The Hidden Story Behind Your Data

A Data-Driven Approach to Boost Development Efficiency

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Today’s Presenters

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22 years in automotive industry

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Product Line Manager
Data Intelligence

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20 years in automotive industry

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Today’s Agenda

1. **Intro**
2. **Motivation**
3. **Processes & Tools**
4. **Use Cases**
5. **Conclusion**

Facts and Figures

AVL

Global Footprint

Represented in 26 countries

45 Affiliates divided over 93 locations

45 Global Tech and Engineering Centers (including Resident Offices)

1948

Founded

11,000

Employees Worldwide

12%

Of Turnover Invested in Inhouse R&D

70+

Years of Experience

65%

Engineers and Scientists

2,500

Granted Patents in Force

97%

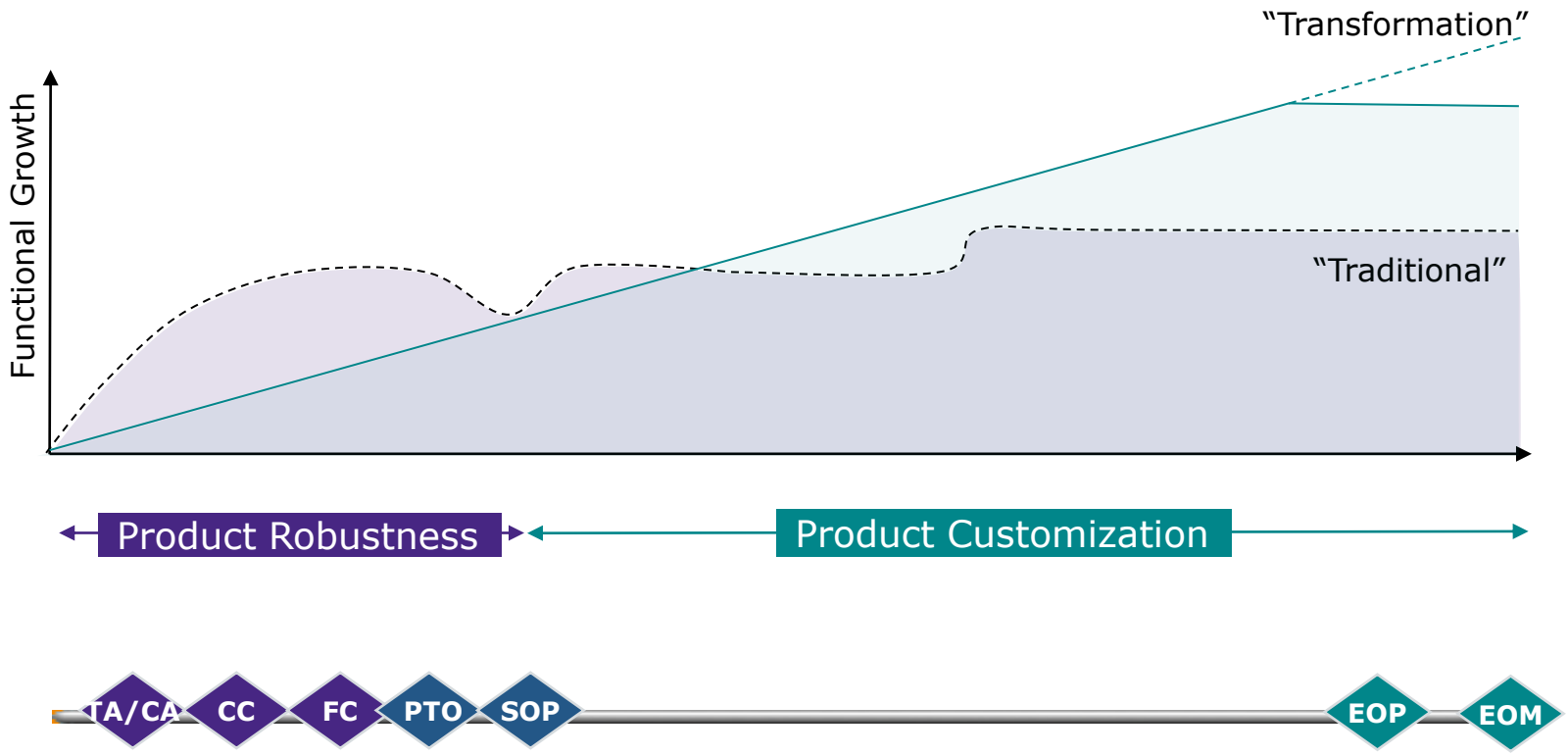
Export Quota

Key Drivers and Challenges for Digitalization

- Pressure on cost and quality
- Connected ecosystem
- Sustainability
- Software-defined product
- Data-driven business

Functional Growth and Transformation of Development Paradigm

The product at SOP needs to be robust but isn't final



Product Development & Maintenance → *Lifecycle Development*

Updates for debug → *Functional Growth*

Transformation Drivers

- §§ Changing Requirements
- Time to market
- $ New Business Models

Requirements

IT Operation
Continuous development
Connectivity & OTA updates
Digital Services

Current Environment of Engineering Teams

David
Validation Engineer

- Desktop tools like Excel, Diadem, Concerto
- No or little programming skills
- Manual data analysis and visualization
- Office Tools for Reports

Alex
Data Analyst

- Bigdata tools Python, PySpark, Matlab
- Desktop tools
- High skill level in programming
- No infrastructure skills

Challenges for Engineering Teams

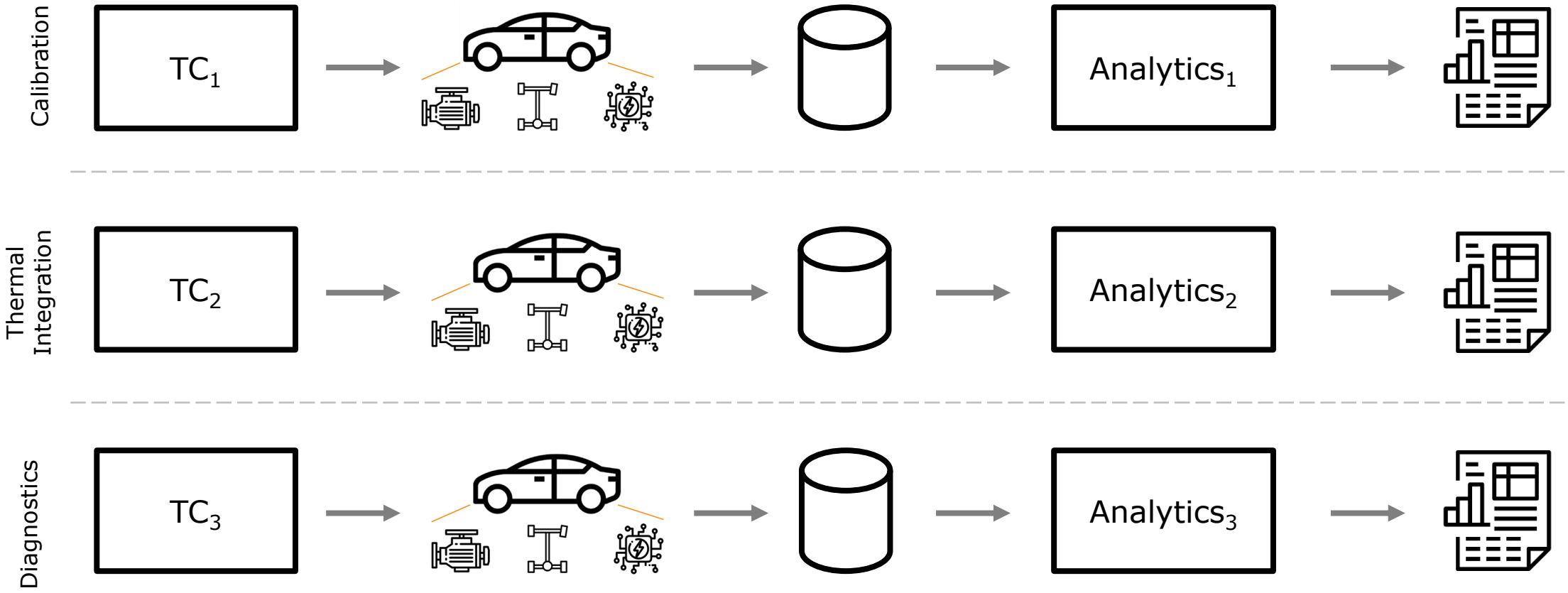
David
Validation Engineer

- Long lasting test with lots of data
- Different file formats
- 10x as much data than can be analyzed
- Long over hours to generate reports
- No idea how to reuse data

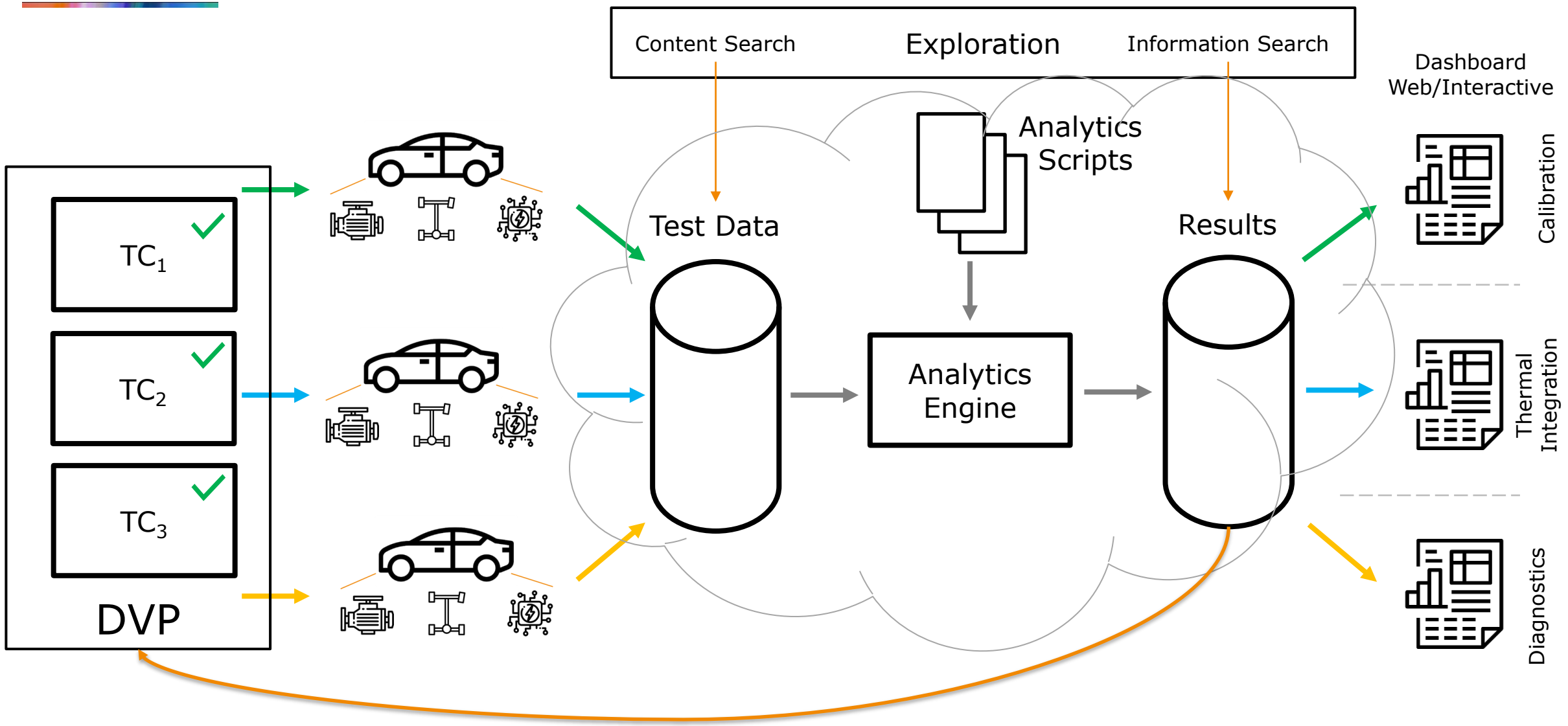
Alex
Data Analyst

- Lot of manual work
- Hard to manage data
- Multiple different formats
- Too many technologies
- Too much groundwork

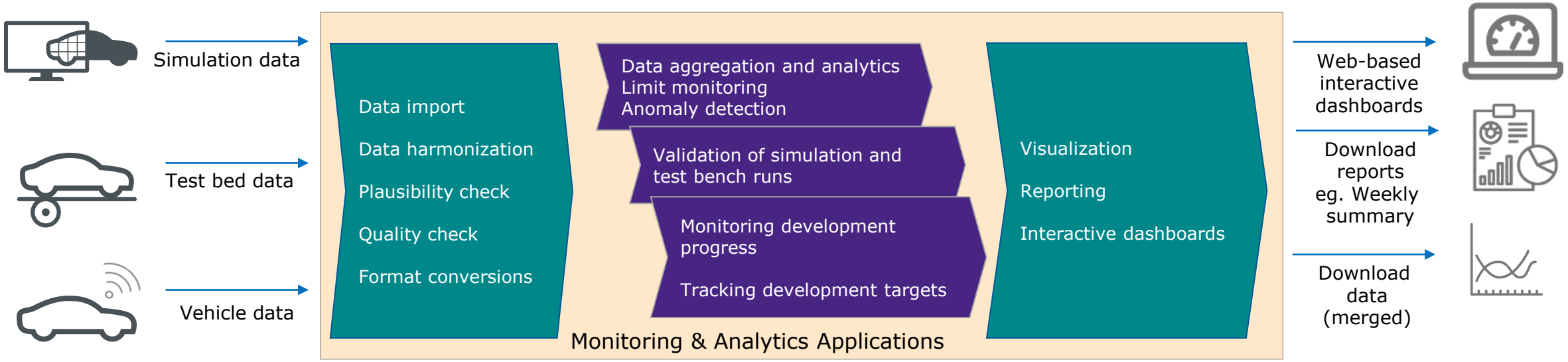
Local Testing and Analytics Silos

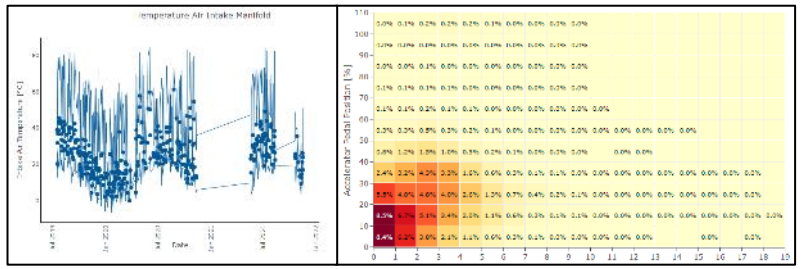


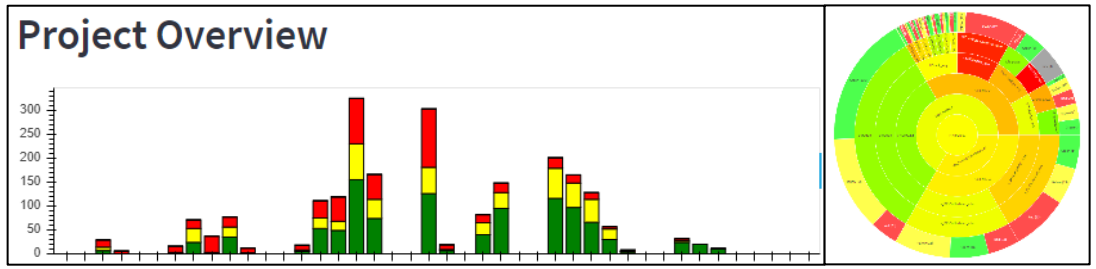
Synergetic Use of Analytics Results



Boosting Development Efficiency with Data Platform







Automation in Analytics and Reporting → Transparency → Immediate feedback and control

Event-based Analytics

Base idea

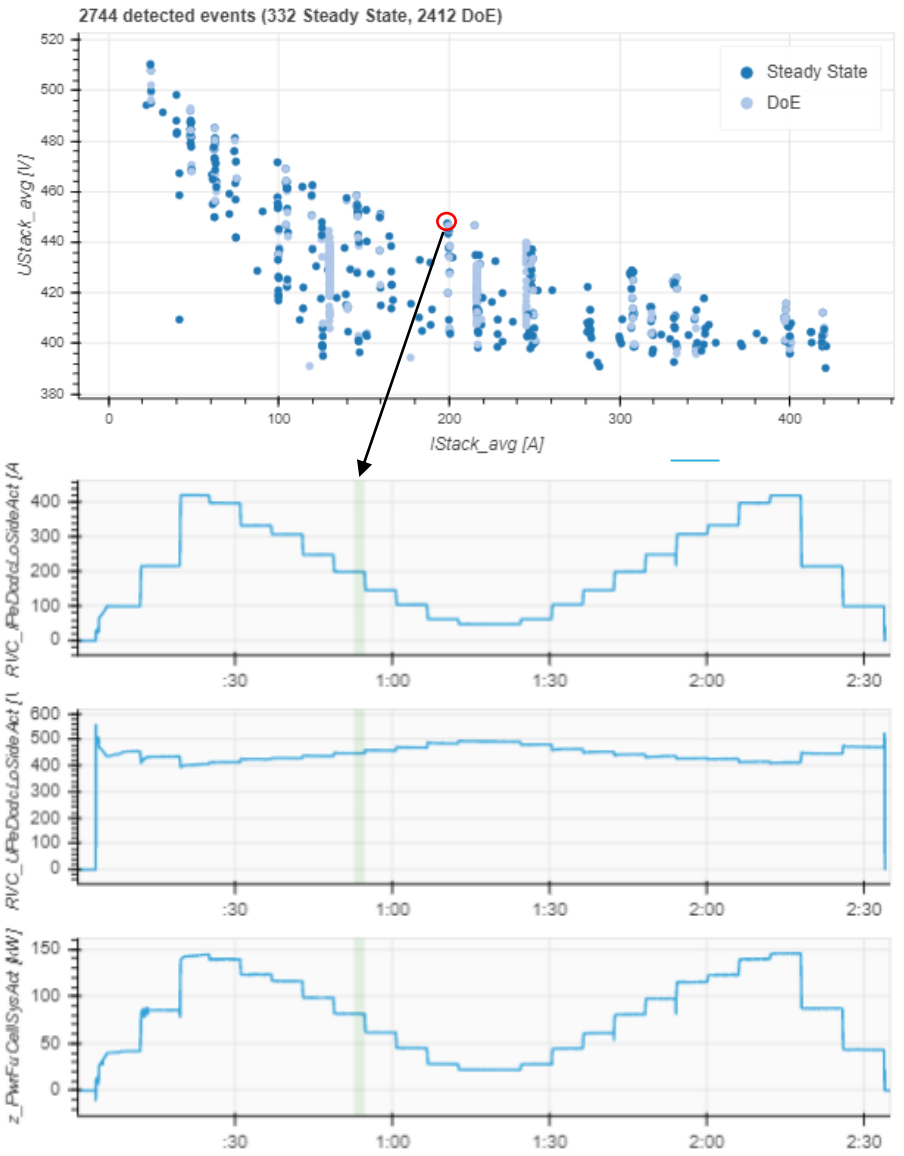
1. Calculate events and aggregates upfront
2. Analyze data based on aggregates instead of measurements

Benefits

- Increased comparability of different test cycles due to event comparison instead of measurement comparison
- No performance issues by analyzing ALL measurements at once as access to raw measurements is not required
- Fast processing for new event

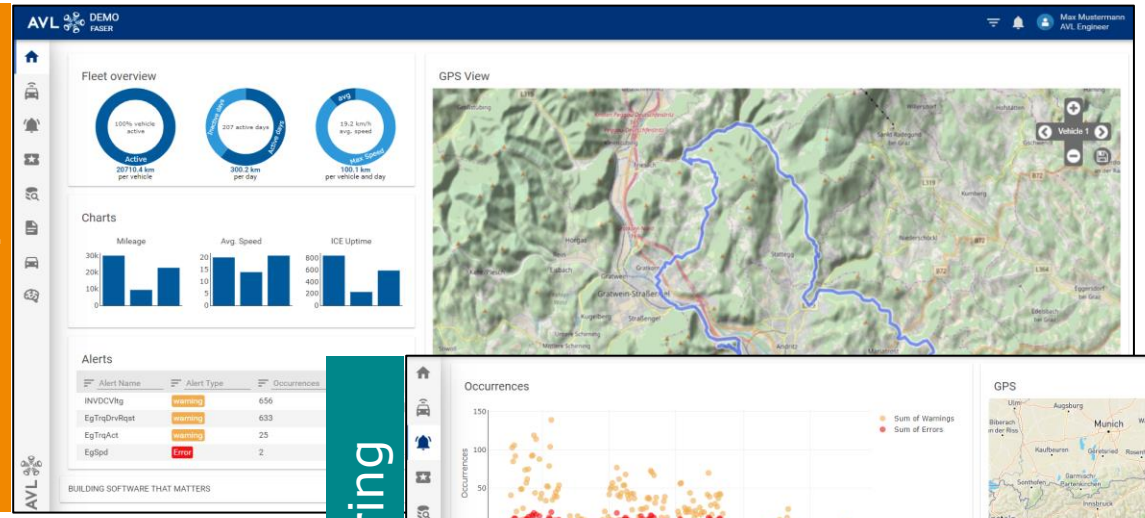
Examples (all processed under < 2h)

Project	Measurements	Events	Aggr./Ev.	Results
Fuel Cell	1.019/357h/250GB	24.431	4.001	97 mil.
Battery	2079/837h/638GB	86.139	5.921	510 mil.
Function Verification	5.373/1.108h/874GB	71.838	1.496	107 mil.



AVL Ecosystem for Analytics Services

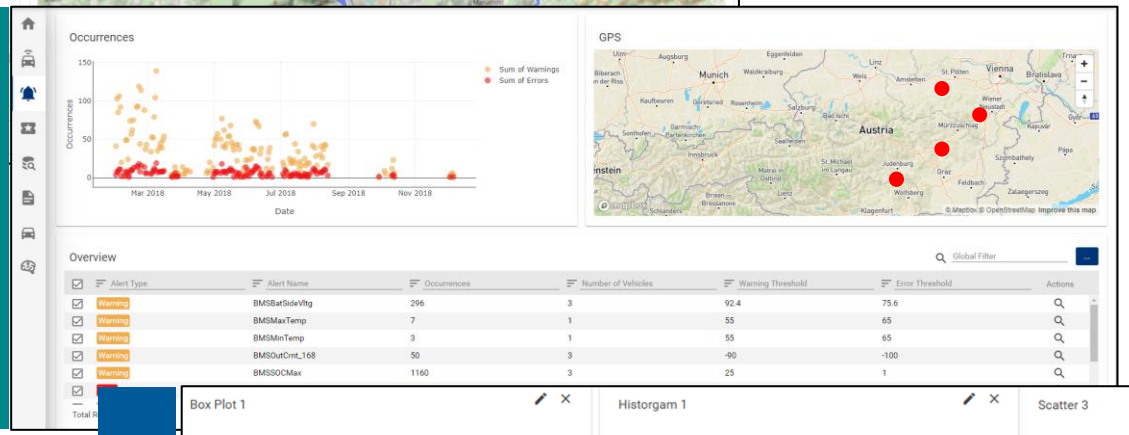
Analysis



Key Features:

- Web-based data analytics
- GPS Vehicle tracking
- Data upload and processing
- 100% Transparency on project progress
- Option: Integration of Meta-data from digital logbook (tablet app for drivers)

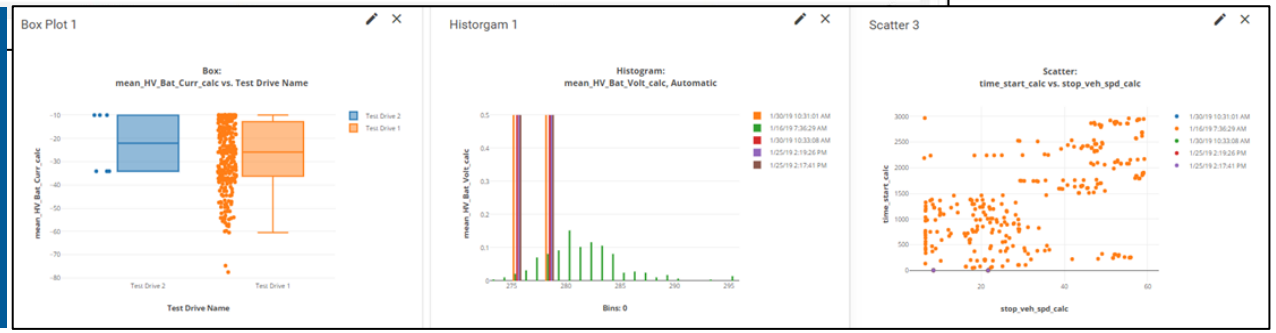
Monitoring



Key Features:

- Visualization of DTCs, Knock Events, etc.
- Fast analytics of issues
- Easy (merged) data download
- Customized, project specific data analytics

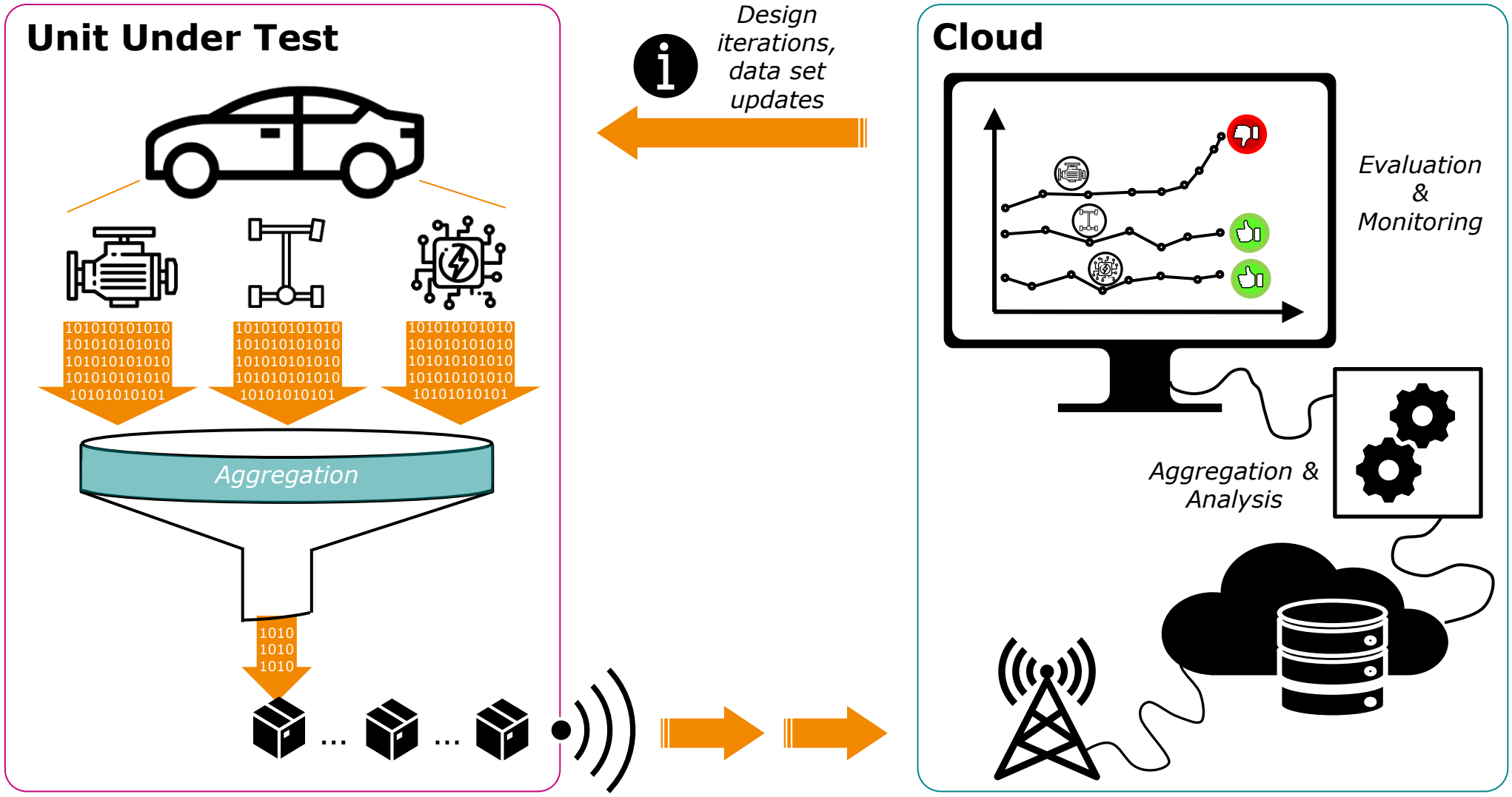
Reports



Key Features:

- Automated report generation
- Customized dashboards
- User self-service analytics

Enhanced Data Flow for Remote Analytics



Solutions for Engineering Teams

David
Validation Engineer

Alex
Data Analyst

A platform providing **Visual Data Analytics** for **Non-Data Analysts** in the area of Component and Vehicle **Verification and Validation.**

It allows engineers to unlock the **power** contained in **oceans of** data collected from a variety of sources and control units.

Enabling **data analysts** to implement **automotive applications** for their end users **focusing on logic** and **data presentation.**

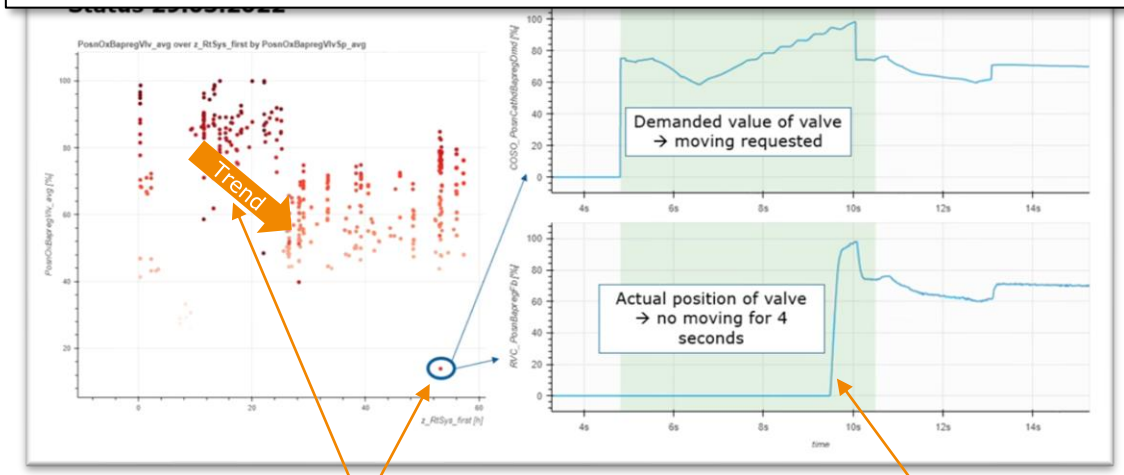
Extendable, open and **fully integrate able** in the **development processes**

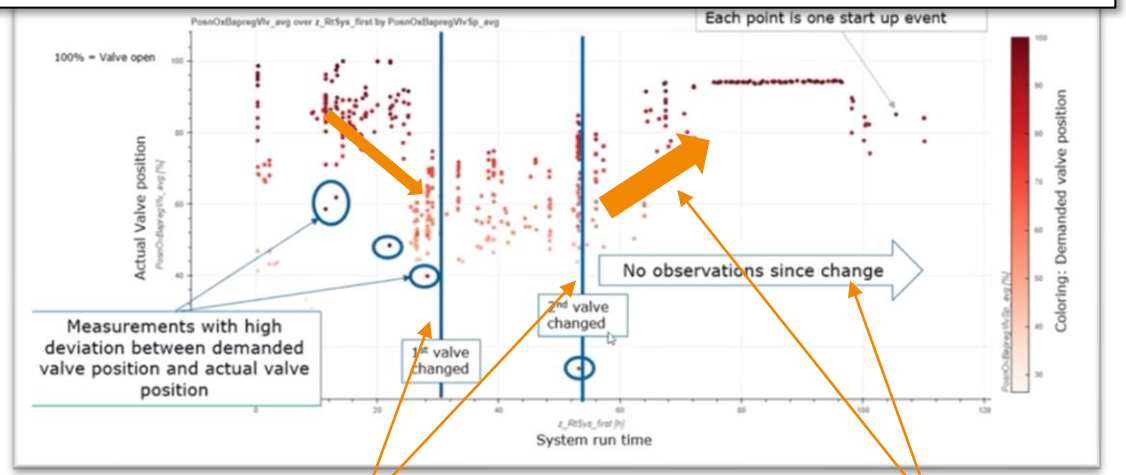
Fuel Cell Analytics Use Cases

Public

Use Case – Backpressure Mis-behavior

Problem statement: Identify issue, investigate root cause, decide on the right technical action and monitor!





Find the needle in the haystack!

Detect a **continues decrease on backpressure** in the system

What is going on?

Immediately **identify relevant "events"** and investigate the root cause (→ lagging valve opening)

Take the right deci

Use evidence in data to **exchange the right component** in the system (EGR valve)

Monitor!

Continuously monitor the measures with zero additional effort

Reactive/on-demand event detections and aggregations

Pro-active event detections and aggregations

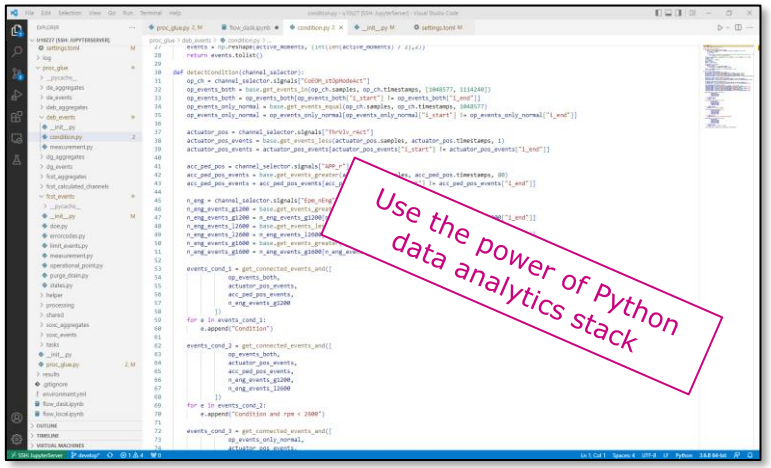
Preserve and gain Know-How / Information

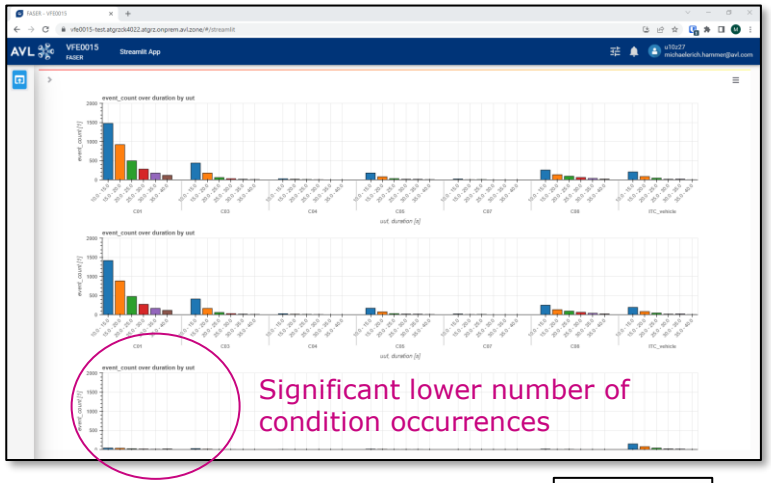
As root cause is known now → develop **dedicated event detector** for EGR valve opening

Demands highly performant analytics because we want to **treat historic data** also!

Use Case – Optimal Diagnostic Enabling Condition

Problem statement: Select the optimal "enabled condition" for diagnostic monitor by re-use of historic measurement data already collected!





Formulate algorithmic

Formulate different variants of "enabled condition"

Process all historic data!

Utilize scalable analytics framework to apply different algorithms an **all historic data**

Take the right decision!

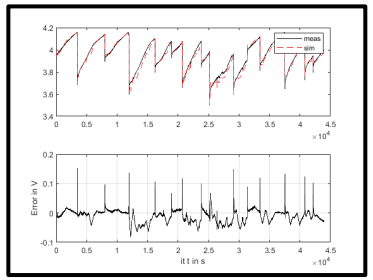
Activation frequency and timing could be easily explored, and influence factors identified

Battery Analytics Use Cases

Public

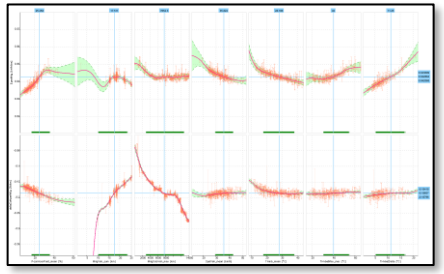
Fleet Data Analytics for Battery Electric Vehicles

SoH Estimation
(RC-Modelling for single vehicle)



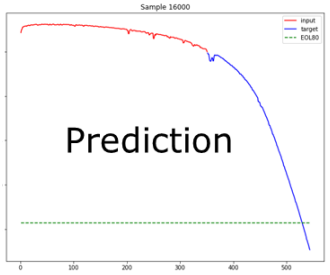
Current RC & SoH for each vehicle

Range and SoH
(Meta modelling for complete fleet)



Influencing factors on range & SoH for complete fleet

Lifetime Prediction
(Federated learning)



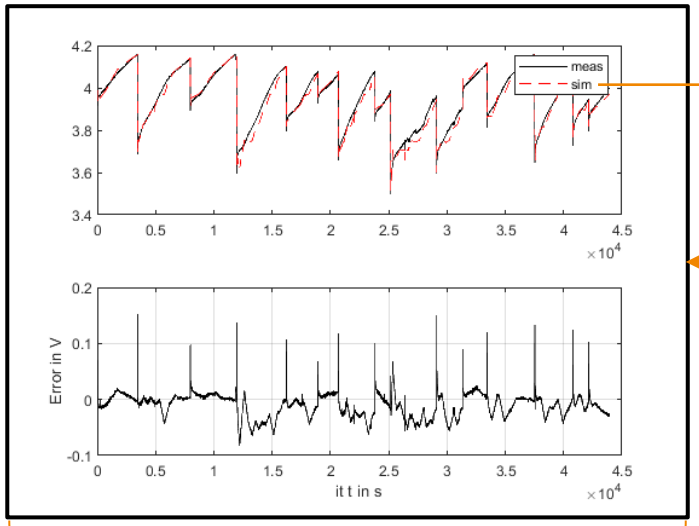
Remaining Useful Life for each vehicle

Estimation of Battery health based on RC parameter identification for dynamic driving cycles for each vehicle.

Neural Network model training for range and SoH depending on driving and ambient conditions based on the complete fleet

(Federated) machine learning approach to predict the future behavior of the SoH based on the historic driving and ambient conditions.

High Voltage RC Battery Model (Re-)Training



Validation of simulated voltage

Model validation

HV battery (pack, module, cell) parameters (U, I, T)

In-Vehicle measurements

Data Pre-Processing

(event detection and aggregation)

- Transient event detection for charging/discharging
- Segmentation into time windows (e.g. month)

Event segregated time series data

2-RC Model Parameter Fitting

- Optimization method to autofit 2-RC model parameters

Model Parameters

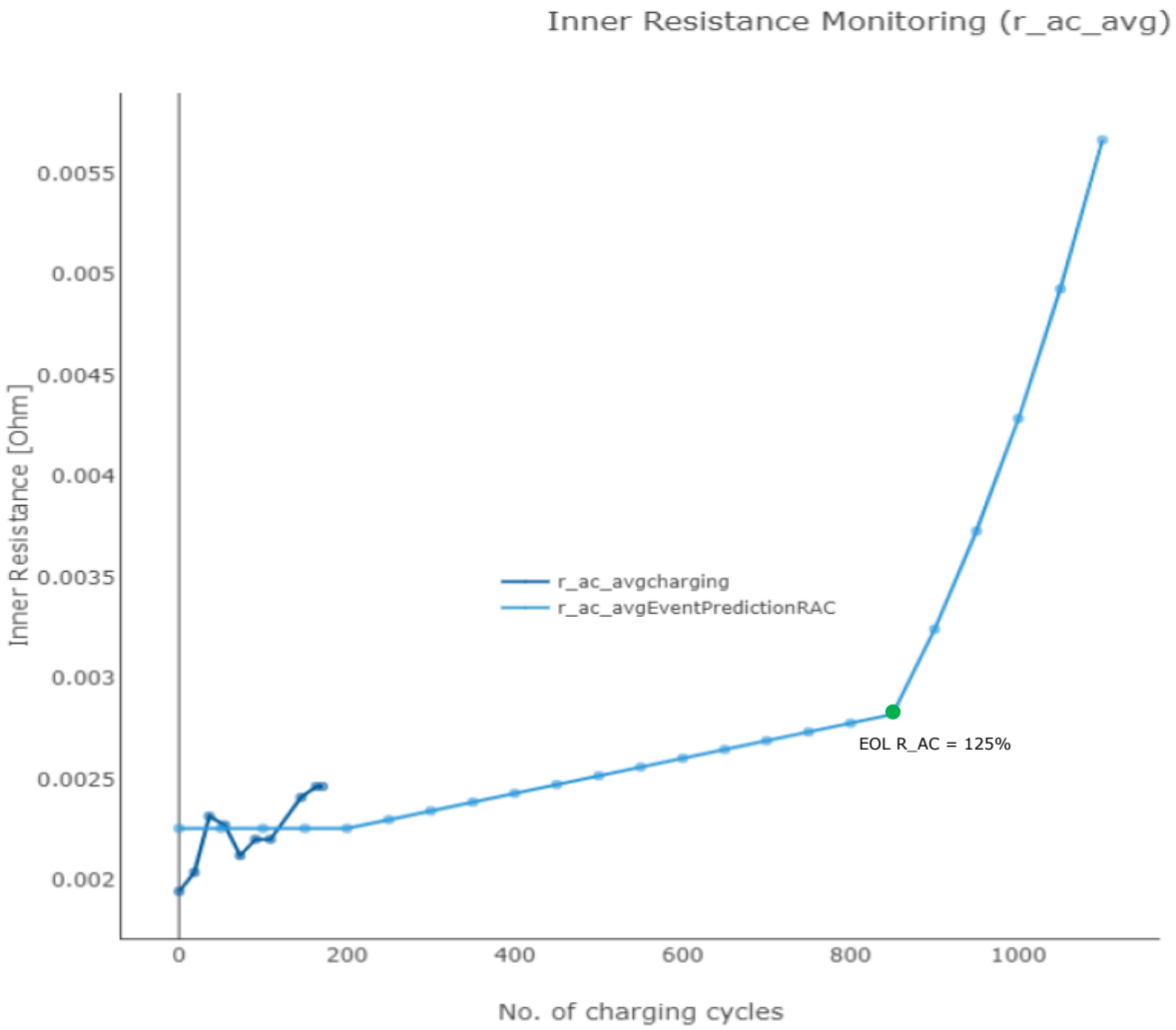
Age depended 2-RC Model

$R_0, R_{BV}, \tau_{BV}, R_{WB}, \tau_{WB}$

Fleet optimized SoH model

Age depending behavioral battery model creation from fleet data

Inner Resistance Monitoring - Results



- Estimation of inner resistance R_{AC} over full charging cycles
- Light blue line —— is the expected behaviour of the inner resistance over time
- For a more accurate reference, real data can be used and improved using a regression model which is updated based on the incoming data
- Dark blue line —— is the estimated R_AC using the equivalent RC circuit model

- The estimated R_AC can be used as an indicator for monitoring the battery condition.
- Number of full charges represent the frequency of usage of the battery

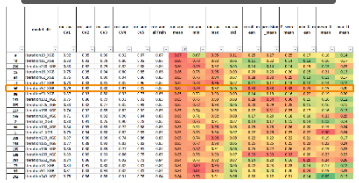
EV Adaptive Range and HV Battery SoH Prediction

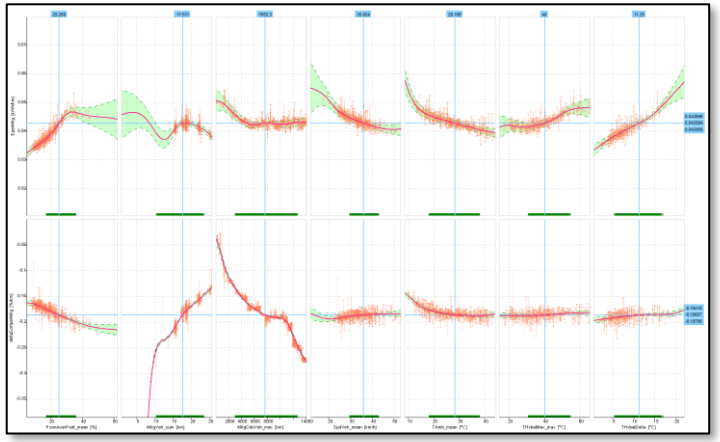
Result
(events and aggregates)

Model/Training/Validation parameterization

Model training and selection

Multi dimensional response surface model





No.					PosnAcerPedl_me [%] Variation	MilgVeh_sum [km] Variation	MilgOdoVeh_max [km] Variation	SpdVeh_mean [km/h] Variation	TAmb_mean [°C] Variation	THvbatMax_max [°C] Variation	THvbatDelta [°C] Variation	EperMilg [kWh/km] Response	deltaSoHperMilg [%/km] Response	dSOCperMilg [%/km] Response
4999	19	☑			13.053	12.859	5228	25.707	31.431	42	17	0.032012	-0.27996	0
5801	25	☑			1.3238	0.56175	1557	10.073	31.551	40.5	1	0.013494	-4.9844	-1.7802
5896	25	☑			6.9416	16.092	3248	19.825	33.091	46.5	21.5	0.02222	-0.19886	-1.9028
2271	7	☑			7.118	15.417	3744	19.444	26.654	35.5	2.5	0.022235	-0.15567	-1.9394
4944	19	☑			9.0126	25.647	3976	25.049	32.565	40	15	0.022058	-0.12477	-1.9558
3789	13	☑			8.3822	31.62	3115	22.974	36.765	38.5	4.5	0.022839	-0.088551	-1.9711
3807	13	☑			13.243	31.568	3585	27.009	44.398	39	6.5	0.022607	-0.10137	-1.98
4986	19	☑			9.3128	25.722	4953	25.191	31.308	41.5	16.5	0.022759	-0.13996	-2.0049
3689	13	☑			10.251	23.531	1269	25.033	25.303	30	4	0.02312	-0.10199	-2.0071
4542	18	☑			13.206	31.625	1430	32.723	37.603	42	17	0.023027	-0.088537	-2.0079
3687	13	☑			10.424	23.623	1221	25.021	27.522	33.5	4	0.023089	-0.1016	-2.0108
3691	13	☑			9.3143	23.524	1318	23.938	26.346	31.5	4	0.022572	-0.10202	-2.0158
2362	7	☑			9.6307	21.854	5564	23.809	31.374	44	2.5	0.023396	-0.12812	-2.0252
270	2	☑			7.9213	15.422	5224	19.629	26.1	37.5	3	0.023361	-0.18156	-2.0305
2367	7	☑			5.853	15.405	5659	17.447	27.035	43.5	4	0.023193	-0.18176	-2.0383
304	2	☑			9.3105	21.876	5937	24.41	31.985	46.5	3.5	0.023537	-0.12799	-2.039
5163	20	☑			7.9609	29.601	2866	20.858	26.436	34.5	5.5	0.023437	-0.13513	-2.0405

Every row represents one event (Example: "driving" – from standstill to next standstill)

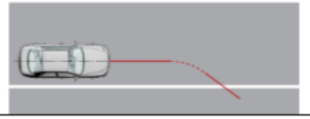
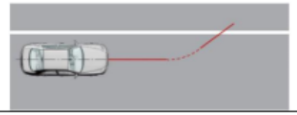
All aggregates which can be considered as variational influence to energy consumption

Response properties from the powertrain system (mainly energy spent per drive event, but as in this example could also include e.g. SoH estimation from BMS)

Functional Performance Verification Use Cases

Public

Test Case: Lane Departure Warning

No.	Scenario description
1.	Solid line- Departure to right side of the vehicle 
2.	Solid line- Departure to left side of the vehicle 

- Scenario: **Lane departure**

- Start condition:
  - Line detection quality left or right >= 80%
  - Ego vehicle lateral speed >= 0.1m/s
  - Absolute DTL left or right < 0.4m
  - Heading towards left or right line (DTL_gradient_smo5 > 0.015m/s)

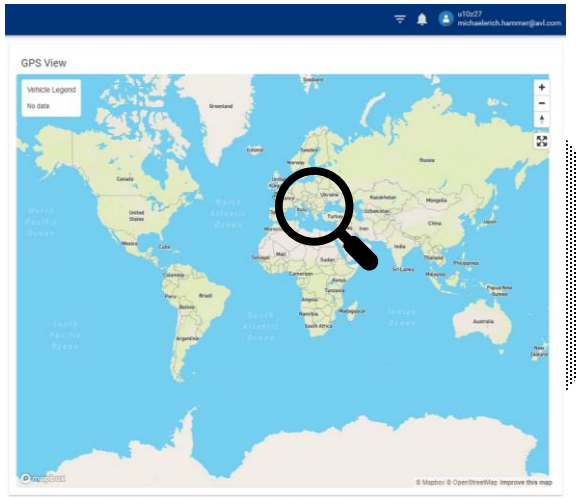
- End condition:
  - Lane control is good (Lane lateral deviation inside 0.15m for 1s)
  - Ego vehicle is standing

Additional Parameters	Unit	Description
LDW_active	-	Lane departure warning signal occurred (1/0)
Time_lane_departure_warning	s	Timestamp at which lane departure warning occurred
Line_type_L/R	-	Line marking type (solid, dashed, road edge,…)
Distance_LDW_active	m	Lateral distance to line marking when LDW becomes active
Ego_speed_x_lc_start	km/h	Ego vehicle speed longitudinal when vehicle begins lane change
Ego_speed_y_max/min/mean/lc_start	m/s	Maximum, minimum, mean, lane change start Ego vehicle lateral speed
Lane_curvature	1/m	Average lane curvature during the maneuver

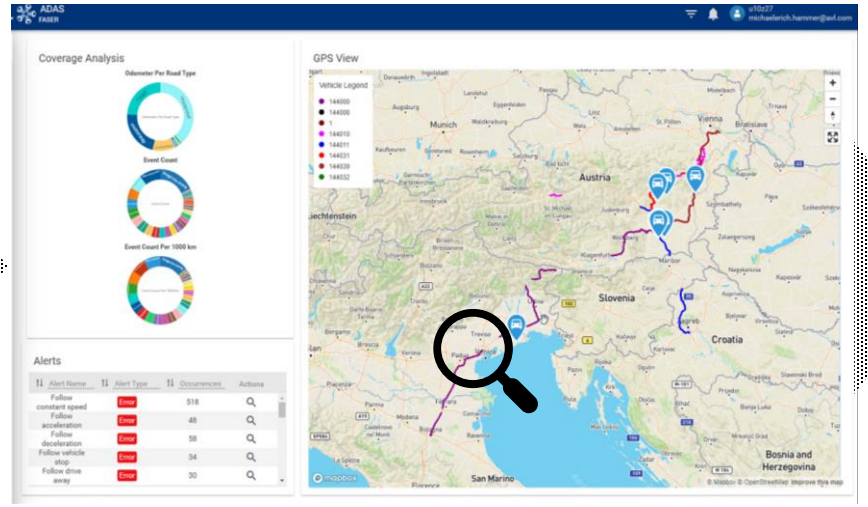
Passed criteria: LDW warning indication latest DTL -0.3m and/or driver assistant pressed confirmation button

Information and Reporting

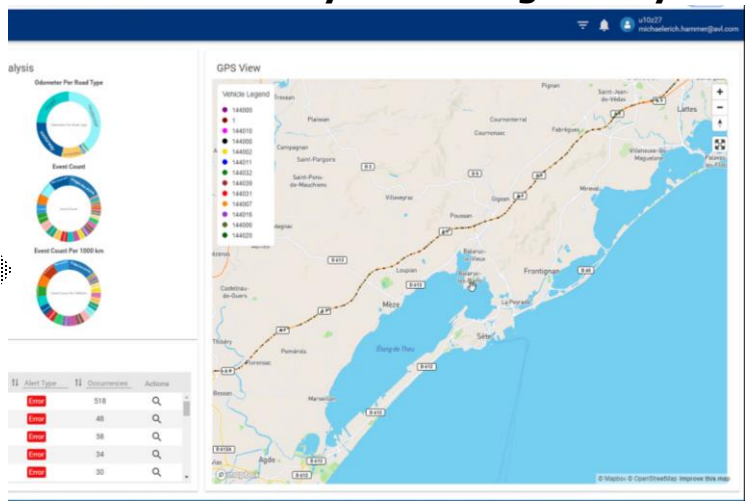
Global Locations



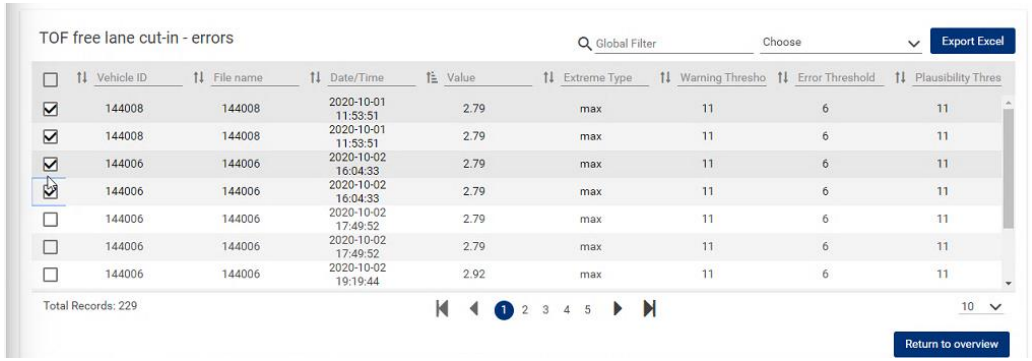
Fleet Monitoring Each Vehicle in Real-time



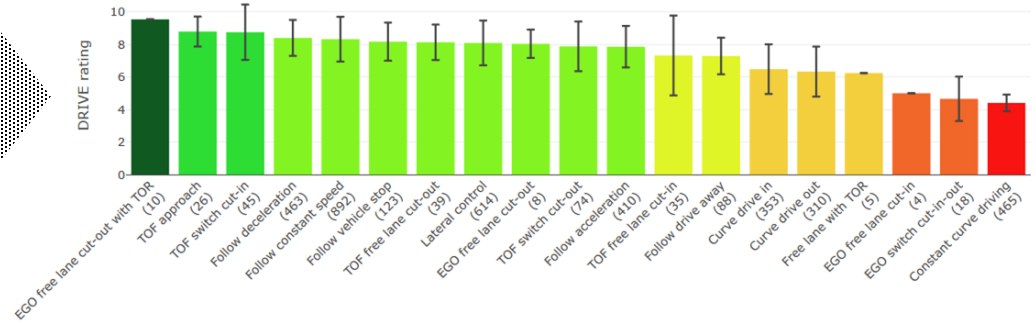
Scenario Diversity & Coverage Analysis



Efficient Detection of Performance Issues



Performance KPI Fulfillment



Flexible Maneuver Statistics

Maneuvers filtered by …

ODD

speed range

rain intensity

country

Example for Performance Monitoring and Reporting

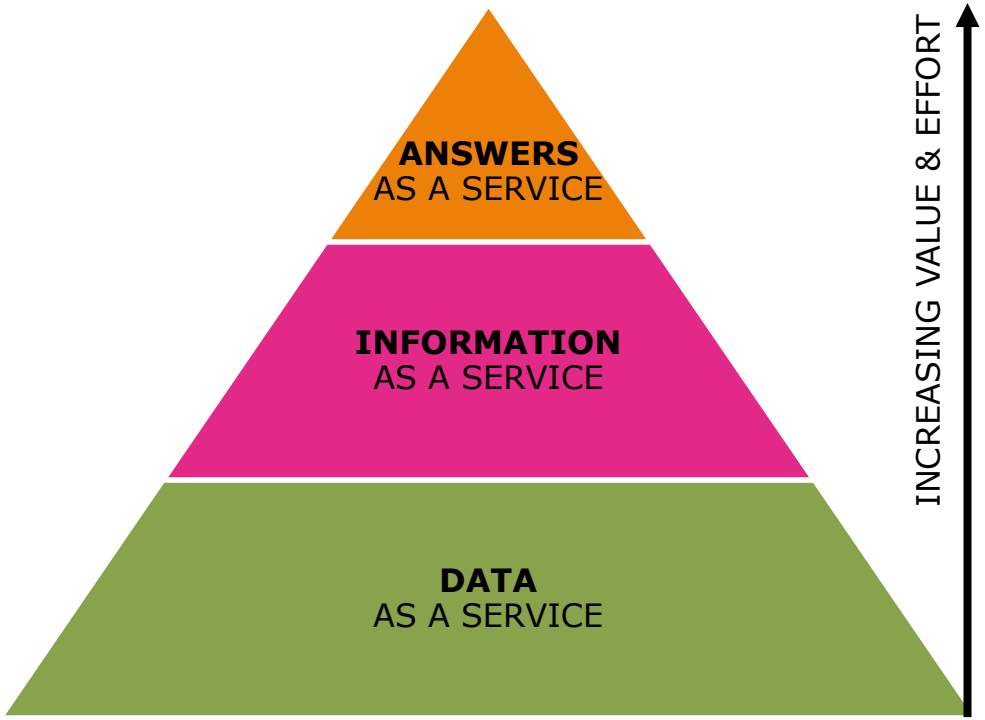
Daily reports can be configured according to customer needs, showing different evaluation charts

LDW coverage analysis				
	lateral departure velocities 0,2 - 0,5 m/s	lateral departure velocities 0,2 - 0,5 m/s	lateral departure velocities 0,2 - 0,5 m/s	lateral departure velocities 0,2 - 0,5 m/s
Event speed	Day Scenario right	Day Scenario left	Night Scenario right	Night Scenario left
65	7	2	3	4
70	7	6	4	2
80	2	4	3	3
90	6	7	6	6
100	5	4	3	8
110	6	6	4	3
120	0	2	0	6
130	7	6	7	1

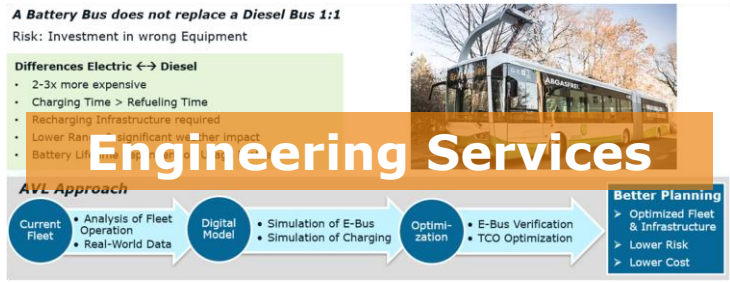
Poor event coverage identified!

References and Offering

Business Offerings

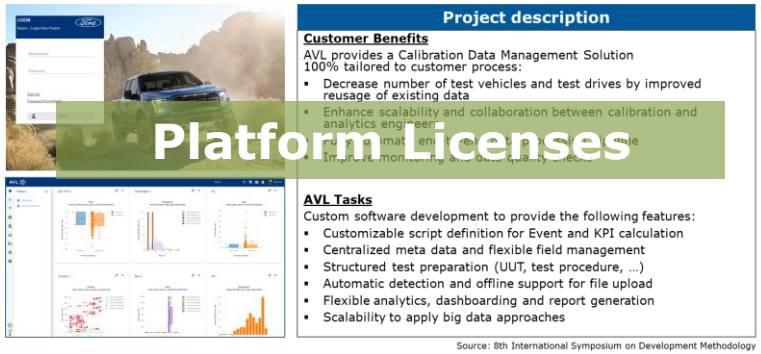


Answers as a Service

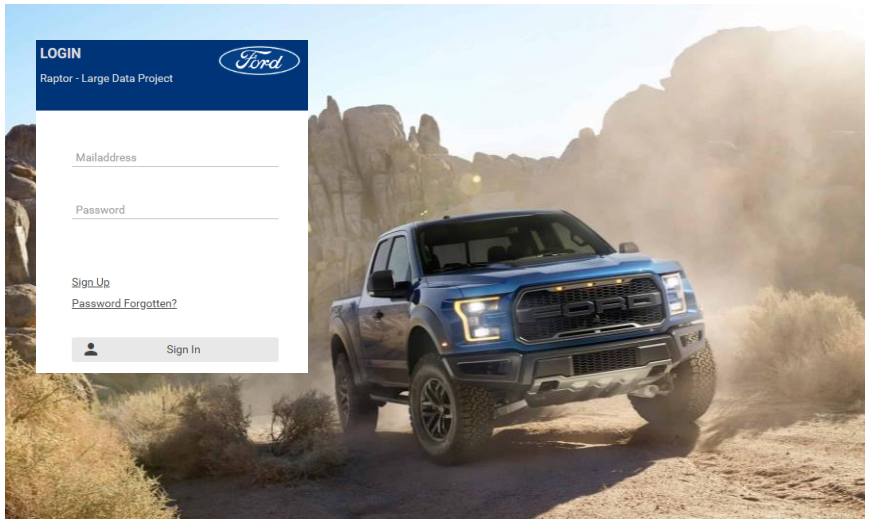


Information as a Service

Data as a Service



Customer: Ford Motor Company
Project: Calibration Data Management



Project description

Customer Benefits

AVL provides a Calibration Data Management Solution 100% tailored to customer process:

- Decrease number of test vehicles and test drives by improved reusage of existing data
- Enhance scalability and collaboration between calibration and analytics engineers
- Fully automate end-to-end data processing pipeline
- Improve monitoring and data quality checks

AVL Tasks

Custom software development to provide the following features:

- Customizable script definition for Event and KPI calculation
- Centralized meta data and flexible field management
- Structured test preparation (UUT, test procedure, …)
- Automatic detection and offline support for file upload
- Flexible analytics, dashboarding and report generation
- Scalability to apply big data approaches

Source: 8th International Symposium on Development Methodology

Customer: Suzuki Motor Corporation

Project: Digitalization of Validation Fleets to Minimize Testing Mileage

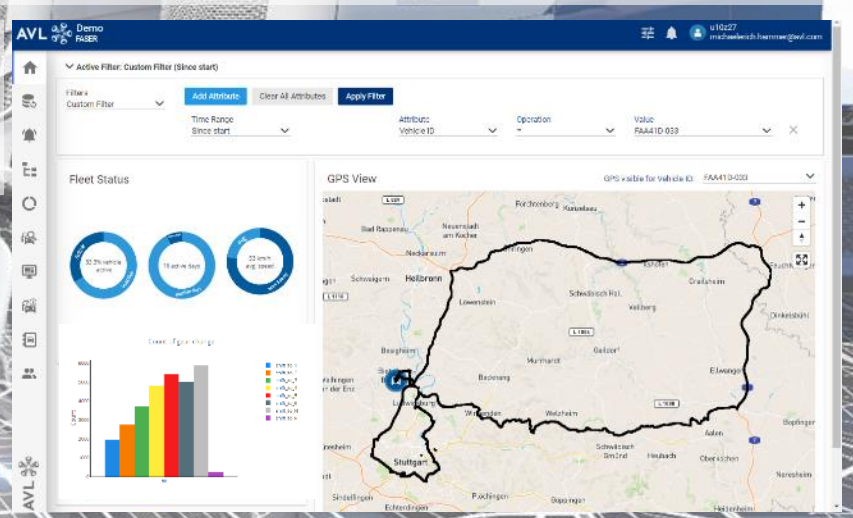
Challenges:

- **Functional Validation with maximum testing coverage and minimum mileage**
- Data processing too **time consuming**
- High effort for **manual reporting**
- Delayed problem identification

Benefits:

- **100% Transparency**
  Real time fleet status, durability target monitoring
- **Immediate** feedback to **control fleet operation**
  → **Reduced Mileage**
- **Automatic report creation**

AVL Approach:
End-to-end
data solution



Joint presentation with Suzuki Motor Company at the 9th International Symposium on Development Methodology

Customer: Public Transport Organization
Project: BEV-System Requirement Analysis and Design

A Battery Bus does not replace a Diesel Bus 1:1

Risk: Investment in wrong Equipment

Differences Electric ←→ Diesel

- 2-3x more expensive
- Charging Time > Refueling Time
- Recharging Infrastructure required
- Lower Range & significant weather impact
- Battery Lifetime dependent on Usage Profile

AVL Approach

Current Fleet
- Analysis of Fleet Operation
- Real-World Data

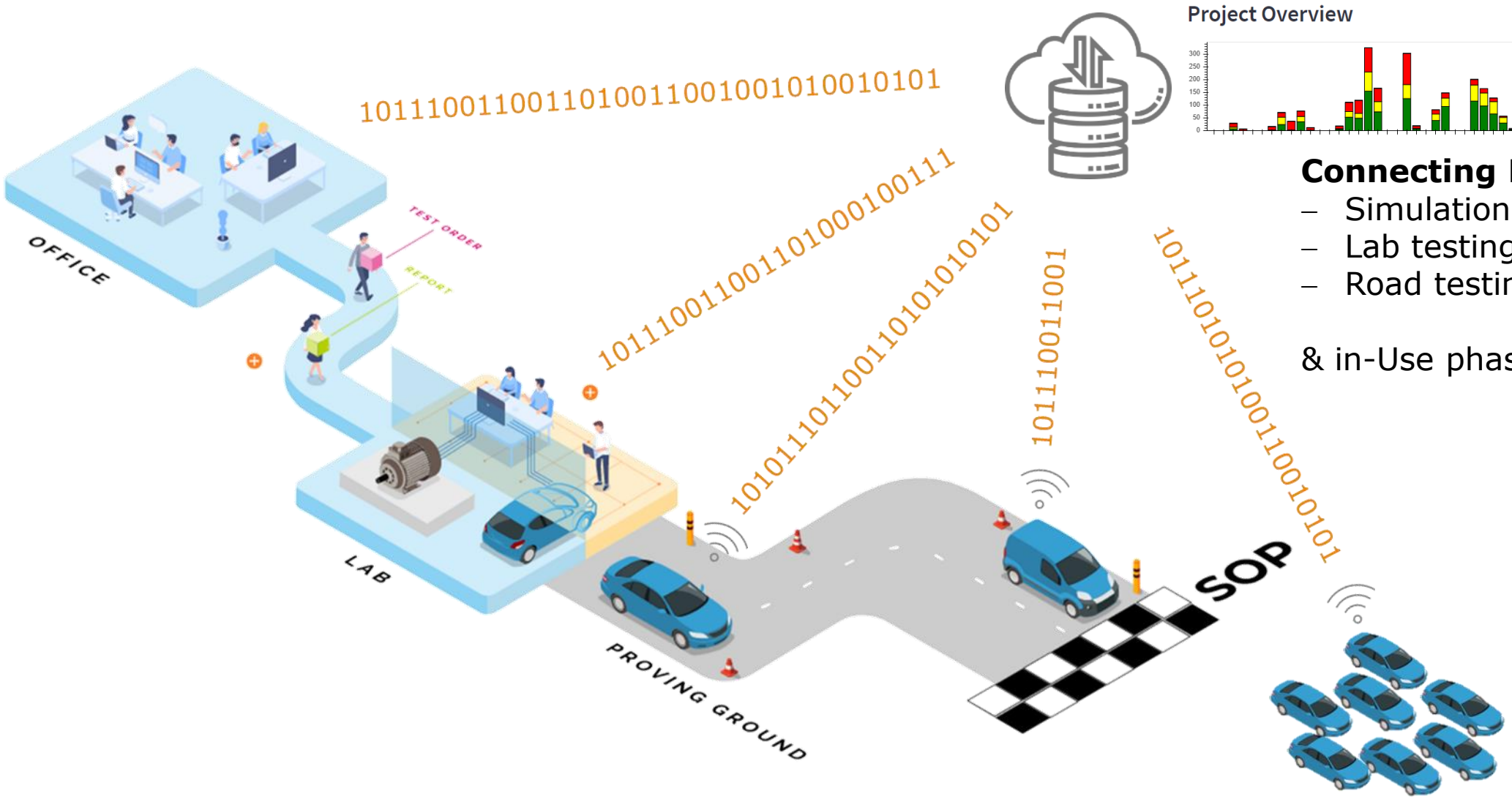
Digital Model
- Simulation of E-Bus
- Simulation of Charging

Optimi-zation
- E-Bus Verification
- TCO Optimization

Better Planning
- Optimized Fleet & Infrastructure
- Lower Risk
- Lower Cost

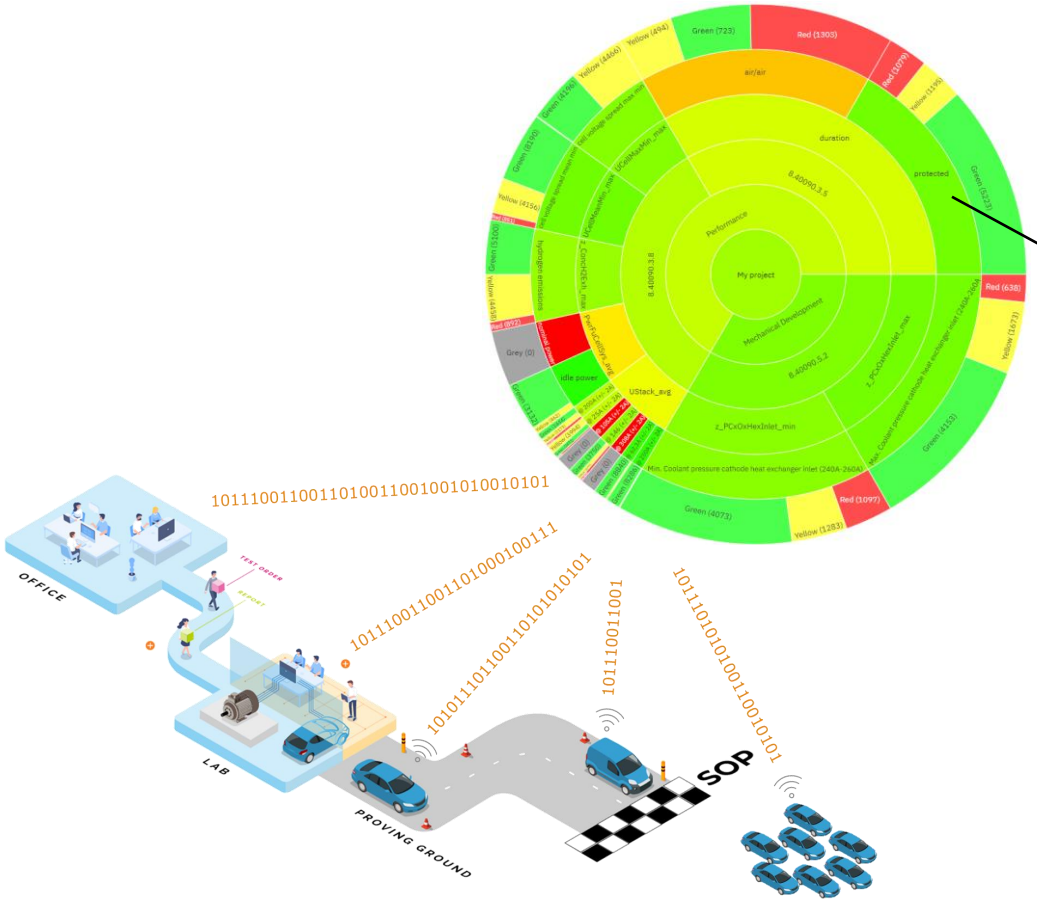
Summary and Conclusions

Boosting Development Efficiency with Data Platform

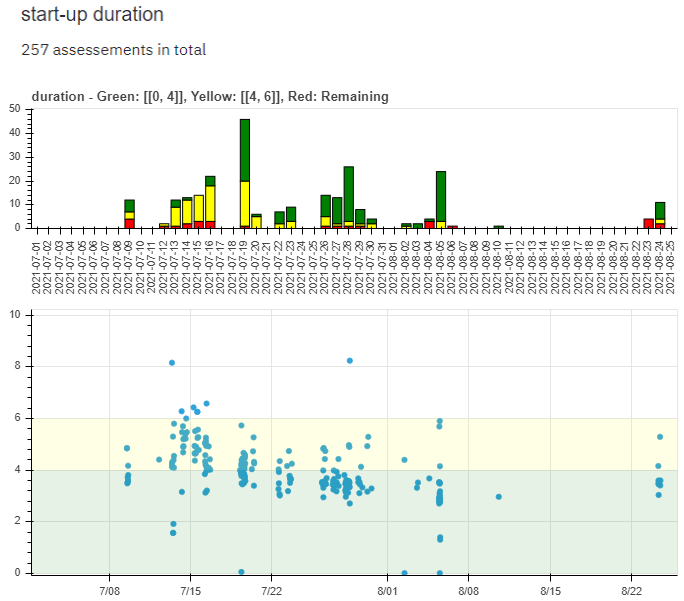


Data Platform Enables Process Monitoring

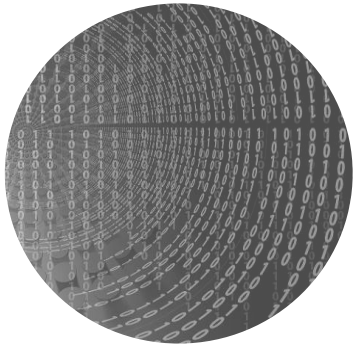
Interactive Sunburst Chart for immediate status check of all DVP tasks and sub-tasks.



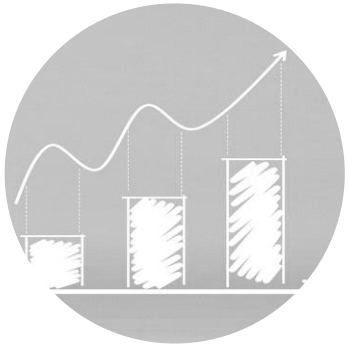
Drill-down to understand the history of the development progress based on detected relevant events and their corresponding quality targets.



Conclusions and Benefits



Accelerated development by reuse of historic data



Same data analytics methodology applied to simulation, test field, validation fleet and even end-customer vehicles create new insights and boosts development efficiency

New big-data technology enables interactive data exploration and self-service analytics of thousands of measurements

Democratization of data instead of re-testing has a huge cost saving potential

Let’s stay in touch and QA

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