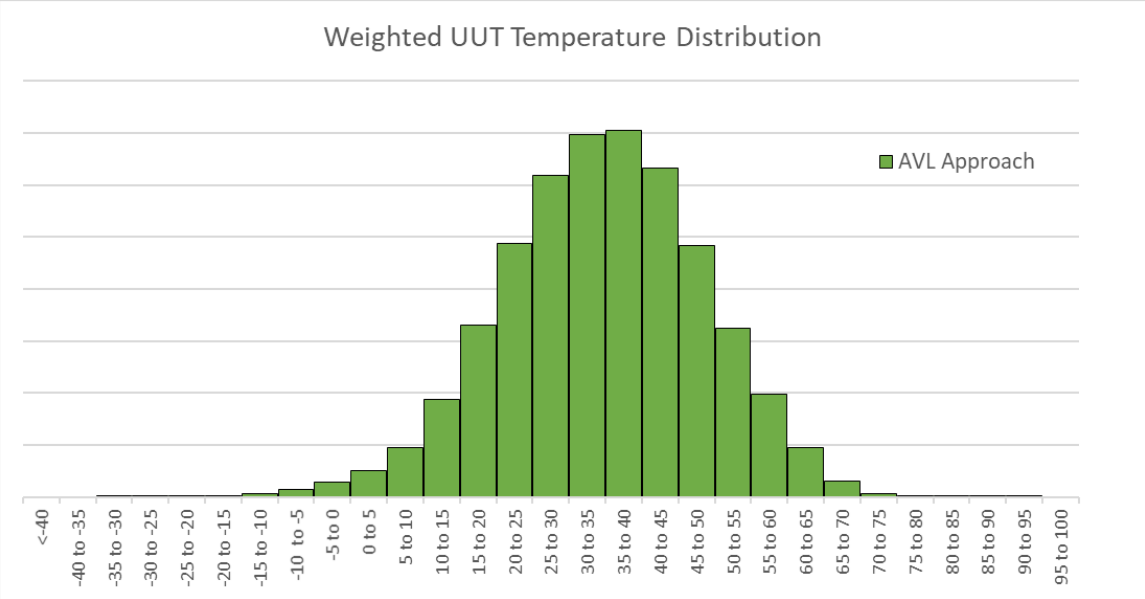
Customer specific **target market distribution** as weighting factor

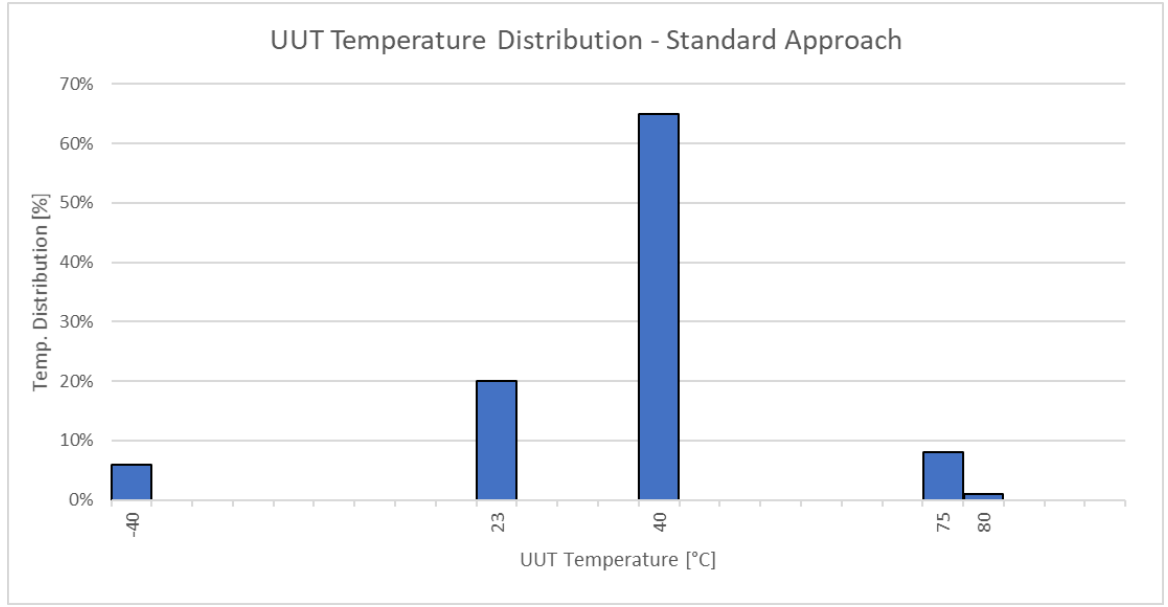
=

corrected temperature distribution as input for standard LV 124

Coolant and UUT compartment temperatures weighting

LV 124 – L-02/L-03 – Temperature
Distribution Comparison





The temp. distribution over several tracks are weighted to achieve a realistic UUT temperature distributing based on the vehicle usage

LV 124 – L-02
HTOE – Testing Time

AVL Approach

Ambient Temperature	Coolant temperature	Duration
°C	°C	hr
~~97.5~~	~~70~~	~~0.0~~
~~92.5~~	~~70~~	~~0.0~~
~~87.5~~	~~70~~	~~0.0~~
82.5	70	0.3
77.5	70	1.5
72.5	70	6.4
69.8	70	20.1
69.8	65	472.5
total test duration		501

Time is < 1 min

Standard Approach

Ambient Temperature	Coolant temperature	Duration
°C	°C	hr
85.0	70	22.5
80.0	70	180.0
71.2	70	117.0
71.2	65	765.2
total test duration		1085

Drastic reduction of required test time from 1085h to 501h due to realistic temperature distribution

Applying weighted temp. distribution for LV 124 – L-02 HTOE calculation leads to drastic testing time reduction

Testing time saving potential HTOE ~ 50 %

LV 124 – L-03
PTCE – Testing Time

LV124

Driving - Coolant temperature limits with derating											
Cycles per day	Days per year	Years of designed life	Thermal cycles in life	Condition	T_min	T_max	ΔT_test	ΔT_field	c	A_cm	N_test
-	days	Years	-	-	°C	°C	°C	°C	-	-	-
2	365	**10**	7300	Ambient	-30	85	115	**36**	2.5	18.24	400
				Coolant	-30	70	100	**36**		12.86	568

Driving - Coolant temperature limits with derating							
t_equ	t_hold	t_soak	rate_t	t_cyc	mins/hou	t_full	t_total
min	min	min	°C/min	min	min	hours	hours
30	15	45	4	28.75	60	174	529
				103.3	60	175	
				105.5	60	179	

Drastic reduction of required test-time from 529 h to 223 h due to realistic temperature distribution

LV124 with AVL recommended Temp. Distribution

Driving - Coolant temperature limits with derating											
Cycles per day	Days per year	Years of designed life	Thermal cycles in life	Condition	T_min	T_max	ΔT_test	ΔT_field	c	A_cm	N_test
-	days	Years	-	-	°C	°C	°C	°C	-	-	-
2	365	**10**	7300	Ambient	-30	85	115	**18.4**	2.5	97.52	75
				Coolant	-30	70	100	**22.1**		43.46	168

Driving - Coolant temperature limits with derating							
t_equ	t_hold	t_soak	rate_t	t_cyc	mins/hour	t_full	t_total
min	min	min	°C/min	min	min	hours	hours
30	15	45	4	28.75	60	26	223
				104.7	60	99	
				104	60	98	

Testing time saving potential HTOE ~ 50%

Testing time saving potential PTCE ~ 50%

Key Topics and Takeaways

Measured or simulated road profiles to create realistic usage space

Temperature distribution of the EDU based on real road load profiles

Testing time reductio for HTOE/PTCE ~50 %

Reduce Time to Market and System Robustness Validation for Complex Powertrain Systems

AVL Powertrain Testbed

Top Benefits of Development on System Testbeds at AVL

SPEED

- 24/7 operation and remote operation
- Test automation and DoE
- Rapid cooling

COST

- Highly efficient prototype usage → less prototypes
- Less test trips

QUALITY AND SAFETY

- High repeatability
- Control of all influencing parameters (climate, vehicle mass, battery condition, etc.) and their combinations
- Highest degree of test coverage

Real-Life Range Testing and Electric Range Optimization

" How the real-life range testing and electric range can be optimized …? "

Real-Life BEV Range Testing

Charging Infrastructure

- Multiple AC/DC charging standards
- All markets in one environment

Robotic Driver

Repeatable driver diffe-rent driver characteristics available

High Degree of Automation

- Ready for CI/CD
- Reuse of MiL/SiL/HiL
- Test cases

Multiple Vehicle Variants

Using the same platform to be tested in one setup

Benefits

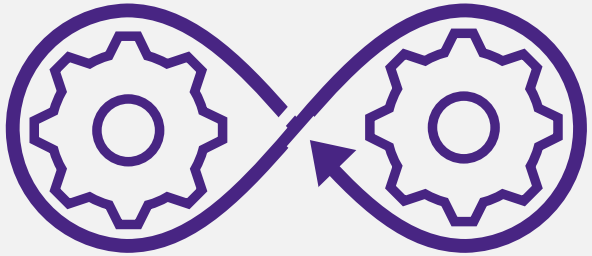
- 24/7 testing possible
- Automated reporting and evaluation
- Almost certification setup with automation capabilities
- Less tests needed due to repeatable driver inputs

Software Regression Testing

In-field Software update verification

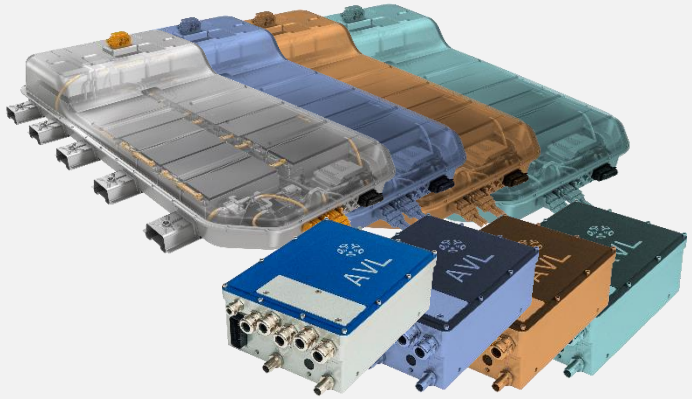
" How shall I do my frequently required software release tests in an affordable way? "

CI/CD



Multi sourcing verification program

" We have multiple suppliers for several components. How do I make sure all combinations are working? "



Software Regression Testing

Charging Infrastructure

- Multiple AC/DC charging standards
- All markets in one environment

High Degree of Automation

- Ready for CI/CD
- Reuse of MiL/SiL/HiL
- Test cases

Robotic Driver

Repeatable driver diffe-rent driver characteristics available

Multiple Vehicle Variants

Using the same platform to be tested in one setup

Benefits

- 24/7 testing possible
- Automated reporting and evaluation
- Almost certification setup with automation capabilities
- Less tests needed due to repeatable driver inputs

Driveability / Mode Change / Operating Strategy Optimization / Predictive Controls

" How did they get the driving performance so great? "

© Daimler AG
Mercedes-AMG GT 4-Door Coupé: A class of its own
Source: https://group-media.mercedes-benz.com/marsMediaSite/en/instance/ko/Mercedes-AMG-GT-4-Door-Coup-A-class-of-its-own.xhtml?oid=41351757

Driveability and Performance Calibration / Validation for Hybrid Powertrain

High Dynamic Wheel Speed Control

For high dynamic driving situations e.g. launch control, ABS braking

Optimization on System Level

- ICE, e-drive, gearbox, battery
- Up to 200 km/h

Drivability Reports

Objective evaluation of the Longitudinal accelerations by AVL-DRIVE™

DoE

Supported test execution and parameter optimization

Benefits

- 3 times more output compared to road testing
- DoE-based System optimum
- Less risk for high-speed maneuvers

Calibration and Verification of Safety Features

" How can I frequently test the safety features of my high-performance vehicle in a safe manner? "

Agile Development	Increasing Vehicle power	New vehicle functionalities	Electrification
Development becomes more flexible and agile, which leads to higher frequency of SW releases	High performance vehicles → high speed road testing is always critical	New vehicle architectures enhance new vehicle functionalities like torque vectoring	New and additional components to be tested

Safety functions have to work where the standard function fails …

Calibration and Verification of Safety Features

High Fidelty Vehicle Models

To simulate longitudinal and lateral vehicle dynamics

Extended Safety Concept

To control HV components even with HV power supply “on”

GPS Simulation

Supporting GPS route simulation according to vehicle speed and steering

Residual Bus Simulation

Communication to missing components and xCUs can be simulated

Benefits

- Highly automated testing equipment for fault insertion
- 80-90% of in vehicle safety calibration and verification activities could be performed on PTTB
- Re-use of existing test cases from MiL/SiL/HiL

Reduction of Test Vehicles for Test Trips

" To test all variants under all conditions I need to take all of them to the relevant locations. "

Chips sold out!

" I don't get my planned test vehicles. How shall I complete my test trips? "

Non-Standard Calibration in Altitude and Climate Cell (Test Trip Alternative)

Remote Testbed Access

Full control of application PC and testbed control possible

Multiple Vehicle and Payload Variants

Instant change of vehicle configuration

Dynamic Altitude and Climate Control

- Road simulation up to 5000 m / -40…60°C
- Up to 200 km/h

Up to 16 cold WLTPs per day

- Rapid cool down system
- 24/7 operation

Benefits

Season independent (e.g. winter trip in August)

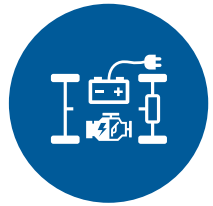
Controllable ambient conditions – 24/7 environment simulation including dynamic altitude simulation up to 165 m/min

Less vehicles needed for same program

Key Topics and Takeaways

Faster time-to-market with AVL system testbeds

Automated test data reporting



Safe test environment for critical driving maneuvers

Contact Information

AVL List GmbH
Hans-List-Platz 1
8020 Graz
Austria

+43 316 787 1763
+43 316 787 8499
+43 316 787 5003

vaughan.morton@avl.com
christian.weiss@avl.com
andreas.haspl@avl.com

https://www.avl.com

Question & Answer

www.avl.com