MOIRA Industrial Meeting
2nd Industrial Session
20th June 2023

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MOIRA industrial meeting
2nd Industrial Session – Agenda

- [9:30-9:45] **Company introduction Siemens Industry Software NV (SISW)**
  Bram Cornelis – SISW

- [9:45-10:30] **End-of-Line Testing and Structural Health Monitoring activities at SISW**
  Bram Cornelis – SISW

- [10:30-10:45] **Coffee Break**

- [10:45-11:30] **A federated learning approach to a fault diagnosis bearing problem**
  Fabrizio De Fabritiis – KU Leuven

- [11:30-12:15] **Dataset shift and its impact on machine learning-based fleet monitoring**
  Deepti Kunte – SISW

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End-of-Line Testing Structural Health Monitoring Activities @ SISW

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Towards *Executable* Digital Twin (xDT)

An evolving object with a **lifecycle** that needs to be managed

The Digital Twin can consist of -or start with- **virtual** design & simulation models *(representation horizon)*

Enriching the model-based Digital Twin with **in-operation** data enables **validating** and **updating** models and **assessing** real use conditions

The Digital Twin can consist of -or start from- **measured** “Digital Shadow” data *(observation horizon)*

Closed-loop digital twin provides for bi-directional **connectivity** between the physical asset and the virtual representation

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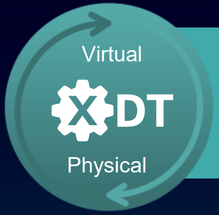
Executable Digital Twin Definition

For smarter
products, systems, processes



Self-contained executable digital behavior of an asset

Can be leveraged at any point in lifecycle

- **developed, packaged & released by experts**
- **real time enabled**
- **leveraging AI and model order reduction techniques**
- **self adapting / calibrating**
- **leverageable by anyone one at any point in the product lifecycle on any certified device**
- **from edge to cloud**

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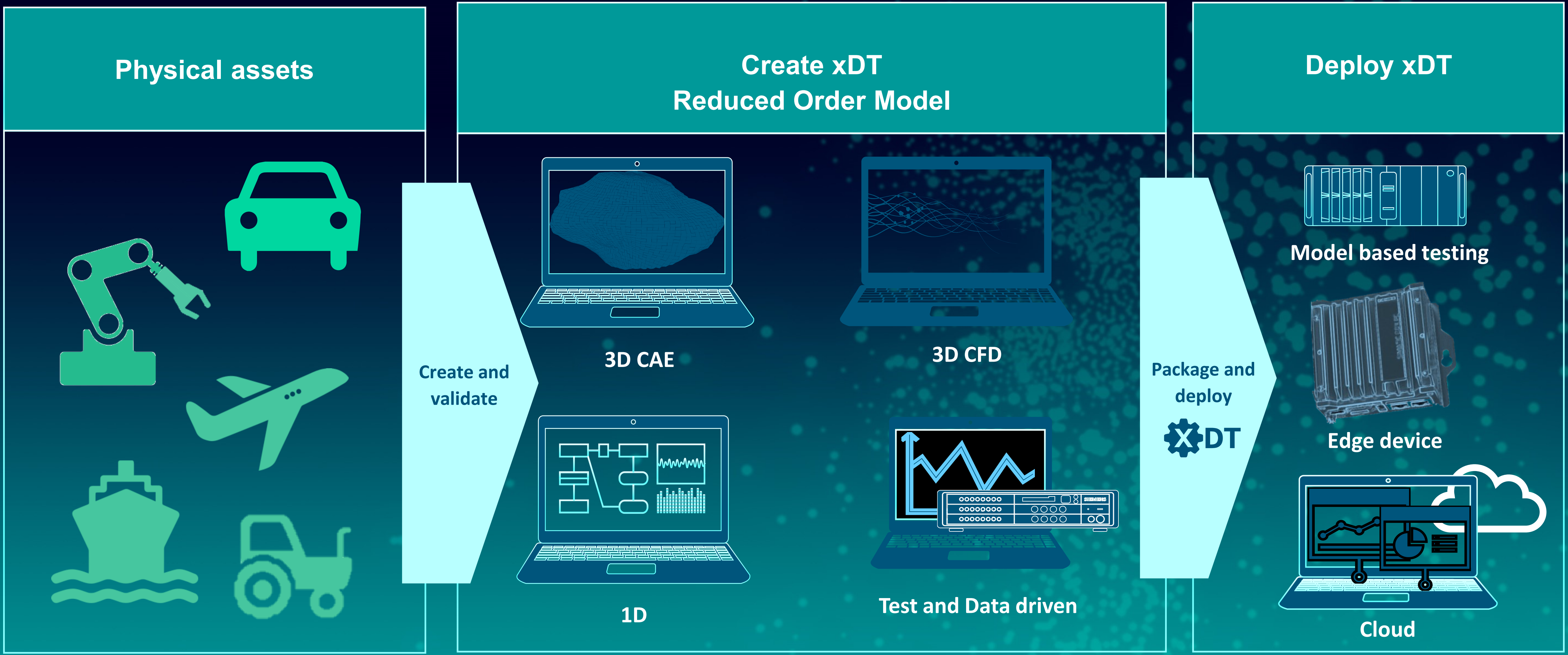
Executable Digital Twin
Creation and deployment process



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Executable Digital Twin
Measure the unmeasurable with smart virtual sensors

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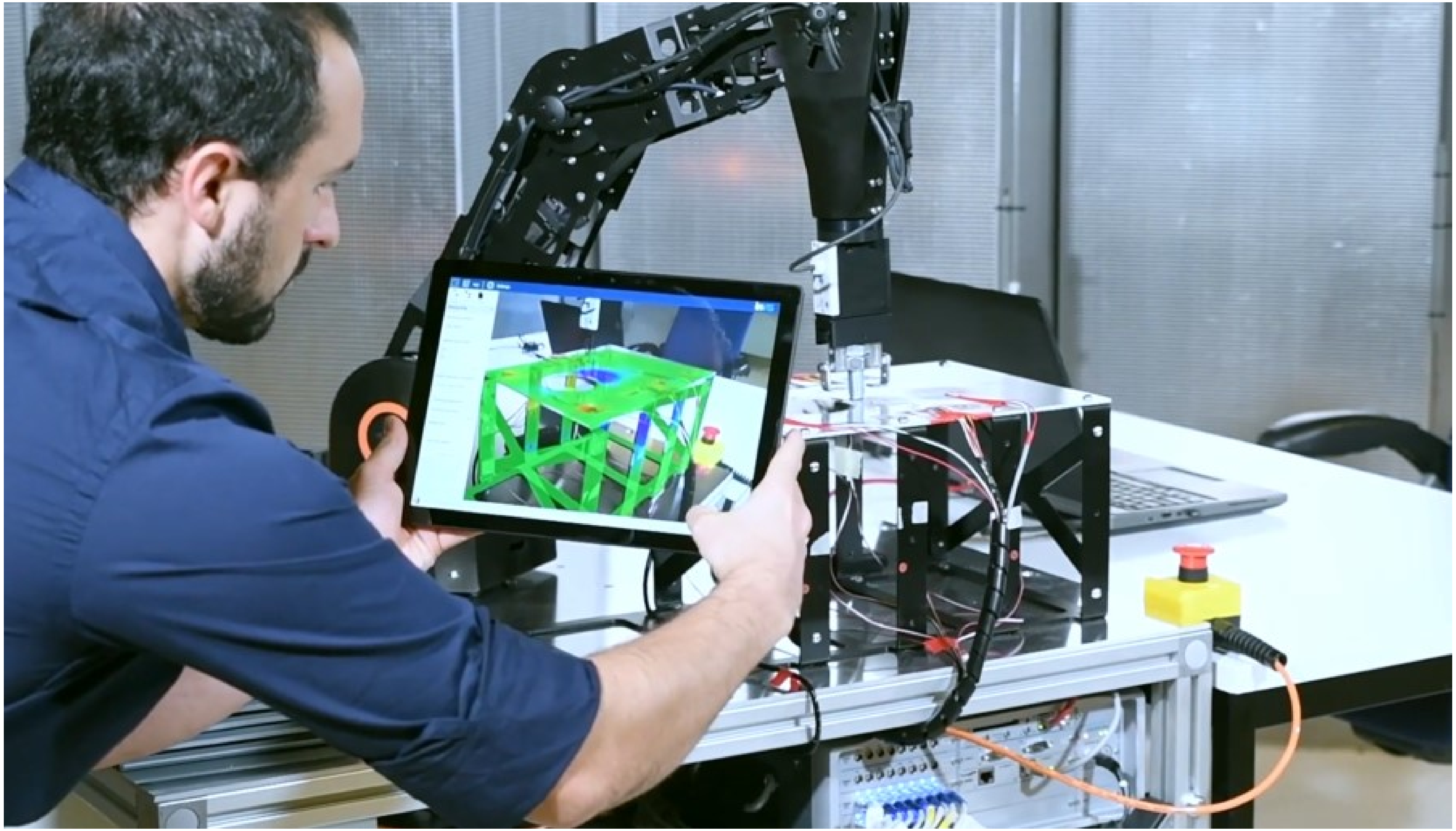
Ingenuity for life



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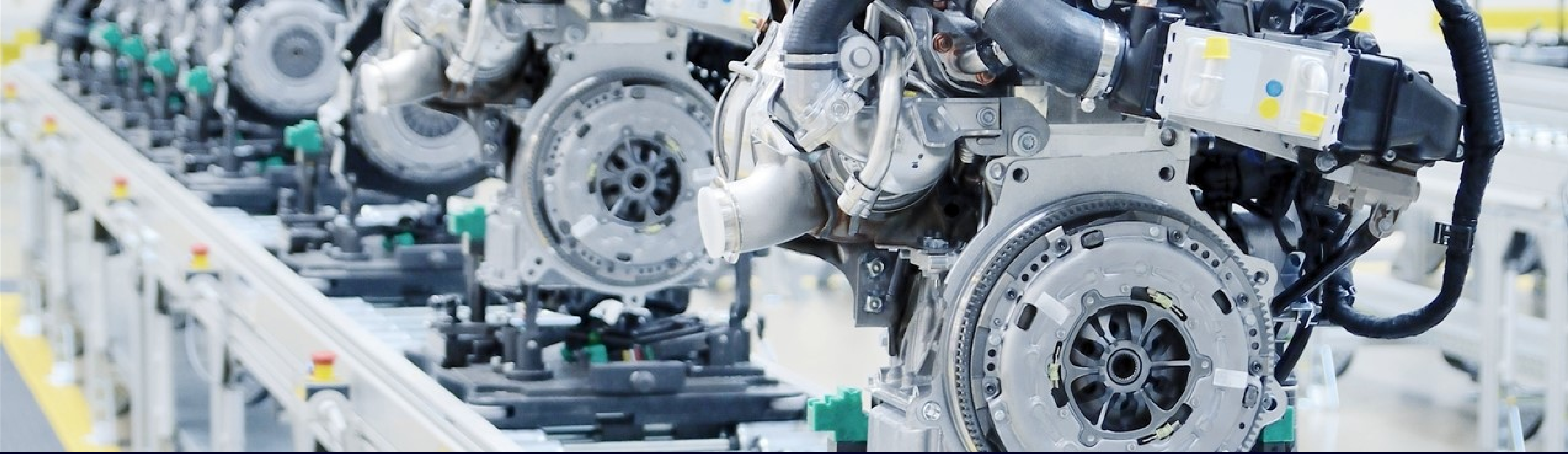

End-of-line testing

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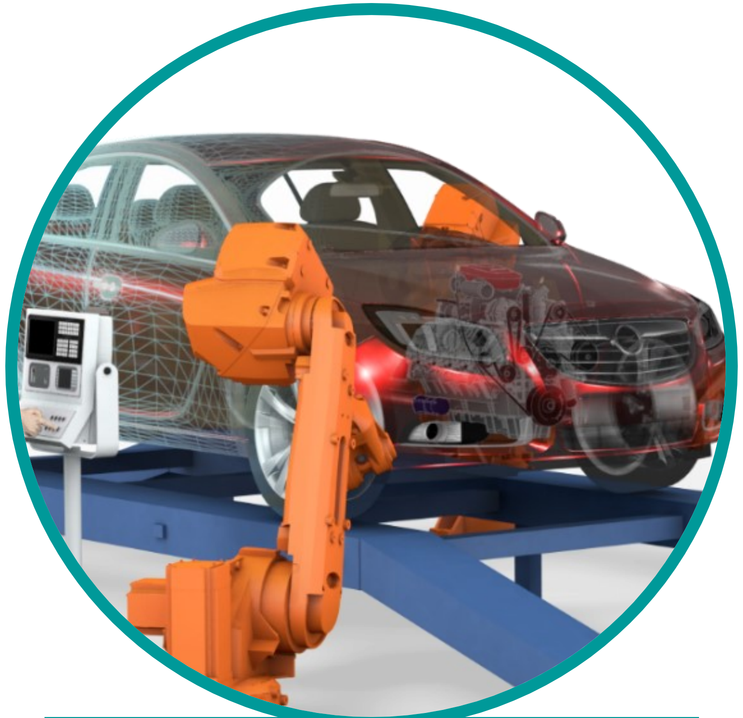
Quality assurance during manufacturing

Quality assurance during manufacturing

Ideation

Performance engineering

Realization



End-of-line testing

Utilization

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End-Of-Line-Test Solutions at SISW

Overall quality

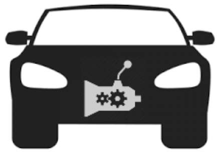
Compliance with tolerances ✓ → Satisfy functionality requirements ✓ → Performance after integration according to targets ✓ → Sales trend → Customers satisfaction

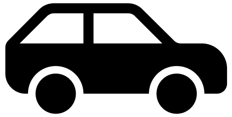
Production line | **Dealership** | **End users**

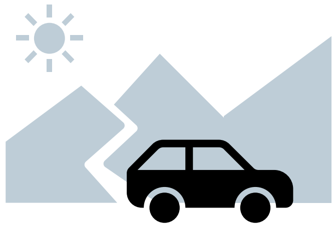
Components

Sub-systems

Full vehicle



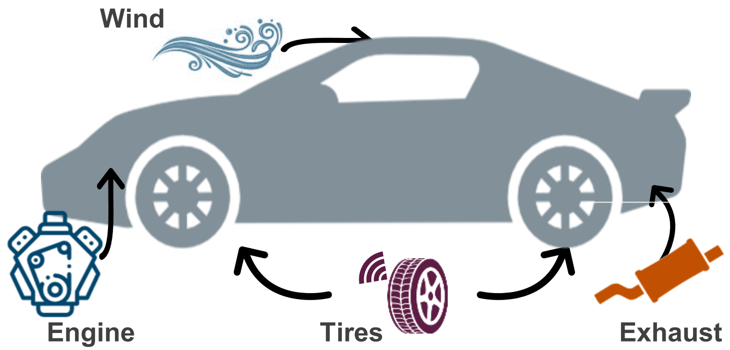




Manufacturing → **Assembly** → **Integration** → **Variance** → **Degradation**

- NVH end-of-line test system integrated in the production line
- **Objective** assessments; very high accuracy requirements
- Commercial solution: **Simcenter Anovis**

NVH quality



- **Current approach**: **subjective** assessment by test driver; low accuracy result
- **Ongoing research**: MOIRA ESR 12

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End-of-line test at the production line
Example: Automatic Transmission Test

- Vibration and sound measurements, tacho signal for order analysis
- Transmission faults:
  1. Shaft and bearing orders
     - Unbalance
     - Misalignment
     - Bearing damage
  2. Gear orders and sidebands
     - Tooth damage
     - Tooth flank shape
  3. Resonances

End-of-line test at the production line
Example: Automatic Transmission Test

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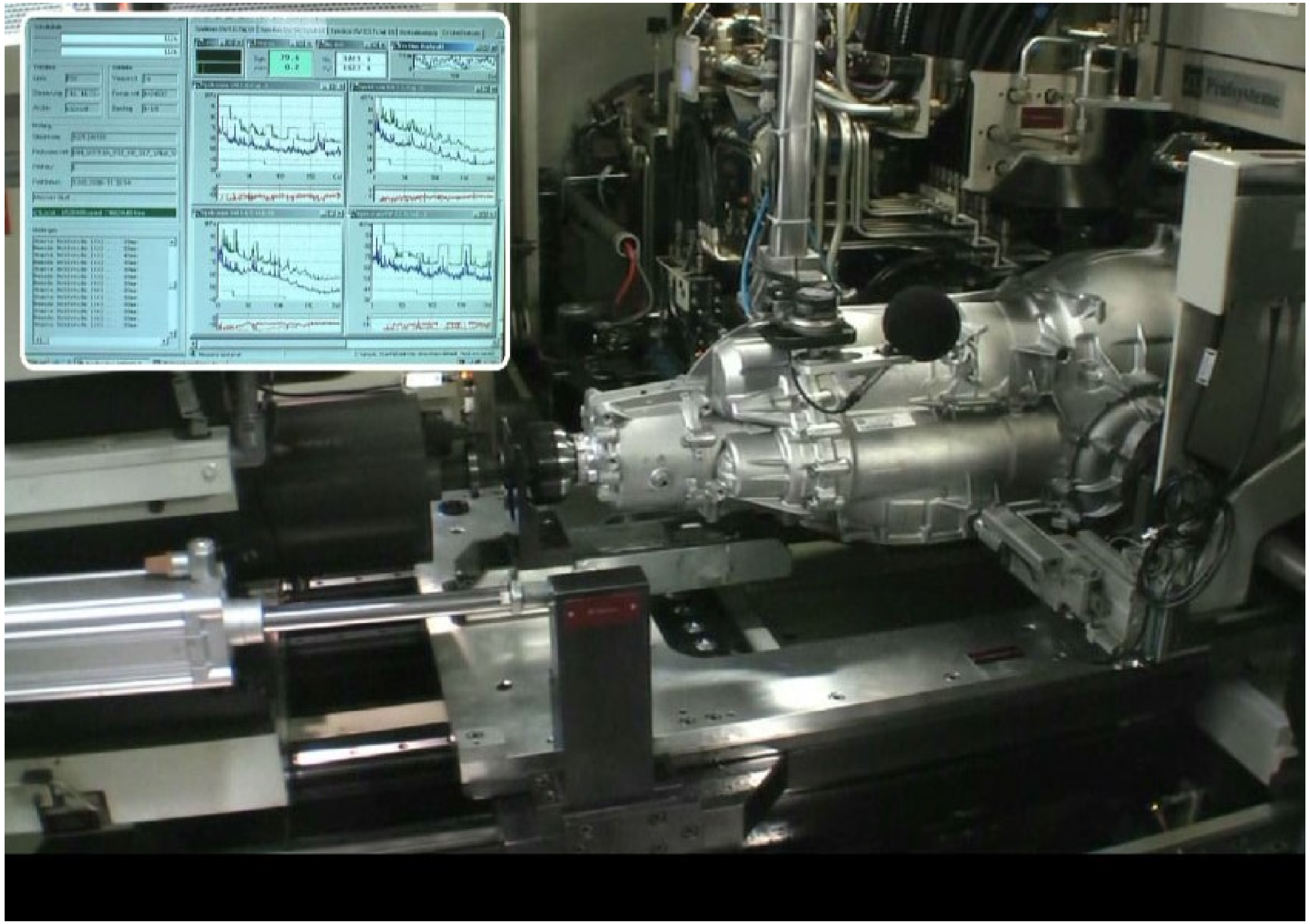


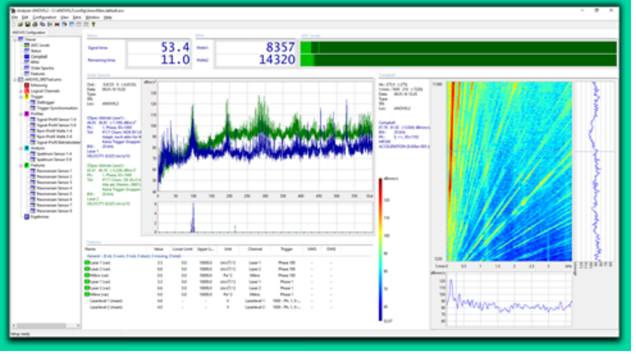
Simcenter Anovis System Overview

Hardware

- Anovis-SRD
- Impact device
- If required:
  PCs, interface cards

Software

- Anovis-professional
- Anovis-lite
- Anovis-Chameleon
- …



Sensors

- Microphones
- Accelerometers
- Laser vibrometers
- …

Deployment Service

- Technical consulting
- Preliminary studies
- Commissioning
- Training
- After-sales support

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Data Acquisition – Simcenter Anovis Signal Recording Device

Different housings

DIN rail unit

19” housing

2 noise/vibration channels per module

75 kHz Bandwidth, 24-bit ADC, integrated AA-filter,

High quality analogue input signal conditioning

Supervised ICP power supply for direct sensor input

2 trigger/tacho channels per module

20 MHz bandwidth

10-bit ADC, integrated AA-filter,

High-speed tacho signal acquisition

Ethernet connection

to Host-PC

operating system independent

(Windows 7, 10, Linux)

Optional modules

Operational data

Switching unit

Simcenter Anovis Software
Flexible configuration software

flowlets
Processing modules to configure a set-up interactively by mouse click

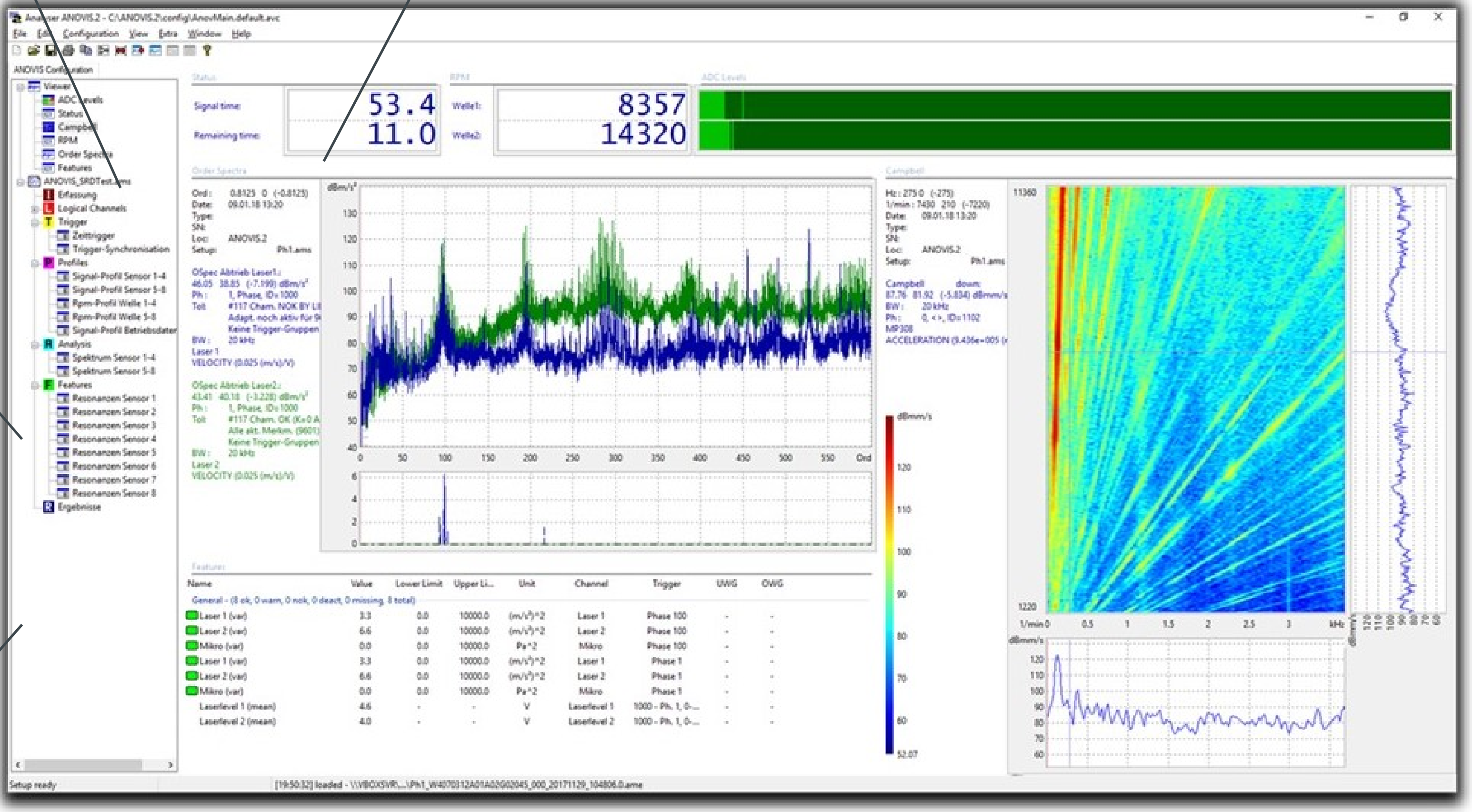
online and offline mode
Data recording using an open and documented file format

Automated playback and offline analysis

phases
Realization of complex signal processing tasks

online and offline data visualization
Viewers configurable by mouse click

Viewers for 1D, 2D and 3D data / Cursors, markers, legends, …



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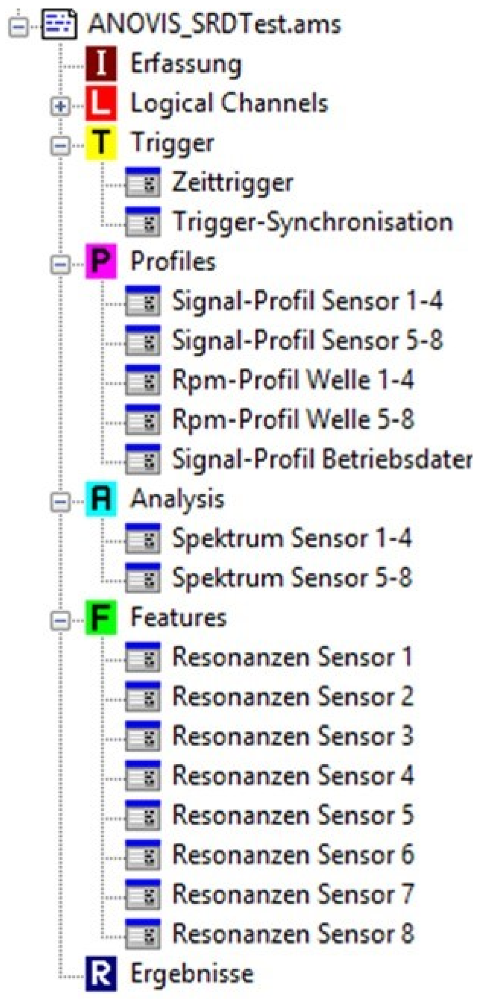
Simcenter Anovis Software
Signal Processing Features

Modular concept

- Signal conditioning: Calibration, Differentiation, Integration, Logical RPM channels, Tacho pulse conditioning
- Trigger and Profiles: Time and Signal Trigger, RPM Trigger, Trigger Combination, Signal and RPM profiles
- Analysis: Frequency analysis, order analysis, digital angle synchronous resampling, envelope analysis, cepstrum, synchronous cepstrum, octave analysis
- Features: Frequency and order spectra, order level tracks:, harmonic levels and tracks, time signal measures, (order-) spectral level values and curves, angle synchronous averaged time signal, frequency / order sonagram
- Psycho acoustic metrics

Creating solutions for new tasks is done by mouse click, without programing, within some hours



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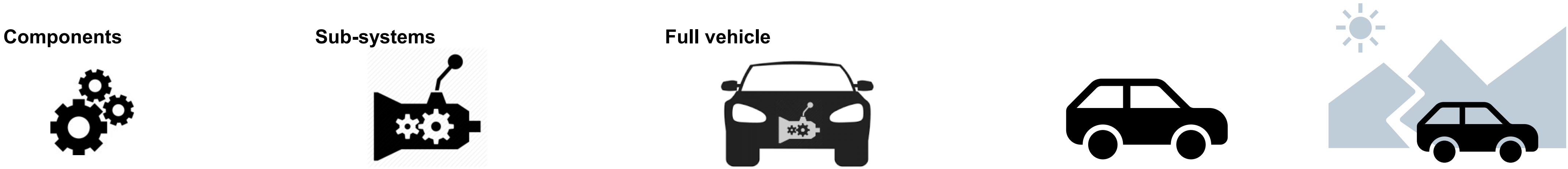
Full Vehicle End-of-Line Testing
Problem statement

Overall quality

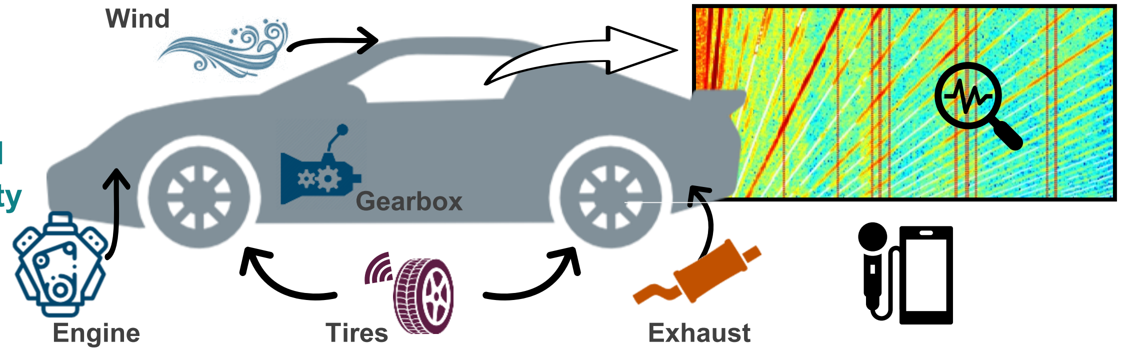
Compliance with tolerances ✓ → Satisfy functionality requirements ✓ → Performance after integration according to targets ✓ → Sales trend → Customers satisfaction

Production line | **Dealership** | **End users**



Manufacturing → Assembly → **Integration** → Variance → Degradation

NVH quality



The integration of multiple sub-systems in a full vehicle assembly implies a complex interior and exterior sound signature. Structure borne airborne and aerodynamic sources interact with the vehicle structure with the risk of generating unwanted phenomena such as:

- Booming
- Whining
- Squeak and rattle
- Wind whistling noise
- Modulation
- Etc.

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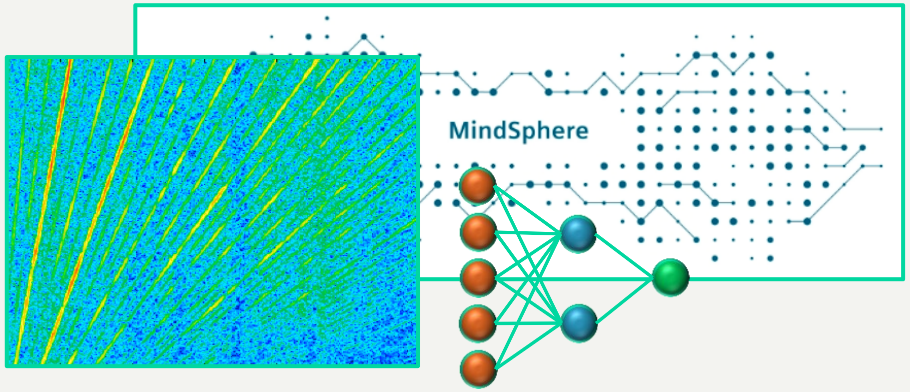
Full Vehicle End-of-Line Testing
Motivation and positioning of work

Why

Generate the ability to monitor the NVH quality control of vehicle production process in real time.

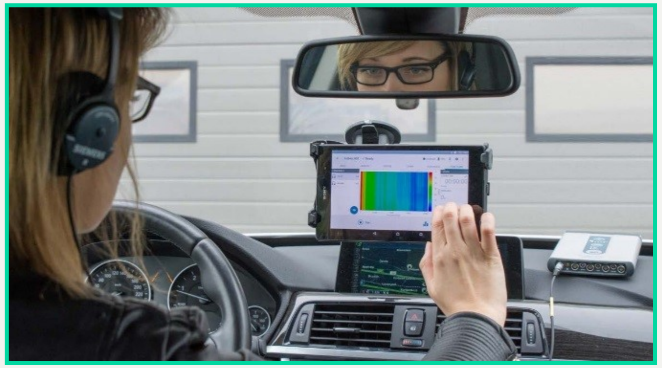
Today: it's a subjective assessment, with an accuracy rating of 45%.

Trend: all vehicle launch tools are moving from subjective to objective based tools.



How

- Use of NVH knowledge.
- Big data analytics and machine learning AI's.
- Efficient infrastructure for computation.



What

- NVH Vehicle Launch App.
- Cloud based processing of vehicle data.
- Production process quality control.

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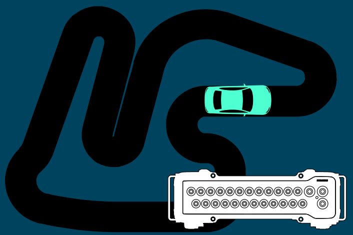
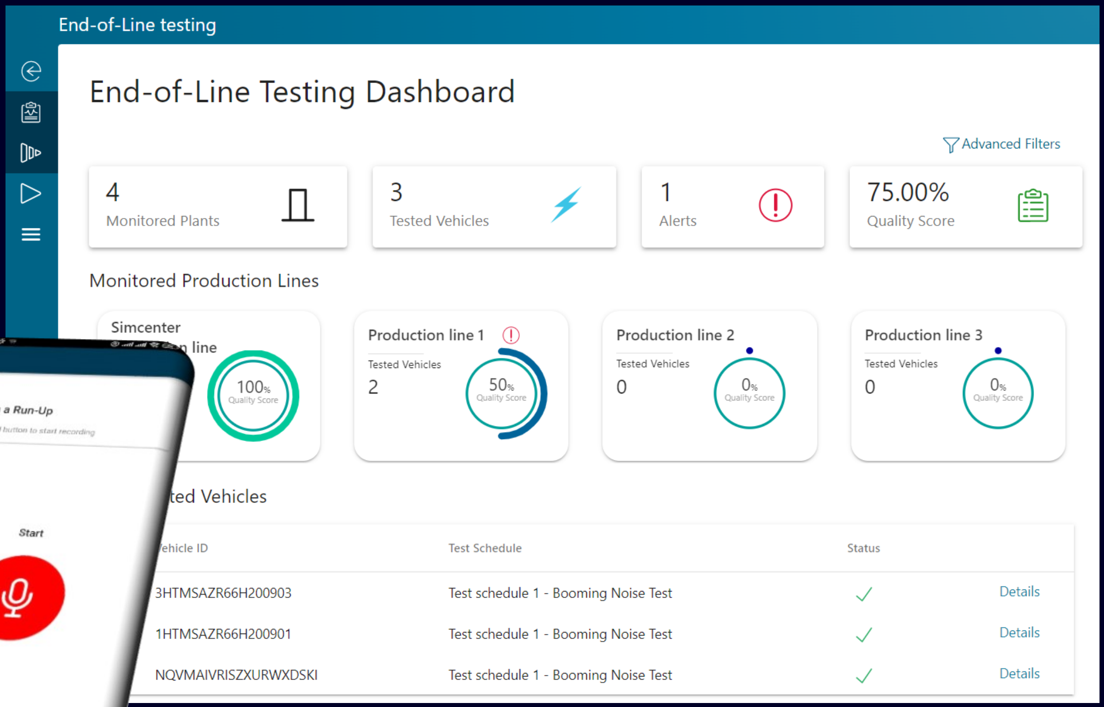
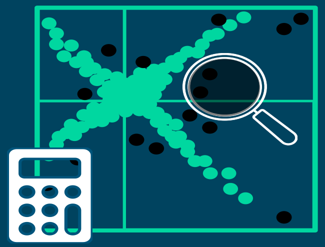
Workflow Automation

Full vehicle NVH end-of-line testing APPs and process orchestrator



Dedicated mobile app for data recording.



End-of-Line testing dashboard

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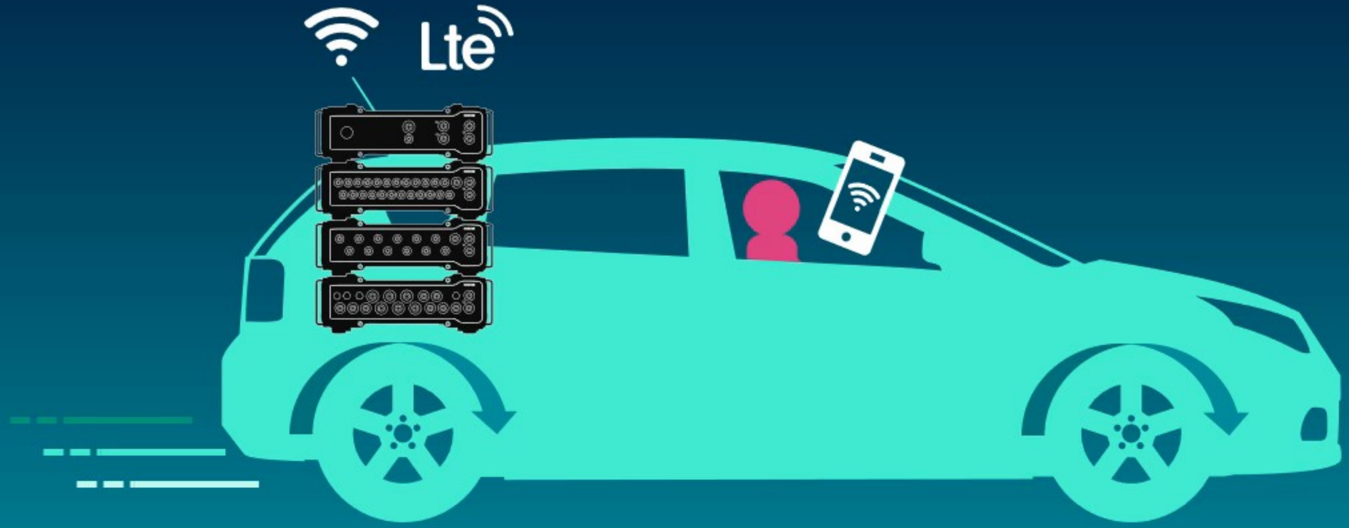
Simcenter Testlab Process Automation Proof of Concept



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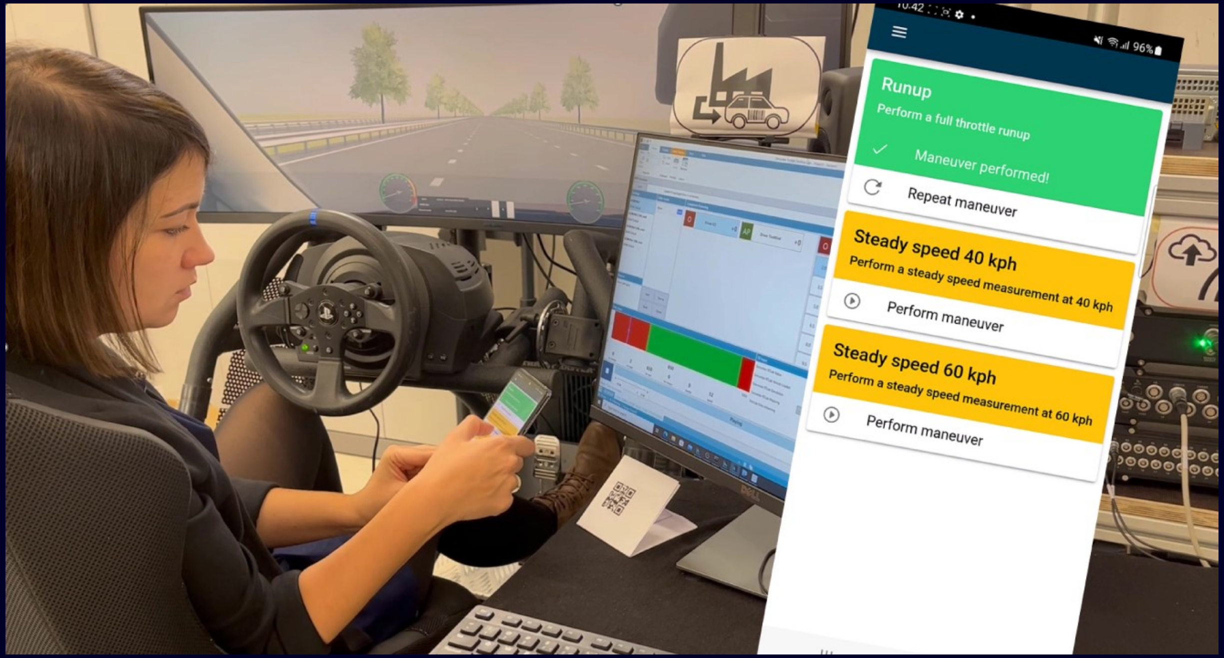
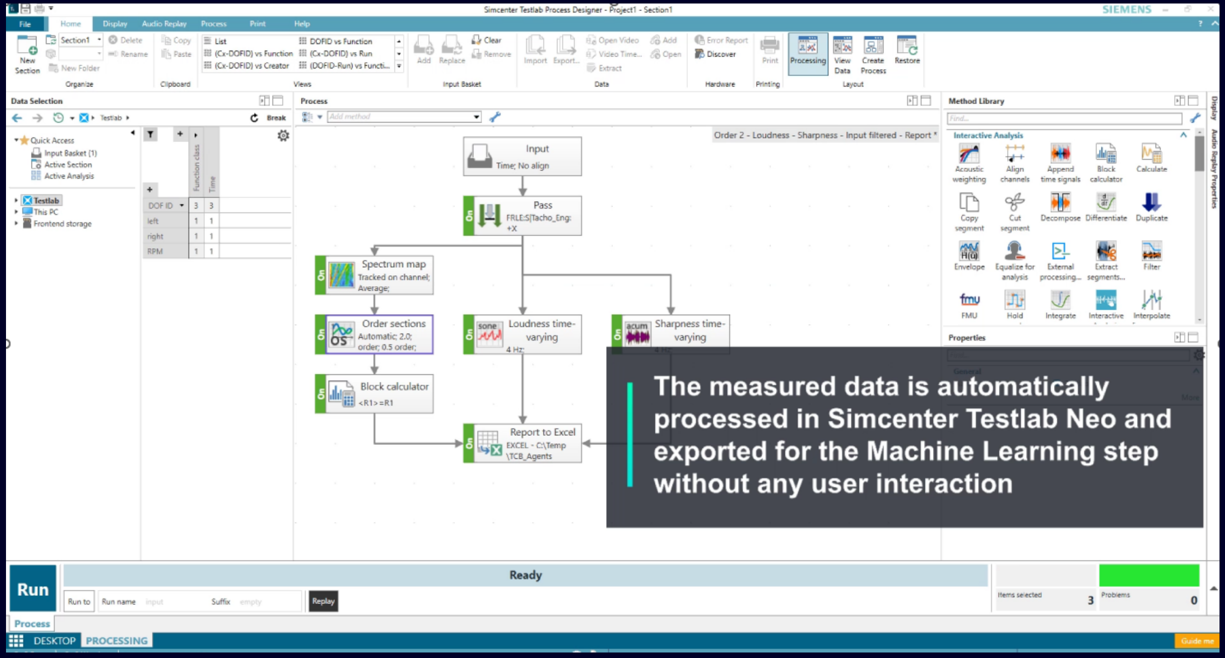

Runup
Perform a full throttle runup
Maneuver performed!
Repeat maneuver
Steady speed 40 kph
Perform a steady speed measurement at 40 kph
Perform maneuver
Steady speed 60 kph
Perform a steady speed measurement at 60 kph
Perform maneuver


Simcenter Testlab Process Designer - Project1 - Section1
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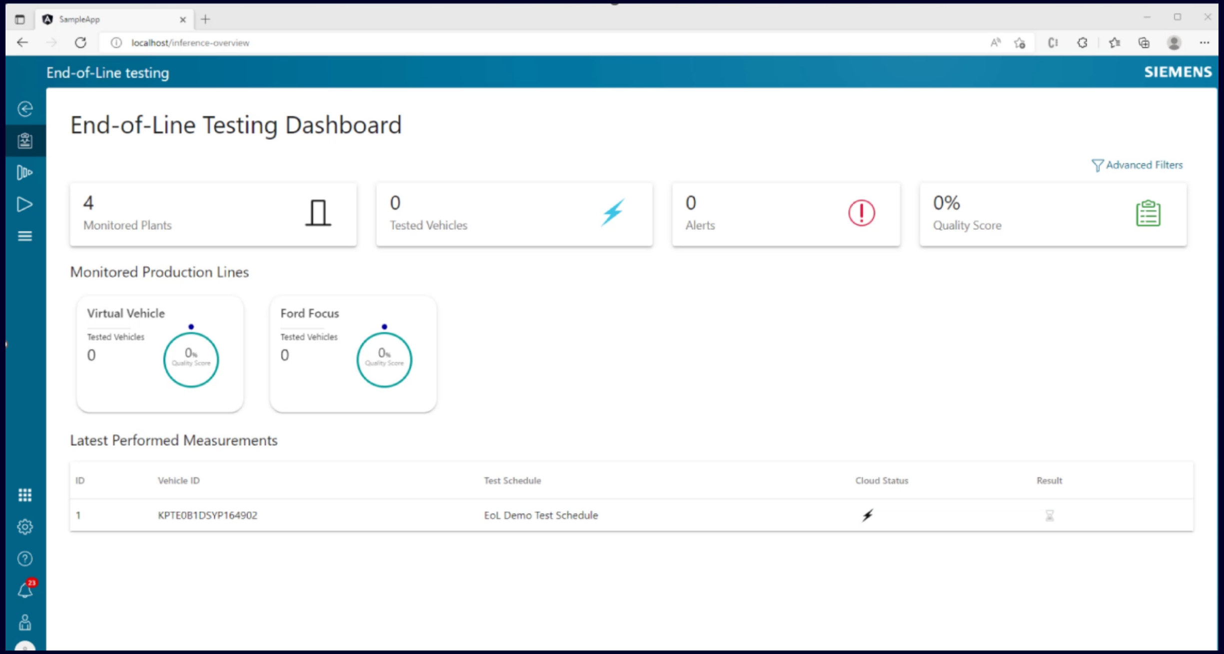
Data Selection
Process
Method Library
Input
Pass
Spectrum map
Order sections
Loudness time-varying
Sharpness time-varying
Block calculator
Report to Excel
The measured data is automatically processed in Simcenter Testlab Neo and exported for the Machine Learning step without any user interaction
Run
Ready
DESKTOP
PROCESSING


localhost/inference-overview
End-of-Line testing
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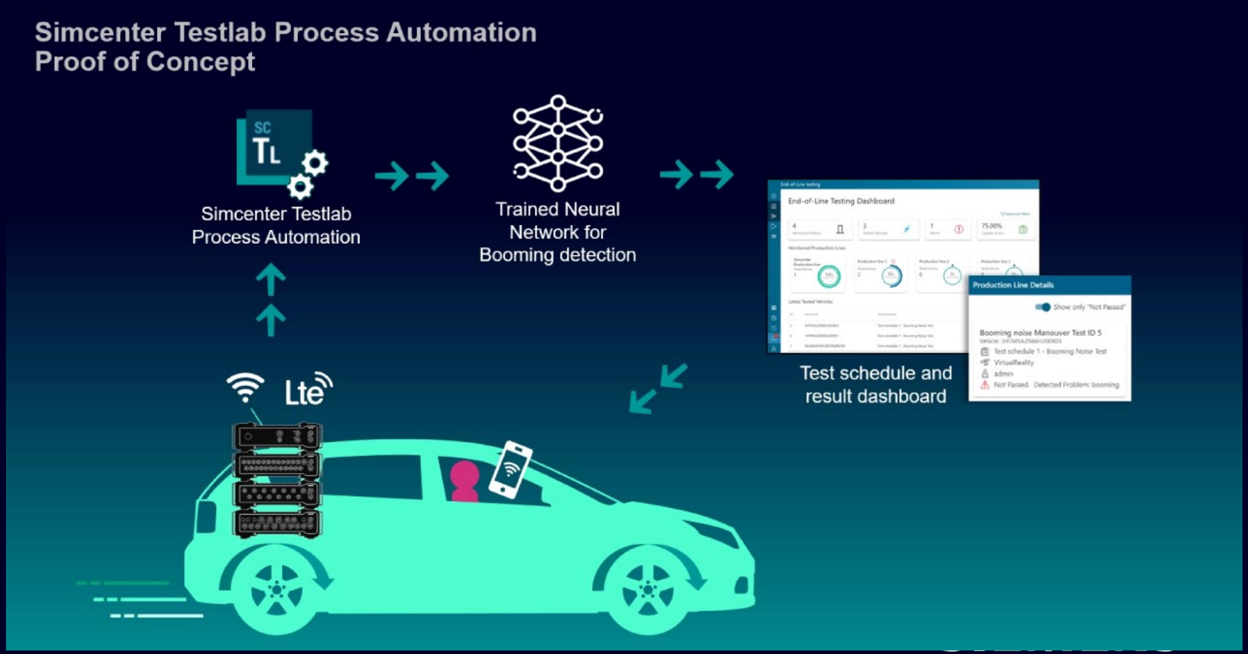
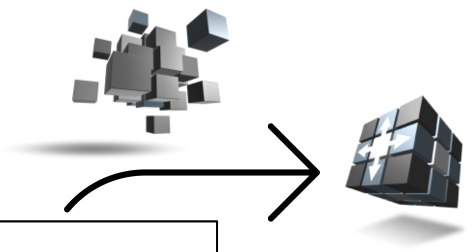
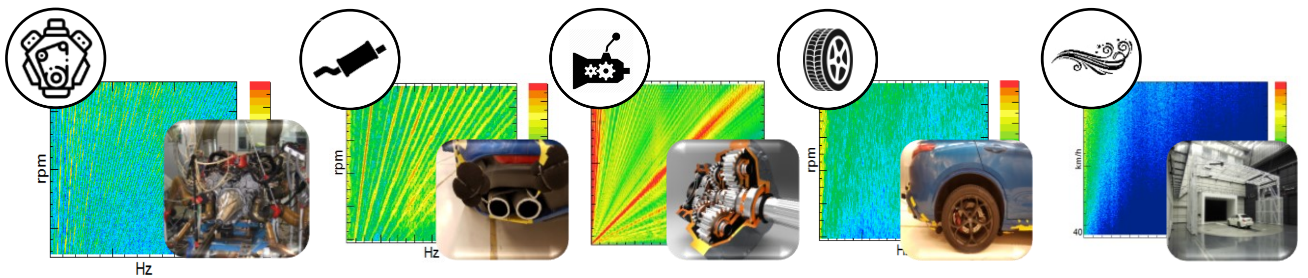
End-of-Line Testing Dashboard
Advanced Filters
4
Monitored Plants
0
Tested Vehicles
0
Alerts
0%
Quality Score
Monitored Production Lines
Virtual Vehicle
Tested Vehicles
0
Ford Focus
Tested Vehicles
0
Latest Performed Measurements
ID
Vehicle ID
Test Schedule
Cloud Status
Result
1
KPTEOB1DSYP164902
EoL Demo Test Schedule


Simcenter Testlab Process Automation
Proof of Concept
Simcenter Testlab
Process Automation
Trained Neural
Network for
Booming detection
Test schedule and
result dashboard
Lte

Why digital twins for vehicle sound and NVH?



Tested or numerically simulated components



How **SHOULD** it sound?
Target setting, compliance with standards and requirements

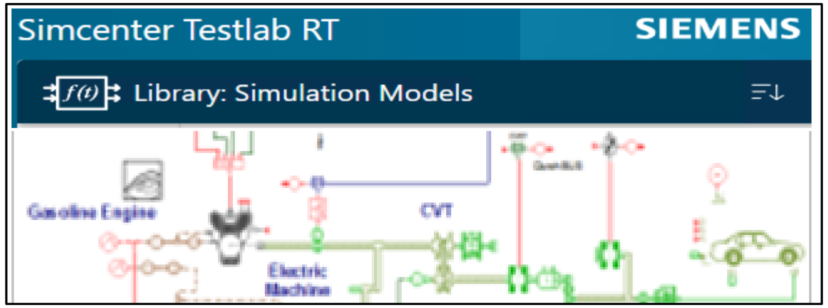
How **COULD** it sound?
What-if analysis, acoustic digital twins

How **DOES** it sound?
Objective analysis, troubleshooting

Your mechatronic system

Encode the NVH model

Real time interface with vehicle performance model



Live synthesis in free drive

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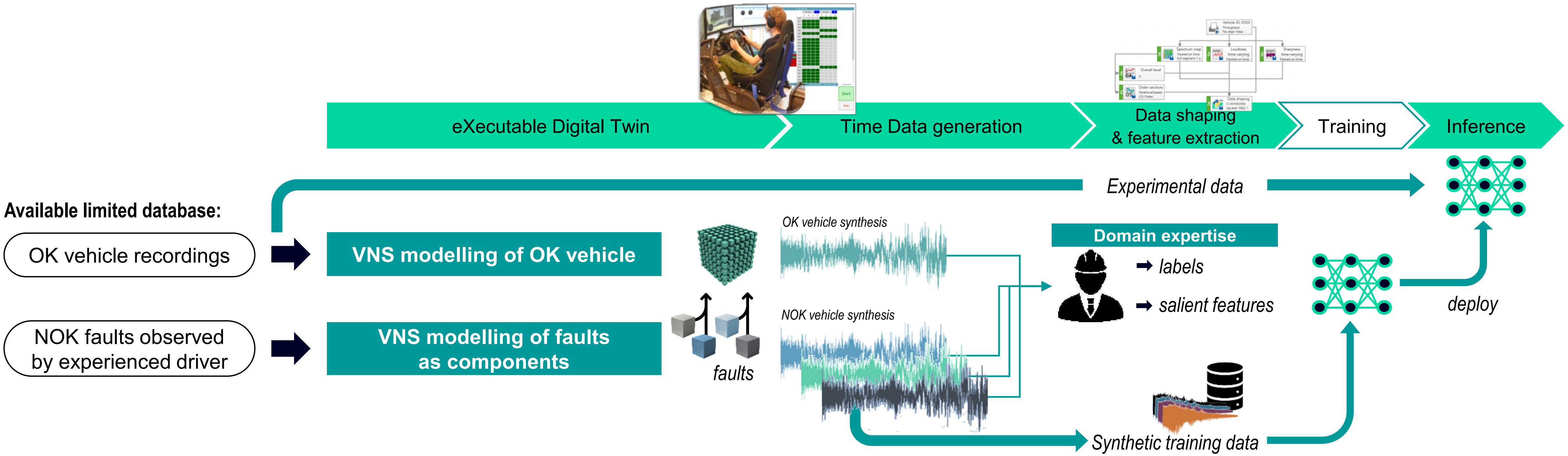
Vehicle NVH Simulator (VNS) as digital framework for data-driven model training database generation



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Simulation-driven machine learning and Transfer Learning

PhD project Deepti Kunte (MOIRA ESR 12)

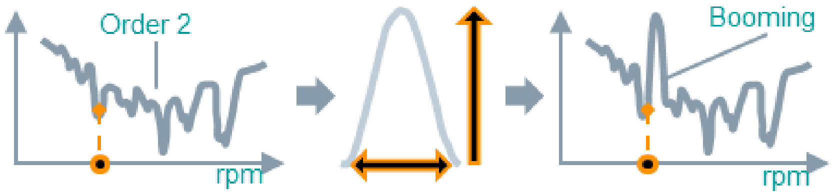
Brand X – Vehicle Type A

Experimental data of OK vehicles available.

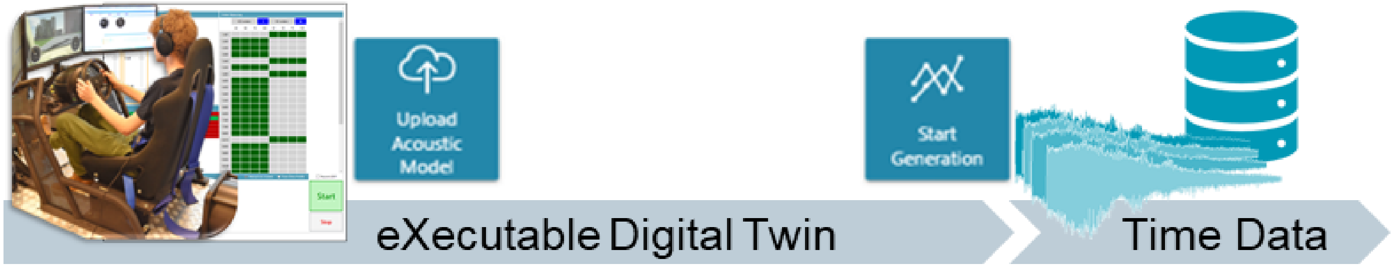
Brand X – Vehicle Type B

Experimental data of OK vehicles available.

Modelling of NVH faults adopting Vehicle Sound Simulator.



Generation of large training database of synthetic faulty data



Problem definition:

Large (partially synthetic) database of OK and NOK data is available for domain A. The objective is to leverage the model trained on domain A in the EOL testing of domain B that could be a similar vehicle type of the same brand.

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Structural Health Monitoring

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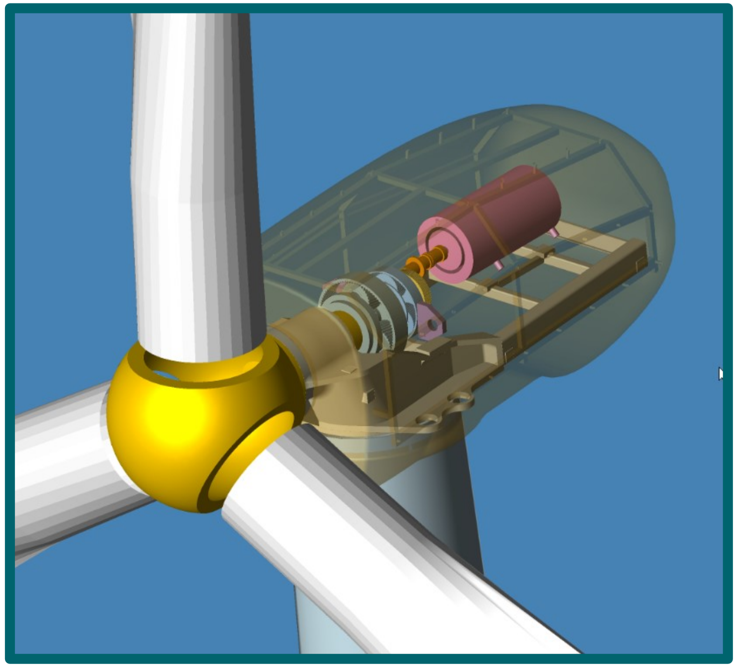
The Digital Twin
Creating value along the life cycle

Ideation



Digital Product Twin

Realization

Digital Production Twin

Utilization

Digital Performance Twin

Wind turbine utilization
We need better maintenance strategies…


5 Windmills which Failed (Enviromental ...
youtube.com


FAILURE OF GEARED WIND TURBINES ...
sites.google.com


Concern expressed after damage to wind ...
wind-watch.org


Fires are major cause of wind farm ...
imperial.ac.uk


FAILURE OF GEARED WIND TURBINES ...
sites.google.com


Wind turbine damaged...
wind-watch.org


WindAction | Wind turbine burns ...
windaction.org


Asian offshore projects uninsurable ...
rechargenews.com


Storms Damage Waterfront Win...
yourerie.com


Automated Drone Inspects Wind Turbines ...
youtube.com


Fire damaged wind turbine to be removed ...
saltwire.com


armour EDGE | An in
armouredge.com


Mitigating threats to onshore wind ...

UFO did not damage giant wind turbine ...


Ignore Puerto Rico Wind Turbine Damage ...


Damage to wind turbin...

Damaged Wind Turbine Images, Stock ...


wind turbine ...

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Winergy

Predicting the remaining useful lifetime of each wind turbine gearbox

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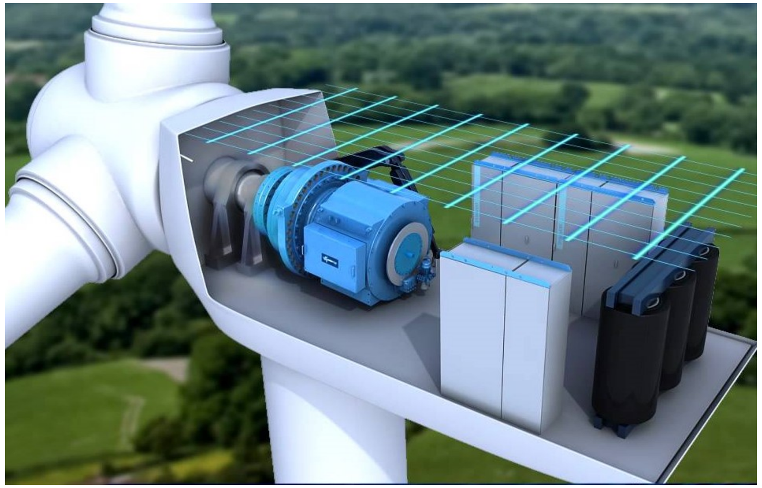
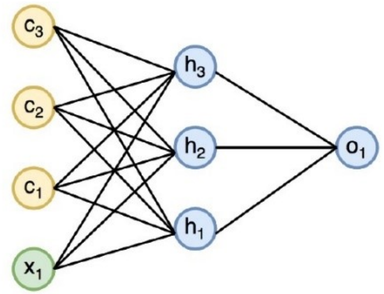
Ingenuity for life



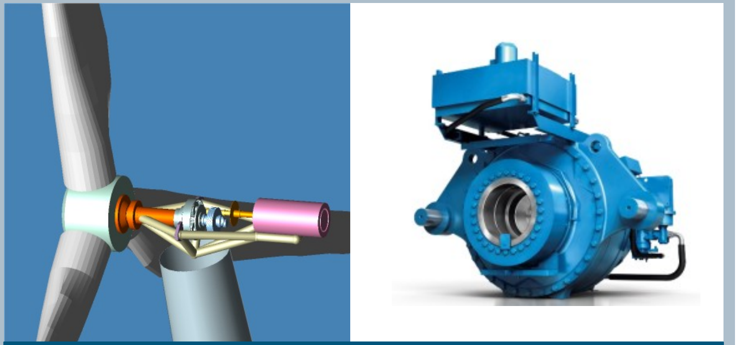
- **Optimize the maintenance planning of the wind turbine fleet**
- **Limit the number of spare parts**
- **Prediction and reduction of failures**
- **Feedback from the field into the development of wind turbine gearboxes**

Radical change in the Operations & Maintenance of the wind industry

Detect damage using a trained neural network



Machine learning based approach



Individualized digital twin based approach

- Use operating data to train a neural network to detect and predict faults
- Sync the model with the operating condition to validate the digital twin

"We wanted to safeguard the functional performance of our gearboxes. Thanks to the Simcenter Engineering expertise, we can now predict the remaining useful lifetime of the bearings and gear teeth in each gearbox."

Edwin Hidding, Head of Customer Project Management

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Dual Technical approach

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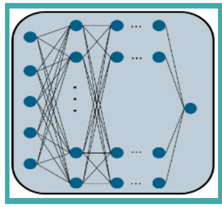
Ingenuity for life

Monitoring data - 78 Wind Turbines (SCADA)
72 channels (wind speed, rpm, gearbox temp, faults, …)

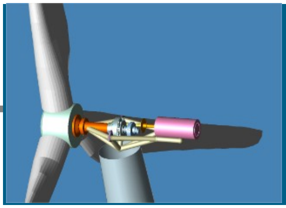
MindSphere



Machine learning

Training Neural Network

Failure prediction and detection



Turbine Model (Digital Twin)

Digital Twin: Model creation and correlation

Accumulate load cases

Remaining lifetime of gears and bearings for each wind turbine gearbox

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Early damage detection by a neural network approach

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Ingenuity for life

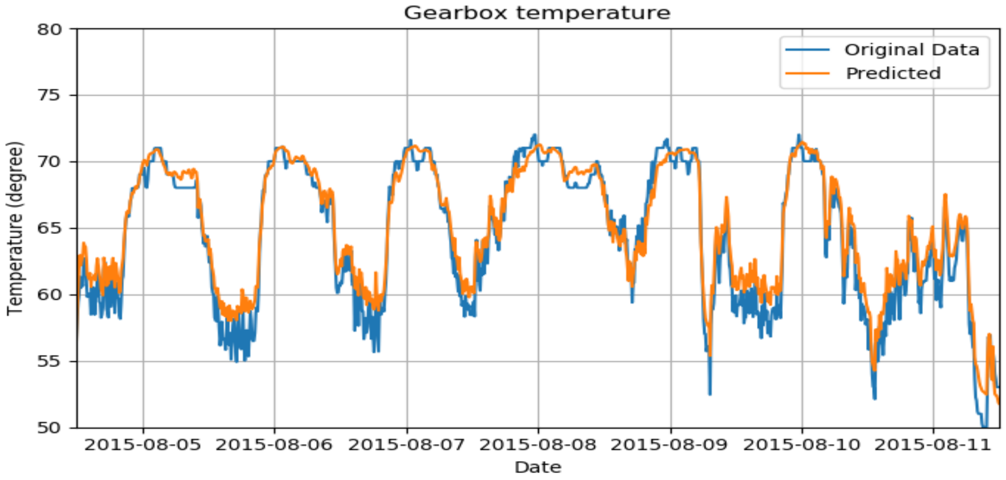
1. **Create a Neural Network that can predict gearbox temperatures from inputs that are not influenced by failures**

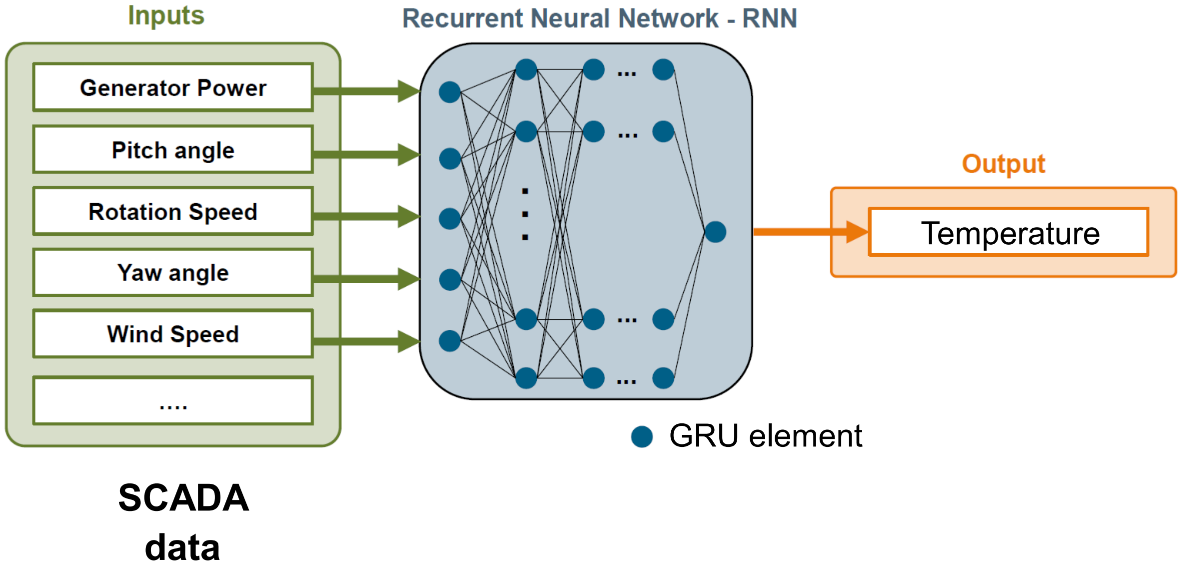
Input → NN → $T_{Gearbox}$

2. **Train the neural network with data when no failure is present**
   - The networks learns how a healthy turbine reacts

3. **Feed the complete dataset to the network**
   - Prediction of gearbox temperature is an indicator for failure
   - Accurate = Healthy state
   - Drifts and inaccuracies = Non-healthy state

Input → NN → Prediction $T^*_{Gearbox}$? ↔ Measurement $T_{Gearbox}$





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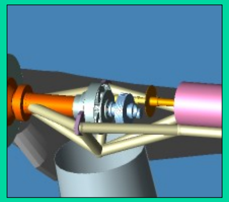
Remaining Useful Life prediction

Loads (per turbine)
As collected over Mindsphere

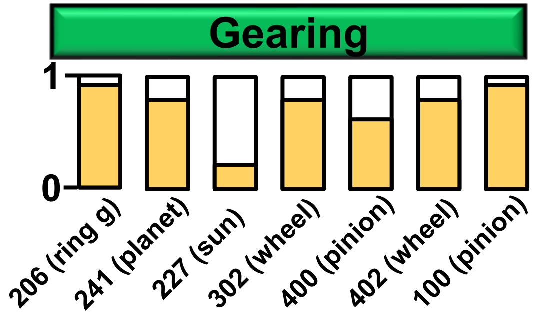
Load capacity – design life time
Material data, manufacturing data, design information, field data, supplier information

Digital Twin

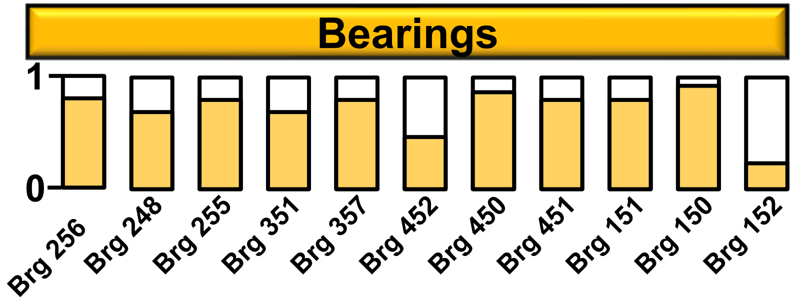
The "DigitalTwin" created individually for each gearbox and contains the connection between load and load capacity.

Output (per turbine)

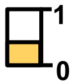


Generals

- ConsumedLoadCycles
- ConsumedLifeTime
- ExpectedLifeTime.
- RemainingYears
- …



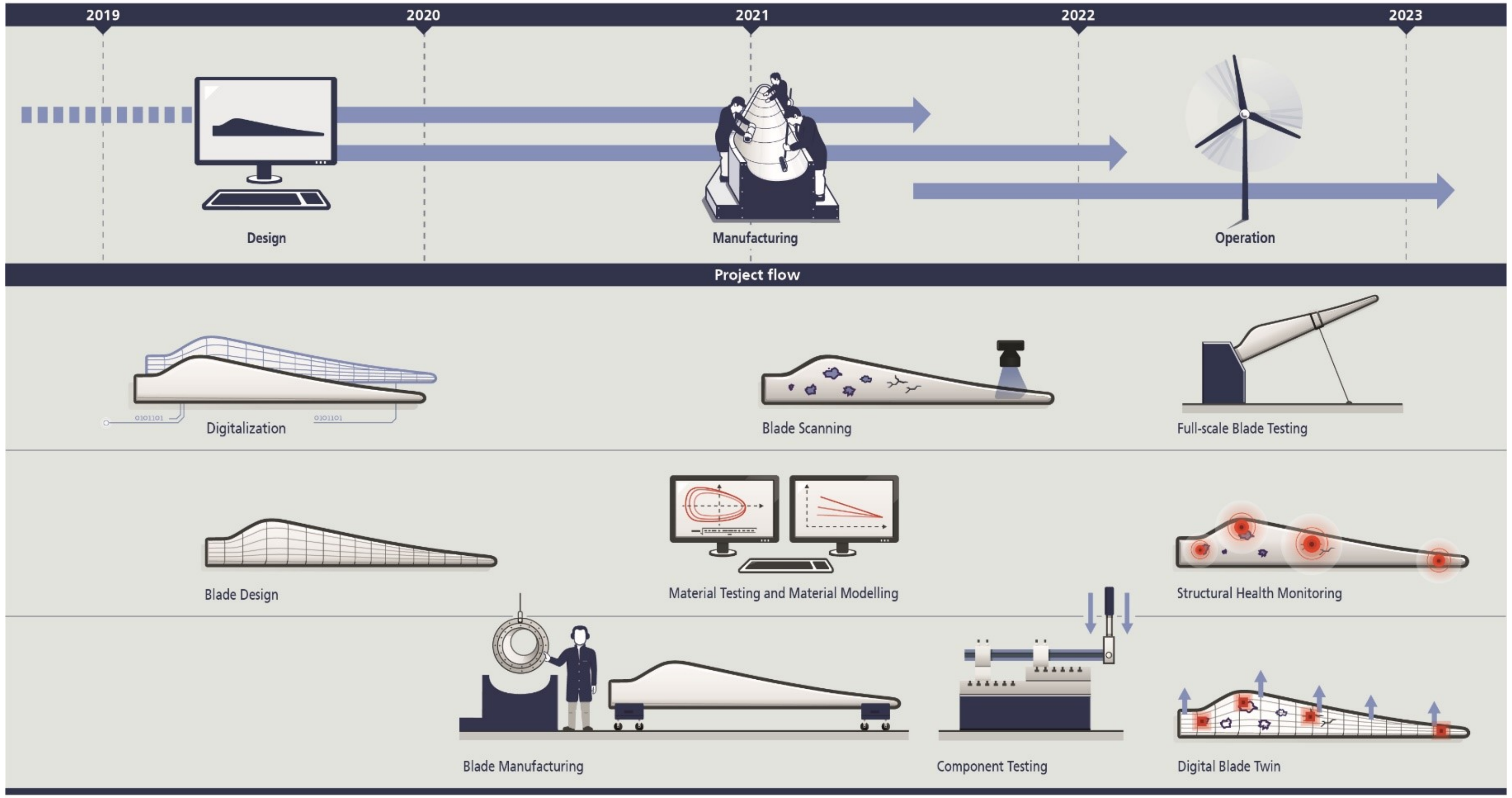
Remaining Useful Life (RUL)



*0 = new component

*1 = lifetime reached (theoretical failure)

ReliaBlade project
Danish-German joint research project



Supported by:
Federal Ministry for Economic Affairs and Energy
on the basis of a decision by the German Bundestag

Developing and demonstrating techniques to create a unique Digital Twin for each individual wind turbine blade with its specific defects and imperfections

Executable Digital Twin

Measure the unmeasurable with smart virtual sensors

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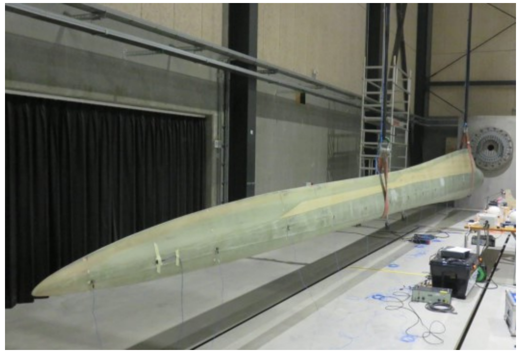
Challenge

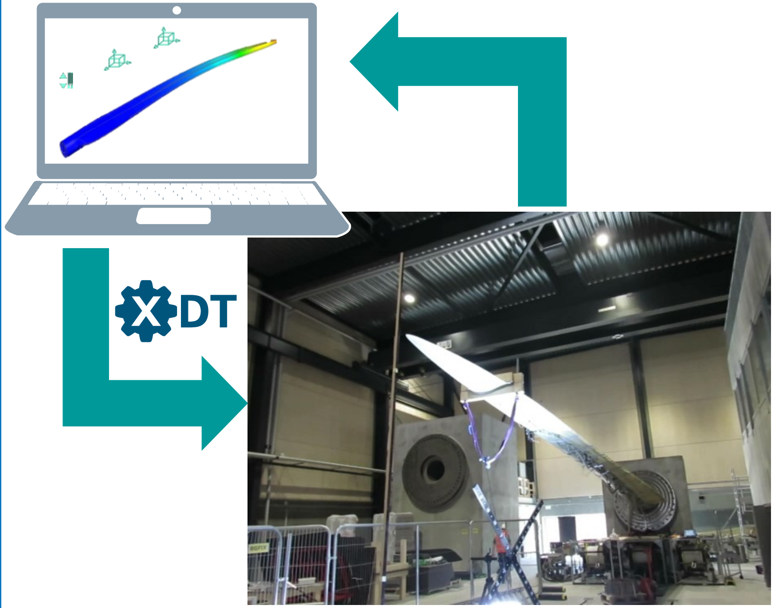
Improve accuracy of durability testing for composite blades



- **Currently relies on a few physical sensors**
- **Suboptimal sensor positioning decreases accuracy of durability results**
- **Model updating can be lengthy and complex**

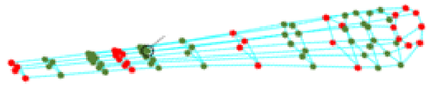
Solution

Estimate full field stress and strain response with smart virtual sensor



Benefits

Detect critical locations on the full blade



Expand strain data from 10's of data points to 100's

Accuracy of durability testing

Up to
50% **Time reduction for model updating and instrumentation**

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Demo preparation: 12.6m wind turbine blade setup

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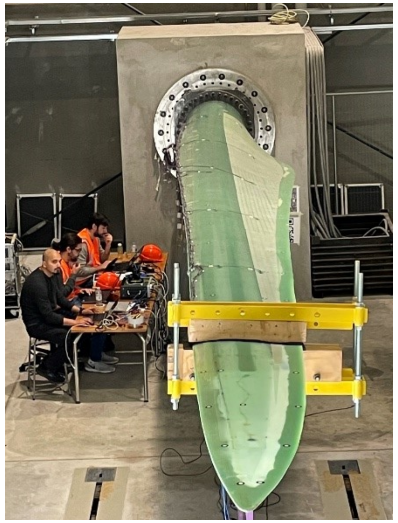
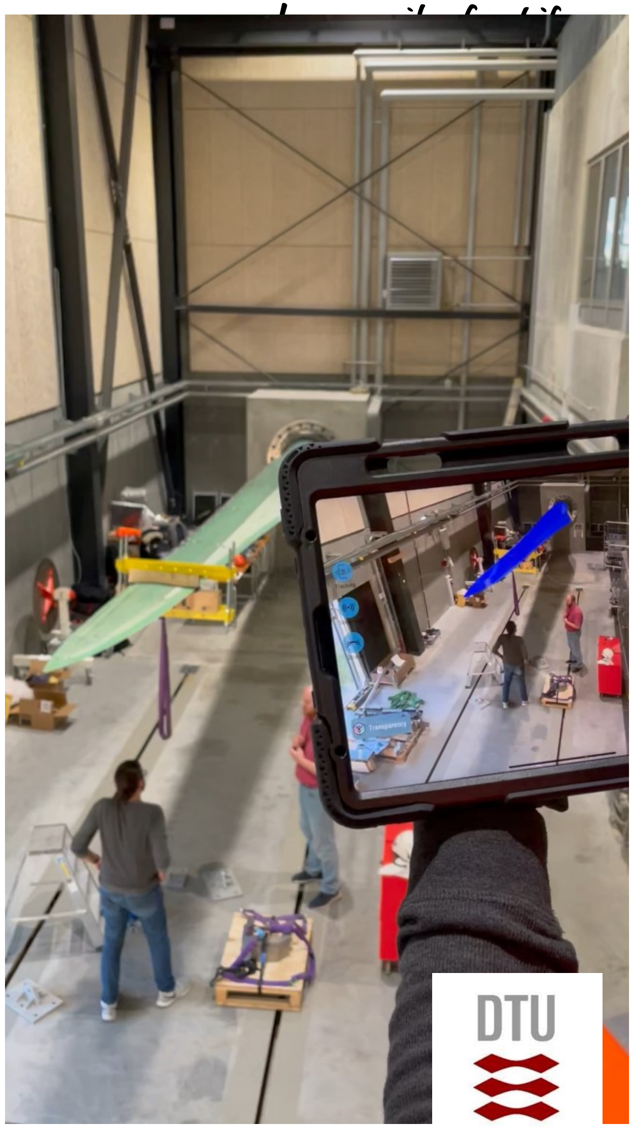
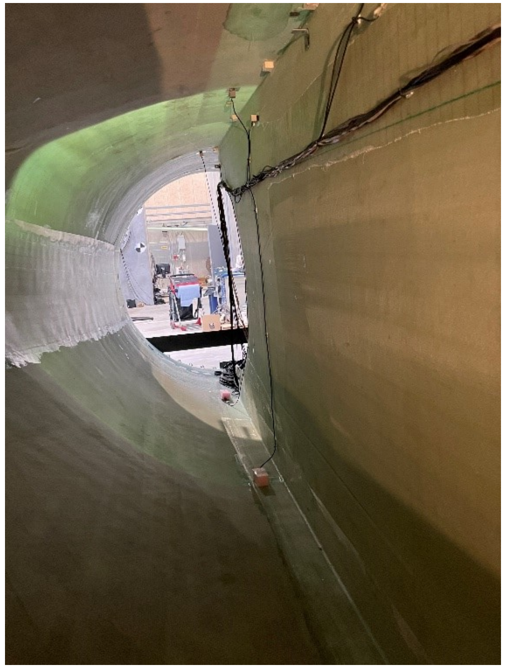


- 64 Installed strain gauges
- 13 Strain gauges measured with the Scadas (handmade cables to connect HBM strain gauges to LEMO)
- 4 Strain gauges used for estimation (Augmented Kalman filter)
- 6 Accelerometers to check modal behavior

Operational tests: pull-release





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xDT toolchain

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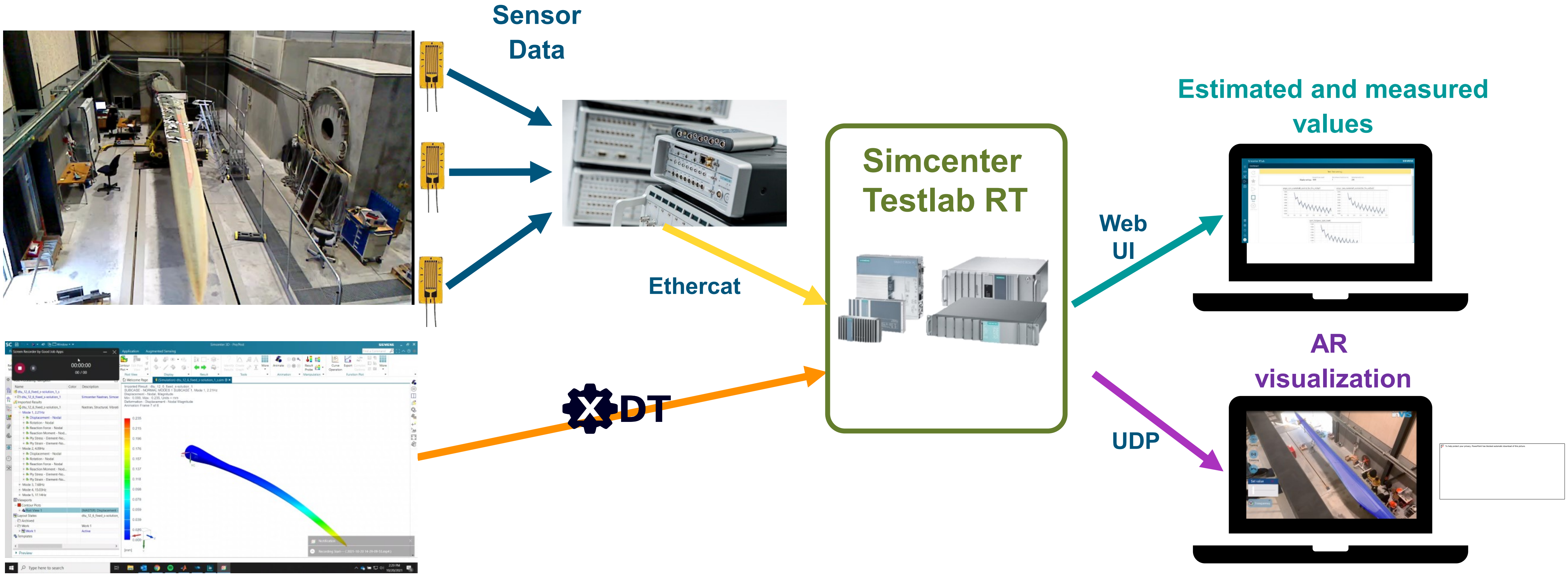
Operate in real-time the xDT of a wind turbine blade and stream the estimated results to Simcenter Testlab RT



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Wind Europe Electric City conference (23-25 November 2021)

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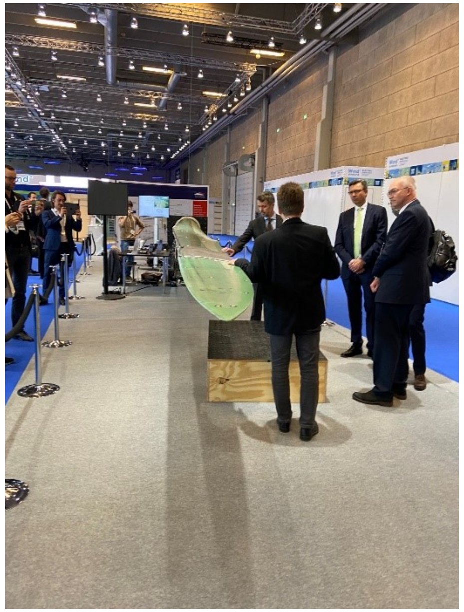
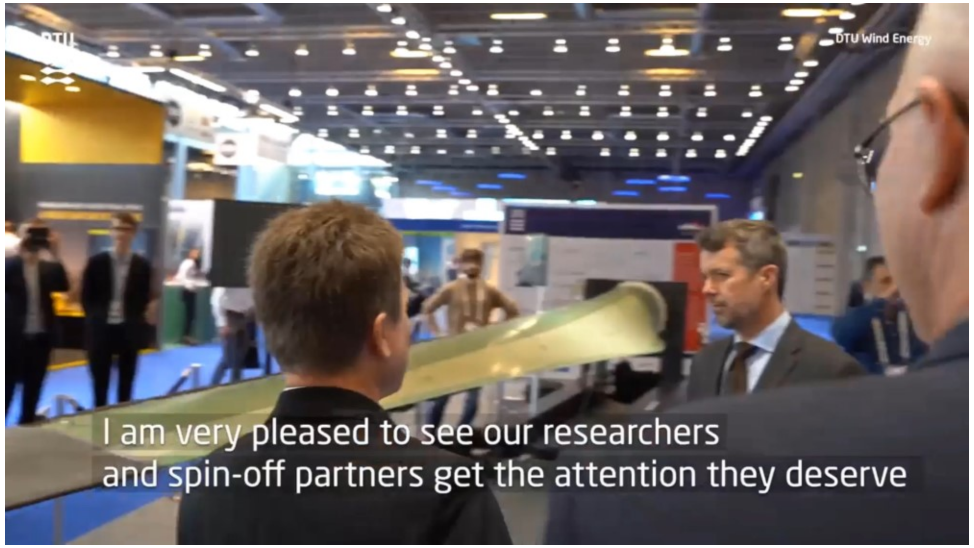
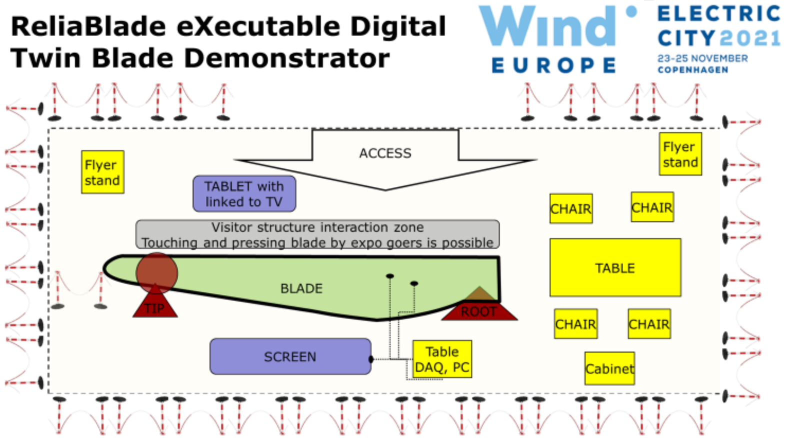
Demonstration on **12.6m long blade**







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Conclusions

- The digital twin concept sits at the center of digitalization
  - Linking all models and data related to products, their production and operational performance
  - Providing them to designers, engineers, operators and service technicians across domains
- The Executable Digital Twin (xDT) leverages the digital twin across the lifecycle
  - Up to real-time models, enabling transparent interchange of physical and digital twin parts
  - Allowing to put the human in the loop
  - Extend the Digital Twin with VR/AR for new user experiences -> Metaverse
  - Allowing to leverage Edge/Cloud & IoT technology
- Open Challenges: How to manage deployments of xDTs in large fleets
  - Both edge and cloud have limitations: power consumption, Tx/Rx bandwidth, privacy
    -> *Federated learning – Fabrizio De Fabritiis*
  - Both physical & digital twins as data source for others in the fleet: there may be dataset shift
    -> *Dataset shift detection and transfer learning – Deepti Kunte*

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Thank You!

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