Battery Health Monitoring for Enhanced Electrical Vehicle Performance

Accelerate your battery development

Dr. Nikolaus Keuth

What is driving the automotive industry?

Challenges

Concept definition **Start of Testing** **Data Freeze** **SOP**

Concept | HW & SW Spec. | PT System Testing & Cal. | Validation

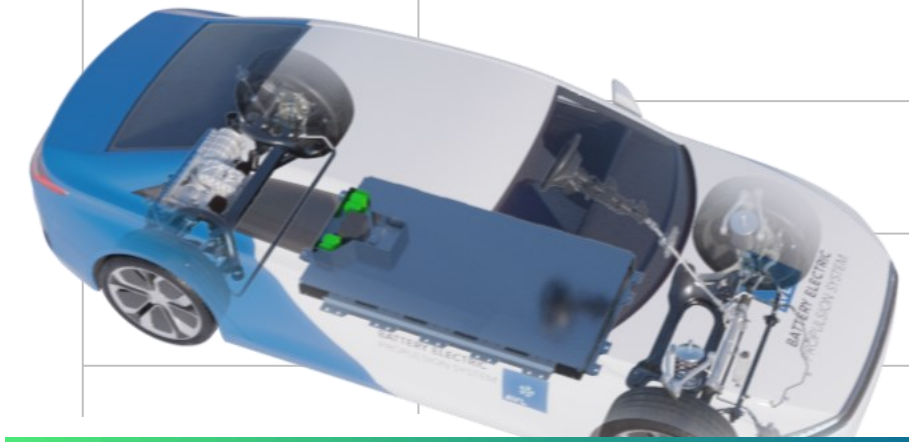
Continuous SW Development Loops

Vx-1 | Vx | Vx+1

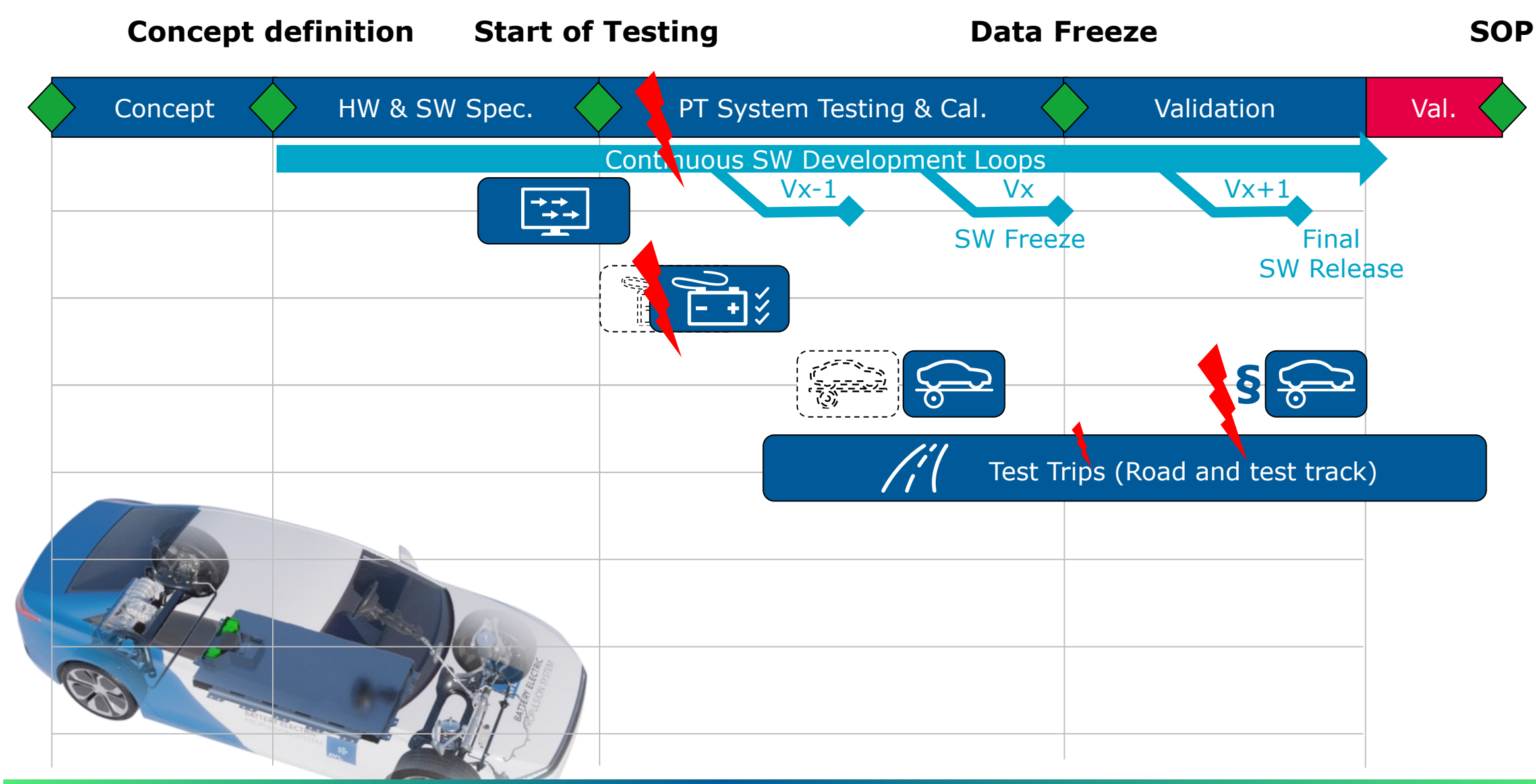
SW Freeze

Final SW Release

Test Trips (Road and test track)

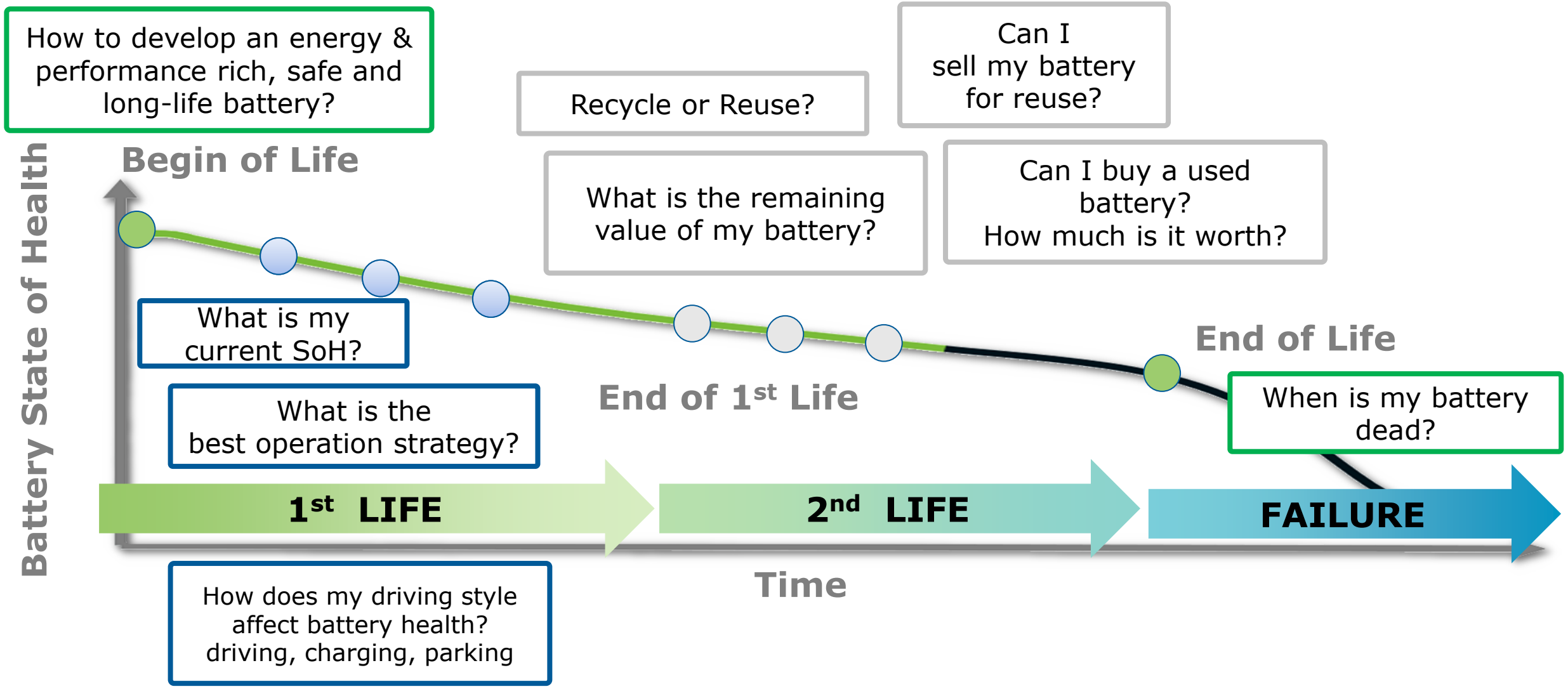


TRADITIONAL APPROACH



ISSUES WITH TRADITIONAL APPROACH

WHAT?
Remaining Useful LIFETIME of a Battery

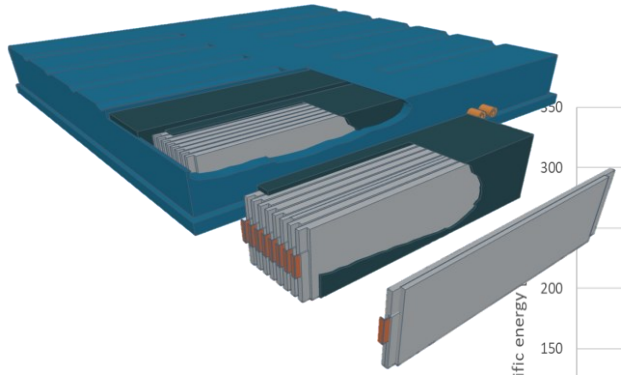


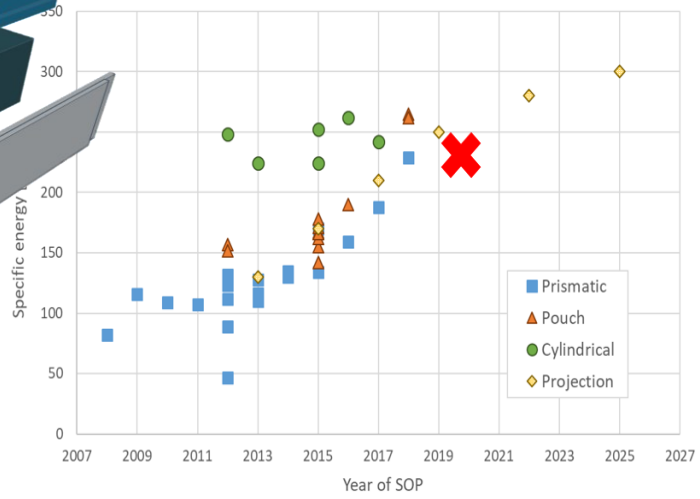
Challenges at Cell Selection

"The battery pack is only as performant as its weakest cell!"

&

It defines the main characteristics of the vehicle!





- Cell chemistry ?
- Cell design ?
- Capacity performance?
- Capacity degradation ?
- Predicted Cell life time ?

Driving Range
Energy storage capability of the cells reflects the driving range of the vehicle.

Driving Performance
Cell provides power to accelerate the vehicle.

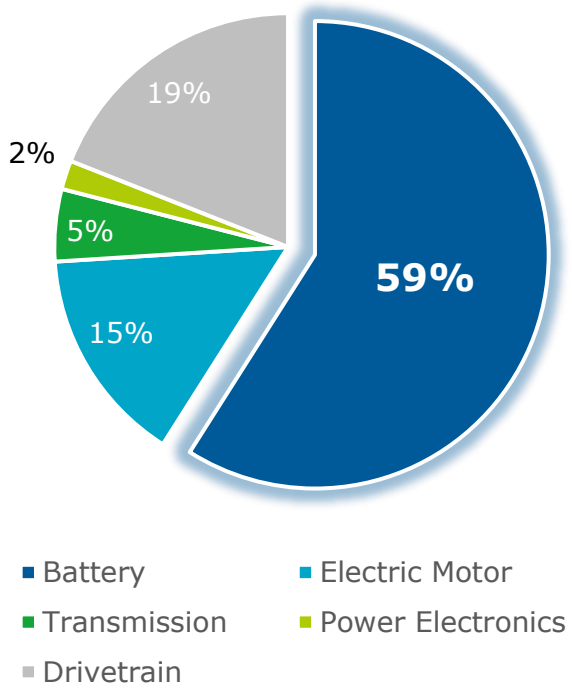
Charging Time
Quick charging relies on the cell current-rate capability.

Vehicle Lifetime
Cell aging reduces powertrain performance over time.

Why – Battery as Most Expensive Component

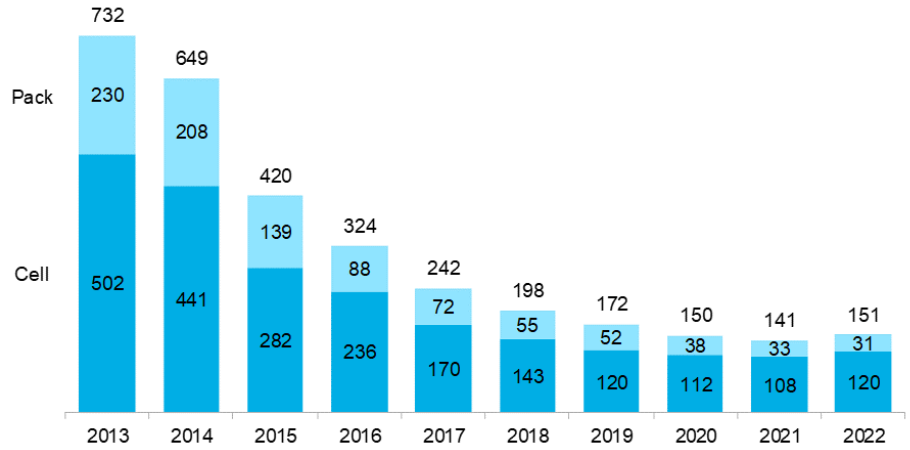
The battery is the most expensive component of a BEV

BEV Powertrain Cost Breakdown



Sources: Valuewalk; Barcleys Research

Battery Pack Cost Breakdown



Source: BloombergNEF. All values in real 2022 dollars. Weighted average survey value includes 178 data points from passenger cars, buses, commercial vehicles and stationary storage.

Motivation: SAFETY - Reduce Warranty Claims

Largest EV recalls due to risk of fire in the US

https://interestingengineering.com/lists/biggest-ev-recalls

2018 - 200.000 vehicles

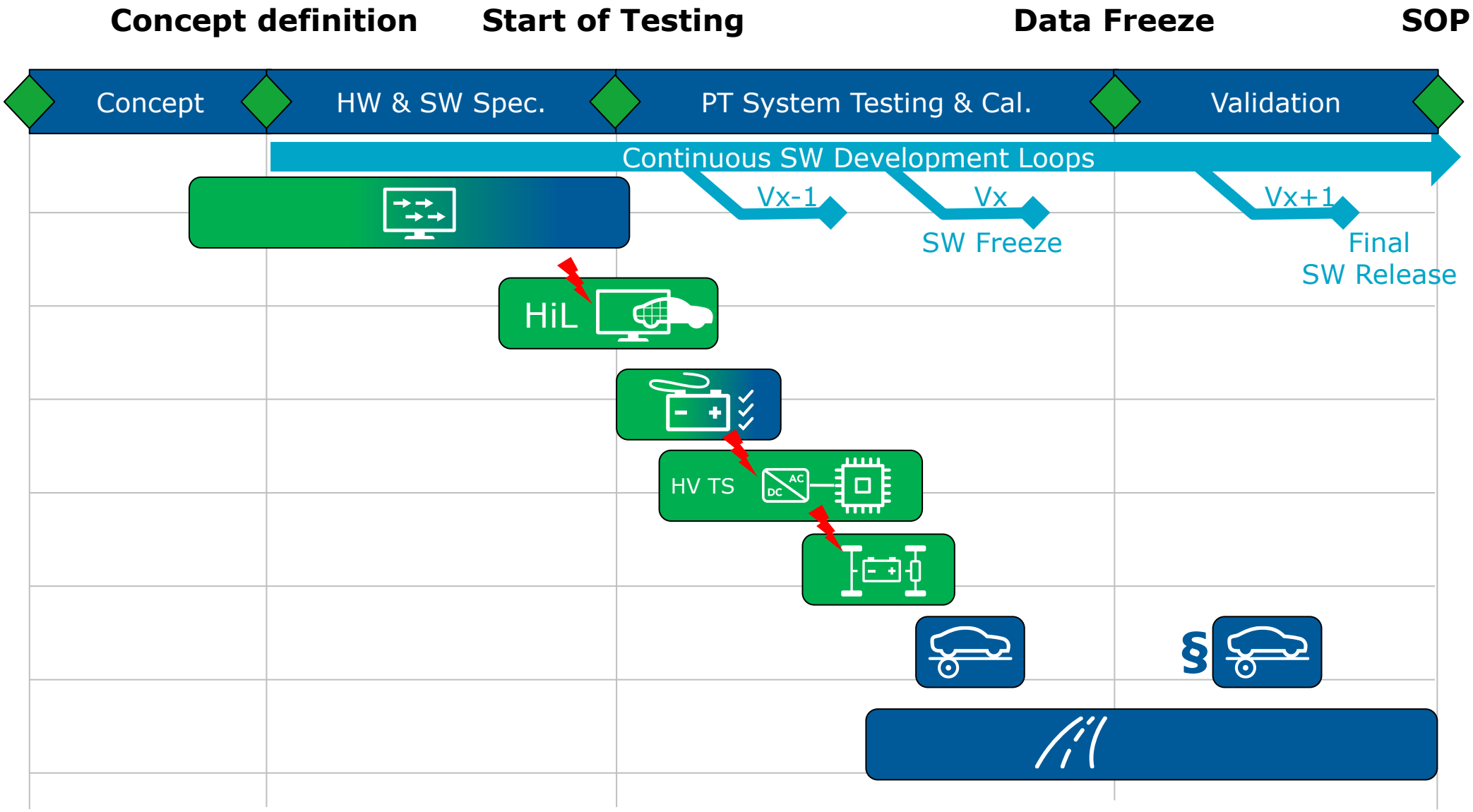
2019 - 100.000 vehicles

2021 - 75.000 vehicles

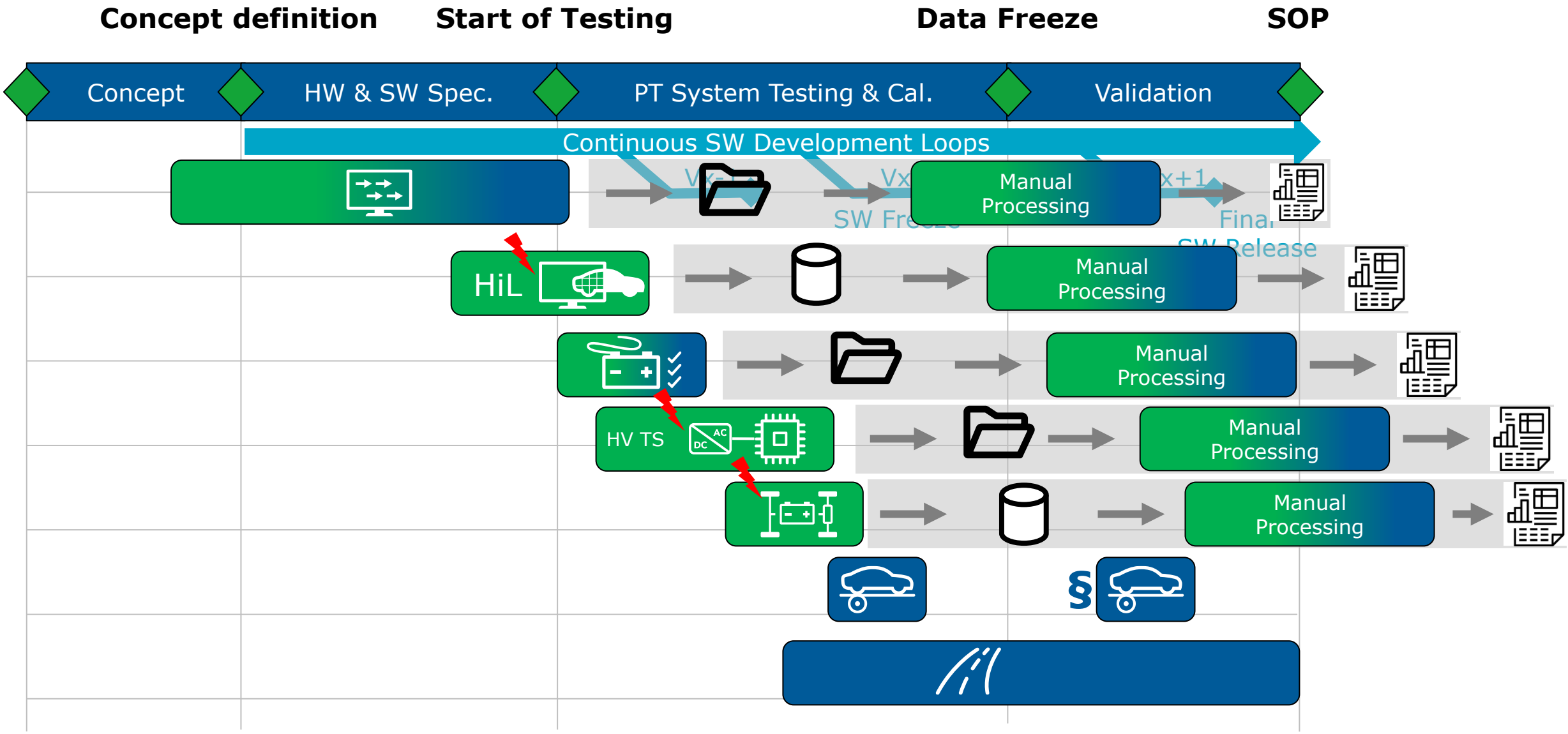
A single vehicle recall action can lead to costs of up to **$1.8 billion**.
The damage to brand reputation is hard to recover.

Warranty claims in the automotive industry have a huge potential for cost savings.

Key to save costs: accurate failure prediction



TRADITIONAL APPROACH WITH EARLY TESTBED USE ENSURES EARLY ISSUE DETECTION & SOLVING!



INCOMPARABLE TEST CASE, UNTRACEABLE STORAGE AND INEFFICIENT PROCESSING

Concept definition **Start of Testing** **Data Freeze** **SOP**

Concept | HW & SW Spec. | PT System Testing & Cal. | Validation

Continuous SW Development Loops

Vx-1

Vx

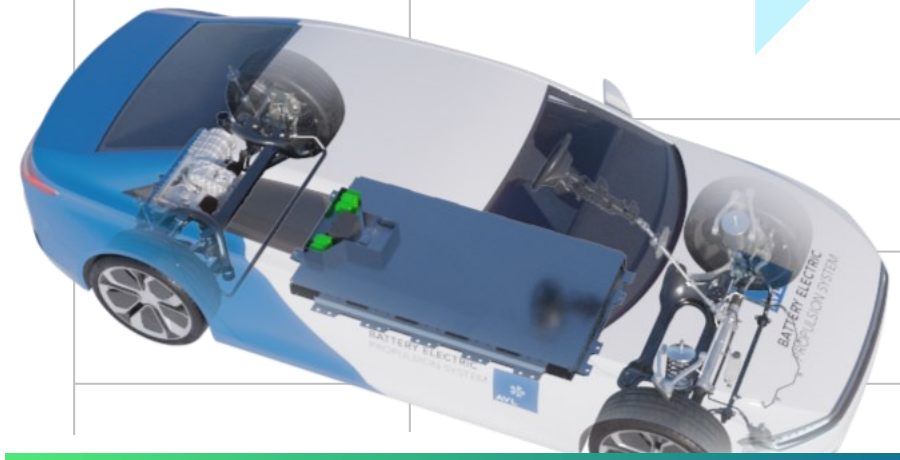
Final SW Release

Data Analytics | Artificial Intelligence

System Engineering

SiL / HiL

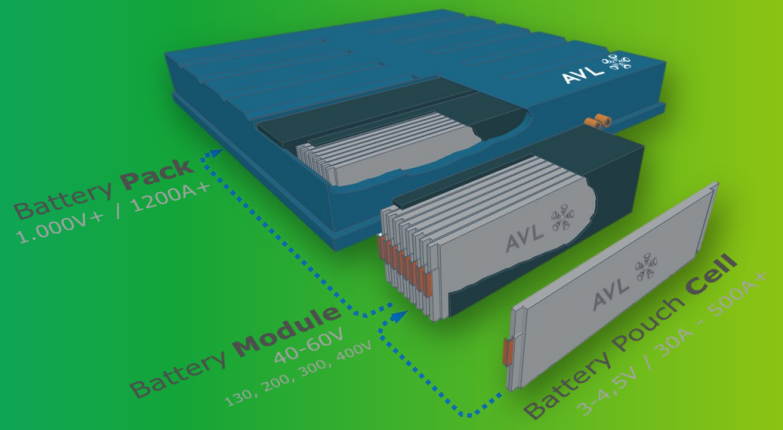
HV TS



INNOVATIVE APPROACH IN POWERTRAIN DEVELOPMENT!

Accelerate your development cycles and set new standards

Data Analytics and Processing for Battery



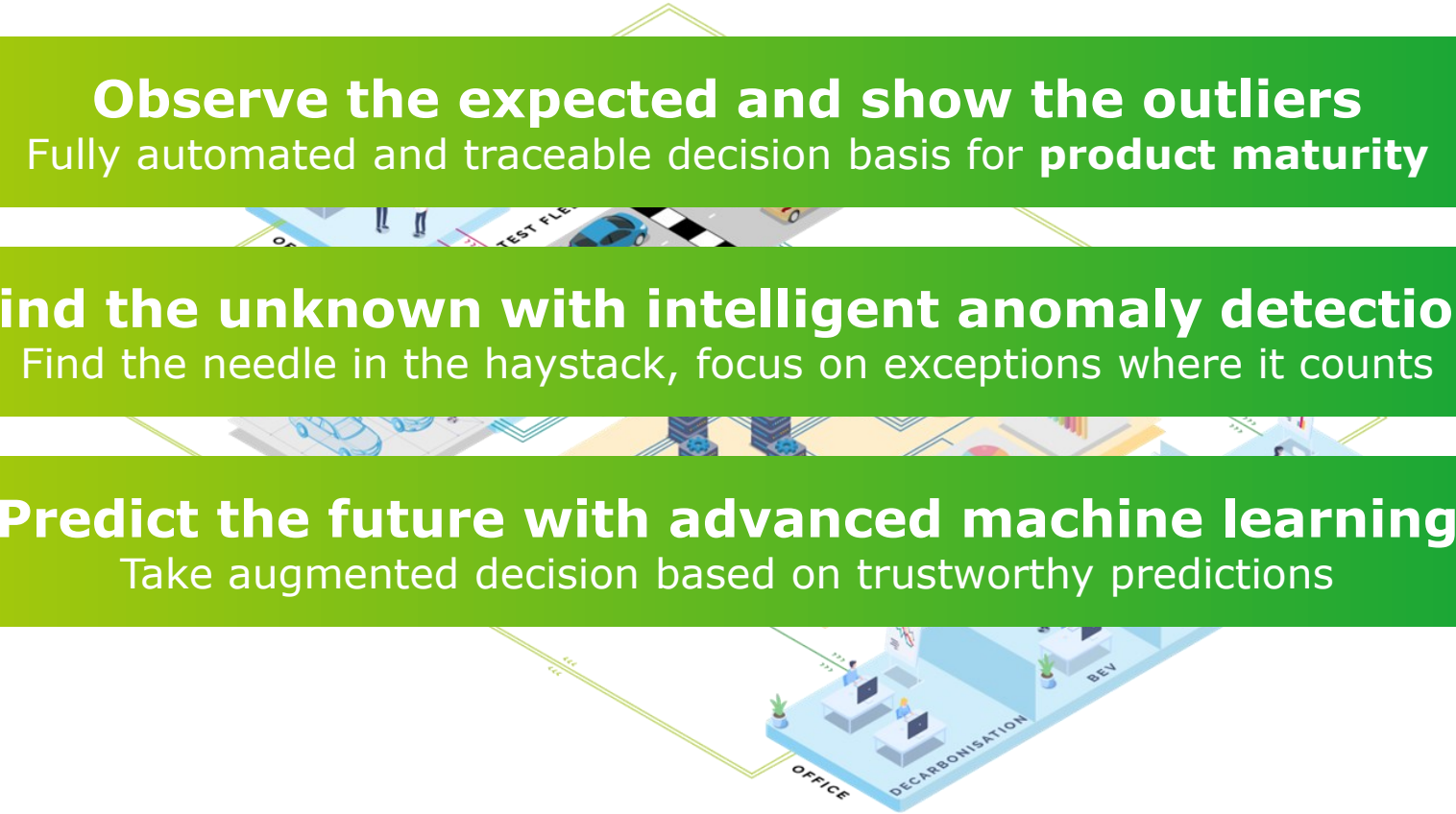
Boosting Engineering Efficiency

(Big) Data Streams → Transform to Insights → Decisions

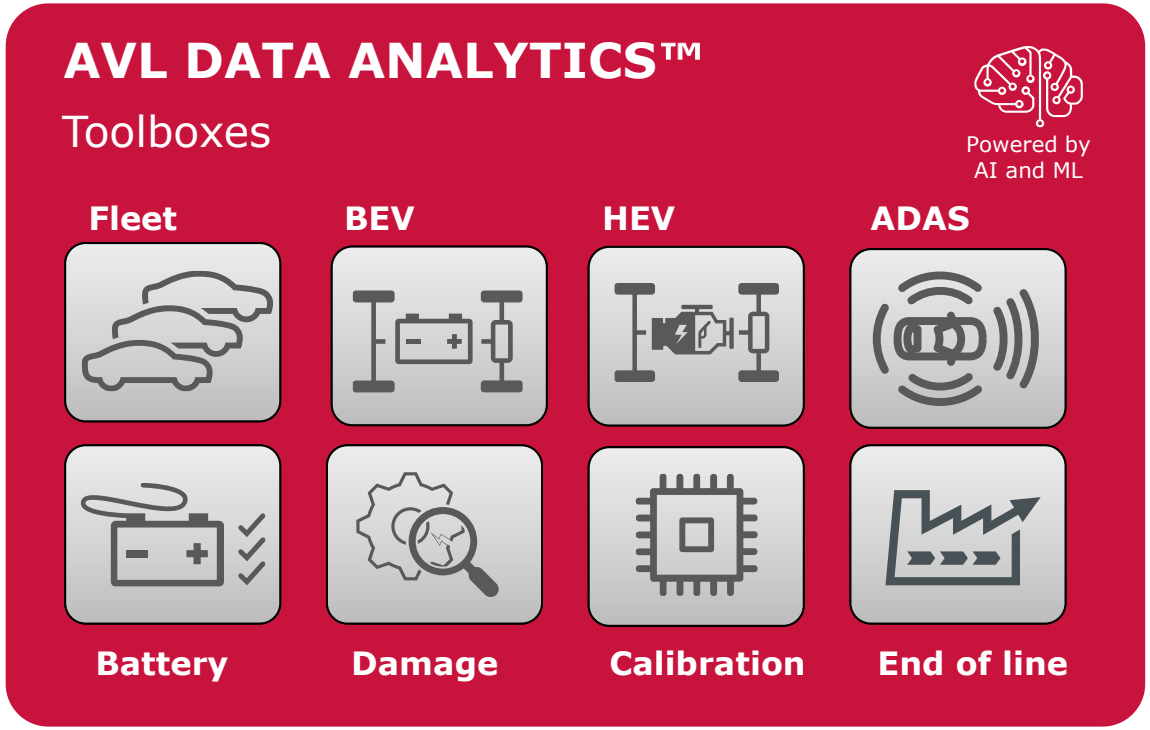
Observe the expected and show the outliers
Fully automated and traceable decision basis for **product maturity**

Find the unknown with intelligent anomaly detection
Find the needle in the haystack, focus on exceptions where it counts

Predict the future with advanced machine learning
Take augmented decision based on trustworthy predictions



Transform Data Streams to Application Specific Insights

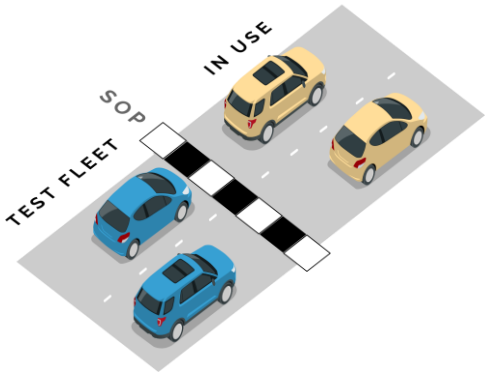


Software as a Service powered by

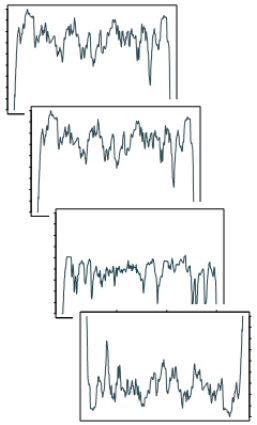
Microsoft Azure

Event-Based Analytics
Focus On Aggregated Information

Meta Data	Time series data	Standardized analytics	Aggregated insights	Interactive Analytics



- Vehicle Identification
- Vehicle net mass
- Nominal power ratings (E-drive, battery)
- …

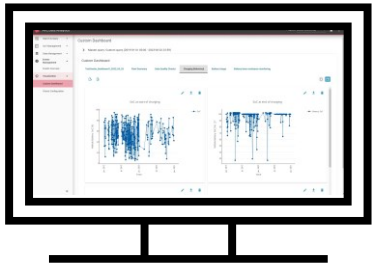


- Vehicle Velocity
- Power demand (driving)
- Power demand (auxiliary)
- HV battery parameters (U, I, T)
- BMS parameters (SoC, SoH)
- Environmental conditions (T)
- GPS

Analytics Engine

AVL
Engineering Know-How

Result
(events and aggregates)

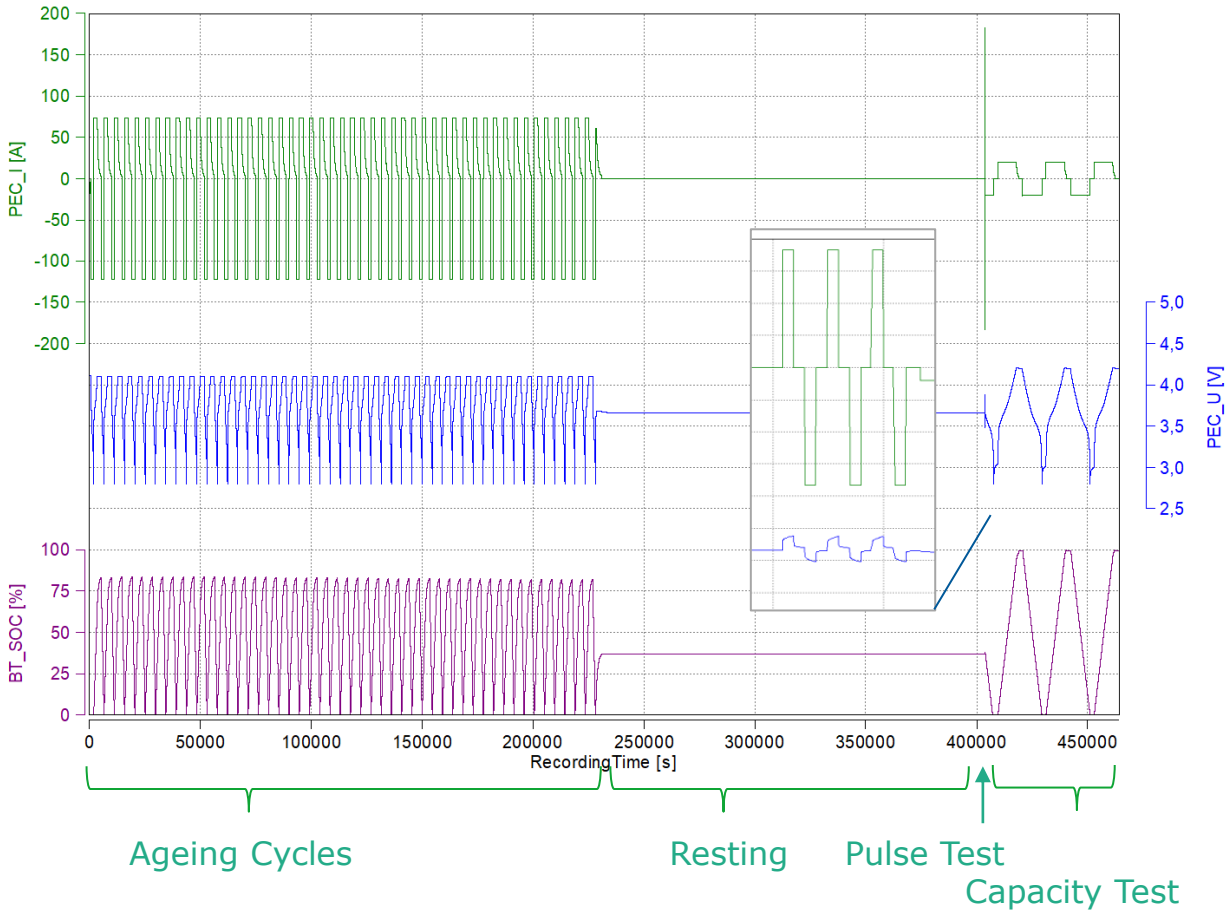


Microsoft Azure

Software as a Service

How Are Test Conducted in the Lab on Cell, Module and Pack Level

Combination of different cycles

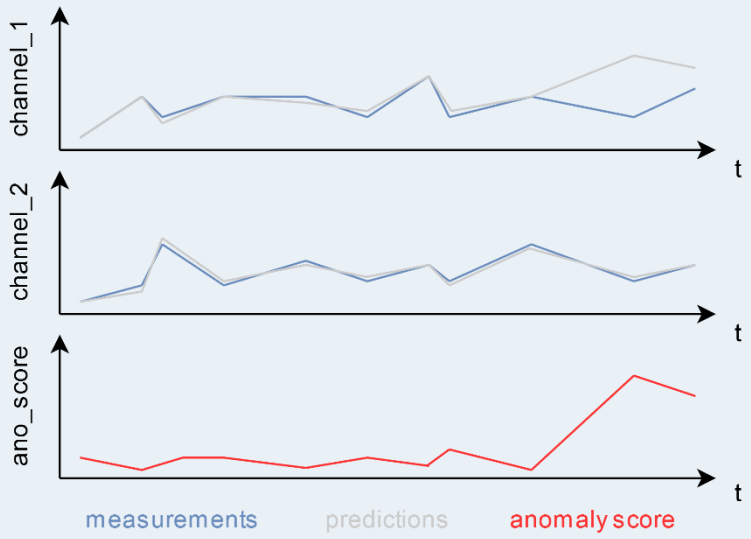


- Combination of different test cycles specific to customers
- Conducted with different C-rates and under different temperature
- Depending on the Design Verification plan
- Trying to mimic real world behavior in the vehicle
- For cell selection 4000 – 5000 cells are tested at the same time
- For module and pack verification 10 to 20 units are tested

Tests running for weeks, months or even years

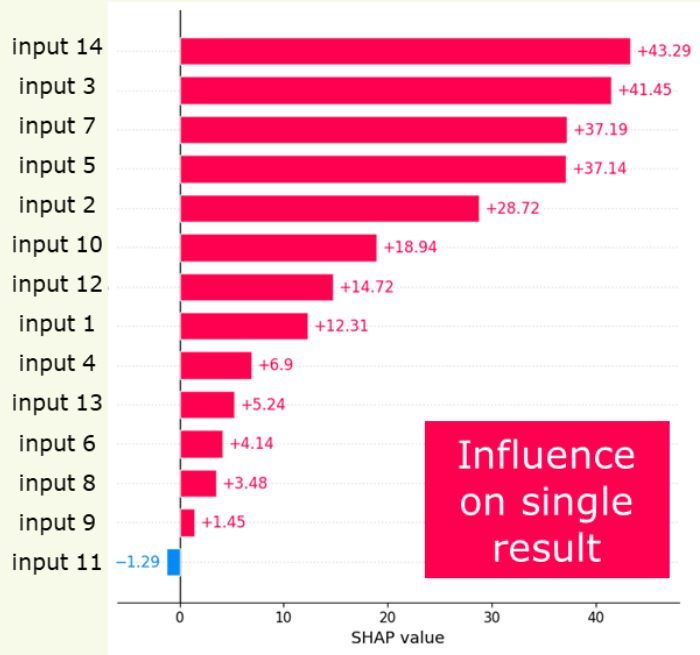
AI Predictive Anomaly Detection to save testing time

CONCEPT
Prediction of time series



ANALYSIS
Robust detection of issues

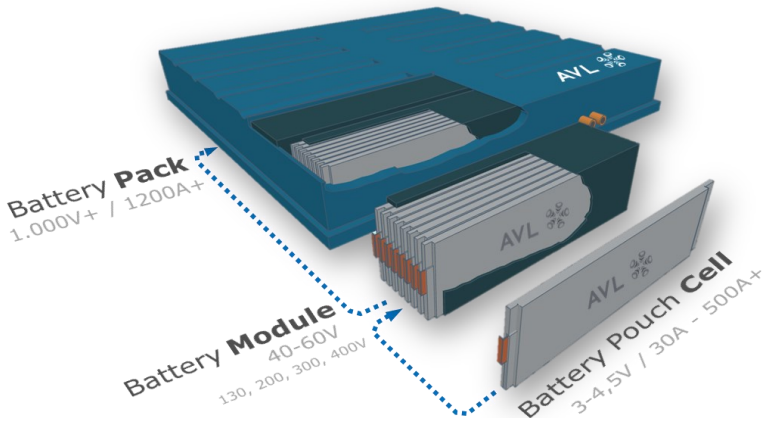
RESULTS
AI-based root cause analysis (e.g. GNN)



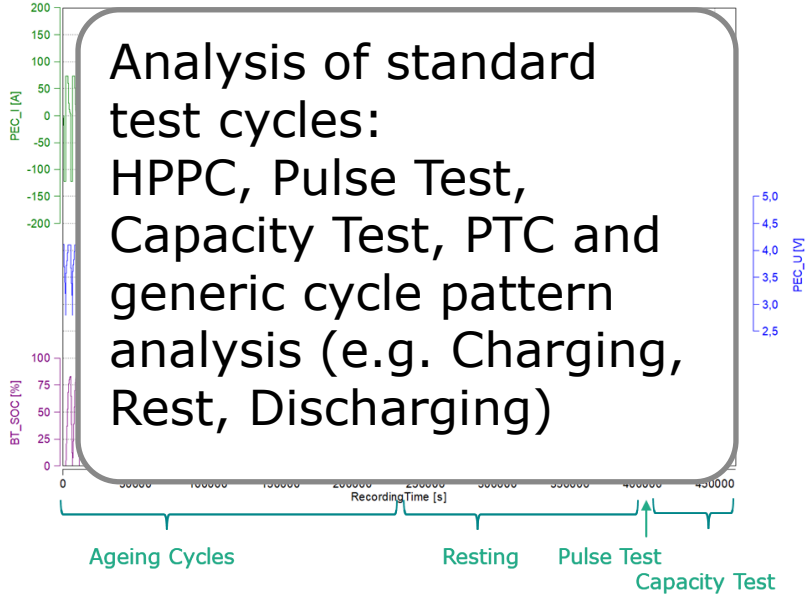
BENEFITS
- Early identification of issues
- Finding unknown failures
- Understanding root causes with explainable AI

Improve testing efficiency
Improve field monitoring
(e.g.: (Pre)-SOP status in field)

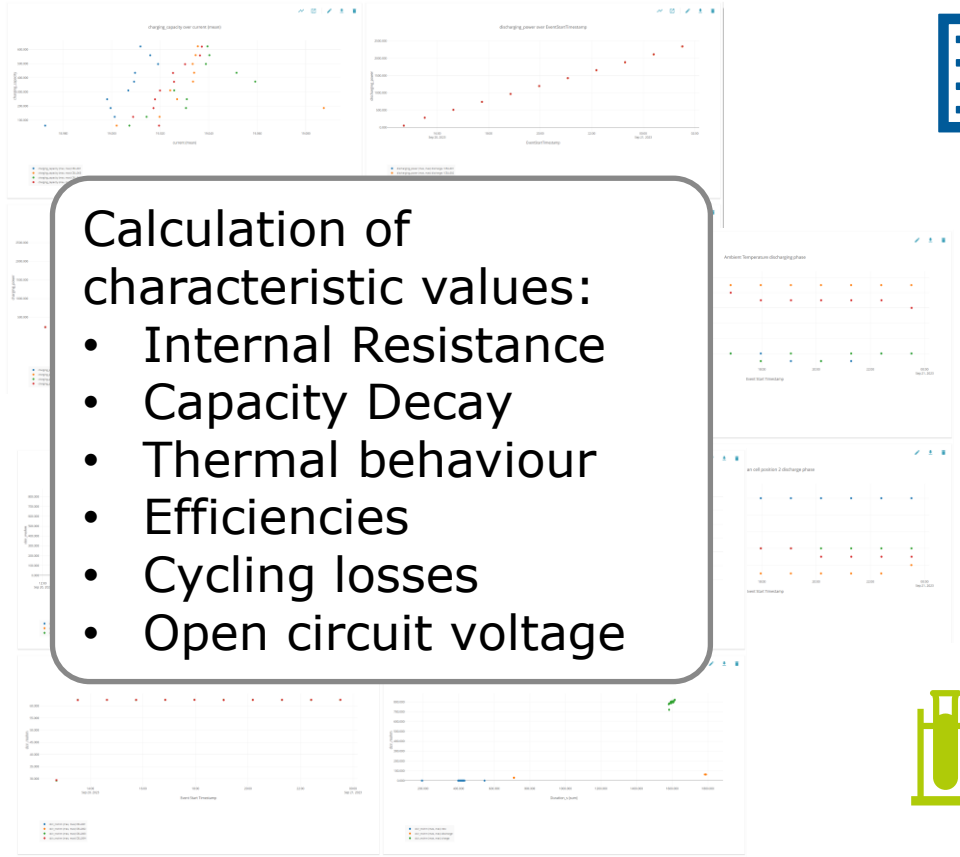
Cell / Module / Pack



Analysis of standard test cycles:
HPPC, Pulse Test, Capacity Test, PTC and generic cycle pattern analysis (e.g. Charging, Rest, Discharging)



Aging behaviors analysis independent cross components based on standardized analytics



Calculation of characteristic values:
- Internal Resistance
- Capacity Decay
- Thermal behaviour
- Efficiencies
- Cycling losses
- Open circuit voltage

Cell selection

Simulation Model parametrization

BMS Software Design

Module and pack design validation

Quickly Navigate the Data to Find the Root Cause

Deep Dive

From Analytics

AVL Data Analytics™

To Data and Take Decision

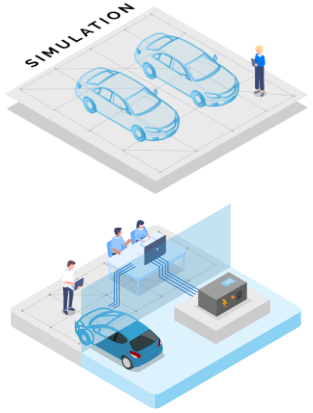
AVL Concerto™

Benefits: Save time in analyzing only the data that is needed.
Navigate directly to the root cause in a view clicks.

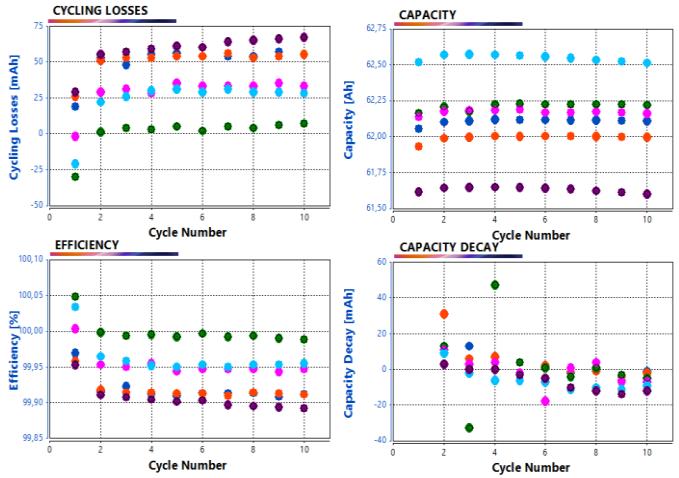
Use Case:
Battery Health Monitoring

(Big) Data Streams → Transform to Insights → Decisions

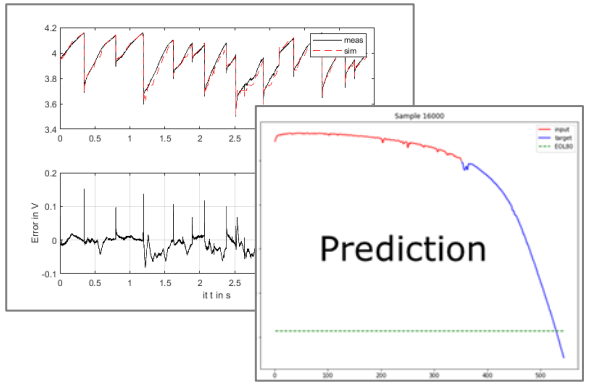
Cross Environment



Time Series data
- Power demand (Torque, Speed)
- HV battery parameters
- BMS parameters (SoC, SoH)
- Environmental conditions (T)
- Cell Temperatures



- Extract key characteristics based on cycles or single charging and discharging events



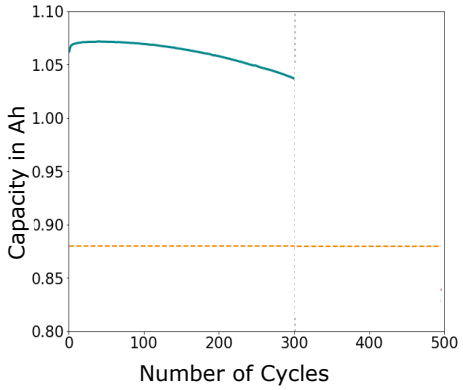
Battery State of Health – SOH – prediction based on real usage profile and external boundary conditions

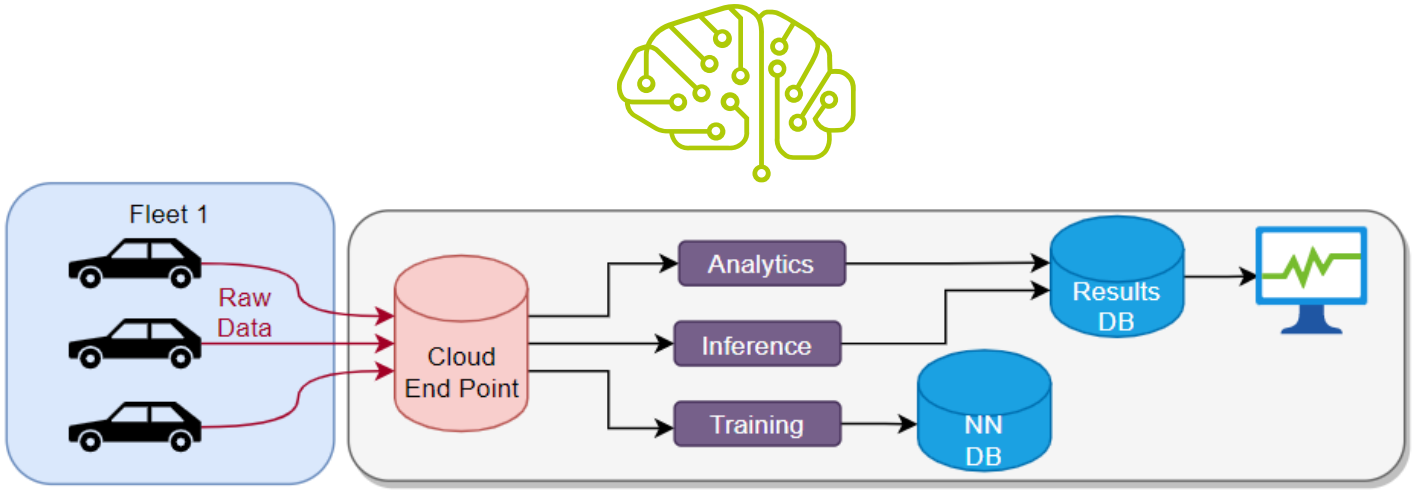
Benefits: Prediction of battery lifetime and main influence parameters on it
Recommendation for 1st & 2nd life usage & warranty costs

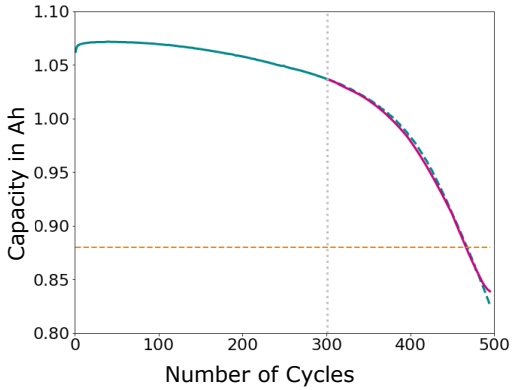
Data-Driven Battery Degradation Prediction

Model Approach

Neural network based on a Long Short-Term Memory (LSTM) Encoder-Decoder architecture[1]







[1] The architecture was chosen similar to [Li].

Battery SOH Estimation and Forecasting

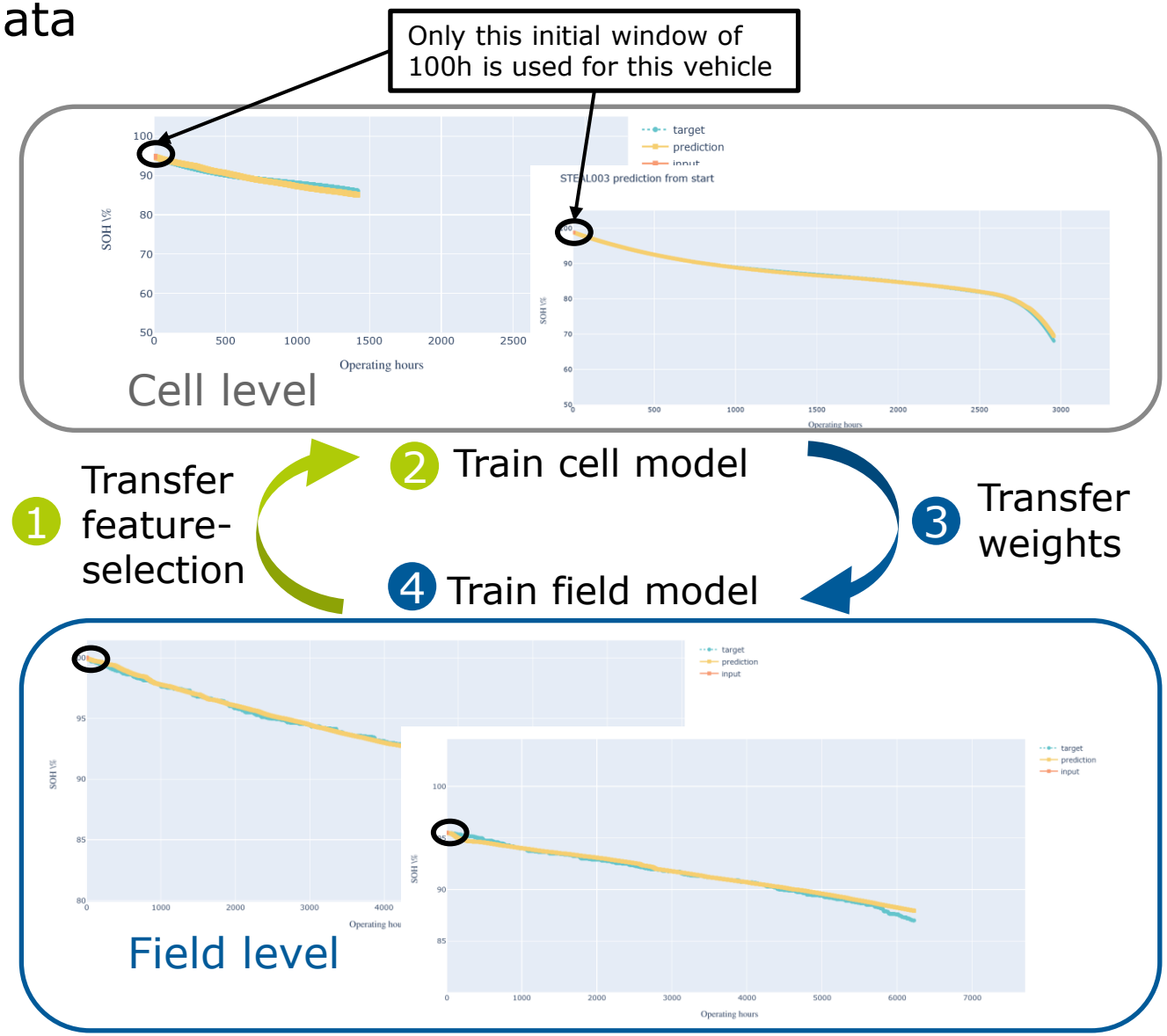
Transfer Knowledge from Lab- to Field-Data

Data:
- Lifetime cell measurements from lab
- Field data from vehicles in use

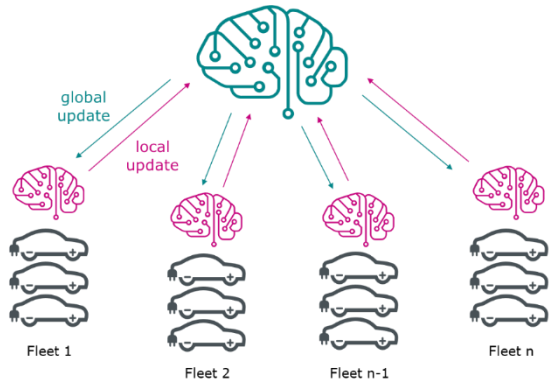
Target:
- Predict delta-SOH

Method:
- Train model on lab data and transfer to field data + feature selection
- Use just the initial as input for SOH prediction for vehicles in the field

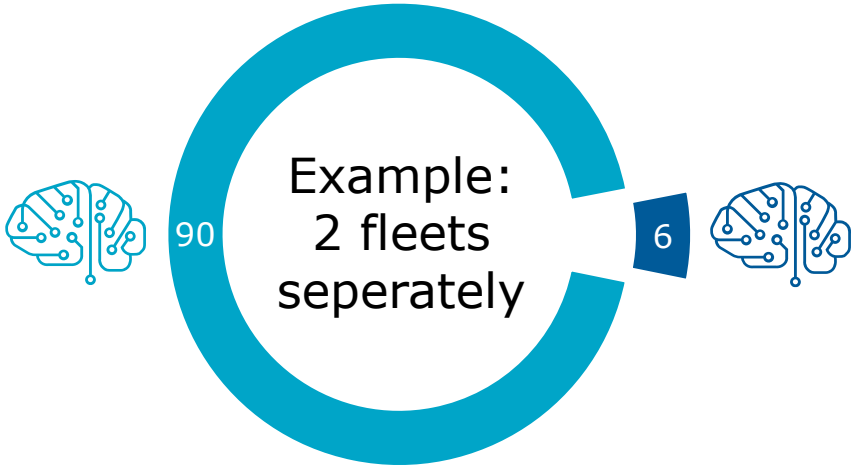
Benefits:
- Reduced testing requirements
- Minimize data requirements
- Early prediction of SOH in the field

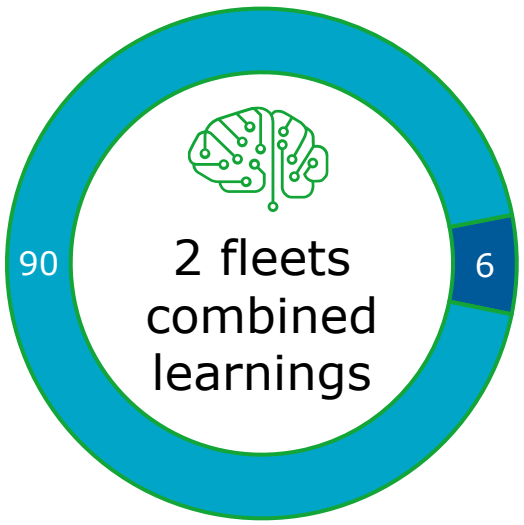


Cross-Fleet Training of a Battery Degradation Prediction Model



- Different settings for model training based on 96 battery cells lead to the following prediction errors:





Machine Learning approach
based on 1 fleet
with 96 batteries:
0.7% MAPE

Machine Learning approach
seperately on 2 fleets
90 batteries: **1.0% MAPE**
6 batteries: **4.9% MAPE**

Federated Learning
based on 2 fleets
90 resp. 6 batteries:
0.8% MAPE

Reduce costs and enhance the quality of your products.

Warranty Cost Reduction with AI Failure Prediction

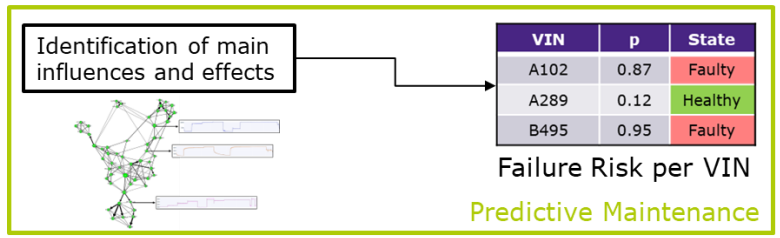
AI-powered Failure Prediction for specific components

Healthy & Faulty Consumer fleet
- DTCs
- Telematics

Workshops / Dealers
- Services
- Part replacements
- Warranty claims
- Diagnosis

Ambient Conditions
- Weather
- Traffic situation
- Road infrastructure

Predictive Maintenance → Reduce Warranty costs



AVL Data Intelligence

1. Feature Selection
2. Machine Learning
3. Prediction

Deliverable 1:
Failure prediction model

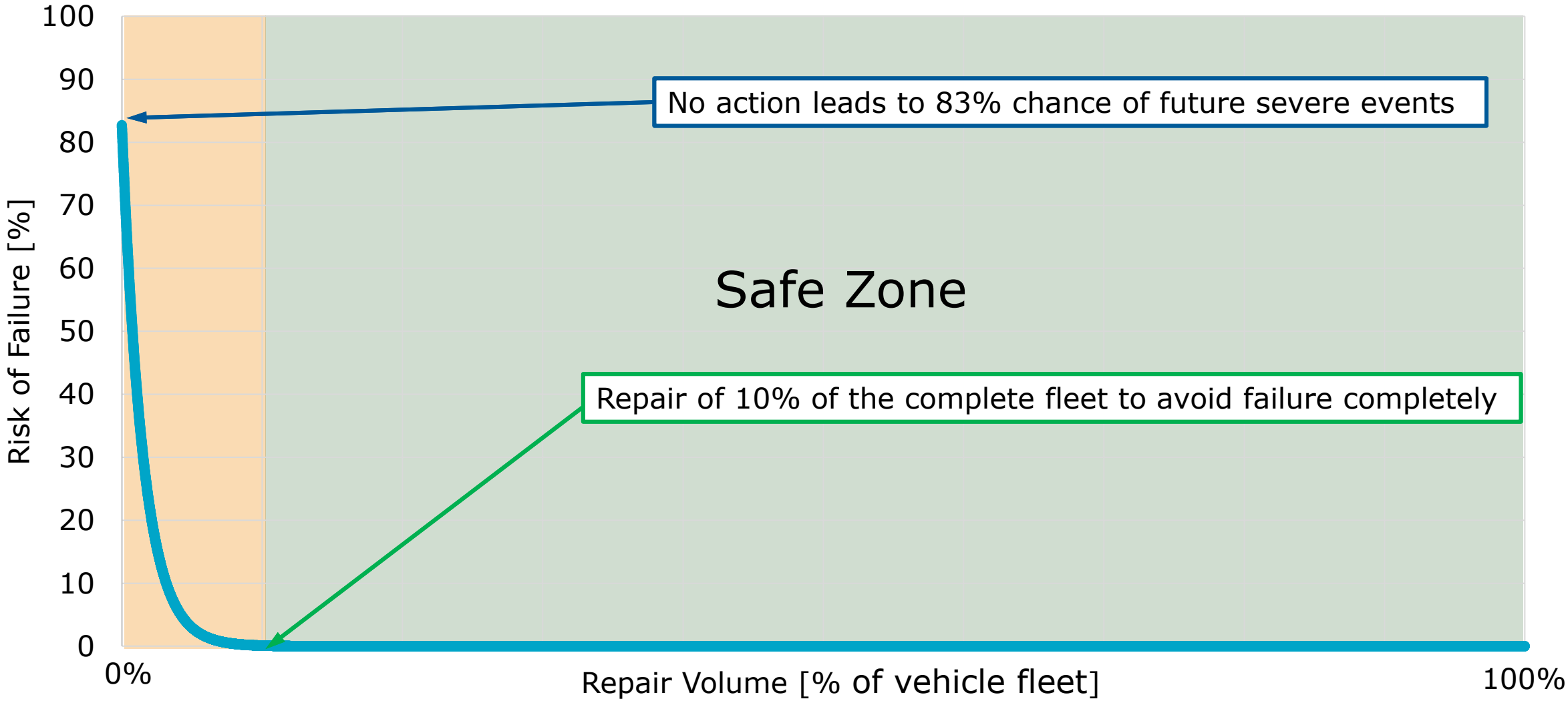
Benefits:
- Predicting known issues on currently healthy vehicles
- Prediction long before issue occurs

Deliverable 2:
Risk of failure for every VIN

VIN	Risk
1FAFP45X83F403461	87,6%
1C4NJPBA1CD661292	82,7%
1G8ZF5287XZ363384	79,3%
WMWRC33474TC49530	74,1%
WP0CA29924S650563	68,9%
WV2YB0257EH008533	64,1%
5TEWN72N63Z275910	60,7%
1GCFG25F6V1059733	54,1%
2G1WH55K5Y9322458	52,7%
SAJWA2GEXBMV00832	46,0%
5XYKT3A69DG353356	43,6%
2B3ED56F5RH142129	43,4%
4V4N99EH3CN554692	42,5%
1G4HP54KX24151104	42,2%
1FMCU14T6JU400773	36,2%
JHMSZ542XDC028494	30,8%
1GCHK23244F199207	28,1%
[illegible]003571	26,5%
[illegible]177991	23,5%
[illegible]A0235007	19,2%
[illegible]000036	16,2%
[illegible]RFL14401	11,0%

VINs are generic and not from actual vehicles

Step 2 Result: Risk Score for every single Vehicle to decide on Preventive Maintenance Actions



Prooven to increase your engineering efficency

References & Benefits

AVL Battery Analytics References

Analytics applied to various applications…

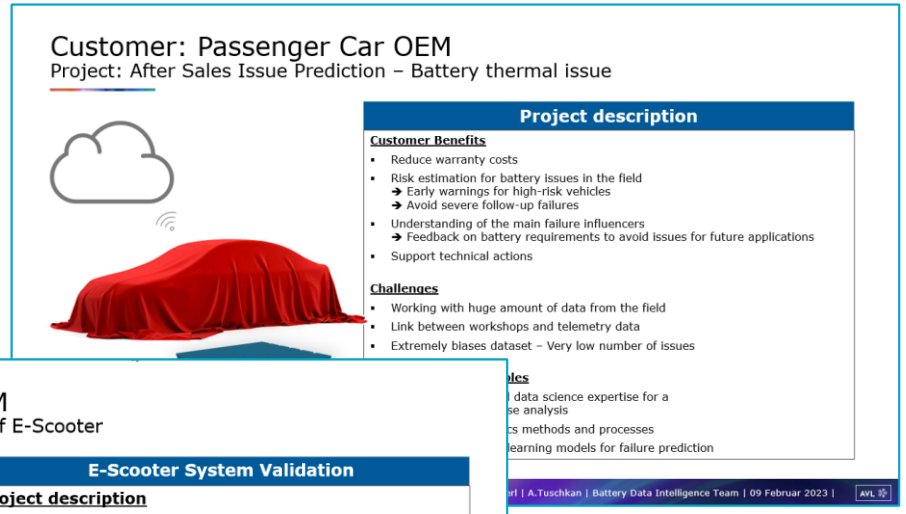
- Passenger Cars, Trucks
- 2-wheelers and stationary systems

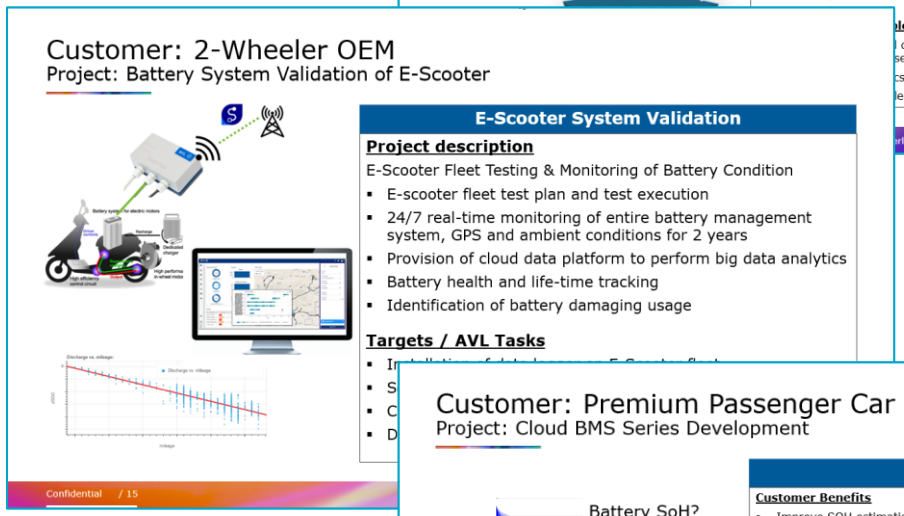
For system validation and

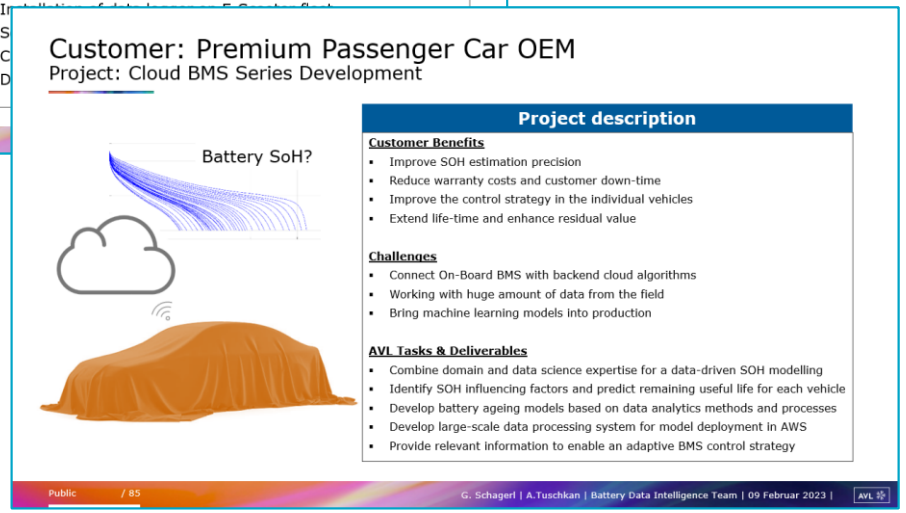
Series development

Deployed and operated on global vehicle fleets

Realized savings worth millions of Euros



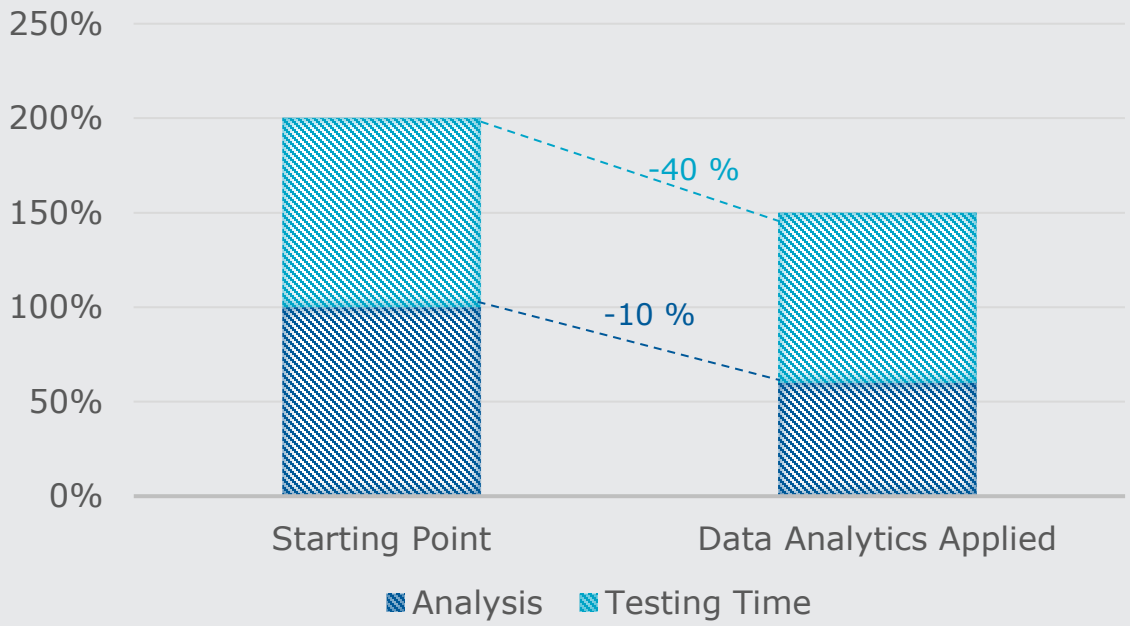




ROI of AVL Data Analytics & Processing

Efficiency Increase with AVL Data Analytics

Typical project: Cell characterisation



Basis: Characterisation projects over 2 years testing time

Potential savings:

-40% Analytics Manpower

Due to automation and focused root cause analysis

Testing time **-10%**

Due early anomaly detection and AI prediction

Benefits

Reduce Development Cost and Time

Improve Quality

Tailored Toolboxes

- Battery Testing
- Fleet Monitoring
- Predictive Maintainance
- ...

Base for AI and Machine Learning

Product

AVL Data Analytics™

Data Sources

Thank You