Combined physical and AI-based predictive maintenance for components

Dr. Walter Lehle

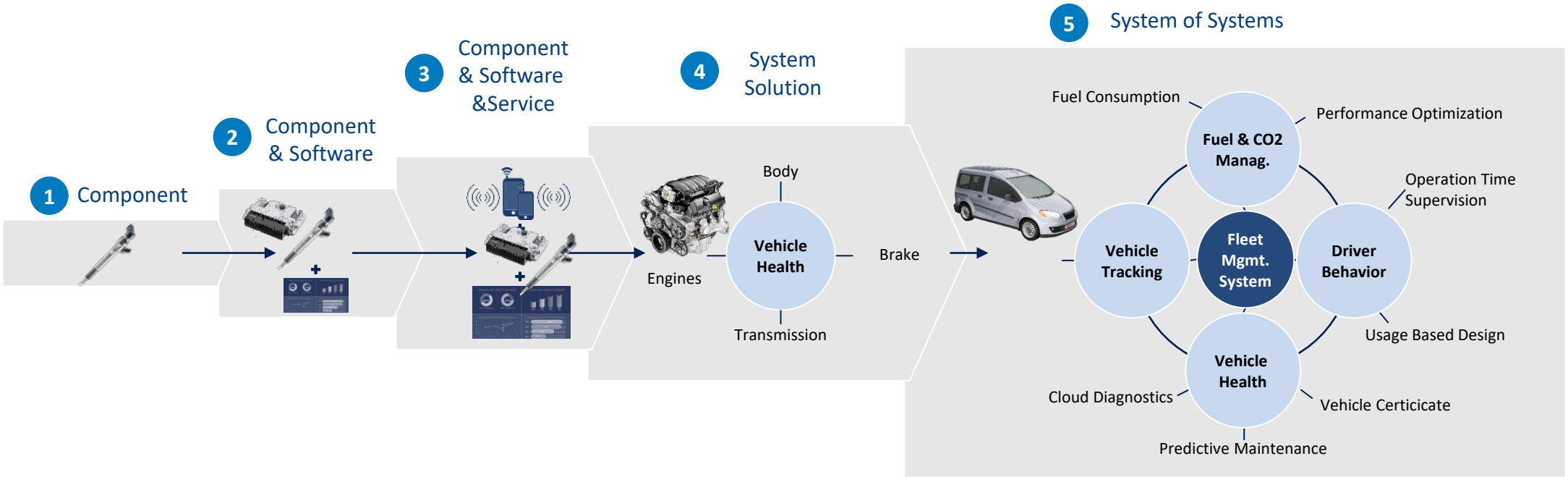
BOSCH

Predictive Maintenance

BOSCH

Predictive Maintenance for Components

Services - intelligent components

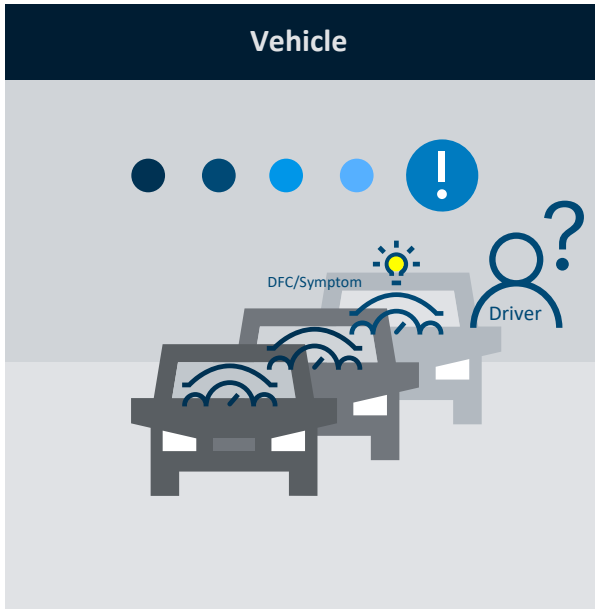


BOSCH

Predictive Maintenance for Components

Predictive Diagnosis - avoid unplanned repair

Upcoming failure during operation



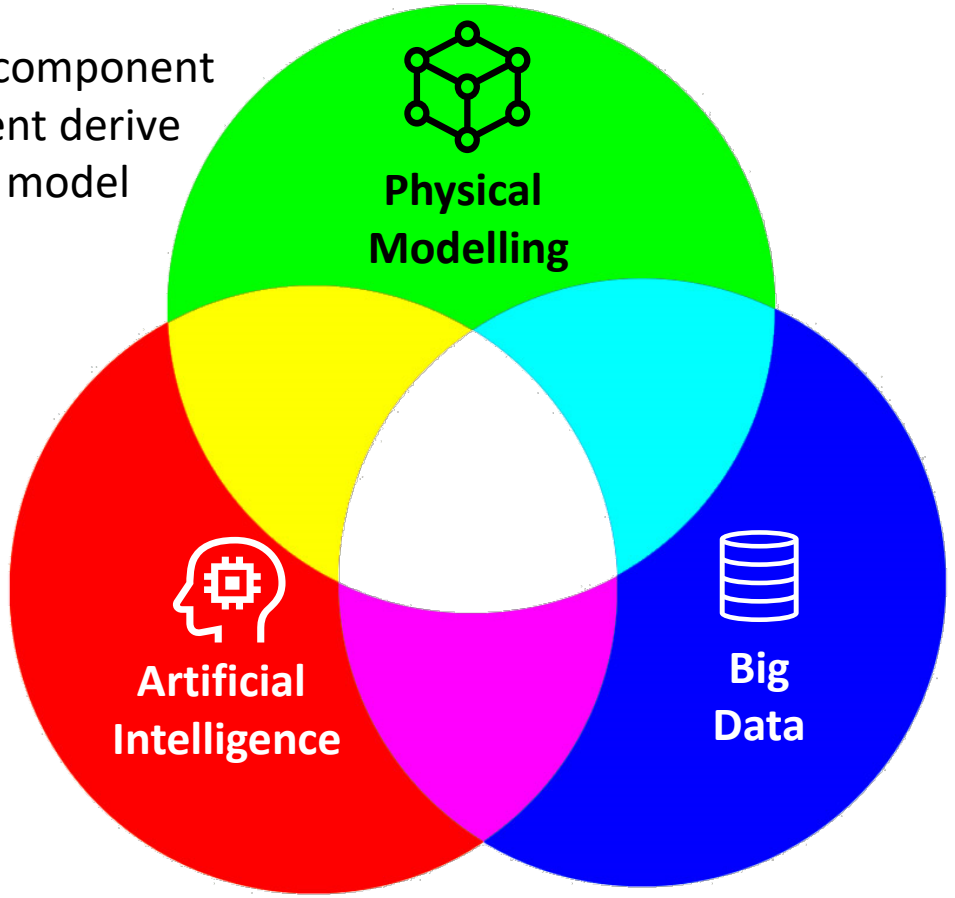
Avoid breakdown - increase uptime
Identify critical components

Optimize maintenance - reduce repair visit
Determine components individual RuL

RuL – Remaining useful Life

Predictive Maintenance for Components
Solution - options versus combination

System and component development derive physical model



Model trained and optimized with artificial intelligence

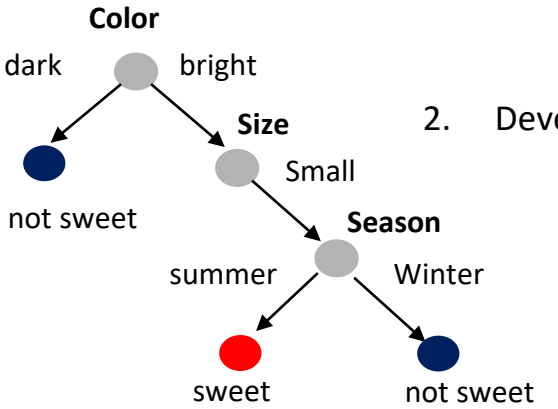
Field data collection and analyzing behavior

Predictive Maintenance for Components
AI outlook - classification example

How to pick up only the sweet oranges ?

→ Differentiate between two <u>classes</u>: “sweet” & “not sweet”

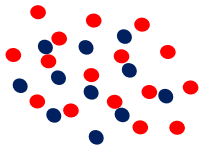
1. Learn from experience: design <u>diagnostic features</u>
    a. **Color**
    b. **Size**
    c. **Softness**
    d. **Land of origin**
    e. **Season**



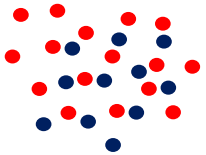
2. Develop an algorithm:

If **Color** == Dark:
Size == Small:
if **Season** == Winter
.....
then: Orange is not sweet

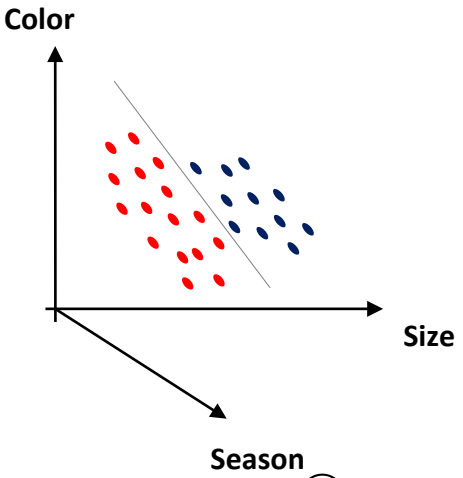
Color/ Season



Season/ Size



BUT! Separable in <u>3D</u>:



<u>Main task of AI:</u>

Automatically determine correlations between <u>diagnostic features</u> (color, size, season etc.) and <u>class</u> (sweet or not sweet) in a <u>multidimensional</u> space.

If a system is complex, it is intractable to analyse the complete search space manually

Example Batteries

Predictive Maintenance for Components

12V/24V Batteries - How it works

Avoid breakdown - increase uptime
Identify critical components

Physical model
to analyze, predict coming breakdowns

Signal transfer
via dongle or CCU

Batterie & vehicle signal collection

Cloud

1) Measure & transmit data

2) Preprocess data

3) Calculate criterion

4) Predict

5) Recommendations & inform user

12/24 V starter battery **avoid breakdown & no starter** information for user

Fleet manager
vehicle health status of the component

BOSCH

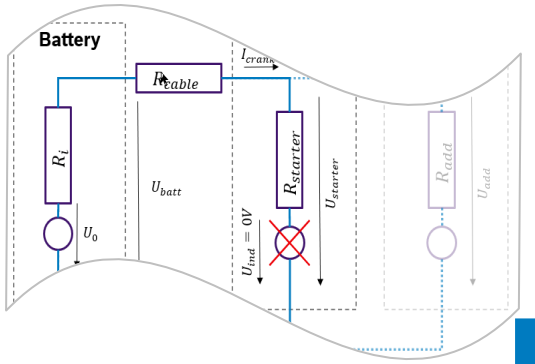
Predictive Maintenance for Components

12V/24V Batteries – Physical Based Approaches add AI

Avoid breakdown - increase uptime
Identify critical components

1 Physical electric model

- Proprietary algorithms to describe system behavior
- Balanced assumptions and approximations

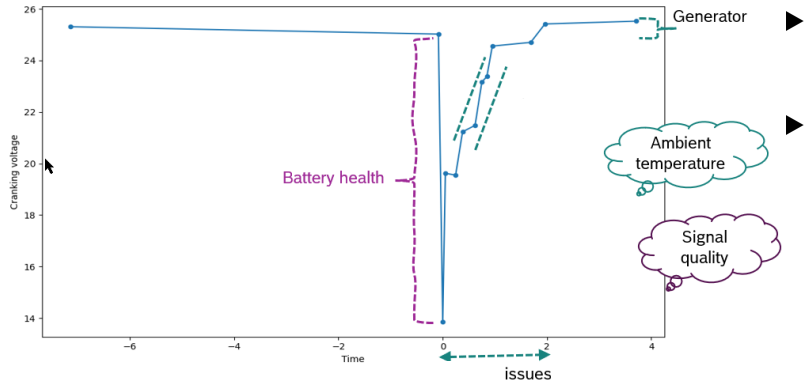


2 Key parameter

Signal Name	Values
Voltage	In „ms“
Vehicle Status	On / Off
Distance	Odometer

- General measured variables
- Focusing on the variables associated phase during start

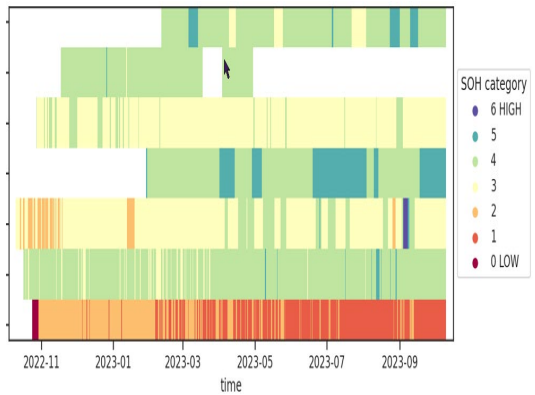
3 Concept: Focus on Cranking Voltage



- Generate customer value by better understanding
- Improve performance or knowledge about SOH

4 Deploying Concept

- Learning about Vehicle Battery Health over time
- Categorizing the Battery Health, thus enabling the Customer to take necessary steps

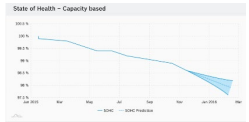


Predictive Maintenance for Components

Battery in the Cloud - How it works

Optimize maintenance - reduce repair visit
Determine components individual RuLc

6 → **Aging prediction** and estimation of remaining useful life



Hybrid physics and machine learning-based models to analyze, predict and optimize battery lifetime

3 — Cloud

7 → VDE → Trusted, real-time **usage certificate** of the battery health and residual lifetime based on actual usage history in collaboration with **VDE**

5 → **Lifetime monitoring** incl. SoH[2] calculation, stress factor analysis and battery **anomaly detection**

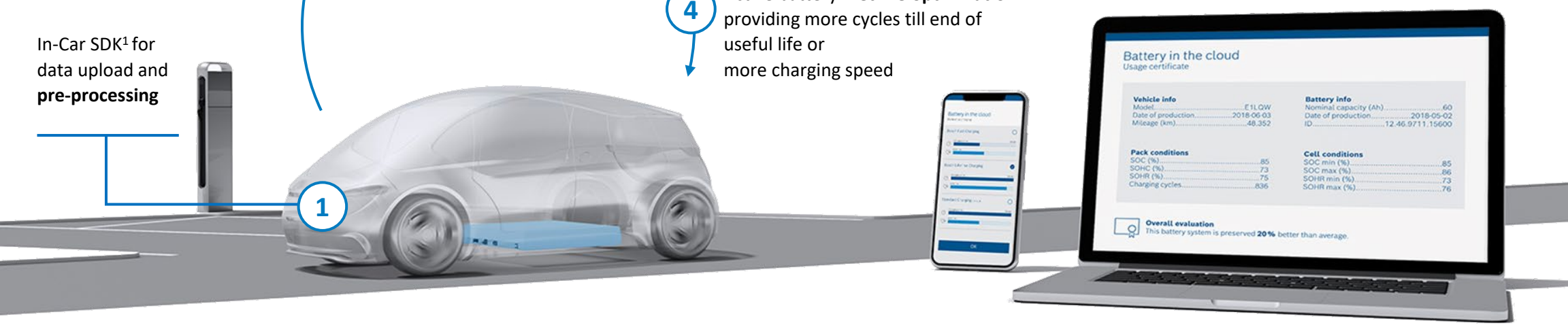
Digital Battery Twin generated out of telemetry data

2

4 → Active battery **lifetime optimization** providing more cycles till end of useful life or more charging speed

In-Car SDK[1] for data upload and **pre-processing**

1

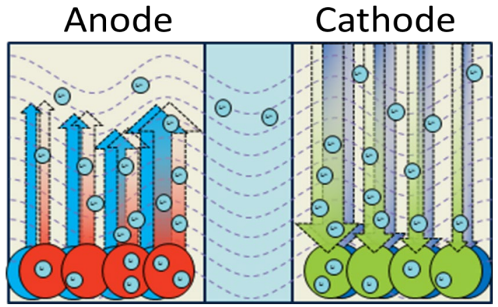


BOSCH

Predictive Maintenance for Components
BitC - Life Cycle of Model Based Approaches

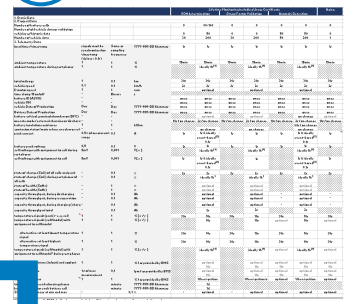
Optimize maintenance - reduce repair visit
Determine components individual RuLc

1 Basis: Battery electrochemical Model



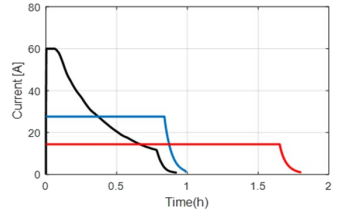
- Algorithms for describe system
- Balanced assumptions and approximations
- Fusion of approaches (e.g., hybrid model)

2 Model Training

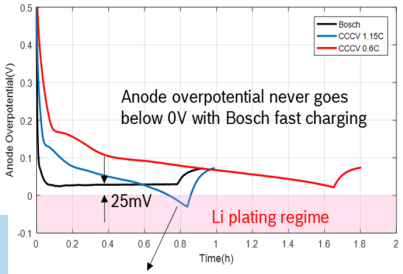


- Material properties
- Size and form
- Usage of the battery

3 Deploy model in battery services

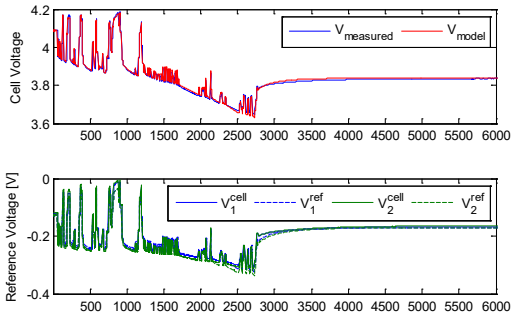


Example:
- El.-chem. model for anode potential
- Enables shorter charging time or reduced degradation



- Generate customer value by better understanding
- Improve performance or knowledge about SOH

4 Validate and optimize model

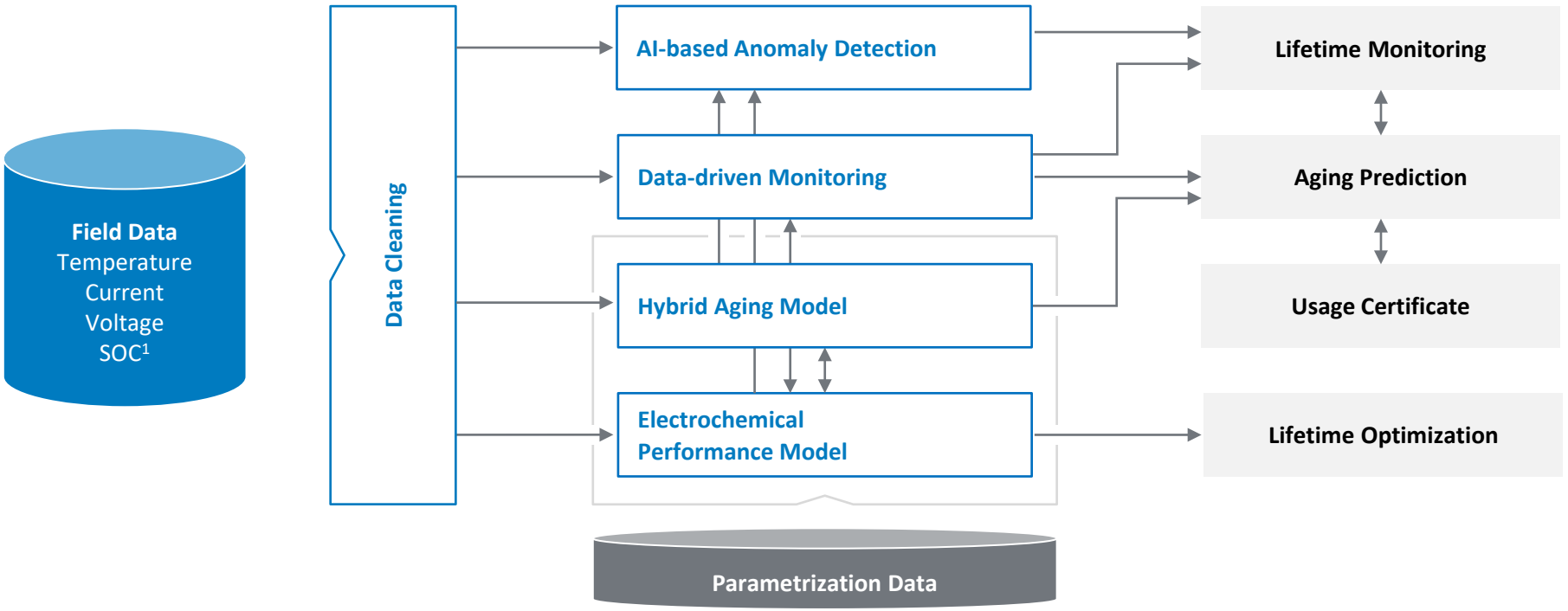


Example:
- 3-electrode measurements for model validation (lab)
- Demonstration of charging speed and SOH effects in lab and pilot fleet

Predictive Maintenance for Components

Optimize maintenance - reduce repair visit
Determine components individual RuLc

BitC - Solution combines Big Data, AI and Electrochemical Models



Battery / Algorithm / Cloud expertise
series availability ww including CN | market proven |
> 180 patents applied for Battery in the Cloud only

Bosch AI & system competence
Worldwide organizations for system integration and dedicated AI R&D organization | >> 800 AI patents

Bosch electro-chemical competence
Broad library of material properties | Aging and performance model | Test infrastructure, labs

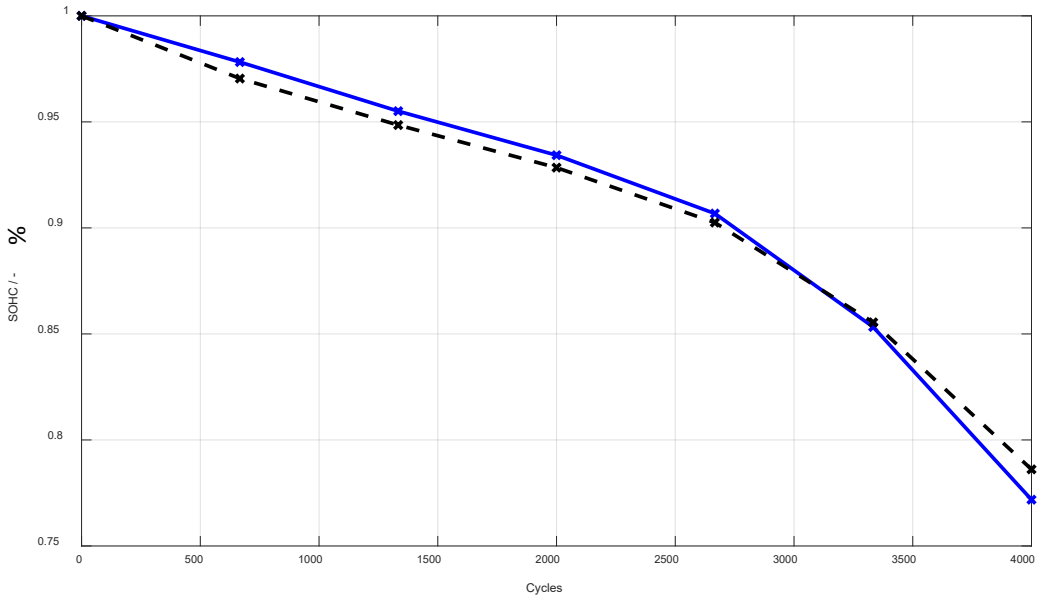
1) SOC State of Charge

BOSCH

Predictive Maintenance for Components

BitC - Aging Prediction

Optimize maintenance - reduce repair visit
Determine components individual RuLc

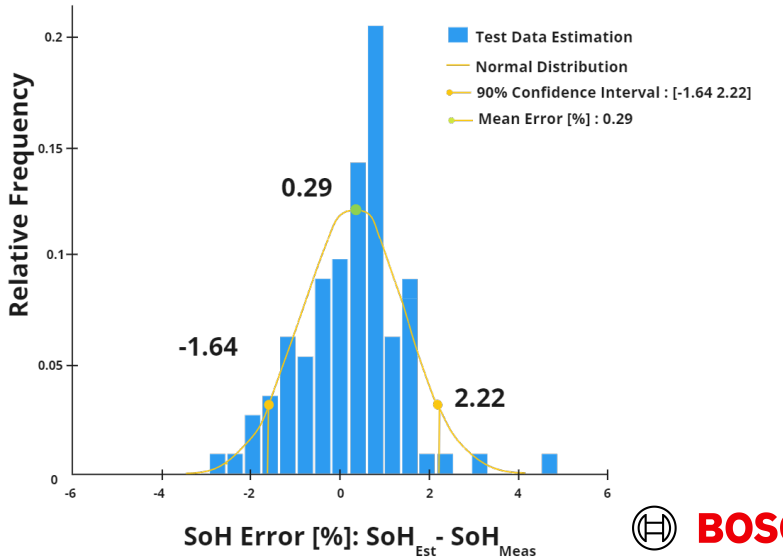


SOHC measurement

SOHC prediction

Precise aging prediction

- Prediction of battery aging and remaining useful life (SoHc, SoHr) over years leveraging electrochemical and historic operations data*
- Accurate results based on fusion of electrochemical and AI model
- Low residuum enables advanced planning of actions on field vehicles
- Due to advanced AI methods number of vehicles/battery data necessary to perform prediction is comparably low to extensive aging tests



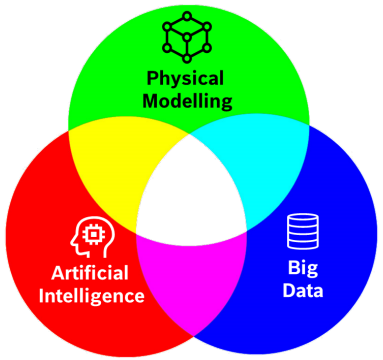
*in case of availability of historic data

BOSCH

Predictive Maintenance for Components
Summary

Predictive Maintenance

- Two use-cases avoid sudden breakdown and optimize maintenance process
- Predictive diagnostics based on components and system behavior
- Key element of prediction are hybrid model – physical and AI models
  - Physical understanding and modeling are base of the predictive functions
  - Application and optimization of the prediction with AI methods



Predictive diagnostics for batteries

- Predictive Maintenance for starter battery and high voltage battery available
- Cloud based physical and hybrid models supported with edge pre-processing in the vehicle
- Common framework for interaction with customer and user