Digital twin development framework for NextETRUCK:

Real-time and 1000x execution speed DT Development

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Today’s Presenter

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Research Manager IODP [Graz]

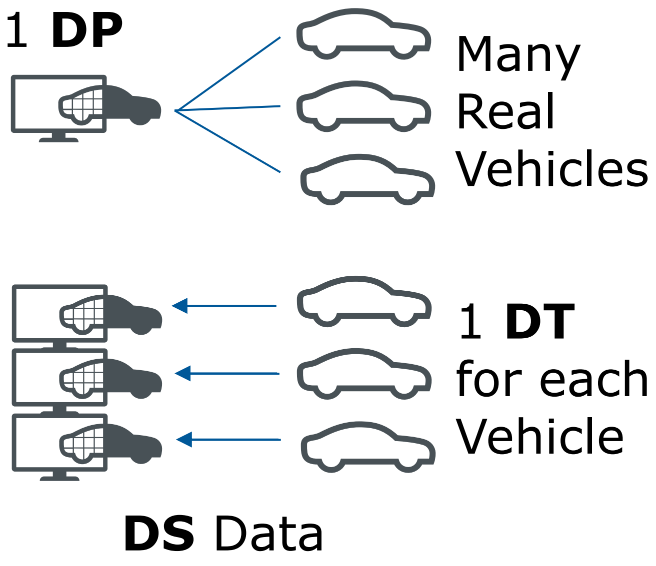
- ~20 years in Automotive / ~5 @ AVL
- ~Half at OEM
- Focus on Collaborative Research Projects to demonstrate and develop cutting edge AVL application solutions
- Languages
  - Japanese / English: Great!
  - German / Greek: Needs work…

Architecture Overview & Background

What is a Digital Twin (DT)?

DT definitions

- **Digital Prototype:** Generic start condition for DT – Standard calibrated model
- **Digital Twin (DT):** A digital representation of a physical system that is kept SYNCHRONISED (updated) with the state of the physical system
- **Digital Shadow:** Telemetry data from the vehicle to update the DT



How is this telemetry data used

- Online data: To perform predictions using the current state of the vehicle
- Offline historical data: To update the calibration / parameterization of the DT

Why Digital Twins?

Fast DT

Future prediction

- Fast x1000 RT execution
- <5% Accuracy
- Future prediction of key variables for vehicle control / management

Use-cases

- **Look-ahead for control (thermal / driver aid etc)**
- **Fleet management prediction algorithms**

High Fidelity DT

Detailed Investigation

- ~ RT execution
- <2% Accuracy
- Accurate representation of vehicle for virtual diagnostics and tuning

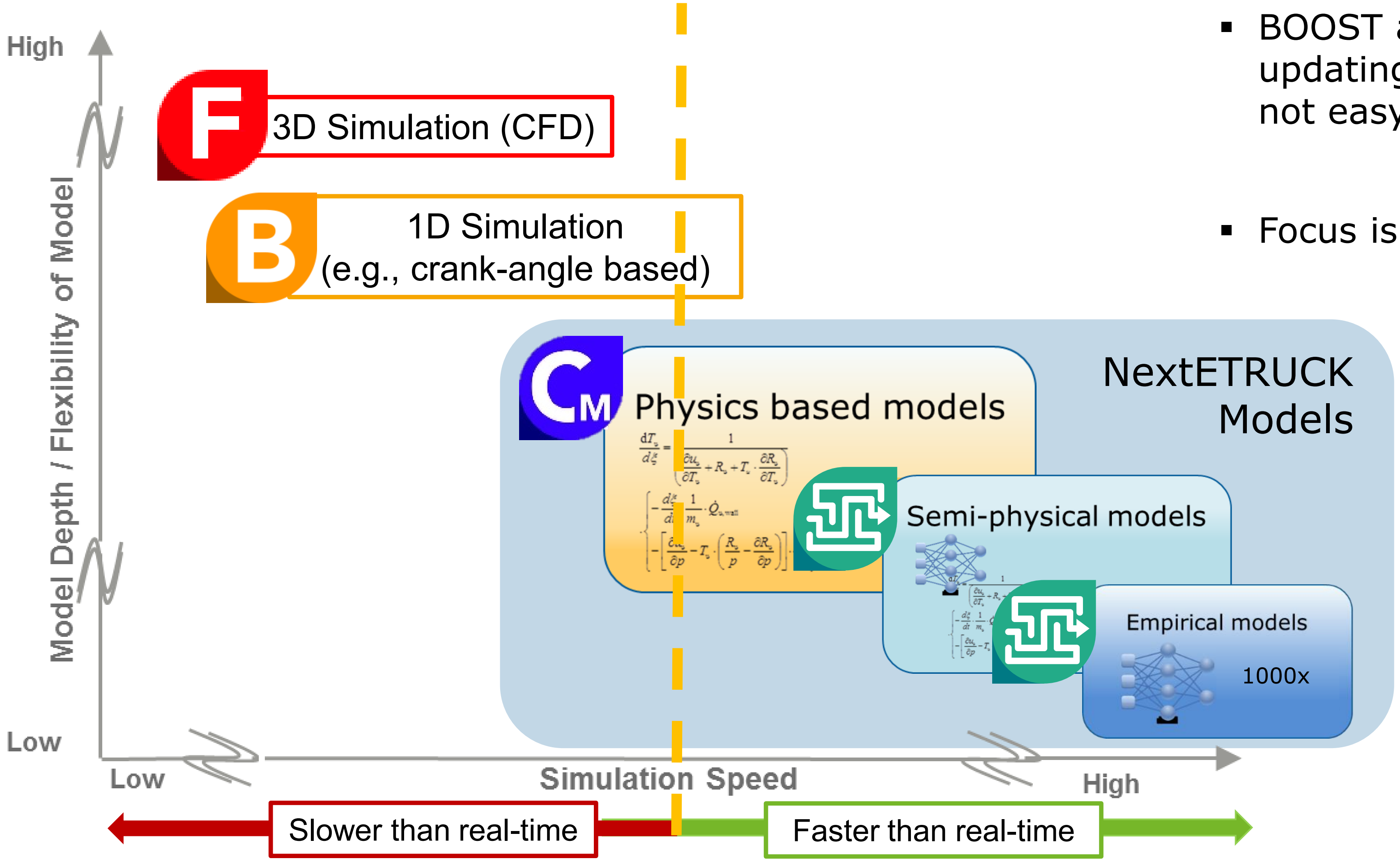
Use-cases

- **Complex issue diagnosis and anomaly detection**
- **Software update validation**

Common Attributes

- Self-Adapting models
- Investigation of any current or historic vehicle/component
- High speed comms with other cloud resources
- Offload compute from vehicle
- Fleet level calculations and interactions

DTs and Simulation Speed Overview



- BOOST and FIRE DTs are possible, but updating such models automatically is not easy
- Focus is on RT or faster models

Digital Twins need not be full fidelity models of the full physical system

- **DTs need only**
  - Have enough fidelity
  - Execute fast enough
  - Model only systems / outputs of interest
- **to fit the use case**

What are the challenges?

Key Issues

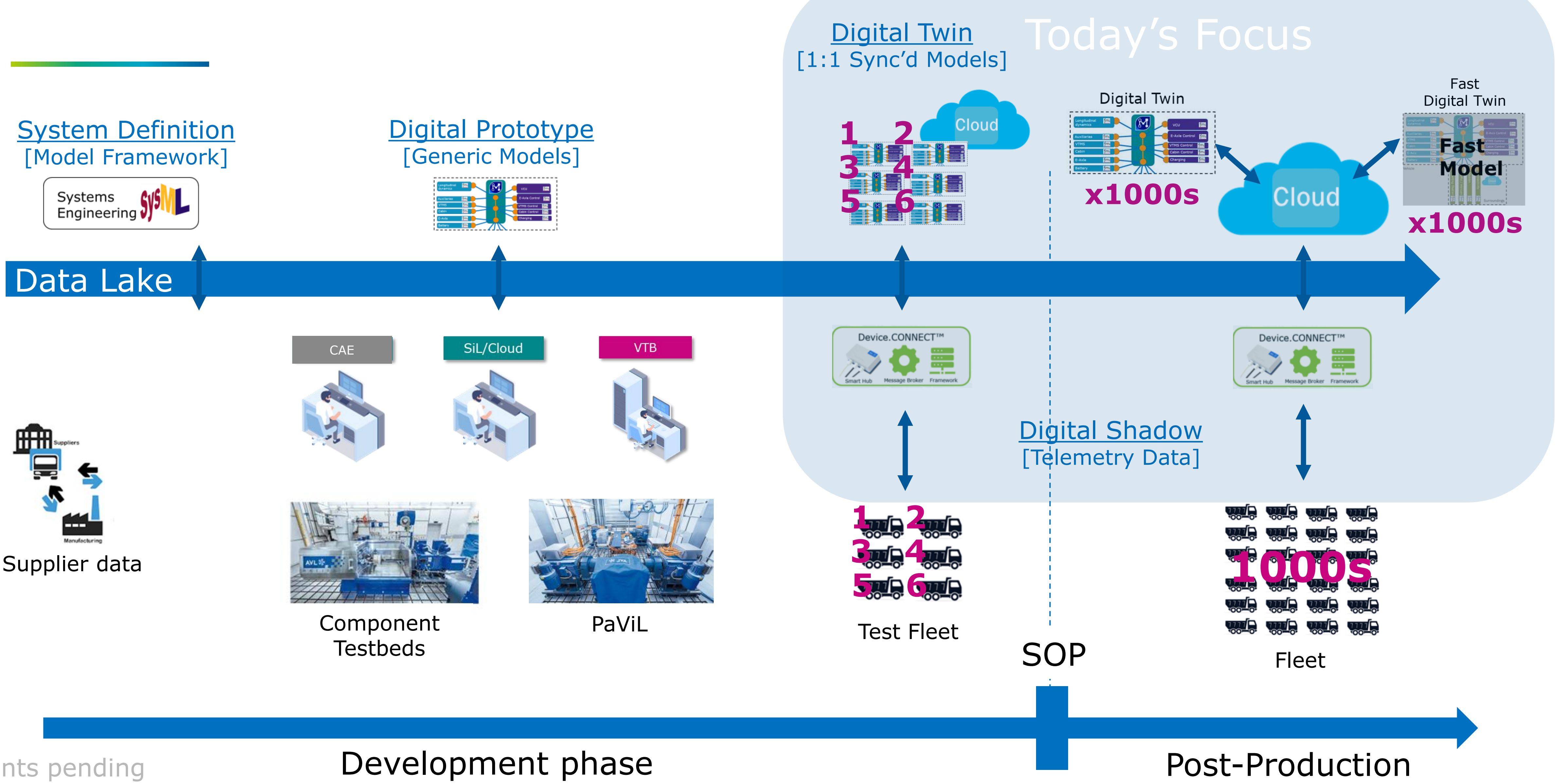
- Live communication between cloud and vehicle
  - Speed / Buffering / Data integrity / Security

- DT creation and update methodology (automation capable)
  - Calculation of delta models
  - Re-parameterize models (inc maps)

- Traceability of models/parameters

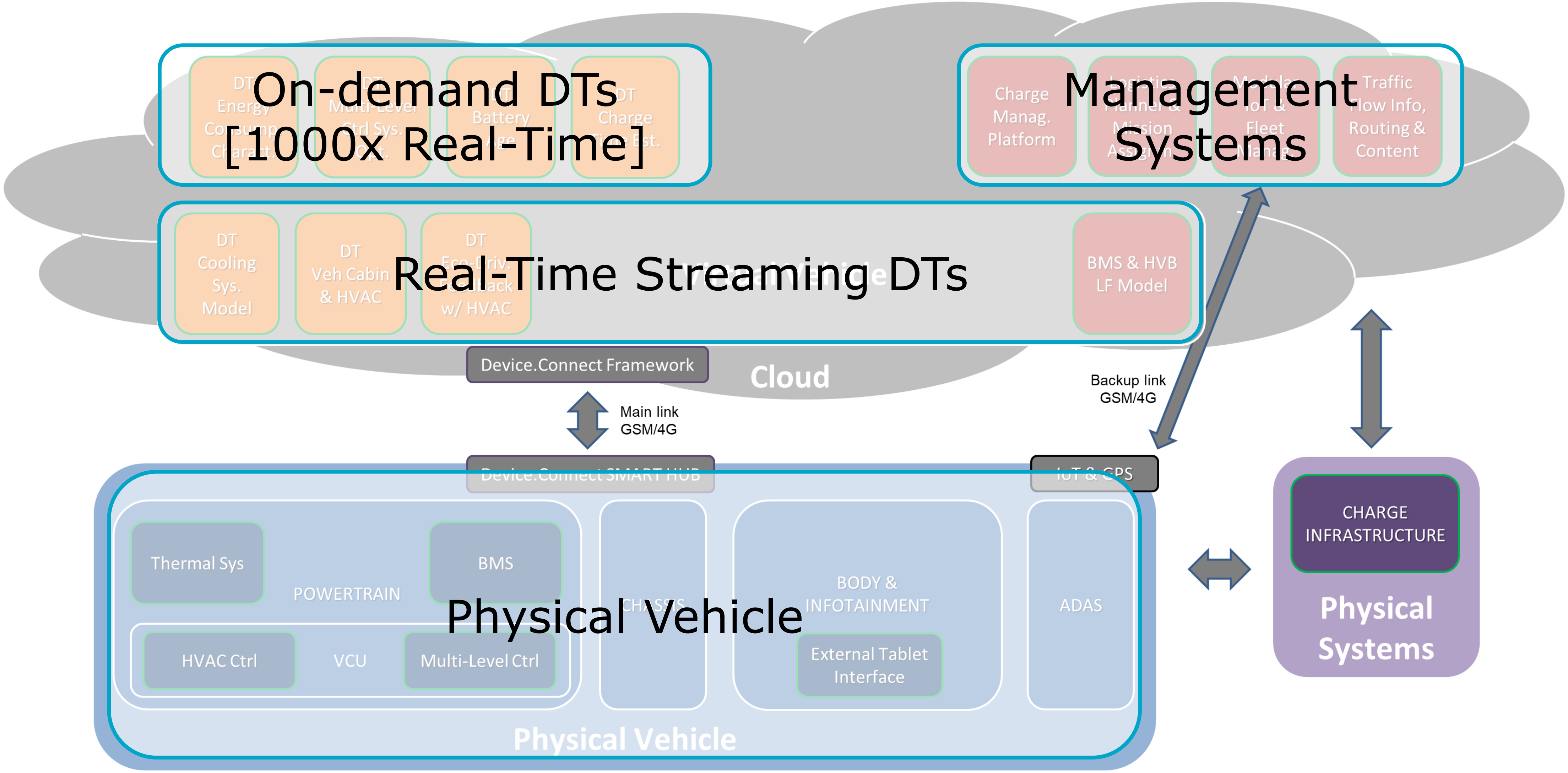
- Automated Pipelines for:
  - Processing large amounts of data
  - Parameterizing / generating updated DTs
  - Cloud capable model deployment and execution

Digital Twin development timeline



Patents pending

NextETRUCK Fast DT Cloud Architecture Overview



NextETRUCK Project Overview

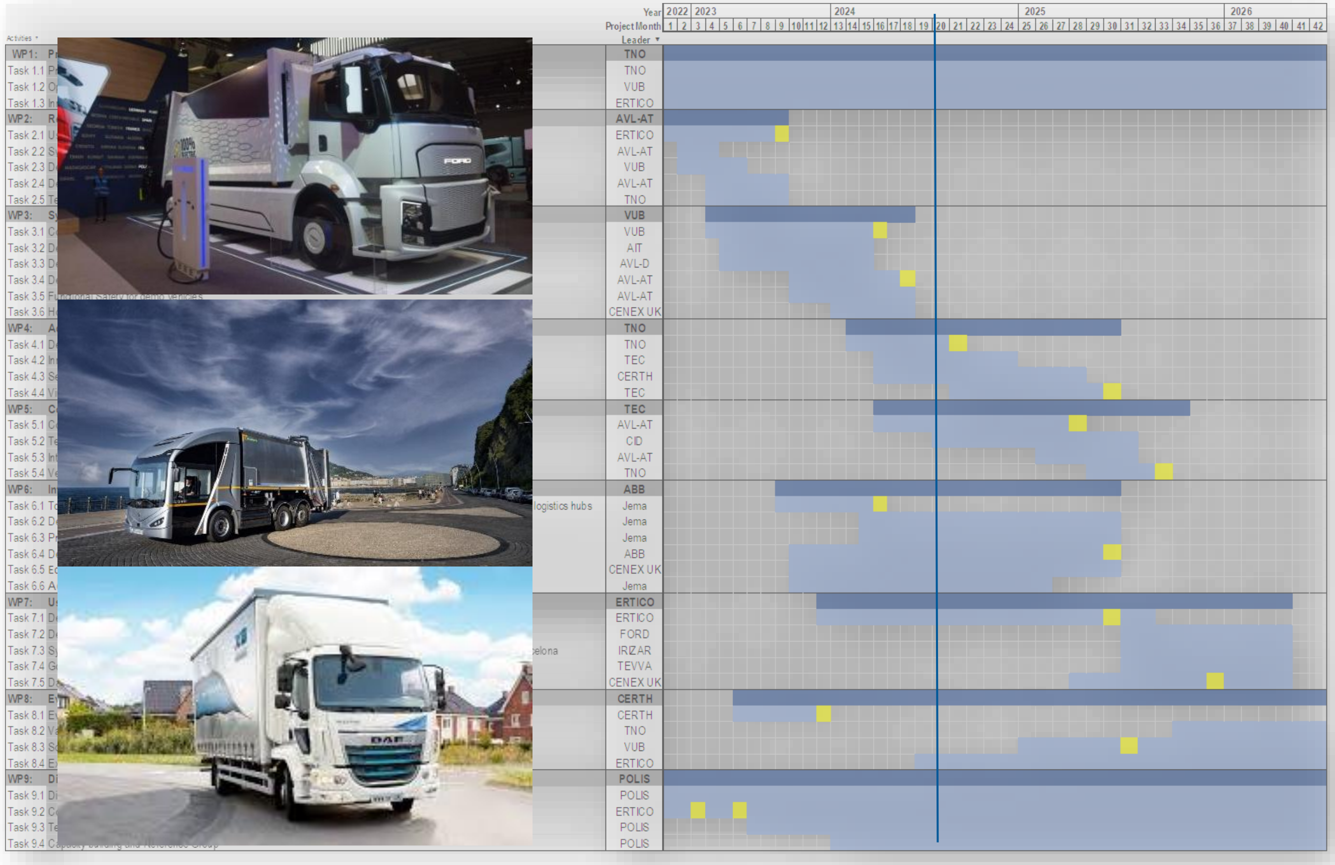
Public

Next generation E-Truck demonstrator project

4 year project with 18 EU Partners

Develop:

- 3 Live demonstrators for 6 months
  - Ford (Turkey), Irizar (Spain), DAF (UK)
  - New required hardware and software
- Digital Twin Development Framework
- Full Fleet Management Framework



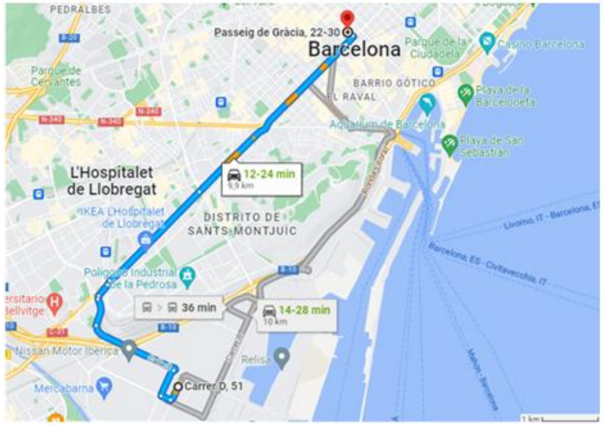
This research has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 101056740, under the title of NextETRUCK.

NextETRUCK Project Specifics

- GVW 7.5-20T
- 2-300km/day
- Overnight charging
- Delivery cycles
  - Refuse / Variable delivery (Fixed base only)
  - Depot - depot (Fixed end-points)

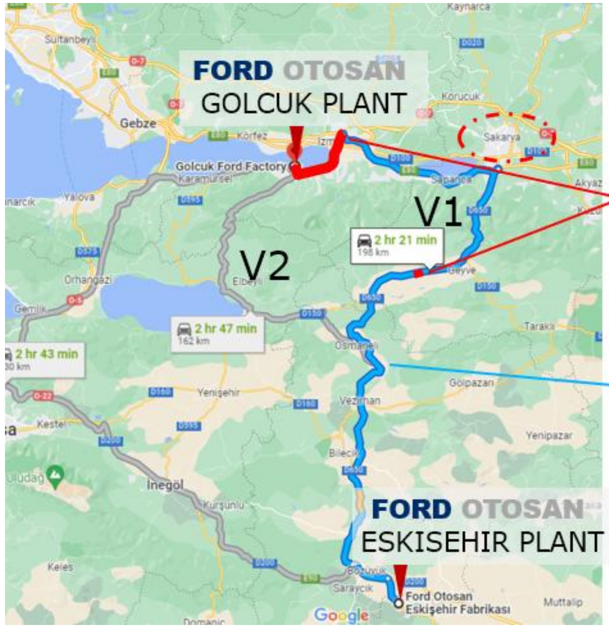
Project Goals

- 20% TCO reduction
- 10%+ improvement in energy efficiency
- Development and demonstration of new technologies



Total:
10 km x2
Round trip

Urban Usage:
20 km
(100% of the total task)



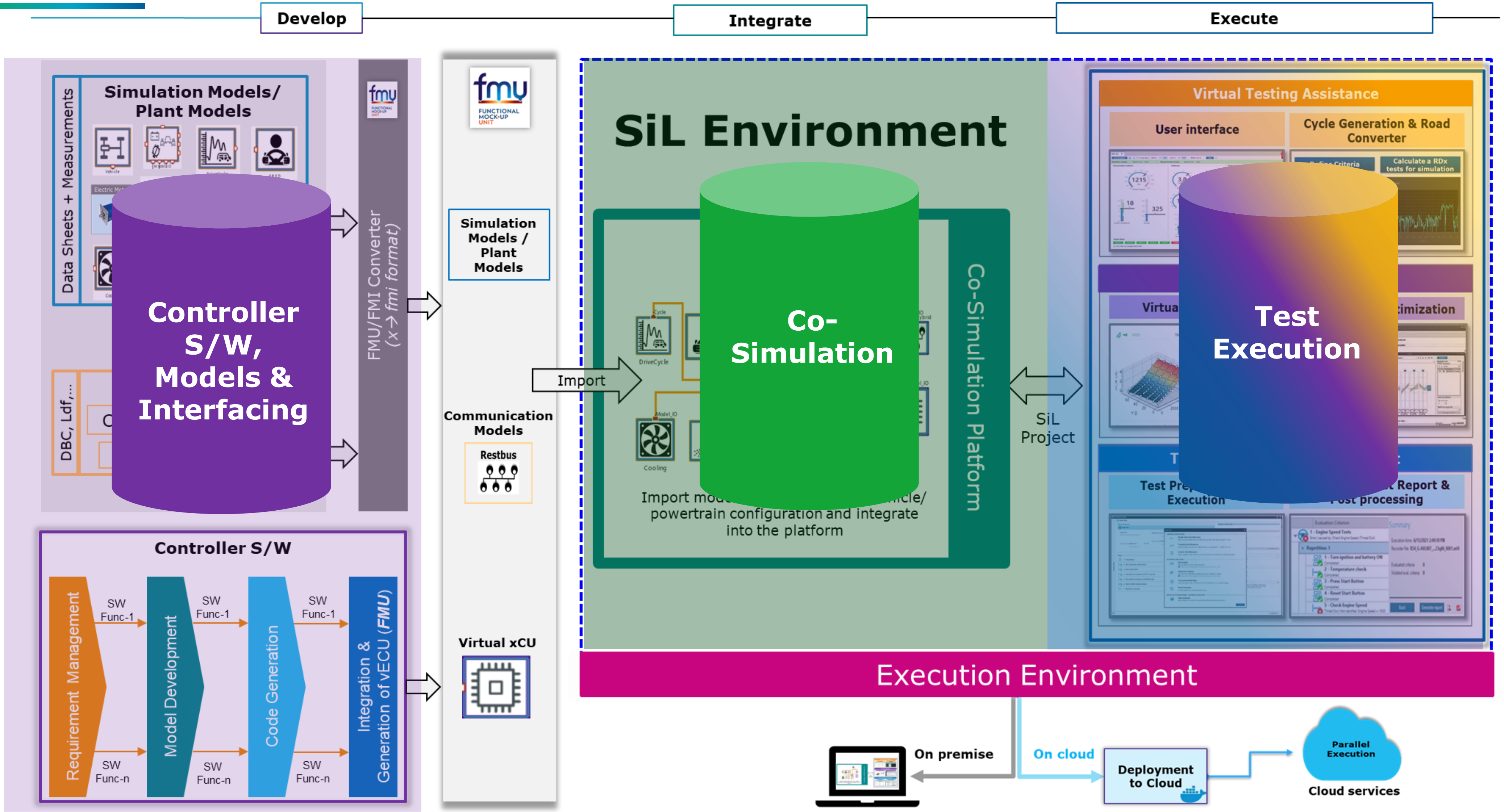
Total: 198 km

Urban Usage:
21 km
(10% of the total task)

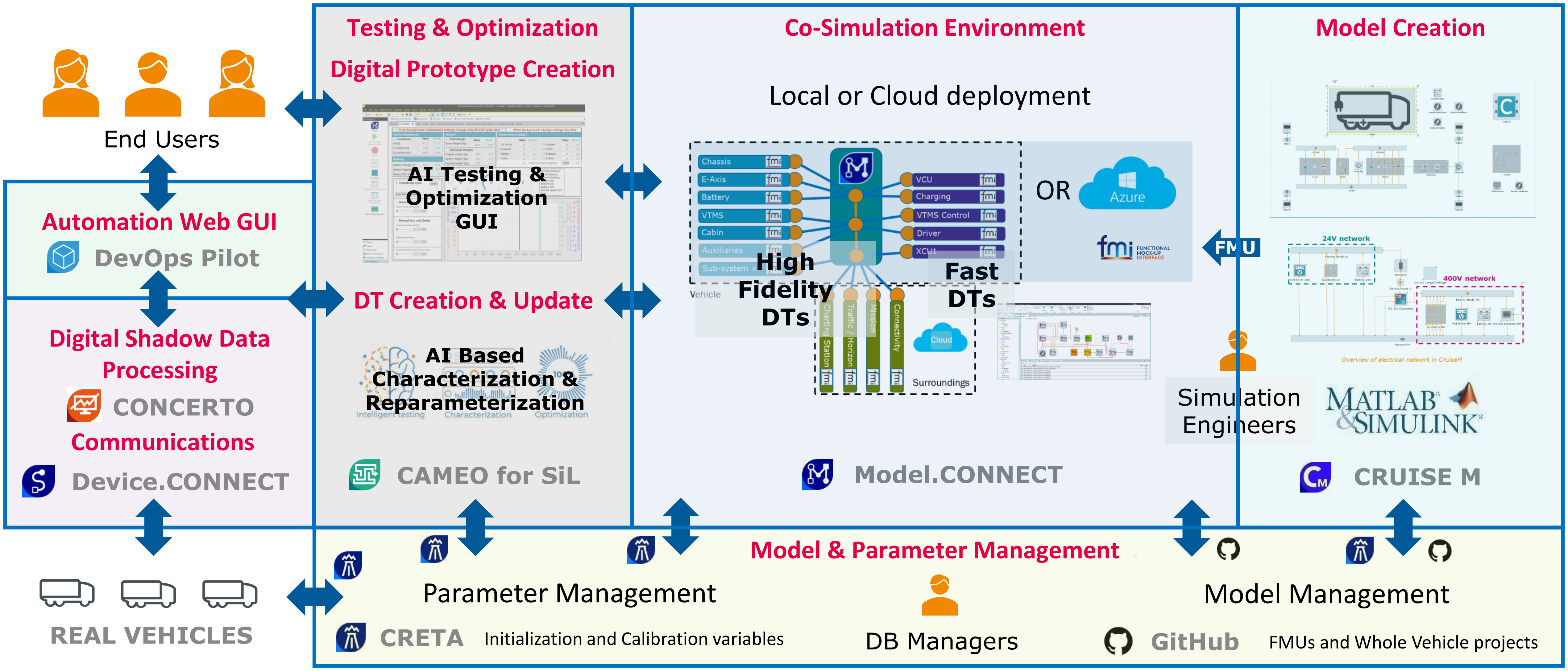
Intercity Usage:
177 km
(90% of the total task)

Digital Twin Creation Framework

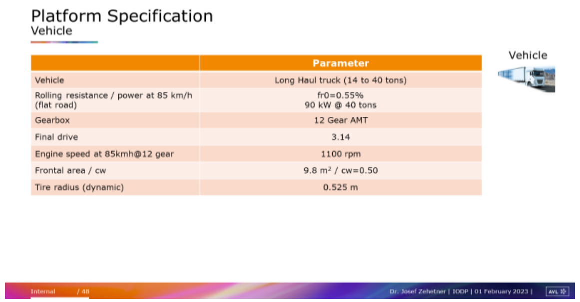
Automotive SiL Components & Workflow

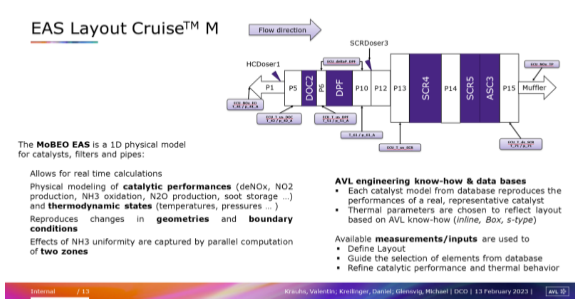


NextETRUCK DT Workflow

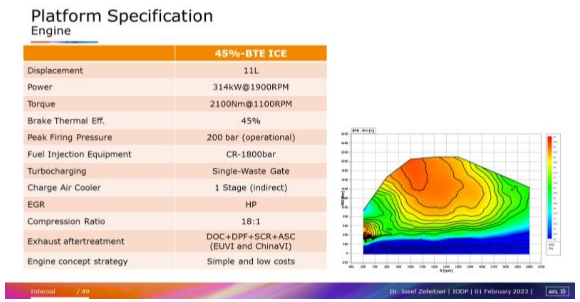


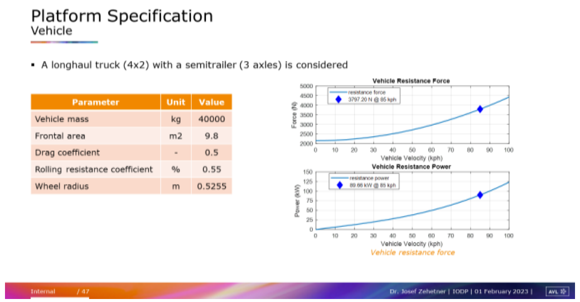
NextETRUCK high fidelity generic model base (FVVCP)

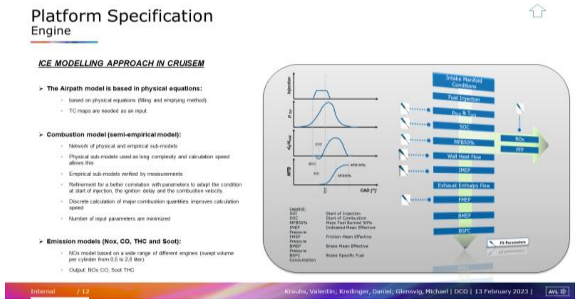


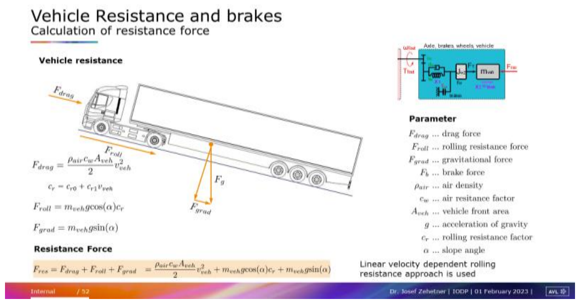


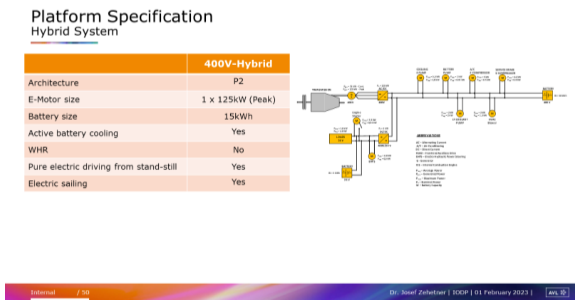
High Fidelity 400V P2 Hybrid Truck Model

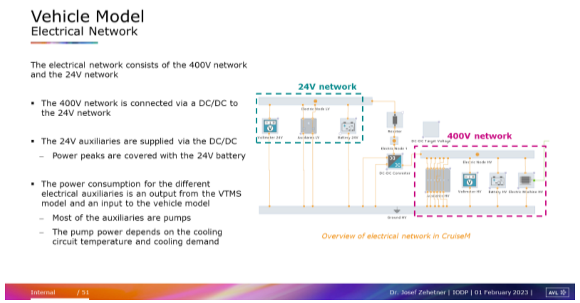


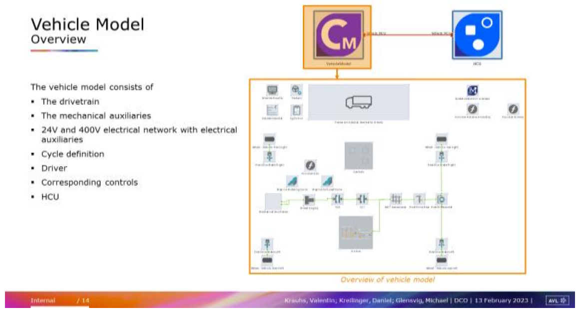


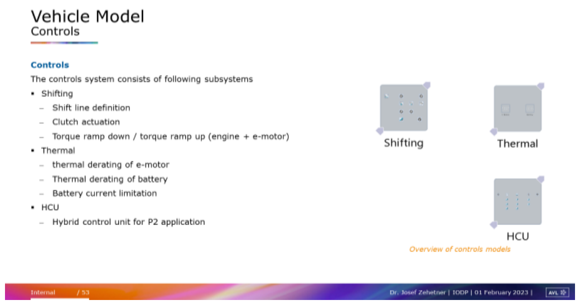






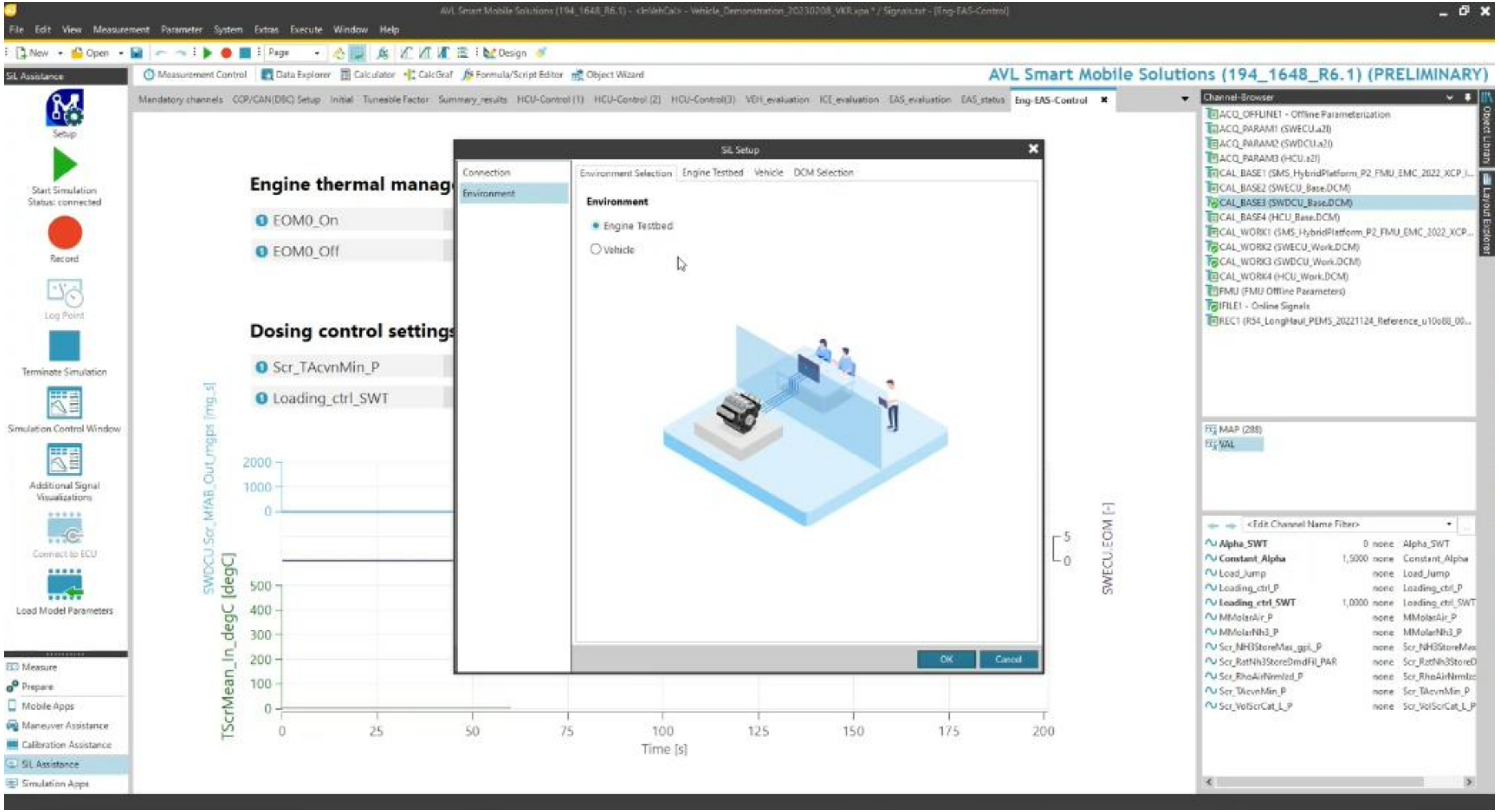






High Fidelity Digital Prototype

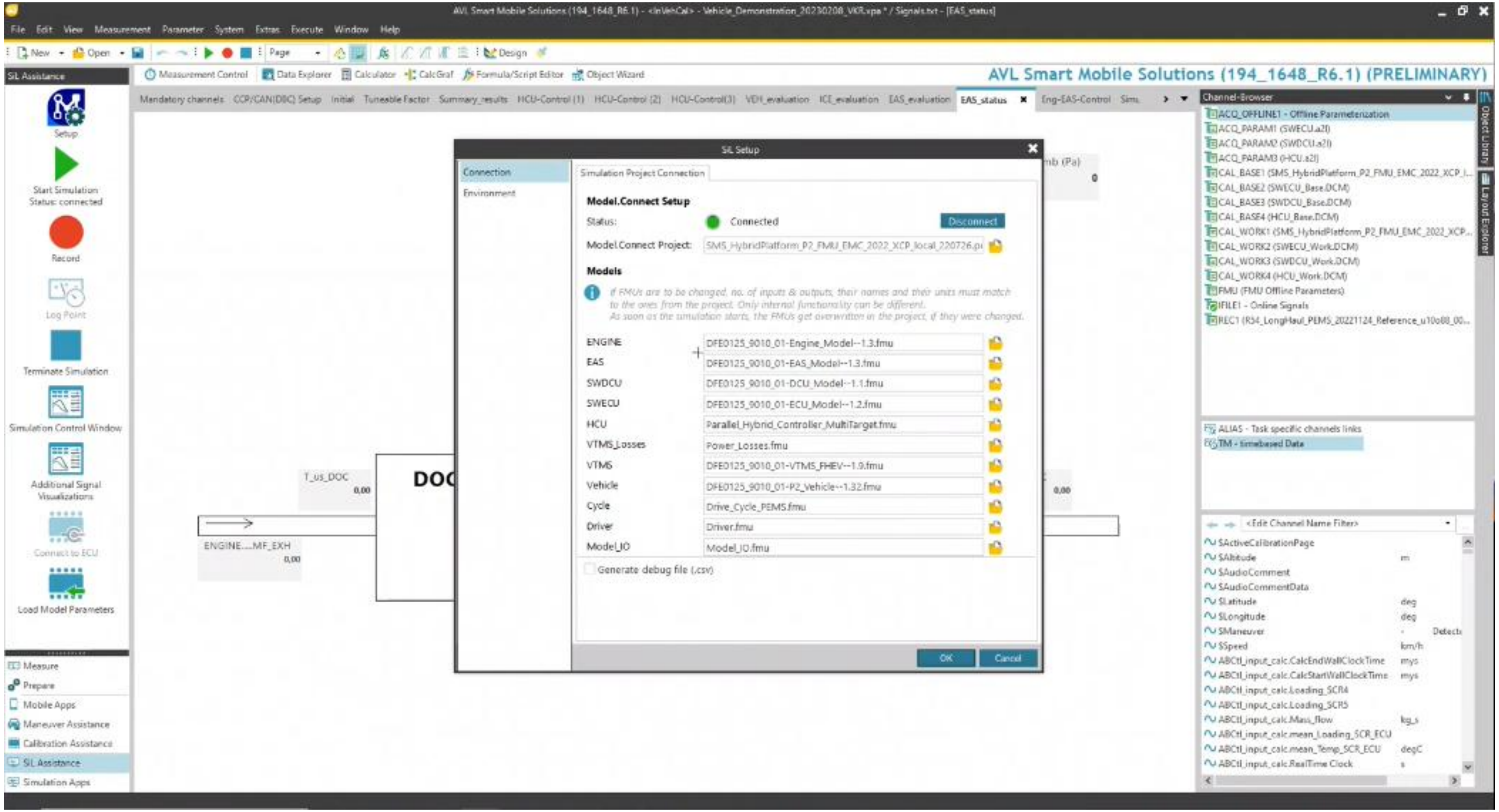
Testbed or Vehicle Configuration



AVL

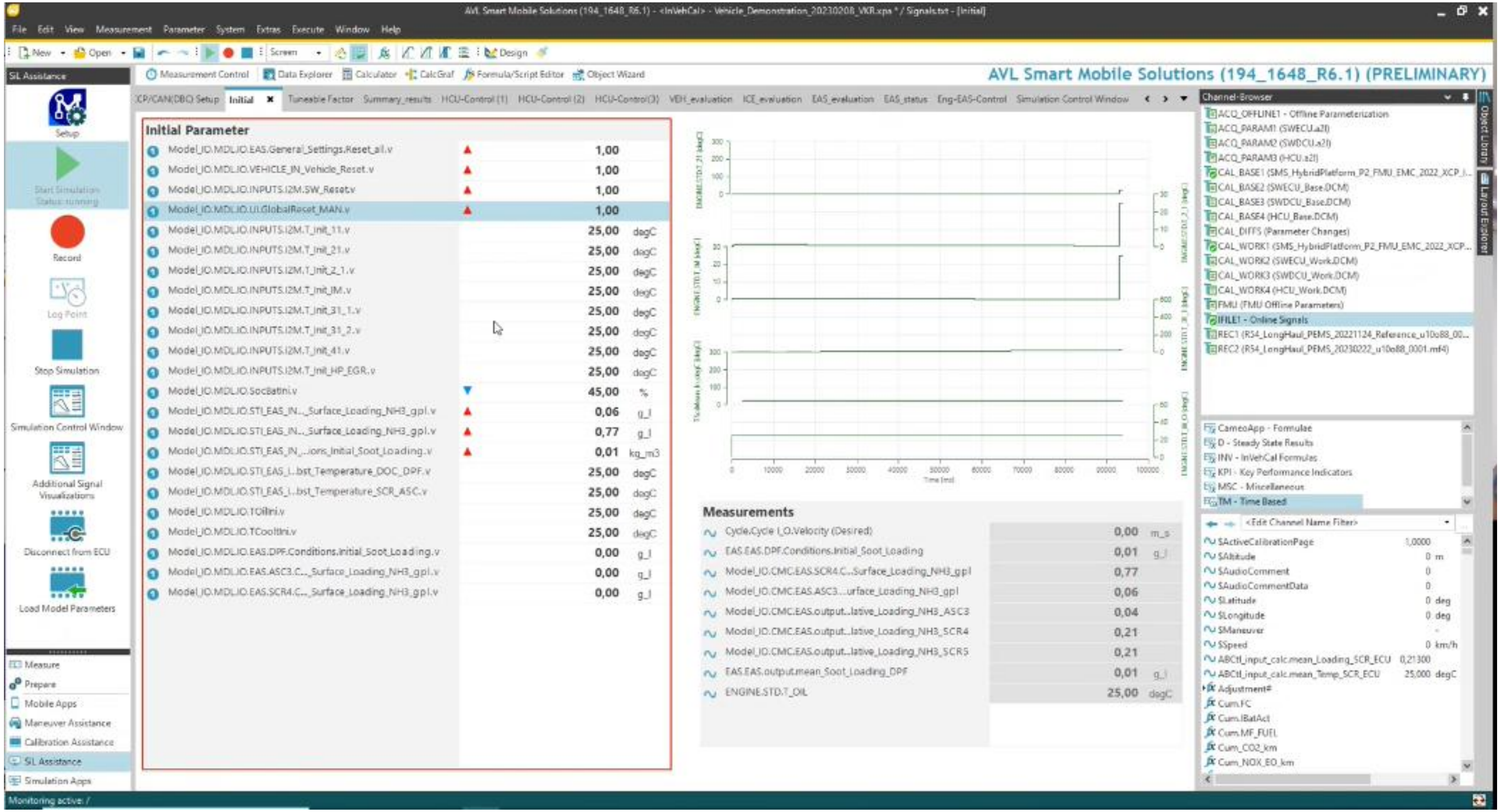
High Fidelity Digital Prototype

Choose FMU components



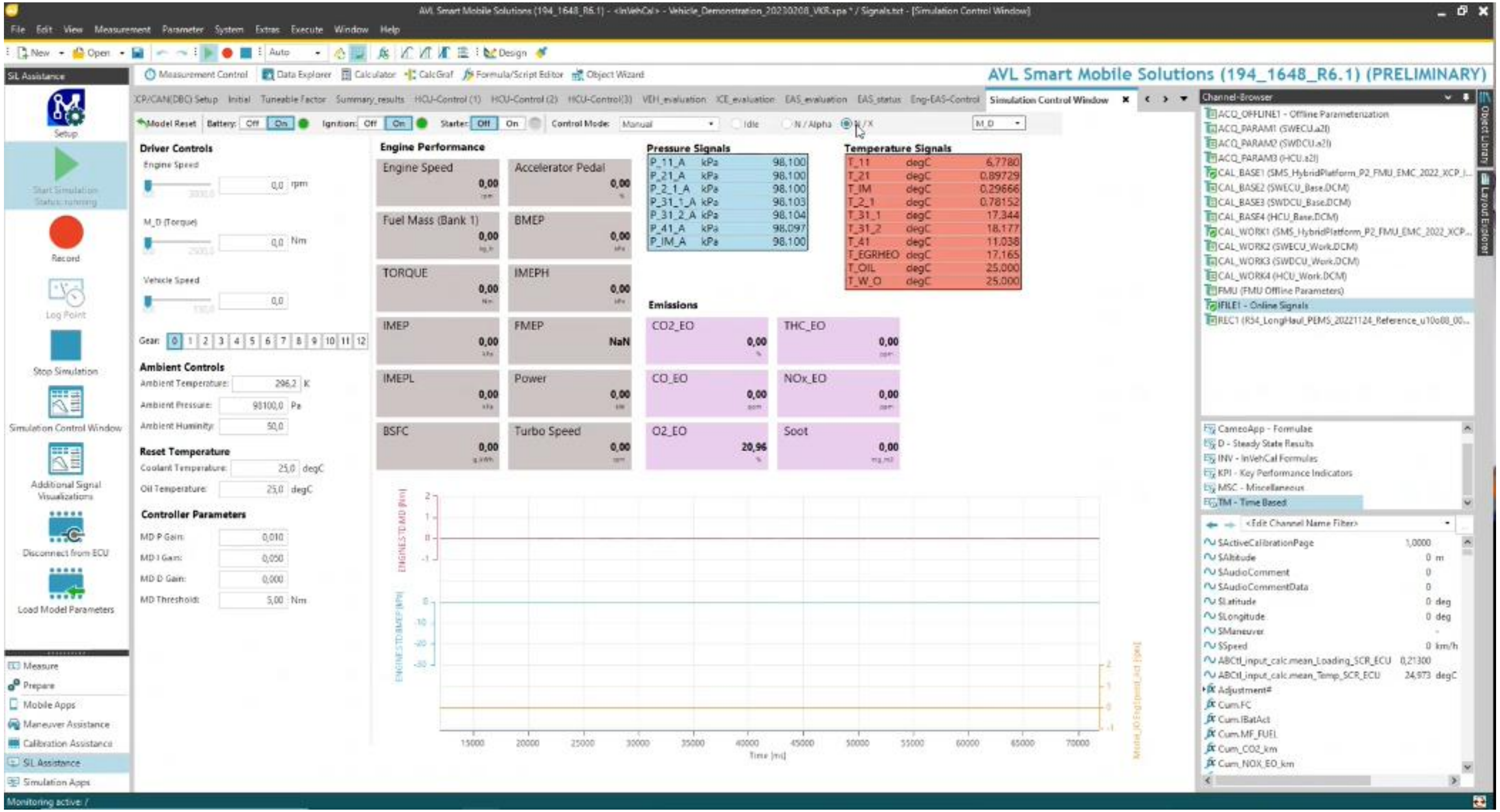
High Fidelity Digital Prototype

Initial Parameter Setup



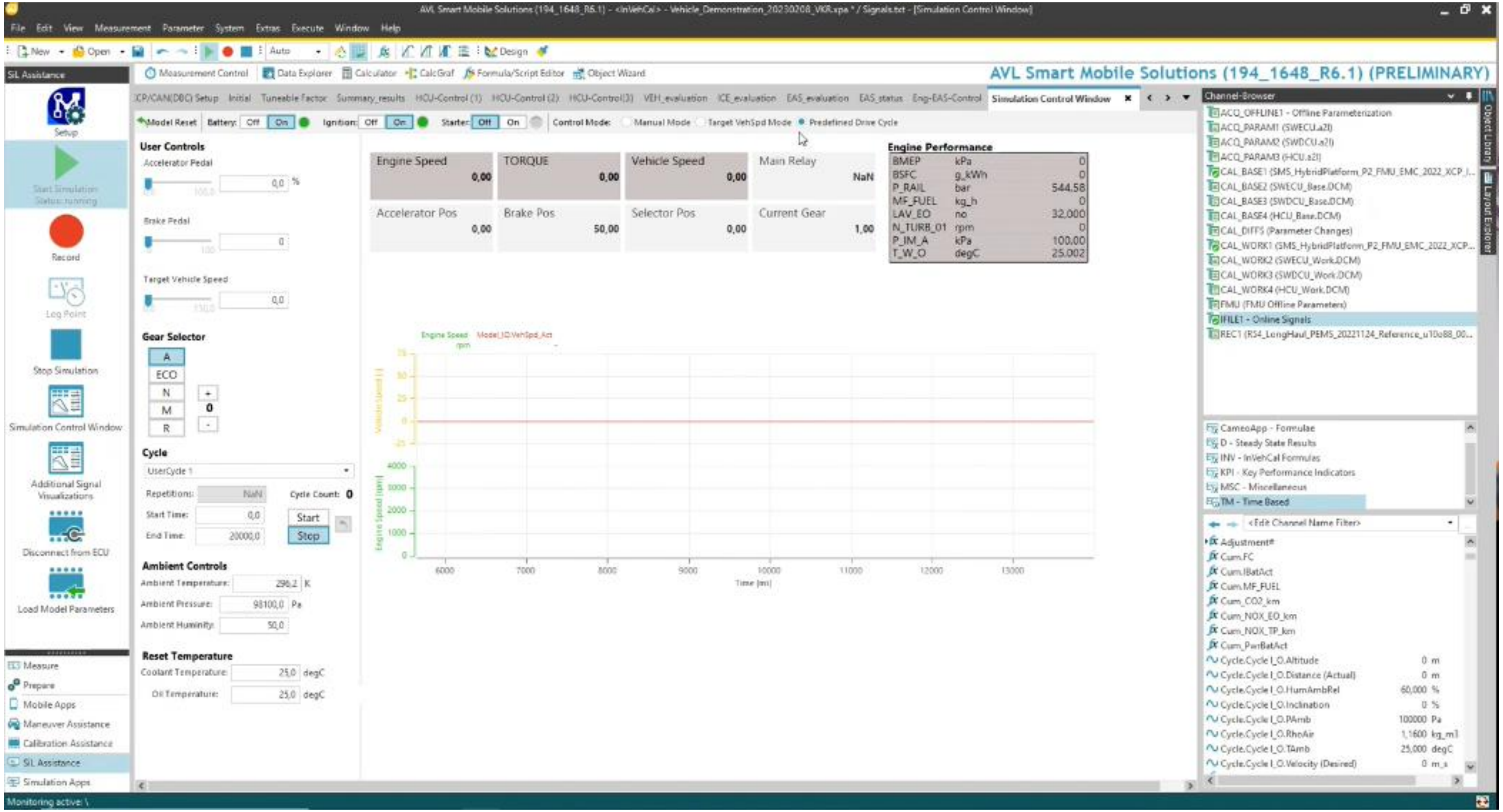
High Fidelity Digital Prototype

Main Control Window – Manual Control



High Fidelity Digital Prototype

Main Control Window – Cycle Execution



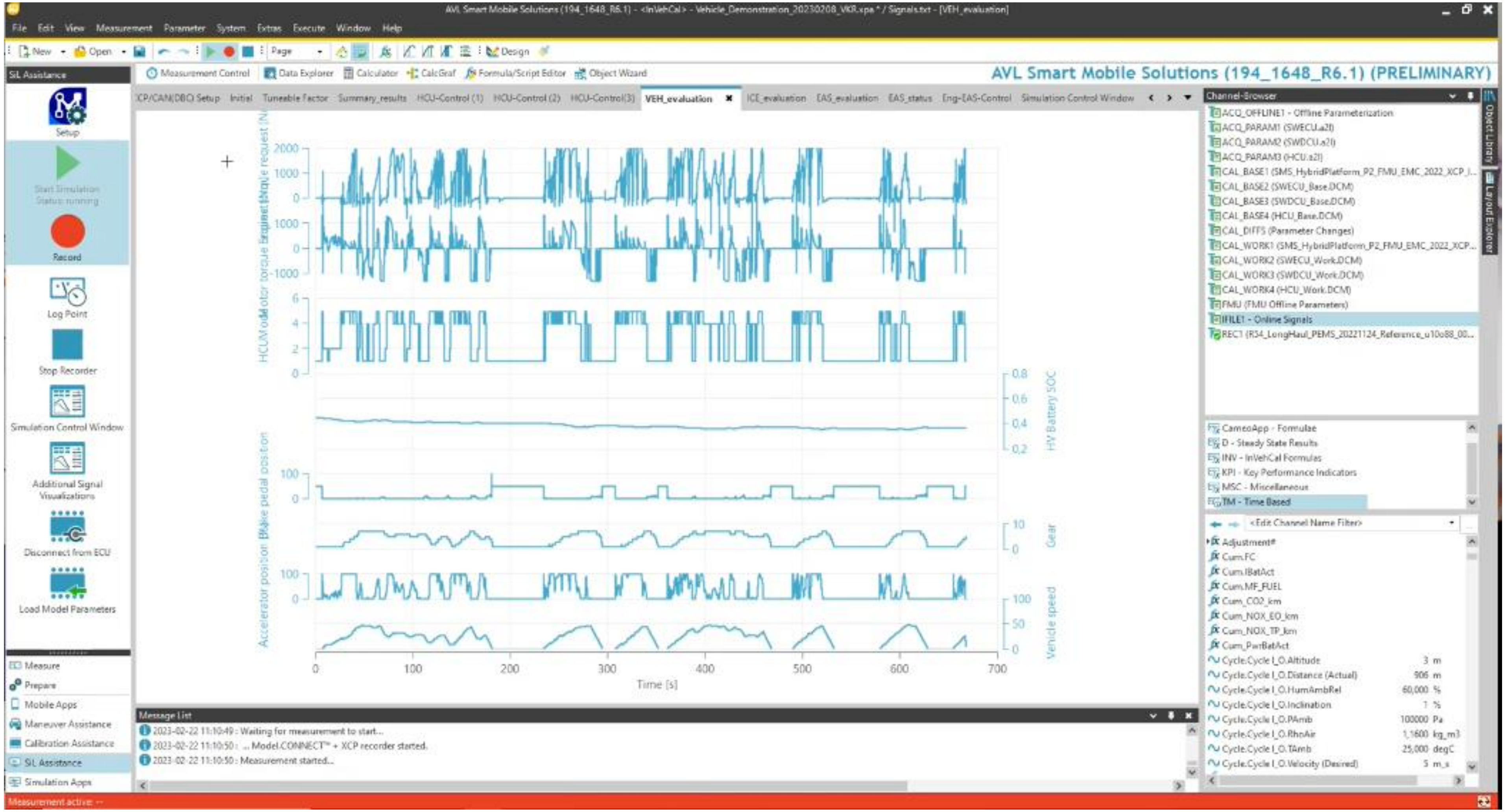
AVL

High Fidelity Digital Prototype

Calibration/Tuning Example

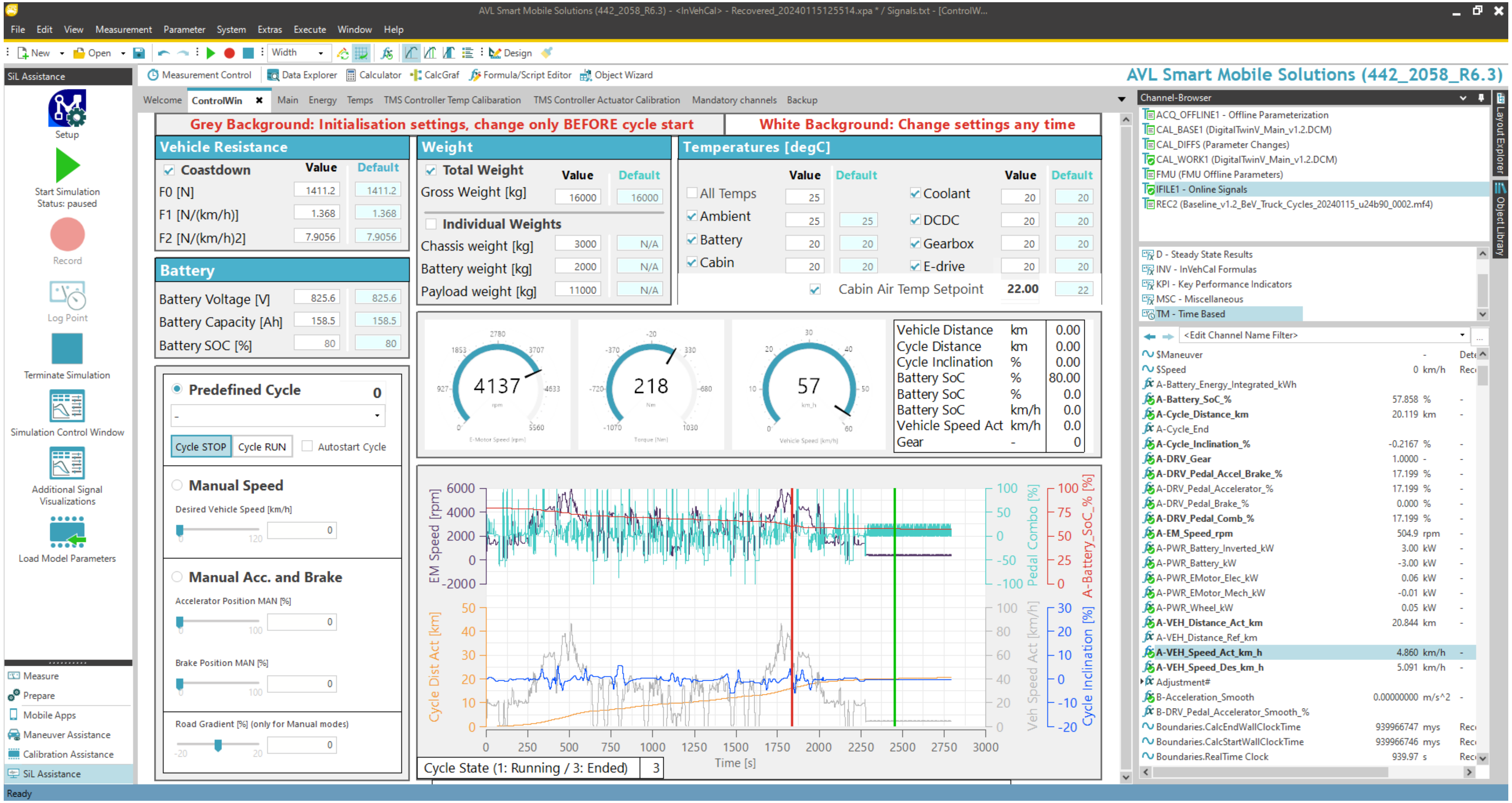
High Fidelity Digital Prototype

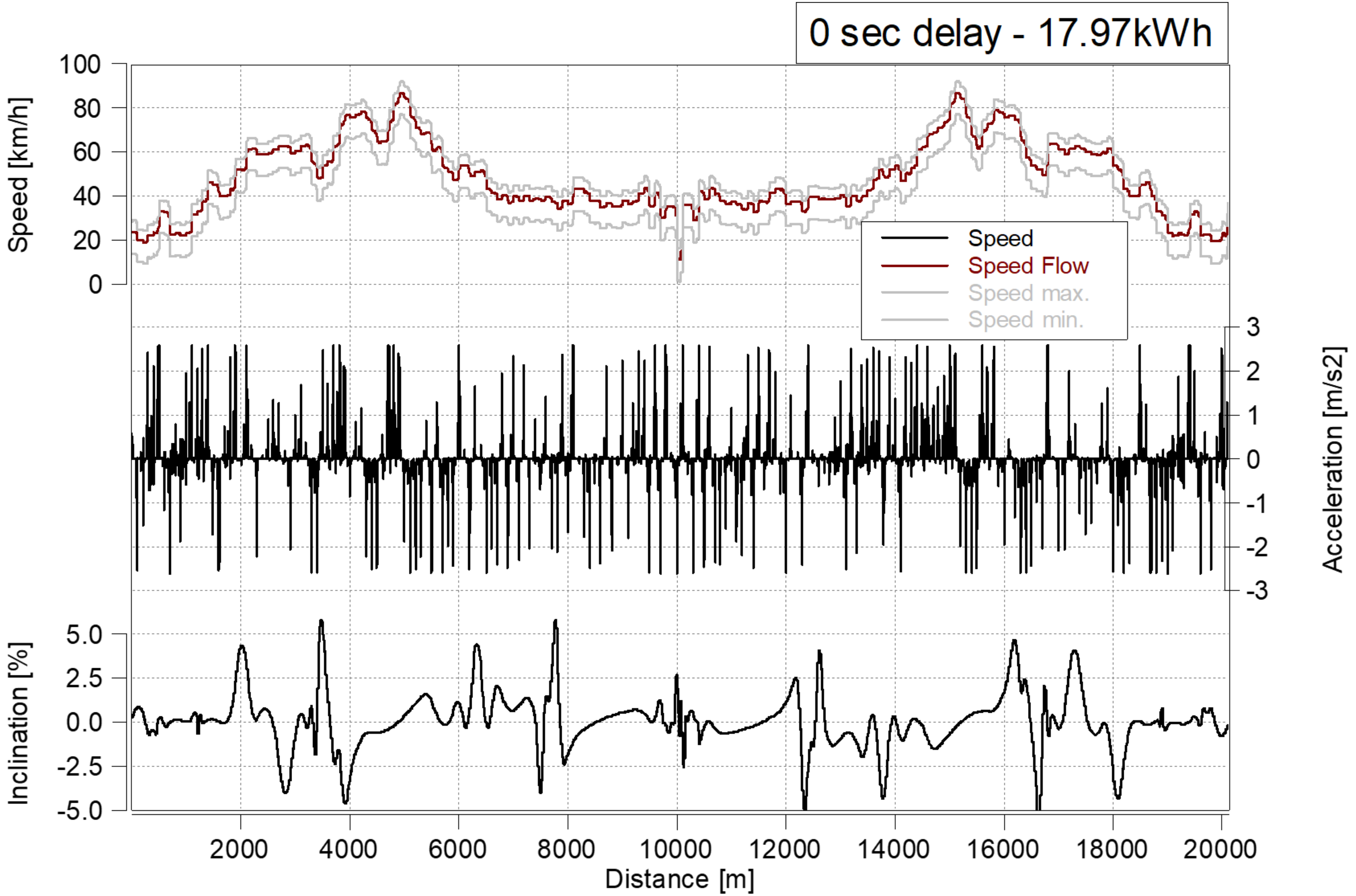
Post-processing Example

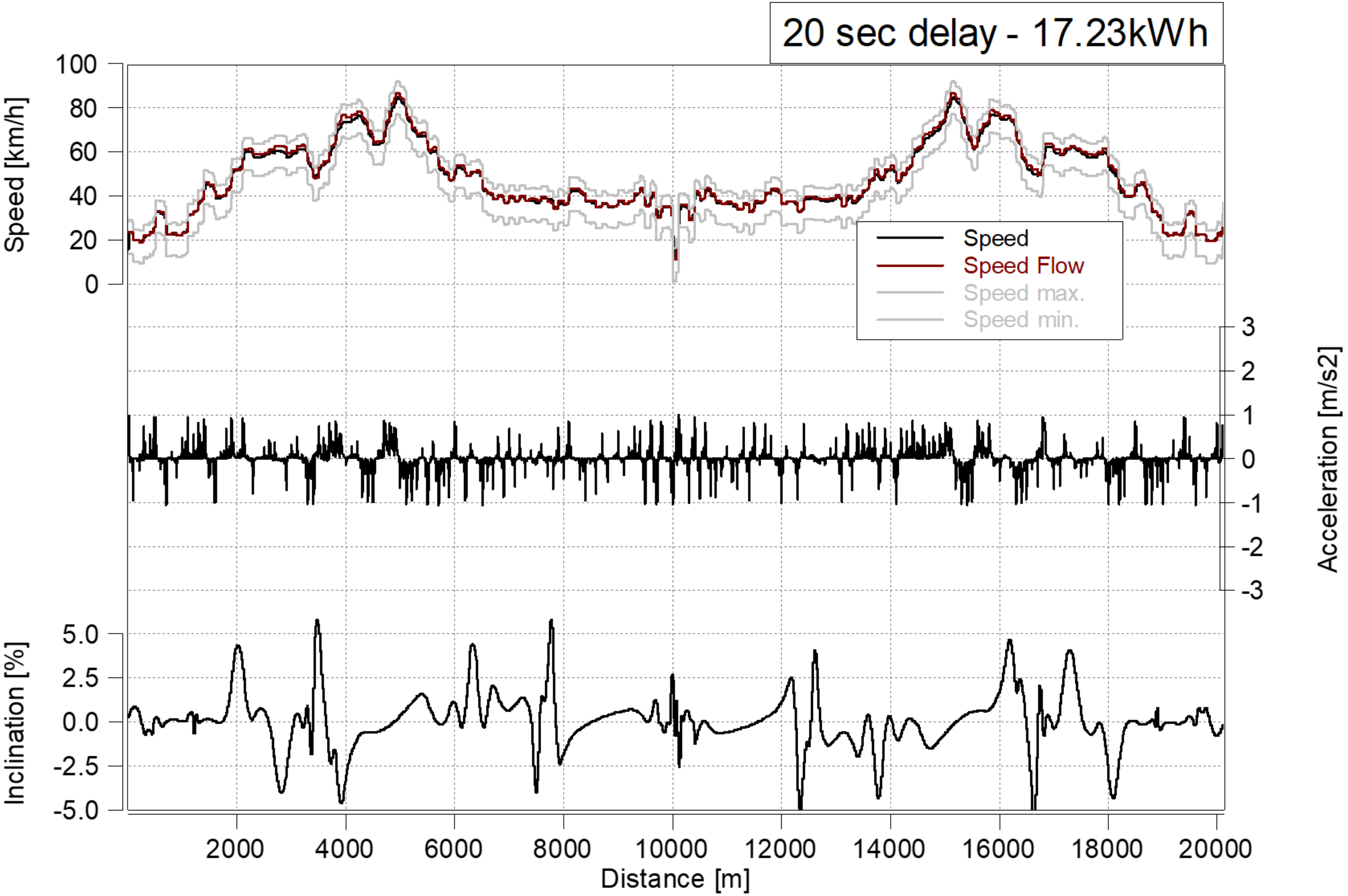


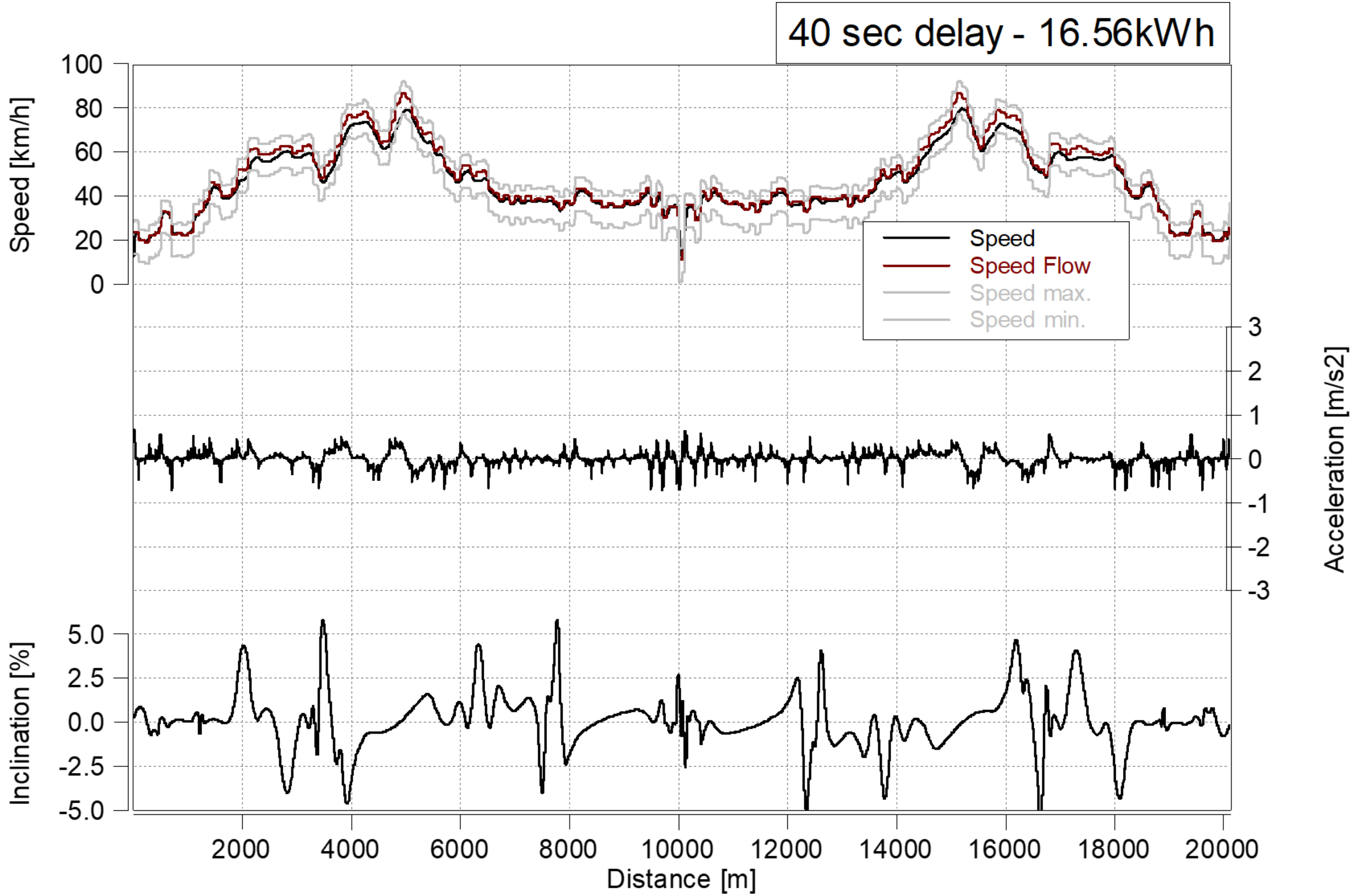
CAMEO for SiL Interface for NextETRUCK

Main Control Window

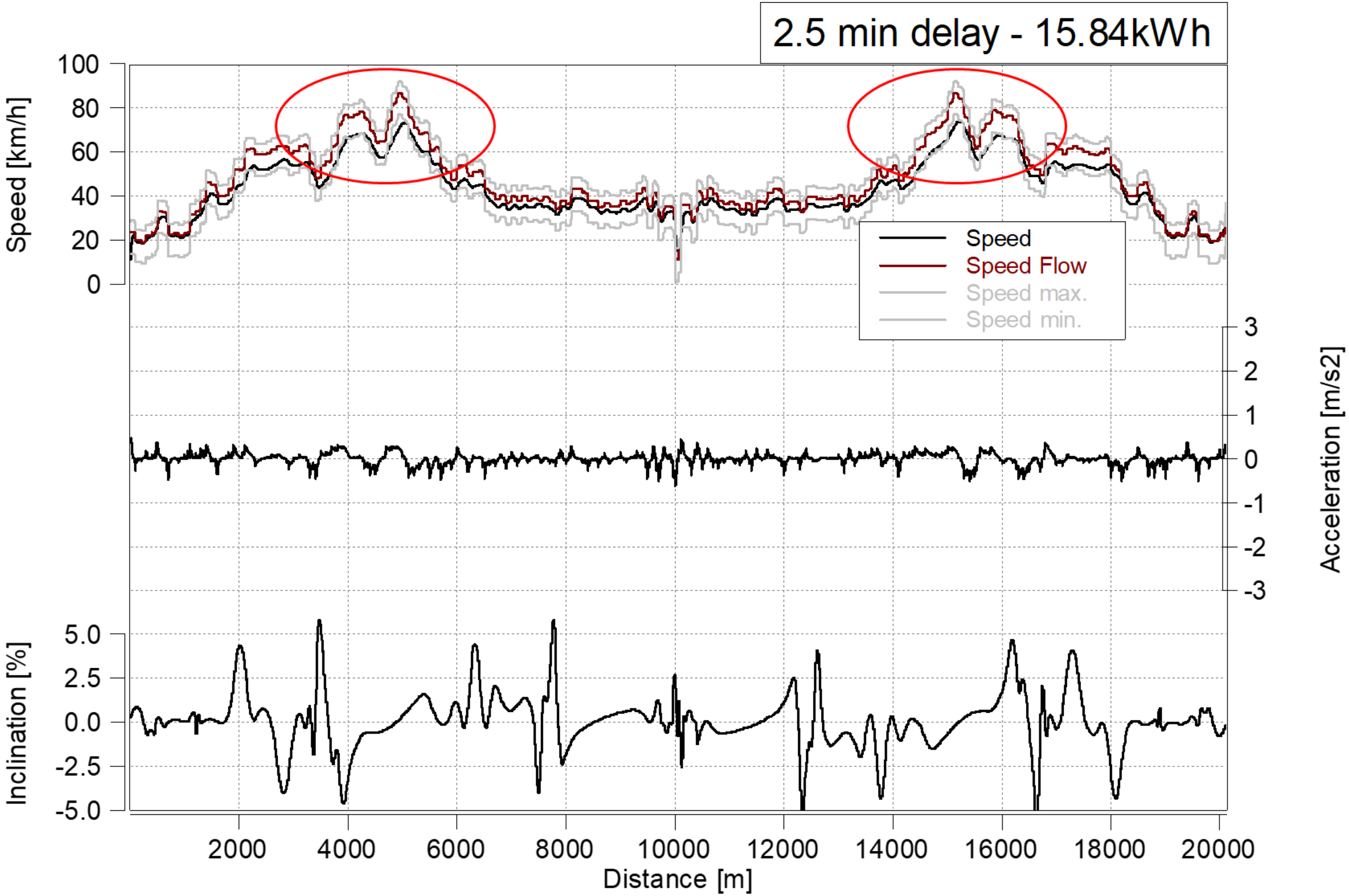


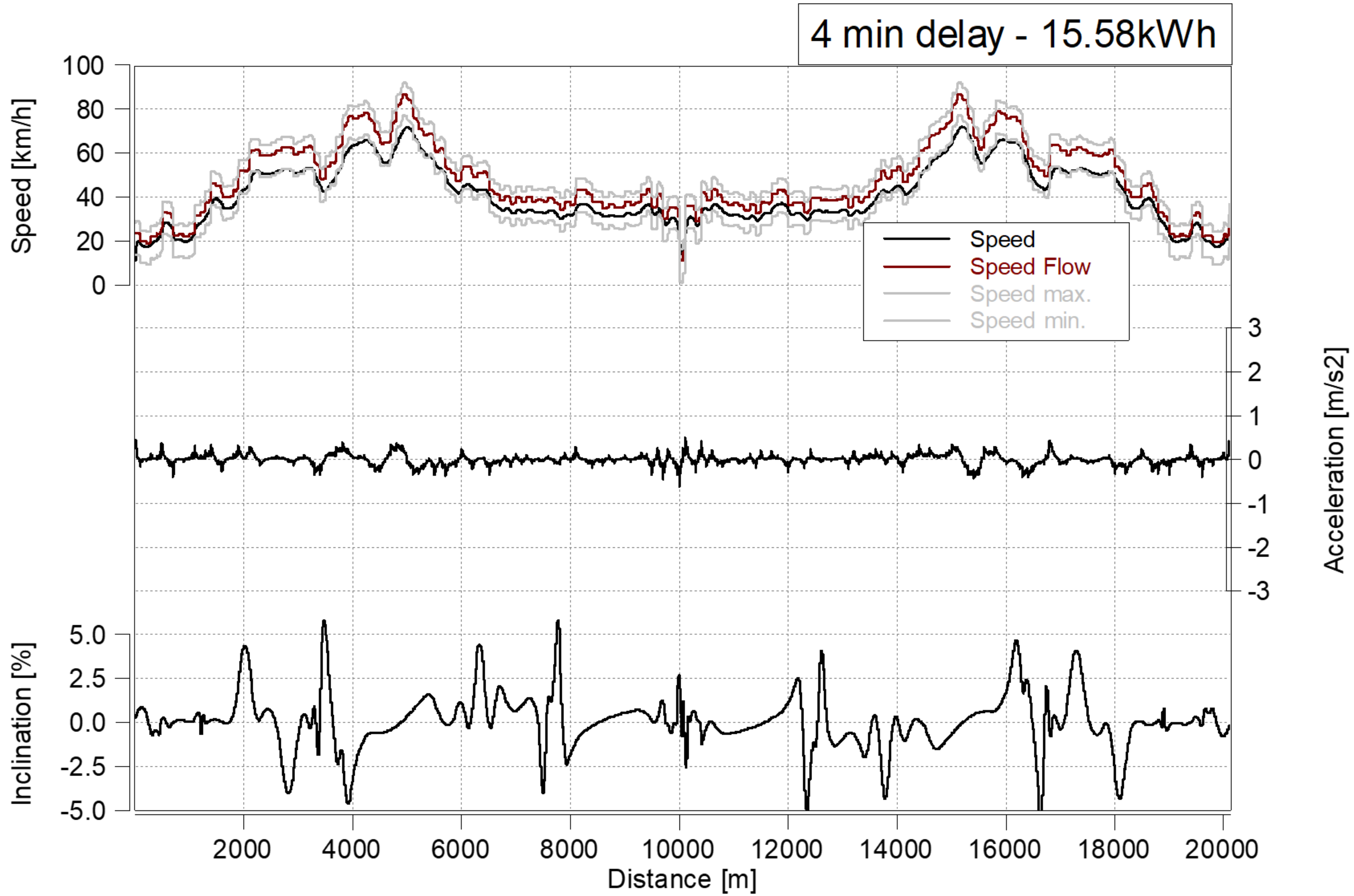

0 sec delay - 17.97kWh
Speed [km/h]
100
80
60
40
20
0
Speed
Speed Flow
Speed max.
Speed min.
Acceleration [m/s2]
3
2
1
0
-1
-2
-3
Inclination [%]
5.0
2.5
0.0
-2.5
-5.0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Distance [m]


20 sec delay - 17.23kWh
Speed [km/h]
100
80
60
40
20
0
Speed
Speed Flow
Speed max.
Speed min.
3
2
1
0
-1
-2
-3
Acceleration [m/s2]
Inclination [%]
5.0
2.5
0.0
-2.5
-5.0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Distance [m]

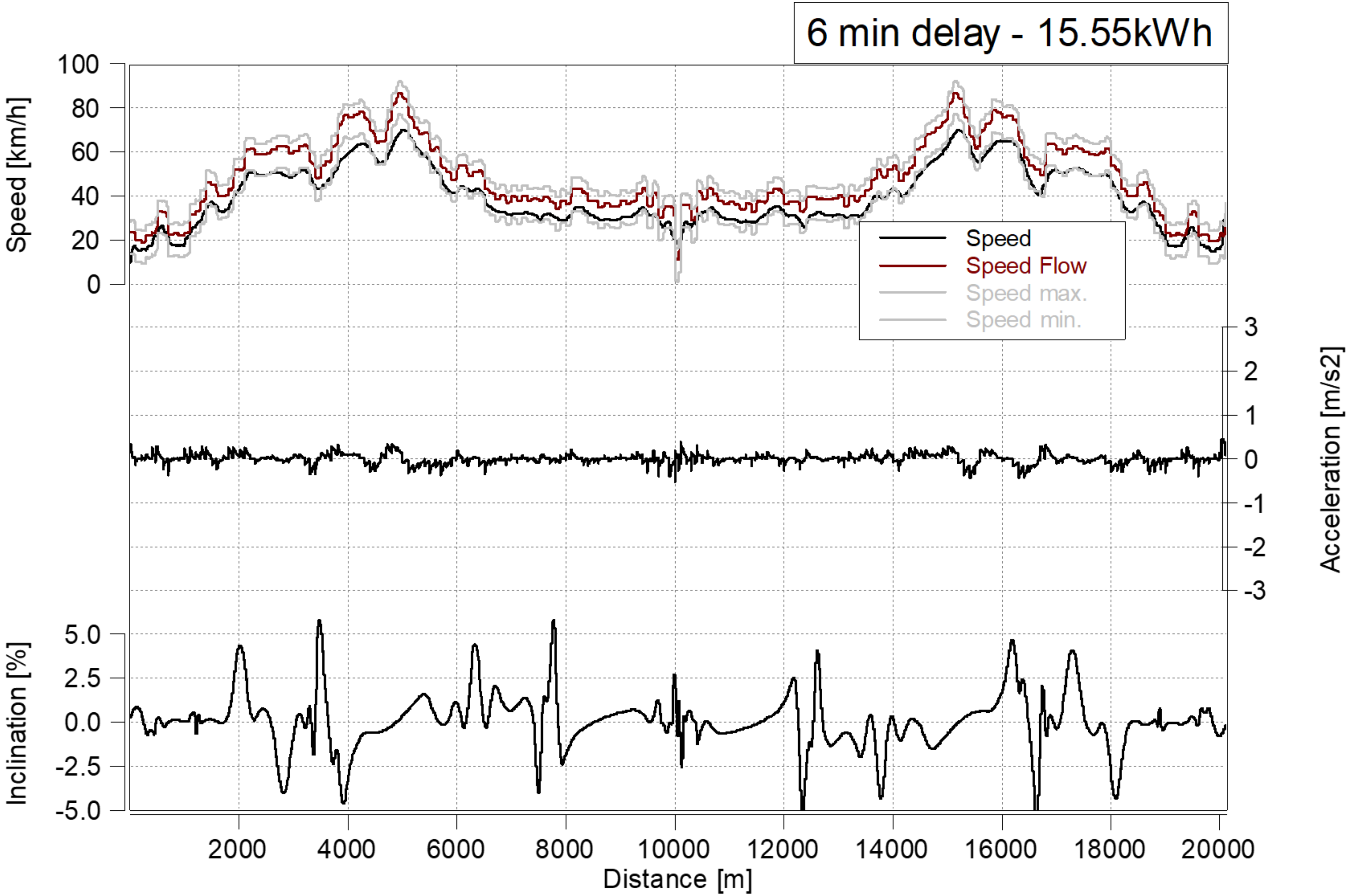


40 sec delay - 16.56kWh
Speed [km/h]
100
80
60
40
20
0
Speed
Speed Flow
Speed max.
Speed min.
Acceleration [m/s2]
3
2
1
0
-1
-2
-3
Inclination [%]
5.0
2.5
0.0
-2.5
-5.0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Distance [m]

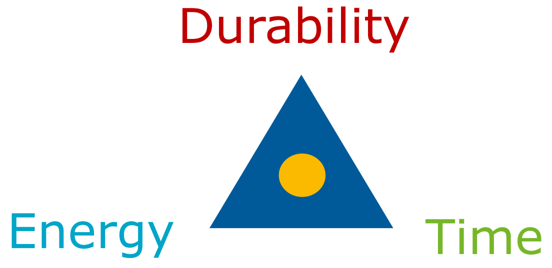

2.5 min delay - 15.84kWh
Speed [km/h]
100
80
60
40
20
0
Speed
Speed Flow
Speed max.
Speed min.
3
2
1
0
-1
-2
-3
Acceleration [m/s2]
Inclination [%]
5.0
2.5
0.0
-2.5
-5.0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Distance [m]

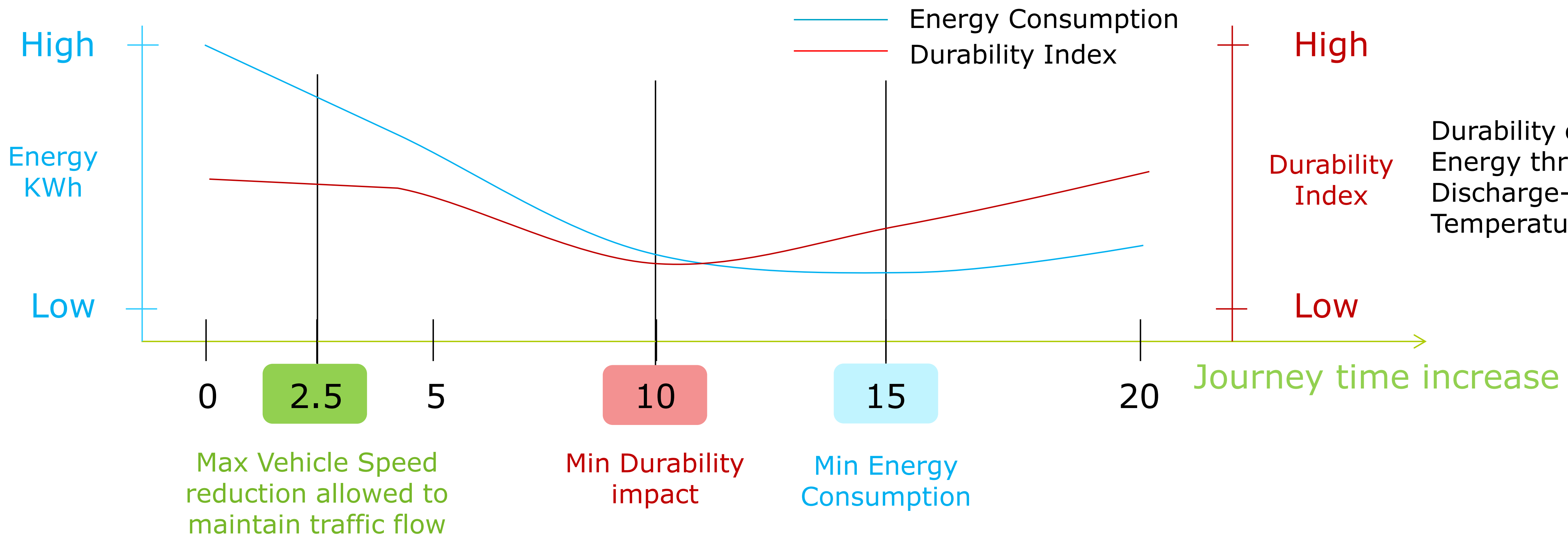


4 min delay - 15.58kWh
Speed [km/h]
100
80
60
40
20
0
Speed
Speed Flow
Speed max.
Speed min.
Acceleration [m/s2]
3
2
1
0
-1
-2
-3
Inclination [%]
5.0
2.5
0.0
-2.5
-5.0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Distance [m]


6 min delay - 15.55kWh
Speed [km/h]
100
80
60
40
20
0
Speed
Speed Flow
Speed max.
Speed min.
3
2
1
0
-1
-2
-3
Acceleration [m/s2]
Inclination [%]
5.0
2.5
0.0
-2.5
-5.0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
Distance [m]

Trade-off visualisation





Durability condition:
Energy throughput
Discharge-rate (max)
Temperature (max)

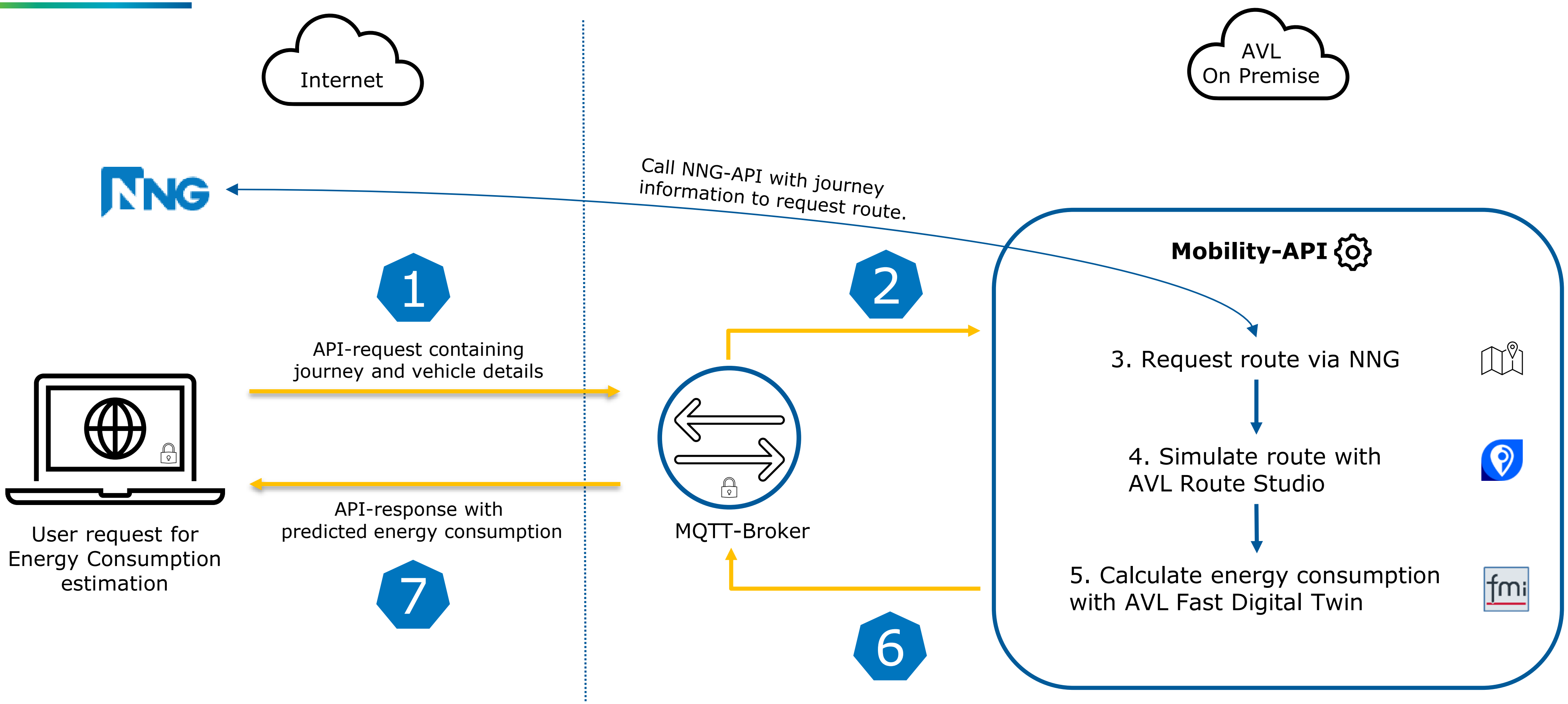
High fidelity Digital Twin with map API data access

- Predicts speed profiles, durability effects and total energy consumption

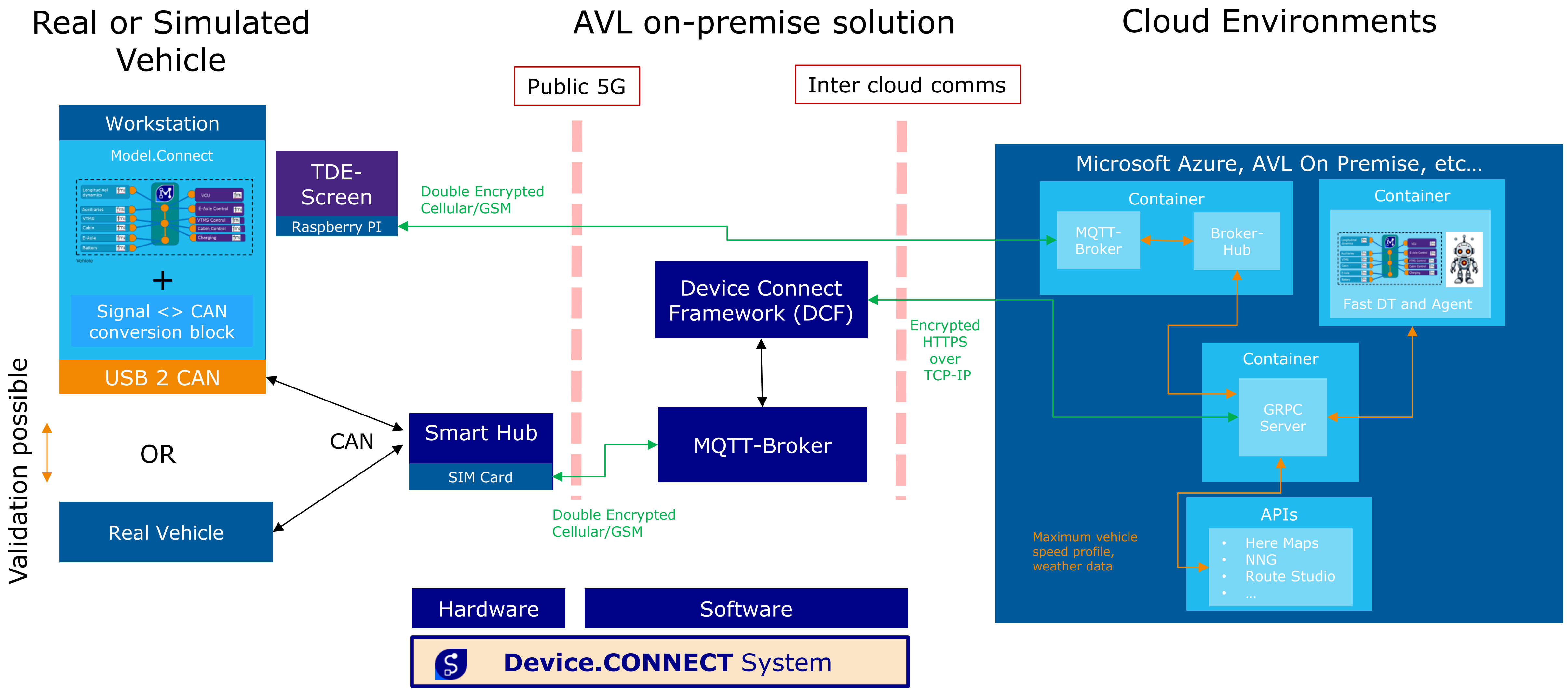
NextETRUCK Project

Secure Bi-Directional Communications System Overview

Energy Consumption EC DT Usage Workflow



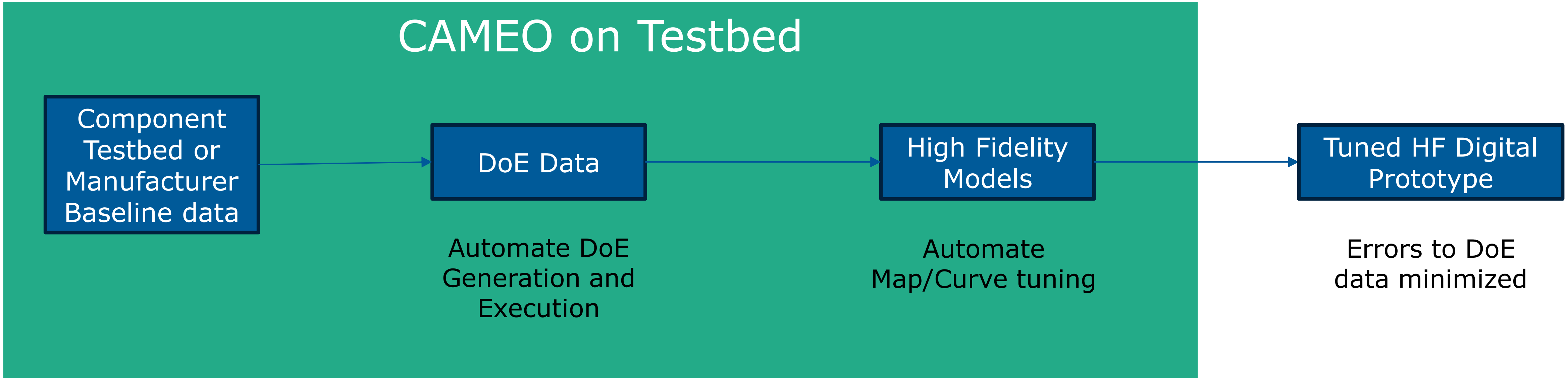
Secure Data Transfer with the Cloud



AVL

Innovations on NextETRUCK

Automation on Testbed/From baseline data - Full Fidelity Digital Prototype creation



CRETA

Parameter Storage

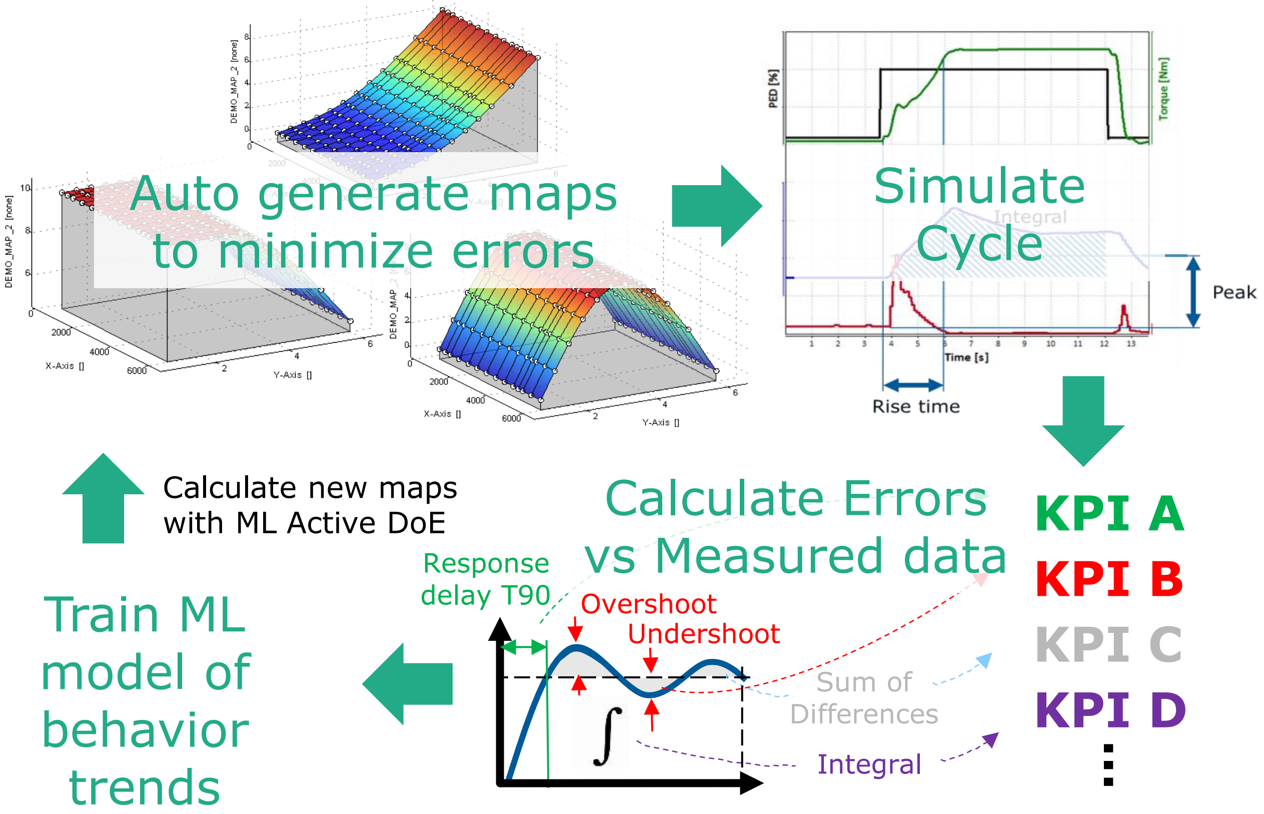
* *Not performed on NextETRUCK project*

Automated High Fidelity DT Tuning

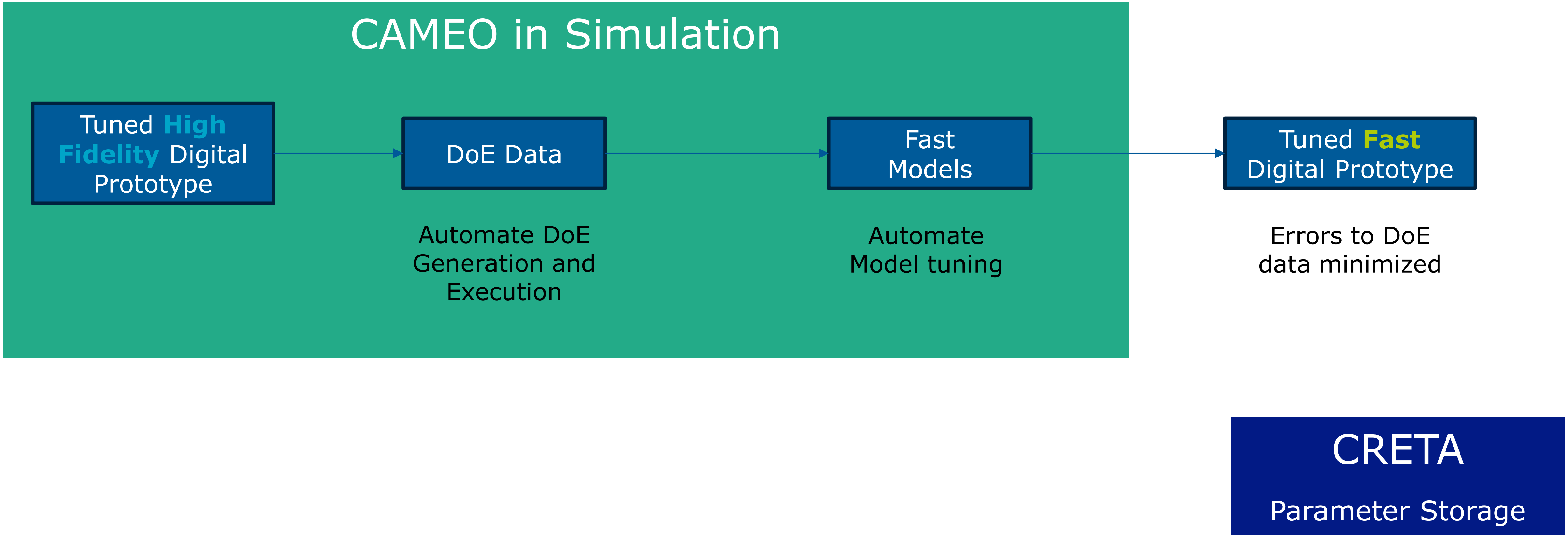
Auto-Tune Physical Model Parameters inc. Maps (Components & Controllers)

E-motor efficiency map, PID controller map, battery ageing map… etc

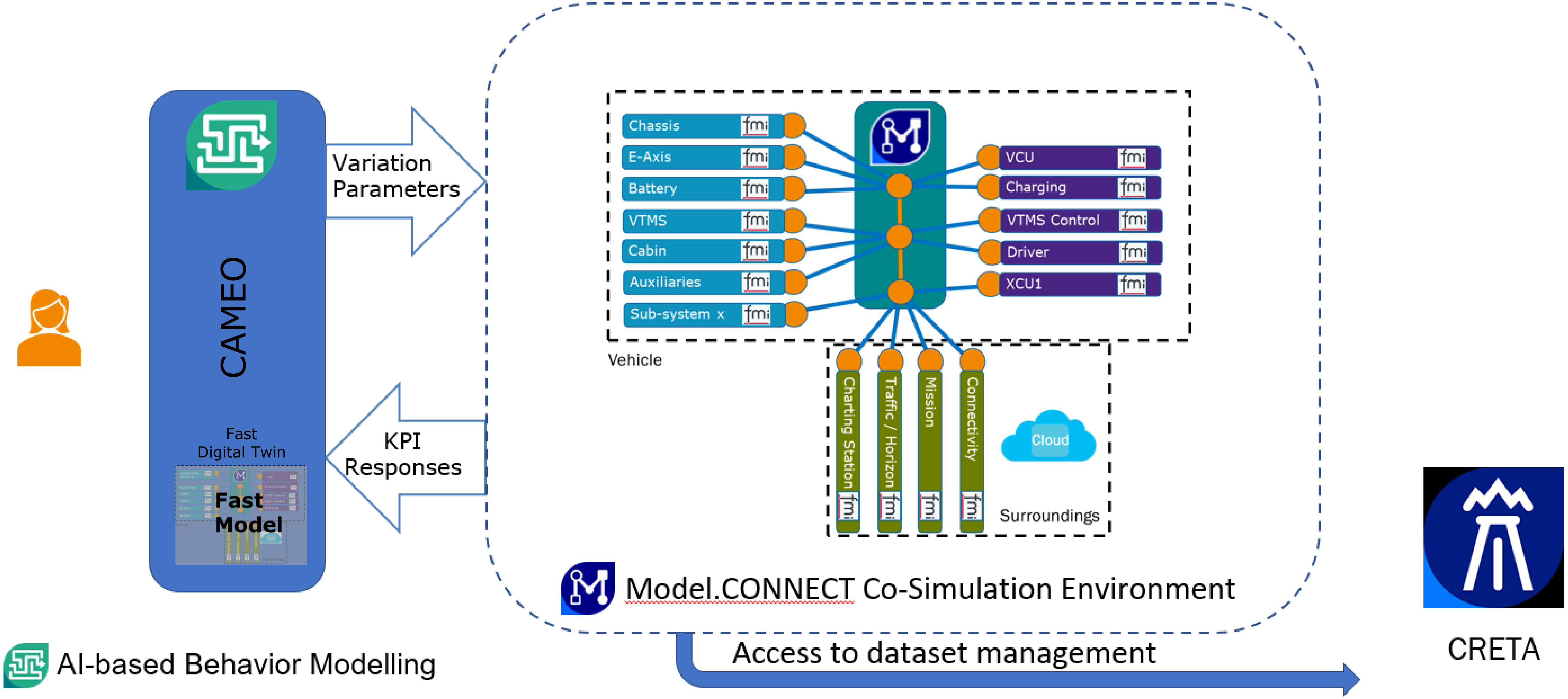
- Easily set limits and criteria to **Auto-generate complex map shapes**
- **AI based map evolution** to quickly get the best physical match
- **No manual intervention necessary and up to 80%** time saved compared to manual tuning



Automated Fast model tuning (from High Fidelity model) - Fast Digital Prototype creation

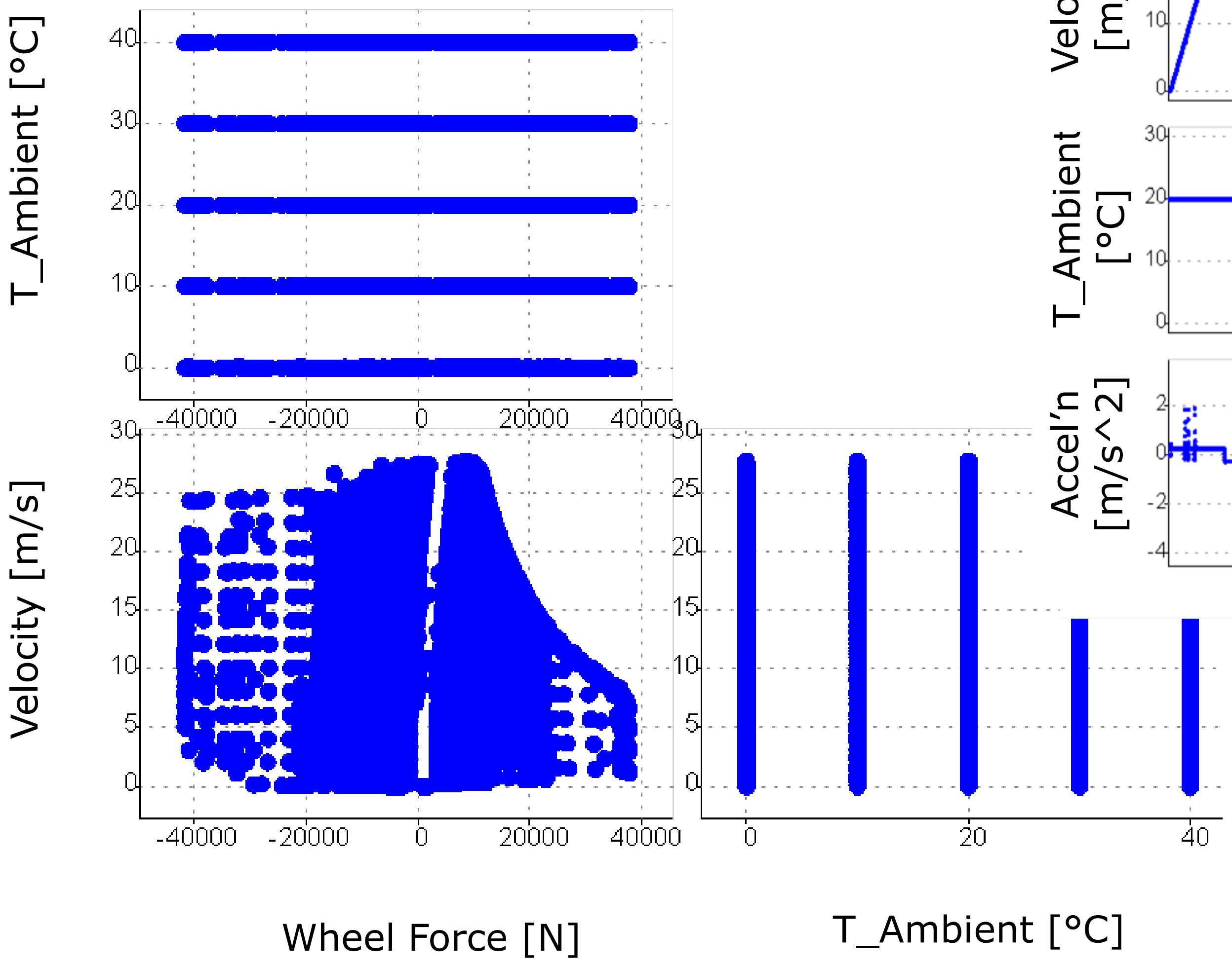


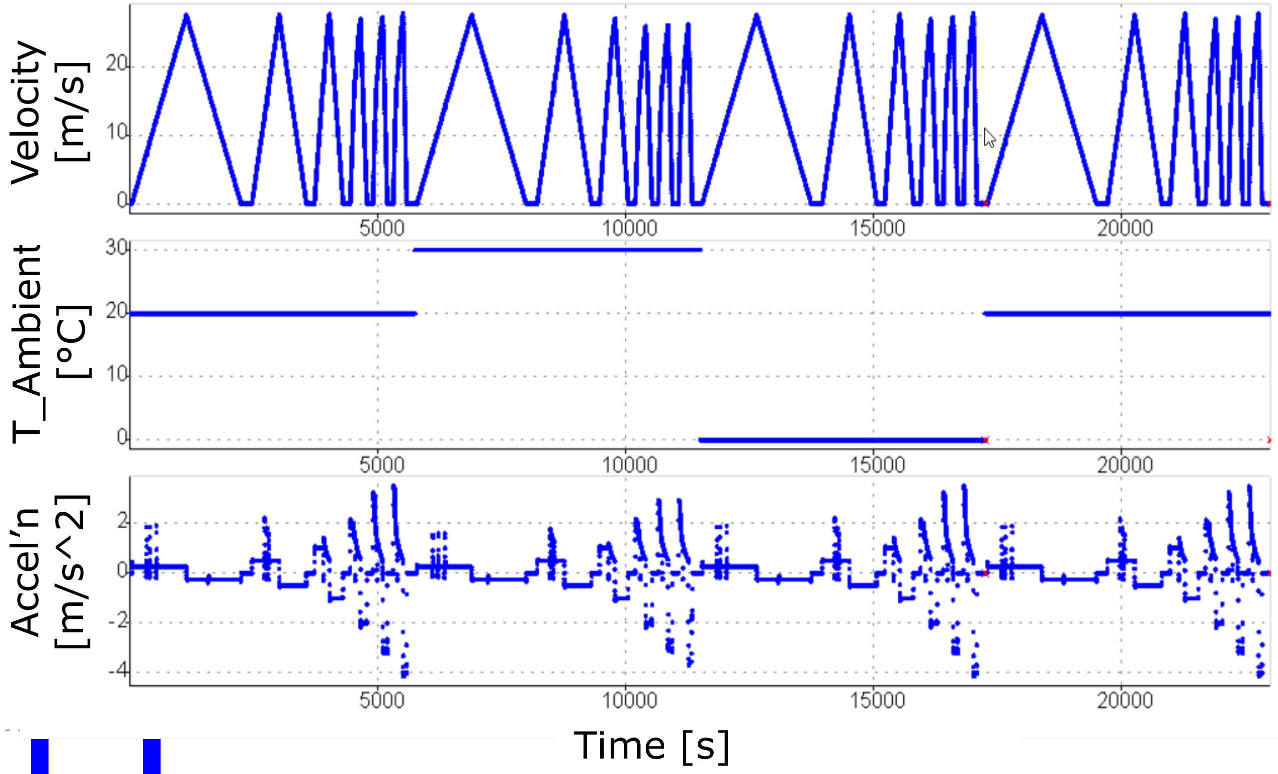
Fast DT of Truck Energy Consumption



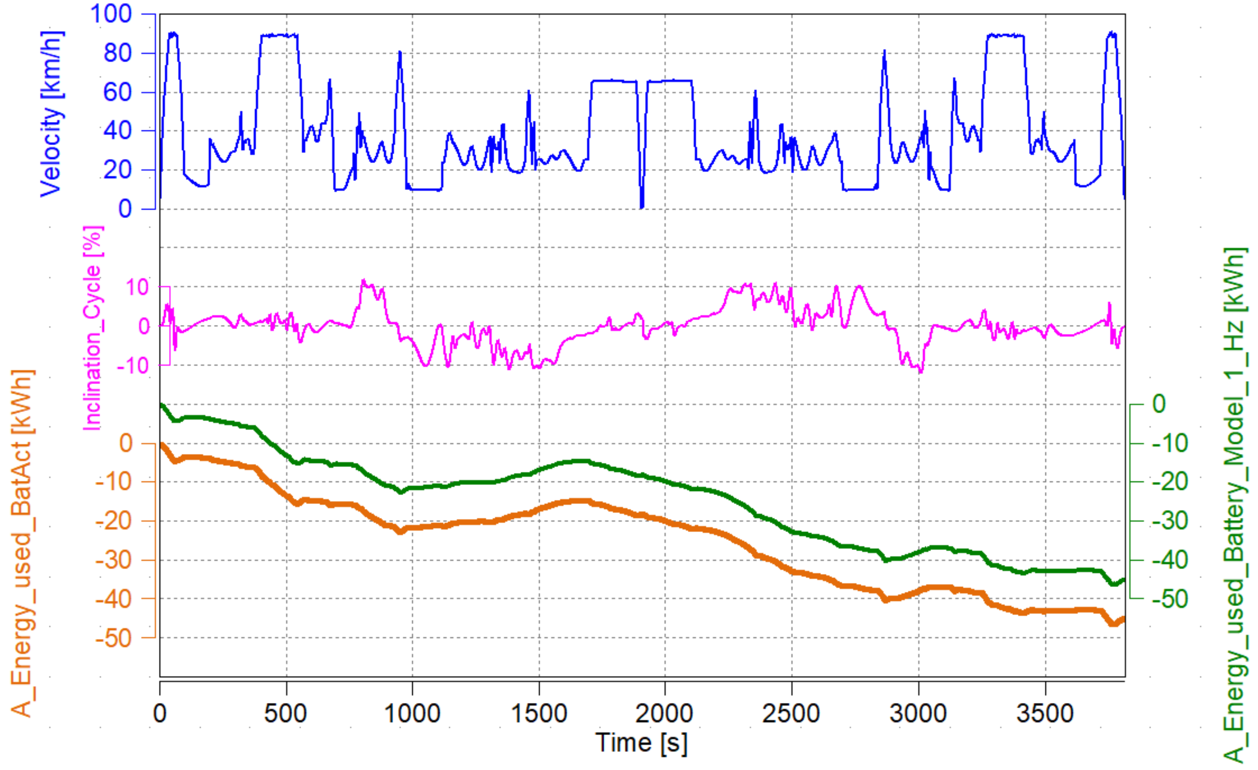
AI-based Behavior Modelling

Variable Acceleration and Speed ramps for EC Characterization





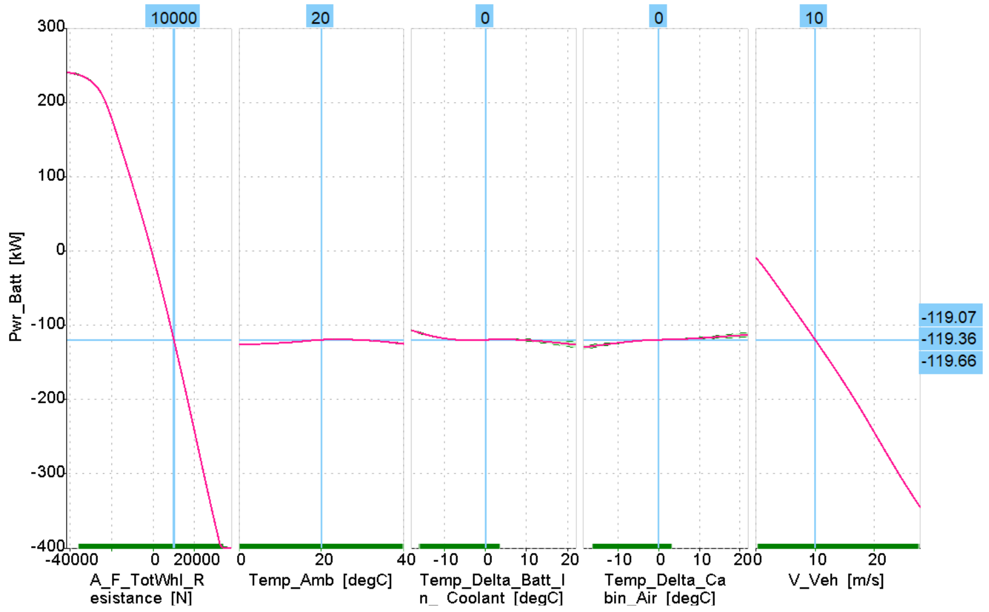
Range Prediction based on “On-Demand DTs” (ca. 1000x Real-Time)



Predicted (Offset for clarity)

Actual

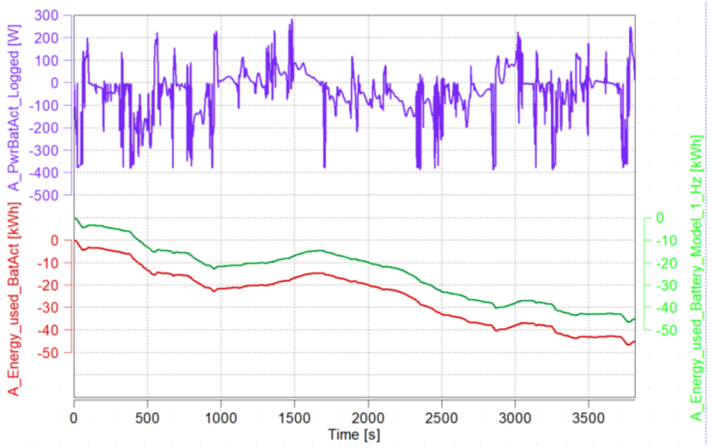
Fast DT Results for Cycle Energy Consumption <3% Error

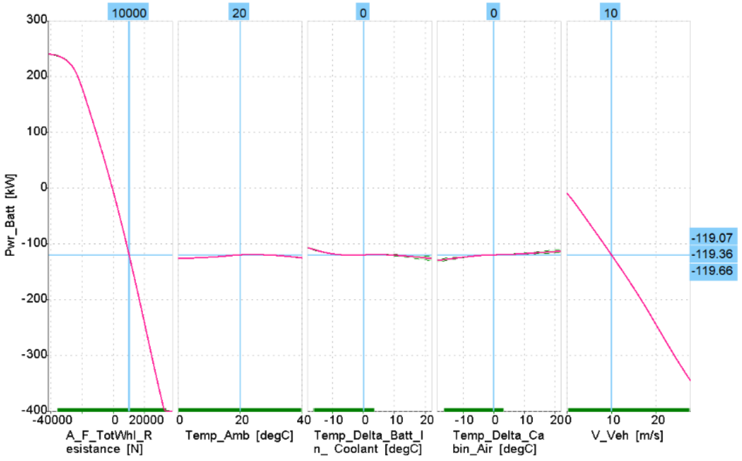


Automated Fast DT Tuning

- For fast DT
  - Empirical – Almost no setup necessary
  - Semi-physical – Formula constrained symbolic regression models (Reduced drift, better extrapolation)
    - eg $F(x,y) = Ax^2 + Bxy + Cy^3 + D$ where A to D can be constants or ML models
- Advantages
  - Built-in Model error prediction
    - Integrated hull calculation shows if interpolating or extrapolating and how much
  - Models compiled to FMU, C, Python and Excel for running in any environment
  - Fully automated via DevOps Pipeline, just feed new data!
    - Including pre-processing of “messy” road data

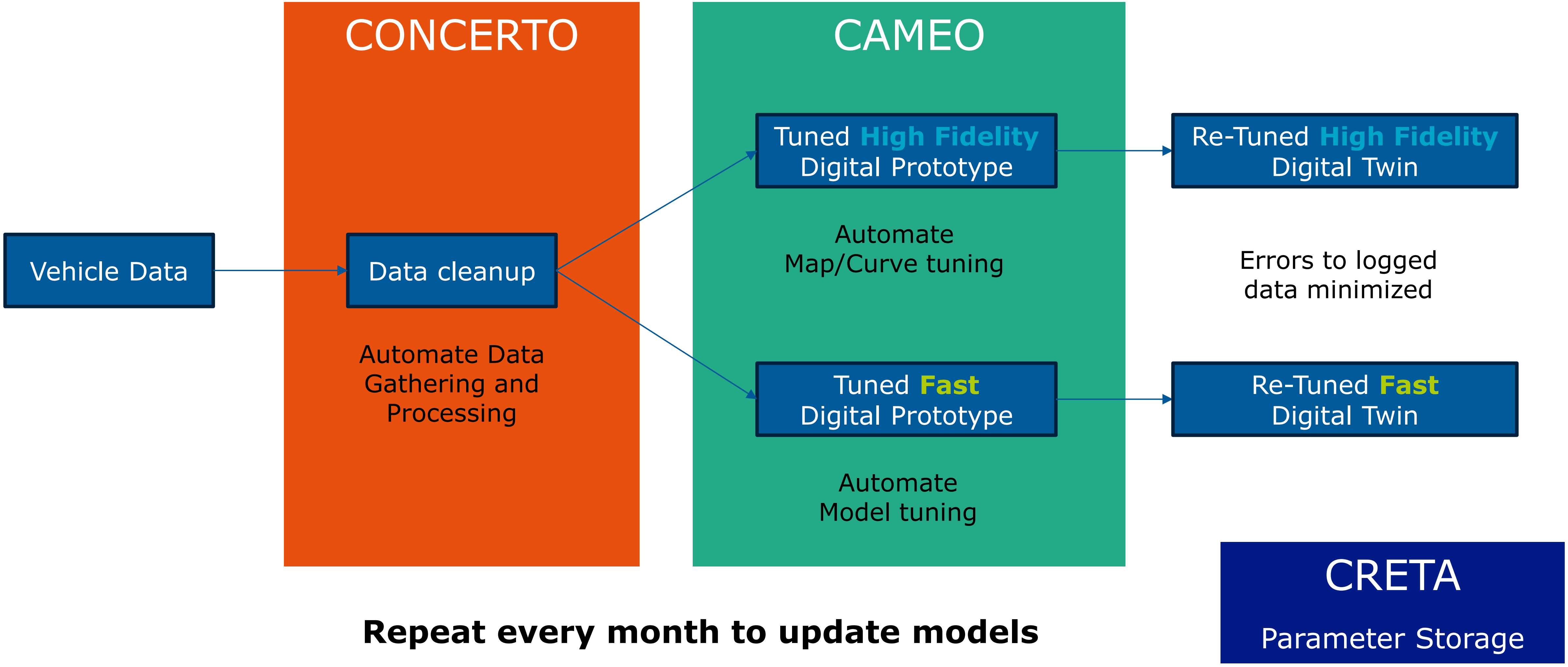
Fast DT Results for Cycle Energy Consumption <3% Error





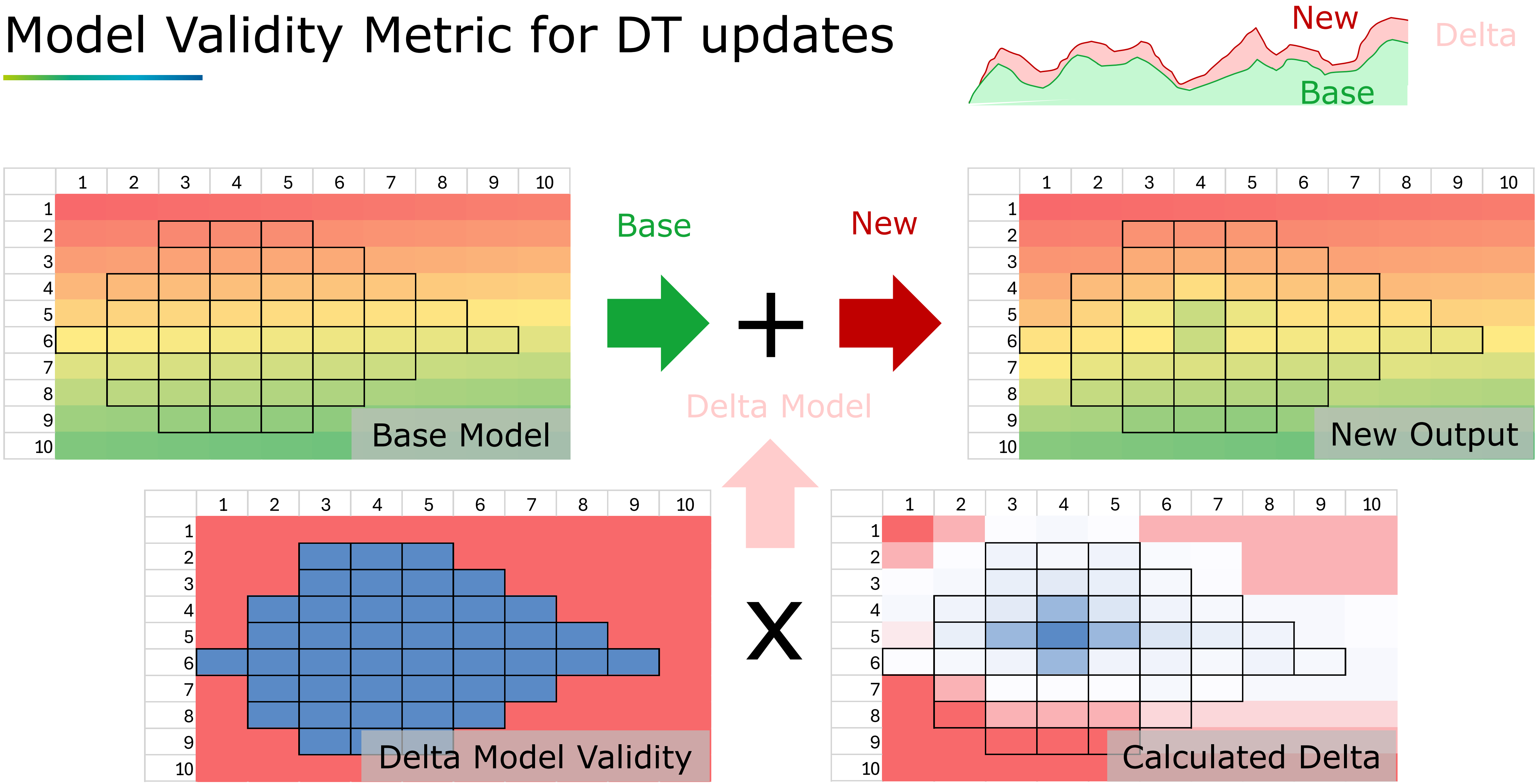
Predicted (Offset for clarity)
Actual

Automated model tuning (from vehicle data) - Digital Twin creation



Repeat every month to update models

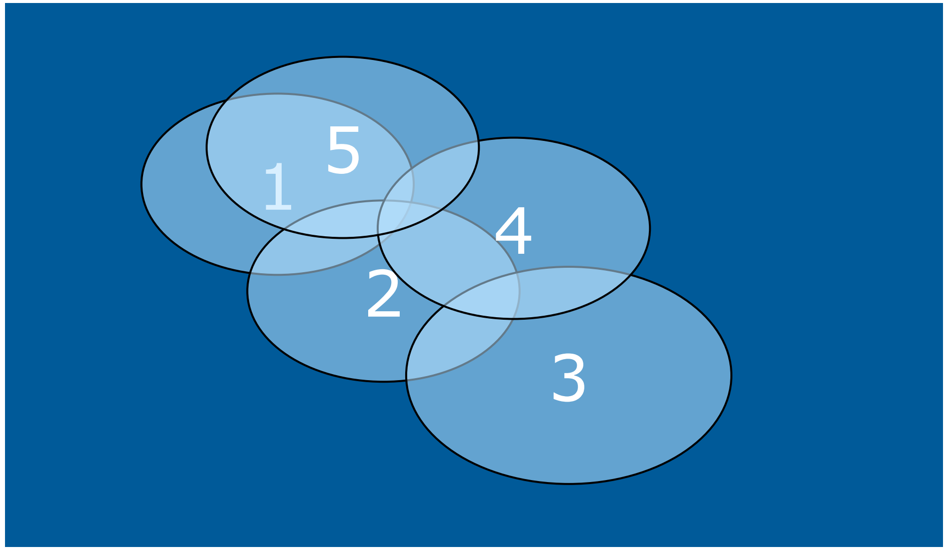
Model Validity Metric for DT updates

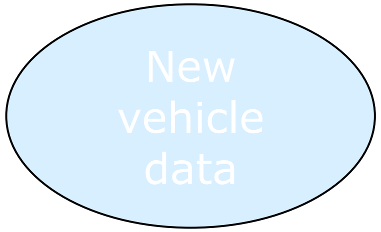


Exercise (please contribute, you know you want to!)

- How to handle multiple DT updates
  - ie How best to combine different updates?

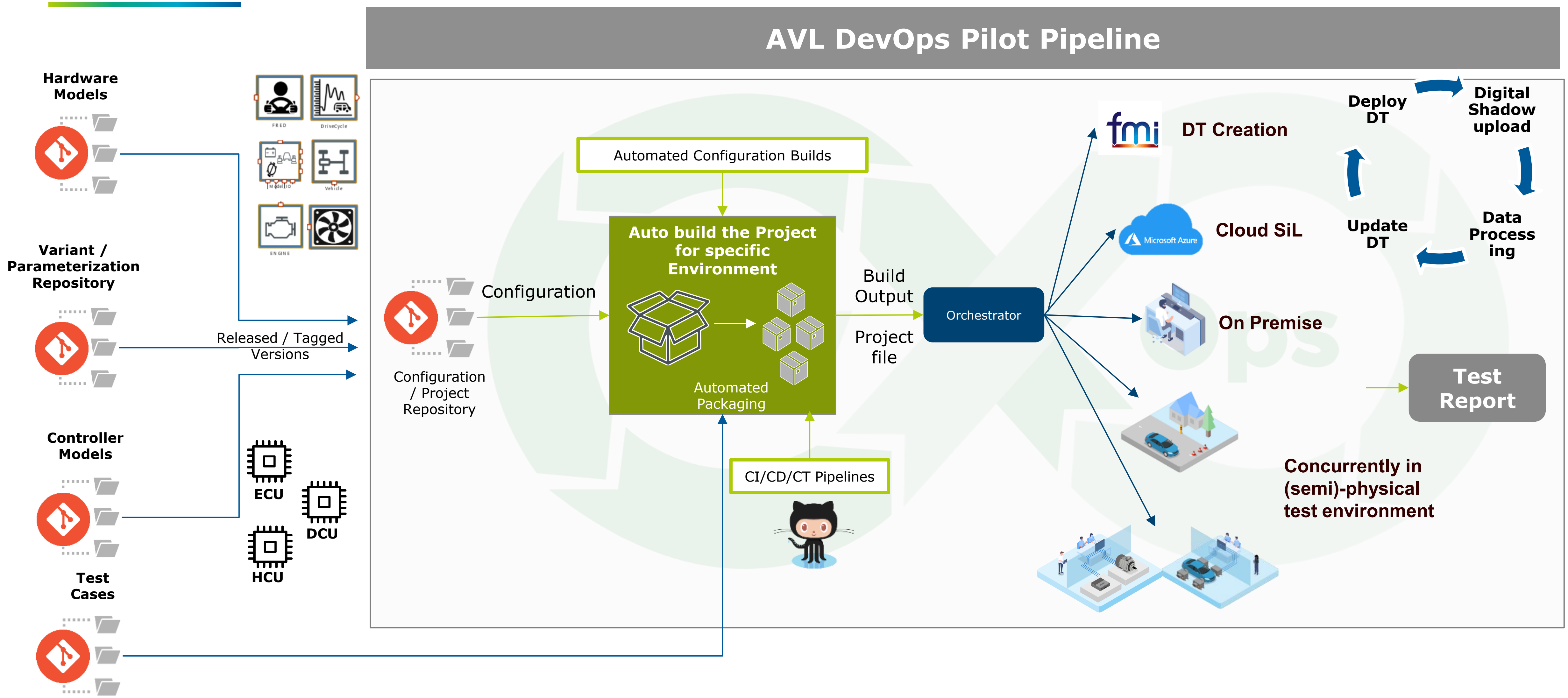
1. Update high fidelity, then recreate fast DT?
2. Delta models? Full new model?
3. Should you be able to “go back in time” with single model?
4. What should be done in the areas not covered by new data (extrapolate? blending? Keep base data?)





Full extent of possible vehicle operating area

Automation of SiL project creation and DT deployment



Summary & Look Ahead

Supporting your full SiL Pipeline!

- **FIRE**: Full 3D CFD Simulation Suite
- **BOOST**: Full 1D Simulation Suite
- **CRUISE M**: Easy Creation of High fidelity vehicle models (inc. FMU creation)
- **Model.CONNECT**: Deploy Co-Simulations in any environment
  - Simulate over multiple sites if FMUs can not be shared
- **CAMEO for SiL**: Front-end for SiL execution and Tuning of DTs and controllers (inc. maps)
  - The power of AI based testing for reduced simulation times and better models
  - Robustness analysis for tolerance stack-up analysis
- **CRETA**: Full development lifecycle Parameter Management
- **CONCERTO**: Powerful Auto-report creation and data analysis
- **Device.CONNECT**: Secure real-time cloud communication
- **DevOps Pilot**: Automated SiL Deployment to cloud
  - Including Auto-Deployment and Auto-Tuning of DTs to SiL environments

Get in touch for LIVE DEMOS or to learn more!

Publicly declared SiL project partners

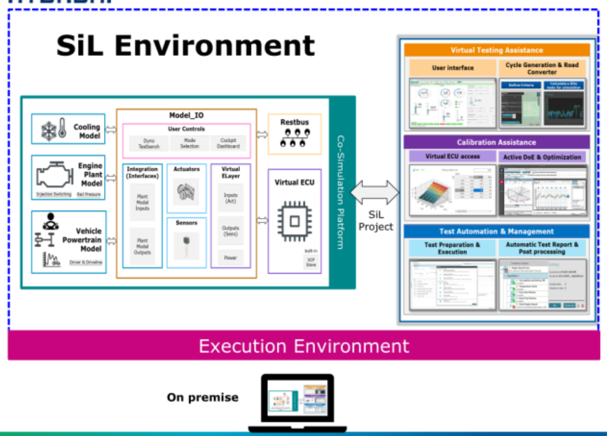
Reference HMC

SiL Configuration:
- **Gasoline ICE 3.5L V6 with Automatic Transmission**

Success story
HMC successfully performed calibration, validation & optimization of maps/Curves of controller software using AVL SiL Environment by integrating their corresponding plant models, Restbus simulation model & Virtual ECU together in the closed-loop.

Uses Cases:
- Stationary Response
- Transient Response
- RDE Concept Validation

AVL's value proposition
- Complete tool chain
- Creation of missing simulation models like Actuators
- SiL Setup
- support with calibration & modelling expertise



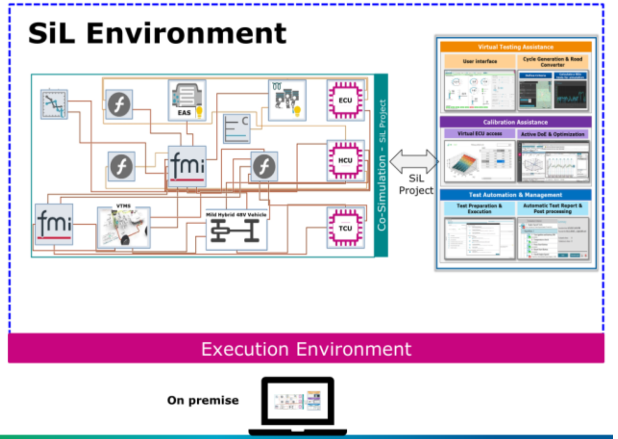
Reference Bosch/Wuxi

SiL Configuration:
- **48V Mild-Hybrid with Automatic Transmission**

Success story
AVL successfully integrated all the plant models (i.e., Engine, EAS, Hybrid Component & Automatic gearbox) and 3 Virtual Control units (i.e., ECU, HCU & TCU) into the AVL SiL Environment and handed over the complete SiL environment to BOSCH WUXI to perform their SiL activities.

Use cases
- RDE & Drivability
- 48V Mild Hybrid
- Robustness

AVL's value proposition
- Complete tool chain
- SiL Setup
- support with calibration & modelling expertise



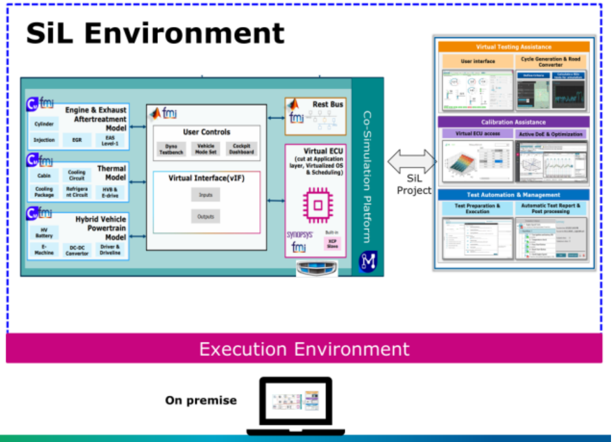
Reference GEELY

SiL Configuration:
- **HEV Energy Management System**

Success story
AVL successfully developed & integrated all the plant models (i.e., Engine, EAS, E-Motor, Battery, DCDC Convertor & Transmission model, …) including Restbus model & Virtual Control units from Geely into the AVL SiL Environment and handed over the complete SiL environment Geely to perform their SiL activities.

Use cases
- Power performance & Energy Consumption
- Overall Thermal behavior in different modes
- Robustness

AVL's value proposition
- Complete tool chain
- SiL Setup
- support with calibration & modelling expertise



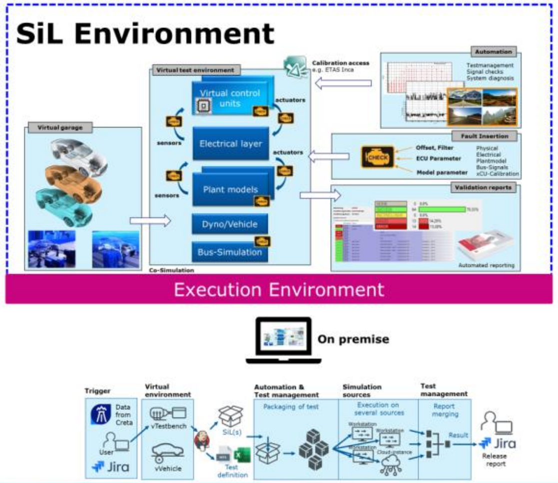
Reference AMG

SiL Configuration:
- **Hybrid Configuration**

Success story
AVL successfully supported AMG to perform calibration and Validation of Controller software using AMG defined SiL Platform – based on Silver & ECU Test

Uses Cases:
- Stationary & Transient Response
- On Board Diagnostics
- Hybrid Optimization
- …

AVL's value proposition
- SiL Setup using AMG defined tools & their models with Virtual ECUs
- PTE Engineering Support
- support with calibration & modelling expertise
- Test setups based on the requirement



Thank you

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Q&A

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