



# Digital twin development framework for NextETRUCK: Real-time and 1000x execution speed DT Development

September 2025

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*This project has received funding from the European Union's Horizon Europe programme under grant agreement No 101056740*

# Today's Presenter



**Leo Xenakis      CEng IMechE**

**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...

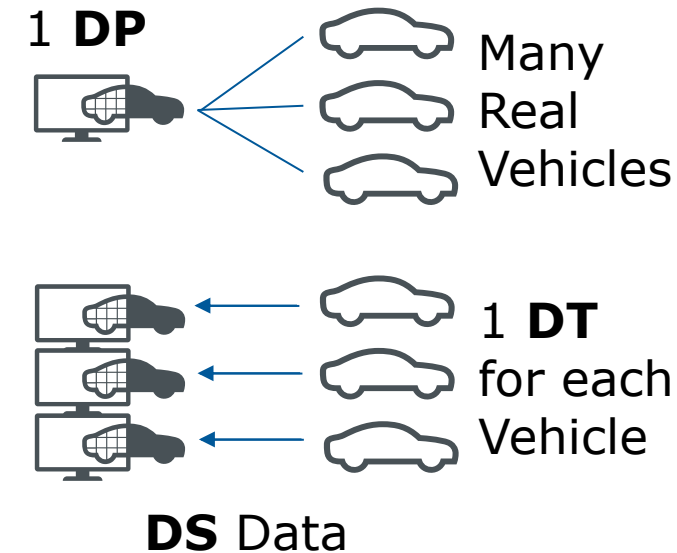


# Architecture Overview & Background

# 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

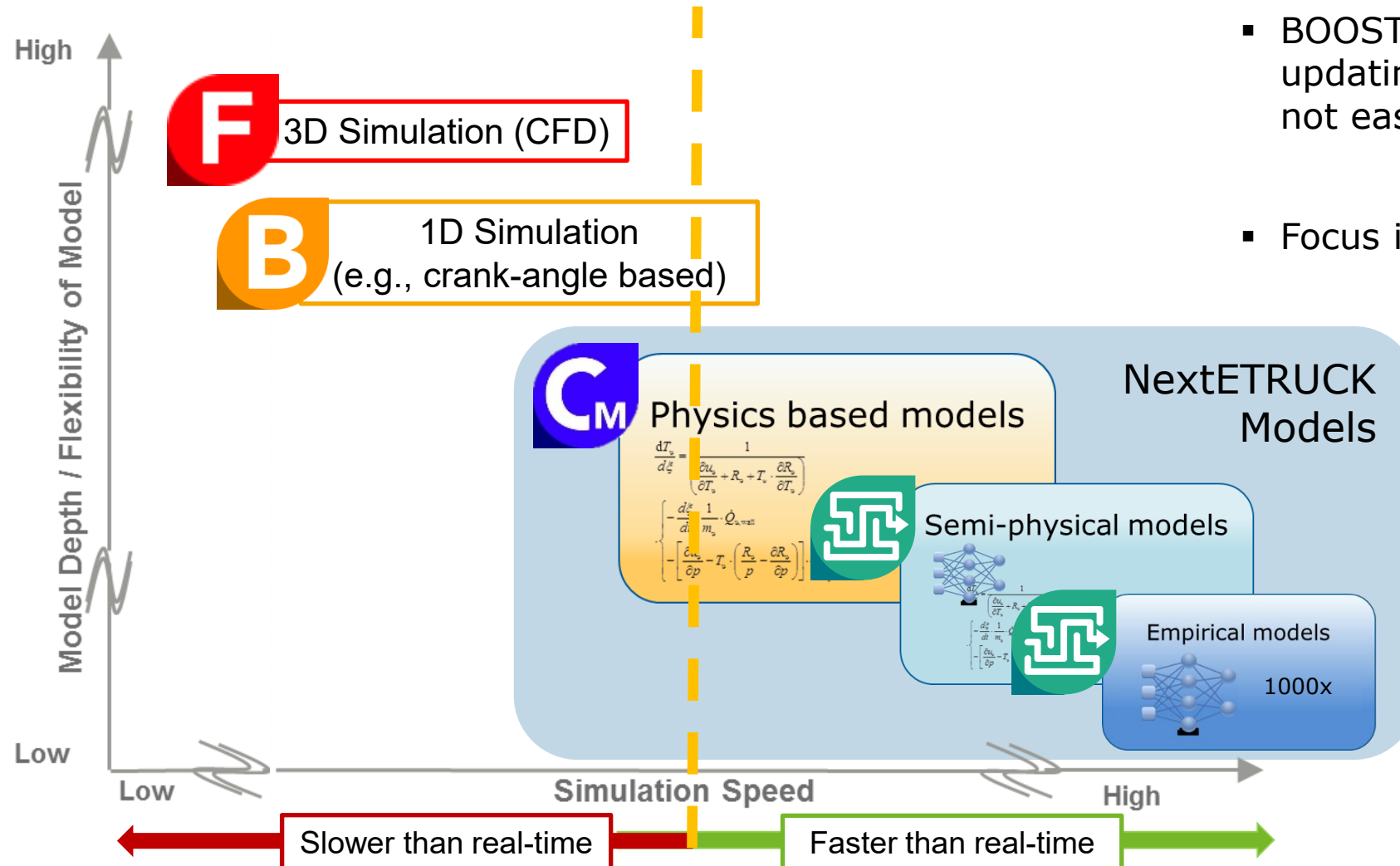
### Use-cases

- **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**

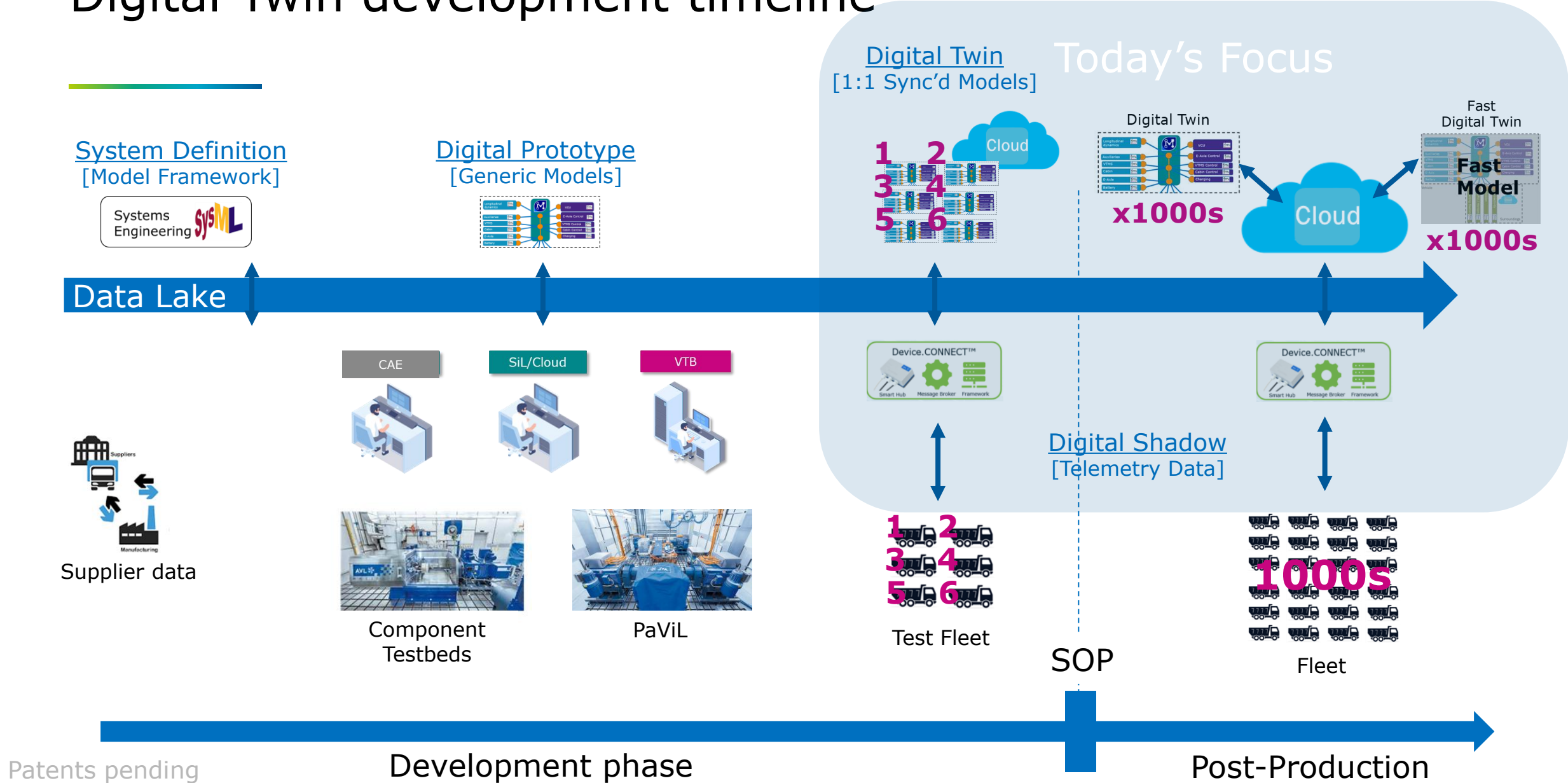
# What are the challenges?

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## Key Issues

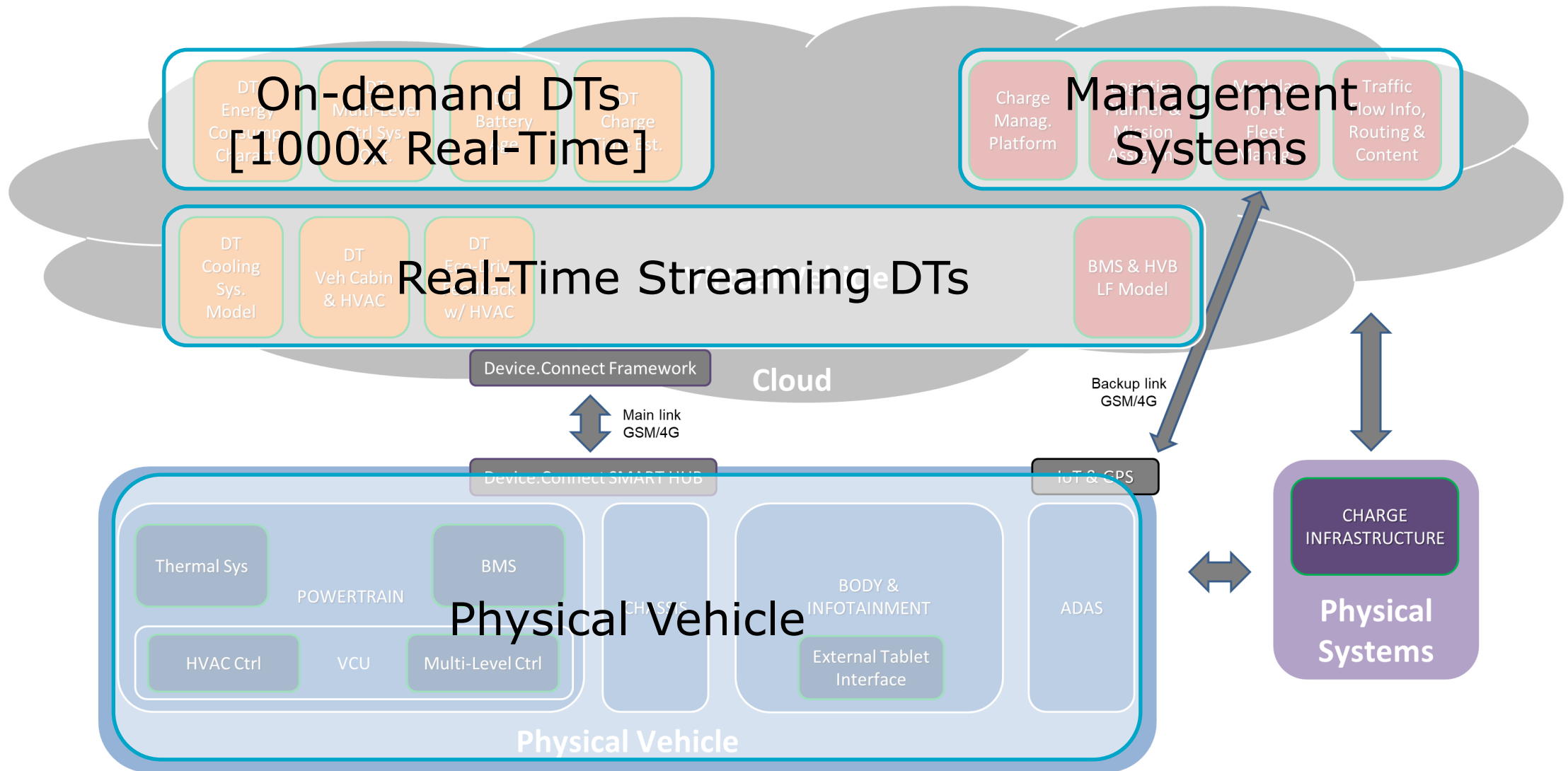
- Live communication between cloud and vehicle
  - Speed / Buffering / Data integrity / Security
- DT creation and update methodology (automation capable)
  - Calculation of delta models
  - Re-parameterize models (inc maps)
- Traceability of models/parameters
- Automated Pipelines for:
  - Processing large amounts of data
  - Parameterizing / generating updated DTs
  - Cloud capable model deployment and execution

# Digital Twin development timeline





# NextETRUCK Fast DT Cloud Architecture Overview





# NextETRUCK Project Overview

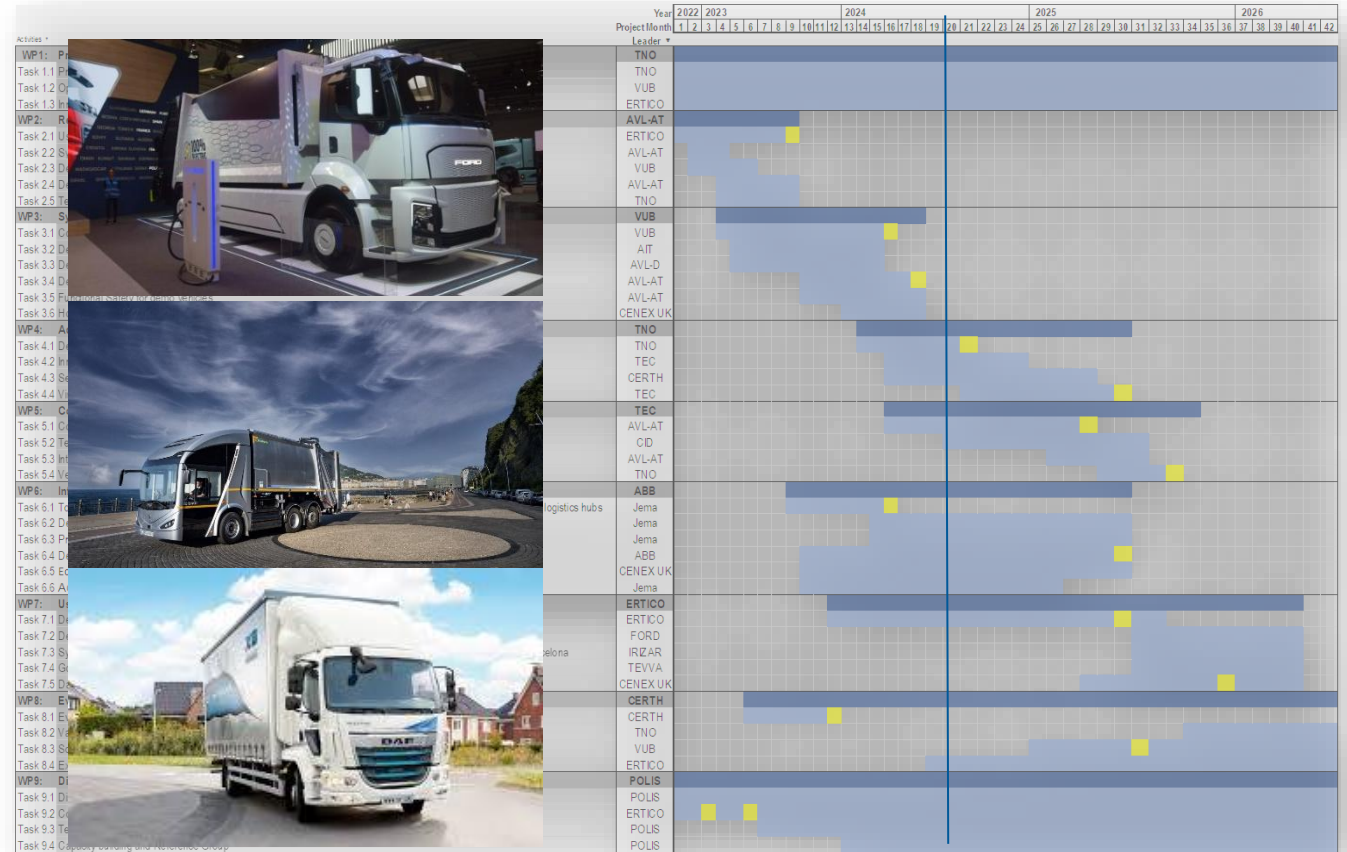
# Next generation E-Truck demonstrator project



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



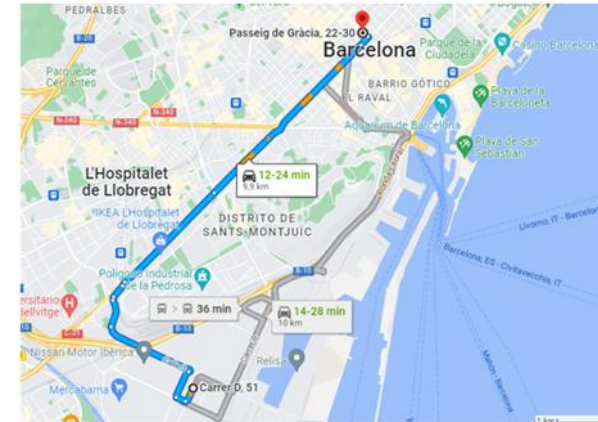
This research has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 101056740, under the title of NextETRUCK.

# 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)

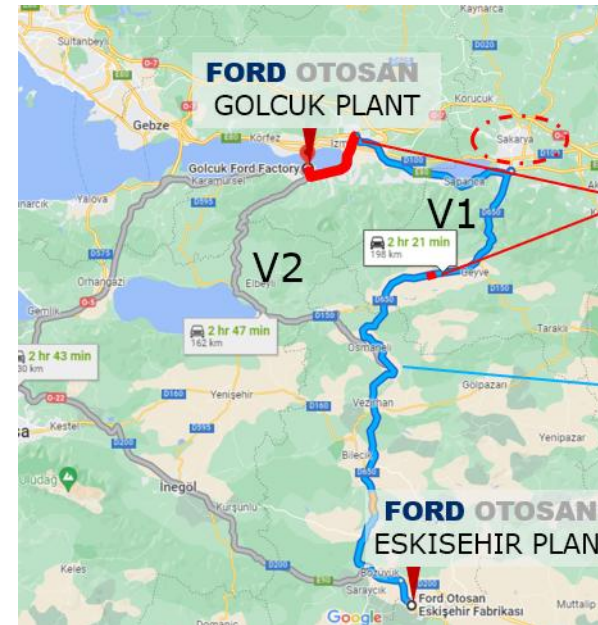
## Project Goals

- 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**

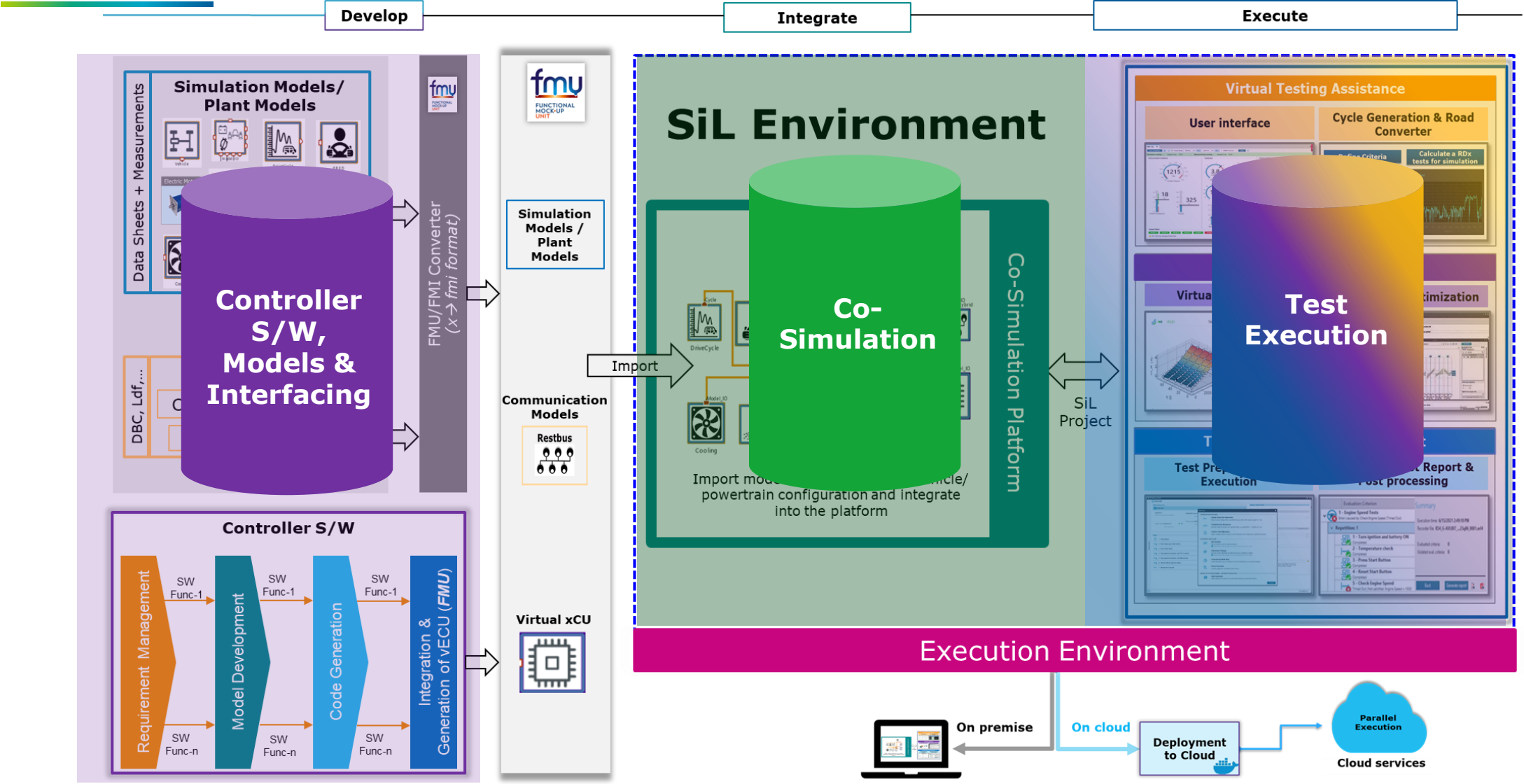
Urban Usage:  
**21 km**  
(10% of the  
total task)

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

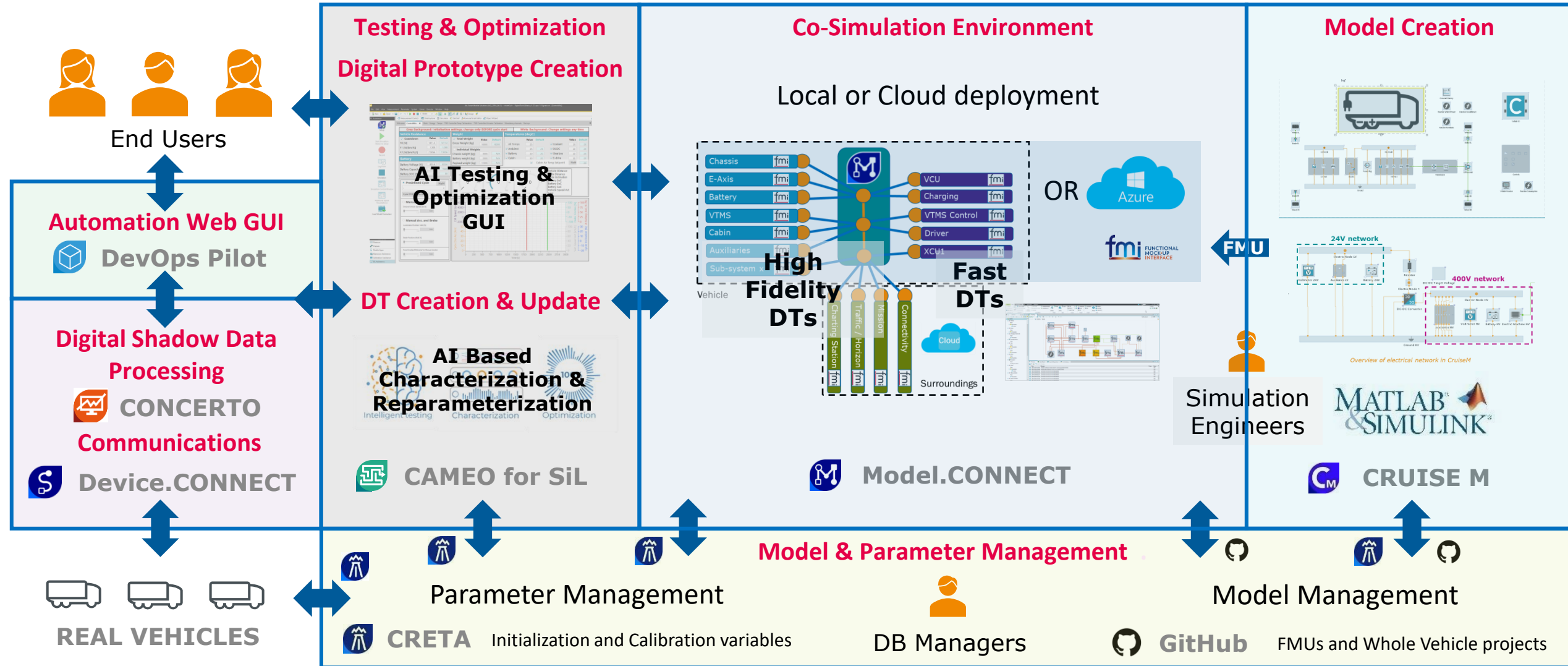


# Digital Twin Creation Framework

# Automotive SiL Components & Workflow



# NextETRUCK DT Workflow





# NextETRUCK high fidelity generic model base (FVVCP)

Platform Specification Vehicle

	Parameter
Vehicle	Long Haul truck (14 to 40 tons)
Rolling resistance / power at 85 km/h (flat road)	$f_{rr}=0.55\%$ 90 kW @ 40 tons
Gearbox	12 Gear AMT
Final drive	3.14
Engine speed at 85km/h@12 gear	1100 rpm
Frontal area / $c_w$	9.8 m <sup>2</sup> / $c_w=0.50$
Tire radius (dynamic)	0.525 m

Vehicle

Internal

7.00

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Platform Specification Cooling System

	45%-BTE Base	400V-Hybrid
MT-Radiator	890 mm x 980 mm x 42 mm	890 mm x 980 mm x 42 mm
LT-Radiator	530 mm x 980 mm x 26 mm	-
MT-Radiator	-	530 mm x 980 mm x 26 mm
AC-Compressor 34 cm <sup>3</sup>	Function: R134a @ 0.8 bar Discharge: 50 L/h @ 13.0 bar Cooling power: 7.5 kW Rated: 1500 rpm	-
AC-Condenser	Op. Refl. side: 180 kPa @ 0.30 kg/s Op. Air side: 0.2 kg/s @ 1.07 kg/s Heat rejection: 400 W/K	Op. Refl. side: 180 kPa @ 0.035 kg/s Op. Cond. side: 0.5 kg/s @ 13.0 bar Heat rejection: 300 W/K
AC-HV Chiller with EVV	-	-
AC-Evaporator with TXV	Op. Refl. side: 22 kPa @ 0.043 kg/s Op. Air side: 0.1 kg/s @ 0.05 kg/s Heat rejection: 200 W/K	-
Pumps	LT Elec. Pump - 250 W Cabin Elec. Pump - 100 W HV Refl. Pump - 4000 W	LT Elec. Pump - 150 W Cabin Elec. Pump - 250 W HV Refl. Pump - 1000 W
Cabin	Same cabin model was used in all different powertrain variants	

400V cooling system

Internal

7.02

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EAS Layout Cruise™ M

The MoBEO EAS is a 1D physical model for catalysts, filters and pipes:

- Allows for real time calculations
- Physical modeling of **catalytic performances** (deNOx, NO2 production, NH3 oxidation, N2O production, soot storage ...) and **thermodynamic states** (temperatures, pressures ...)
- Reproduces changes in **geometries and boundary conditions**
- Effects of NH3 uniformity are captured by parallel computation of **two zones**

**AVL engineering know-how & data bases**

- Each catalyst model from database reproduces the performances of a real, representative catalyst
- Thermal parameters are chosen to reflect layout based on AVL know-how (in-line, Box, s-type)

Available **measurements/inputs** are used to:

- Define Layout
- Guide the selection of elements from database
- Refine catalytic performance and thermal behavior

Internal

7.03

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AVL

## High Fidelity 400V P2 Hybrid Truck Model

Platform Specification Engine

	45%-BTE ICE
Displacement	11L
Power	314kW@1900RPM
Torque	2100Nm@1100RPM
Brake Thermal Eff.	45%
Peak Firing Pressure	200 bar (operational)
Fuel Injection Equipment	CR-1800bar
Turbocharging	Single-Waste Gate
Charge Air Cooler	1 Stage (indirect)
EGR	HP
Compression Ratio	18:1
Exhaust aftertreatment	DOC+DPF+SCR+ASC (EUVI and ChinaVI)
Engine concept strategy	Simple and low costs

Engine

Internal

7.04

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Platform Specification Vehicle

- A longhaul truck (4x2) with a semitrailer (3 axes) is considered

Parameter	Unit	Value
Vehicle mass	kg	40000
Frontal area	m <sup>2</sup>	9.8
Drag coefficient	-	0.55
Rolling resistance coefficient	%	0.05
Wheel radius	m	0.5255

Vehicle

Internal

7.07

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Platform Specification Engine

**ICE MODELLING APPROACH IN CRUISE**

- The **Airpath** model is based in physical equations:
  - Based on physical equations (drag and emptying method)
  - 10 inputs are needed as an input
- Combustion model (semi-empirical model):**
  - Method of physical and empirical sub-models
  - Physical sub-models used as long complexity and calculation speed allow this
  - Empirical sub-models verified by measurements
  - Refinement for a better correlation with parameters to adapt the condition at start of injection, the injection delay and the combustion velocity
  - Detailed calculation of major combustion quantities improves calculation speed
  - Number of input parameters are minimized
- Emission models (Box, CO, THC and Soot):**
  - Box model based on a wide range of different engines (except vintage and vintage trucks 0.2-2.0 liter)
  - Output: SOx, CO, Soot, THC

Internal

7.08

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Vehicle Resistance and brakes

Calculation of resistance force

**Vehicle resistance**

**Parameter**

- $F_{drag}$  ... drag force
- $F_{roll}$  ... rolling resistance force
- $F_{grav}$  ... gravitational force
- $F_{brake}$  ... brake force
- $F_{aer}$  ... air resistance factor
- $A_{veh}$  ... vehicle front area
- $g$  ... acceleration of gravity
- $c_w$  ... rolling resistance factor
- $\alpha$  ... slope angle

**Resistance Force**

$$F_{res} = F_{drag} + F_{roll} + F_{grav} = \frac{\rho_{air} \cdot c_w \cdot A_{veh} \cdot v_{veh}^2}{2} + m_{veh} \cdot g \cdot c_w(\alpha) + m_{veh} \cdot g \cdot \sin(\alpha)$$

Linear velocity dependent rolling resistance approach is used

Internal

7.09

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Platform Specification Hybrid System

	400V-Hybrid
Architecture	P2
E-Motor size	1 x 125kW (Peak)
Battery size	15kWh
Active battery cooling	Yes
WHR	No
Pure electric driving from stand-still	Yes
Electric sailing	Yes

Internal

7.10

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Vehicle Model Electrical Network

The electrical network consists of the 400V network and the 24V network.

- The 400V network is connected via a DC/DC to the 24V network
- The 24V auxiliaries are supplied via the DC/DC
  - Power peaks are covered with the 24V battery
- The power consumption for the different electrical auxiliaries is an output from the VTMS model and an input to the vehicle model
  - Most of the auxiliaries are pumps
  - The pump power depends on the cooling circuit temperature and cooling demand

Internal

7.11

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Vehicle Model Overview

The vehicle model consists of

- The drivetrain
- The mechanical auxiliaries
- 24V and 400V electrical network with electrical auxiliaries
- Cycle definition
- Driver
- Corresponding controls
- HCU

Internal

7.14

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Vehicle Model Controls

**Controls**

The controls system consists of following subsystems

- Shifting
  - Shift line definition
  - Clutch actuation
  - Torque ramp down / torque ramp up (engine + e-motor)
- Thermal
  - thermal derating of e-motor
  - Thermal derating of battery
  - Battery current limitation
- HCU
  - Hybrid control unit for P2 application

Internal

7.15

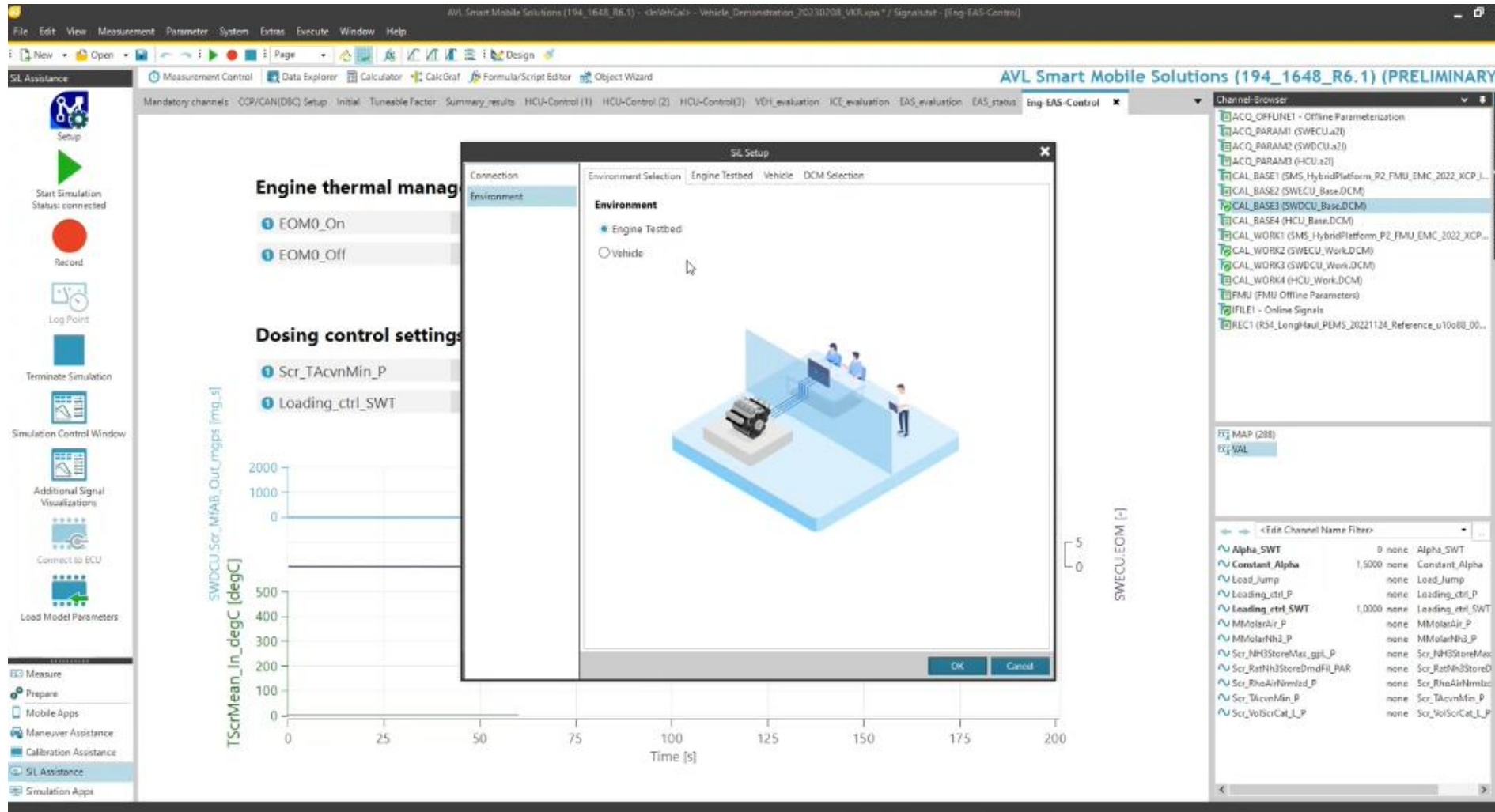
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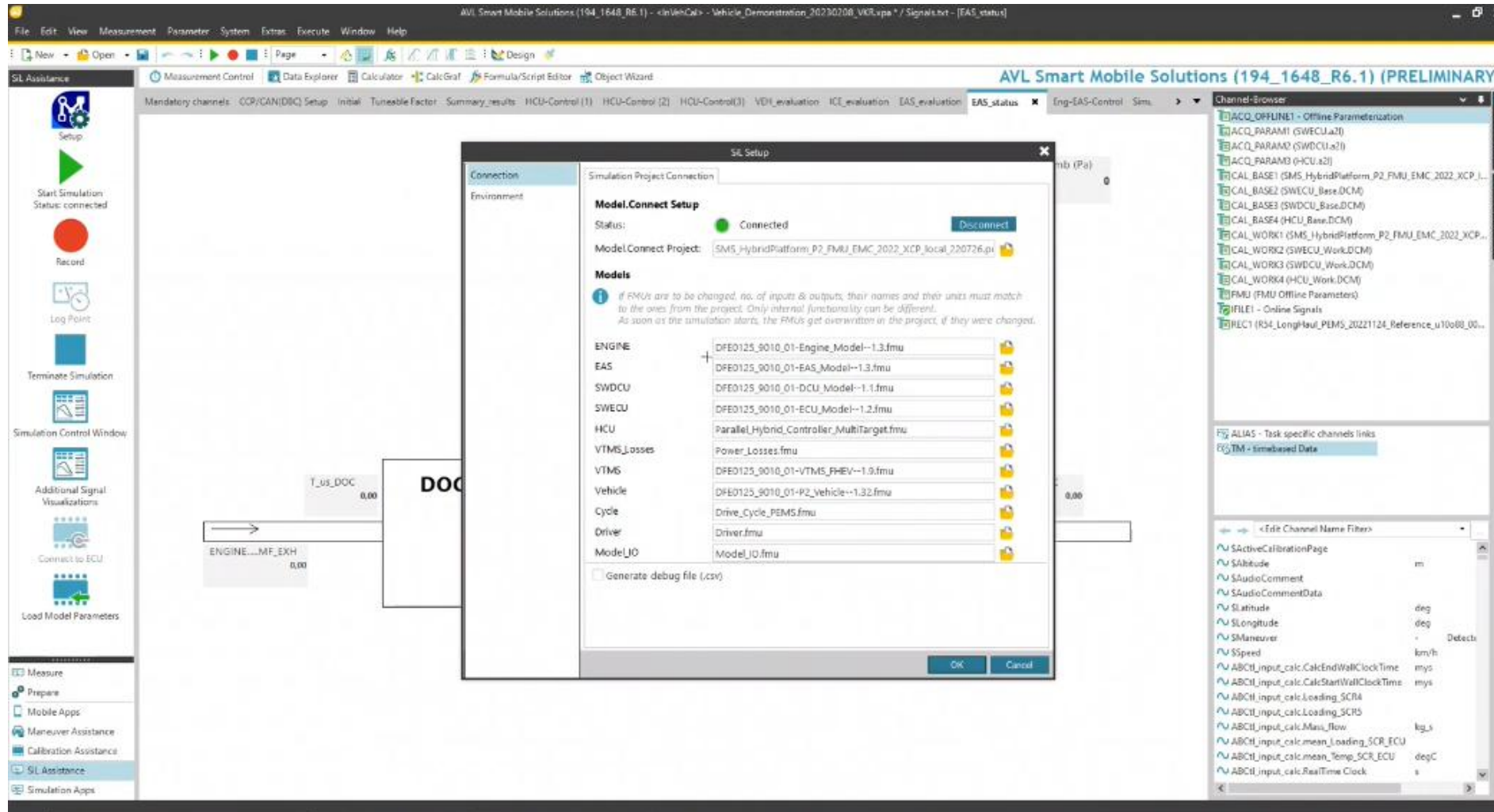
# High Fidelity Digital Prototype

## Testbed or Vehicle Configuration



# High Fidelity Digital Prototype

## Choose FMU components



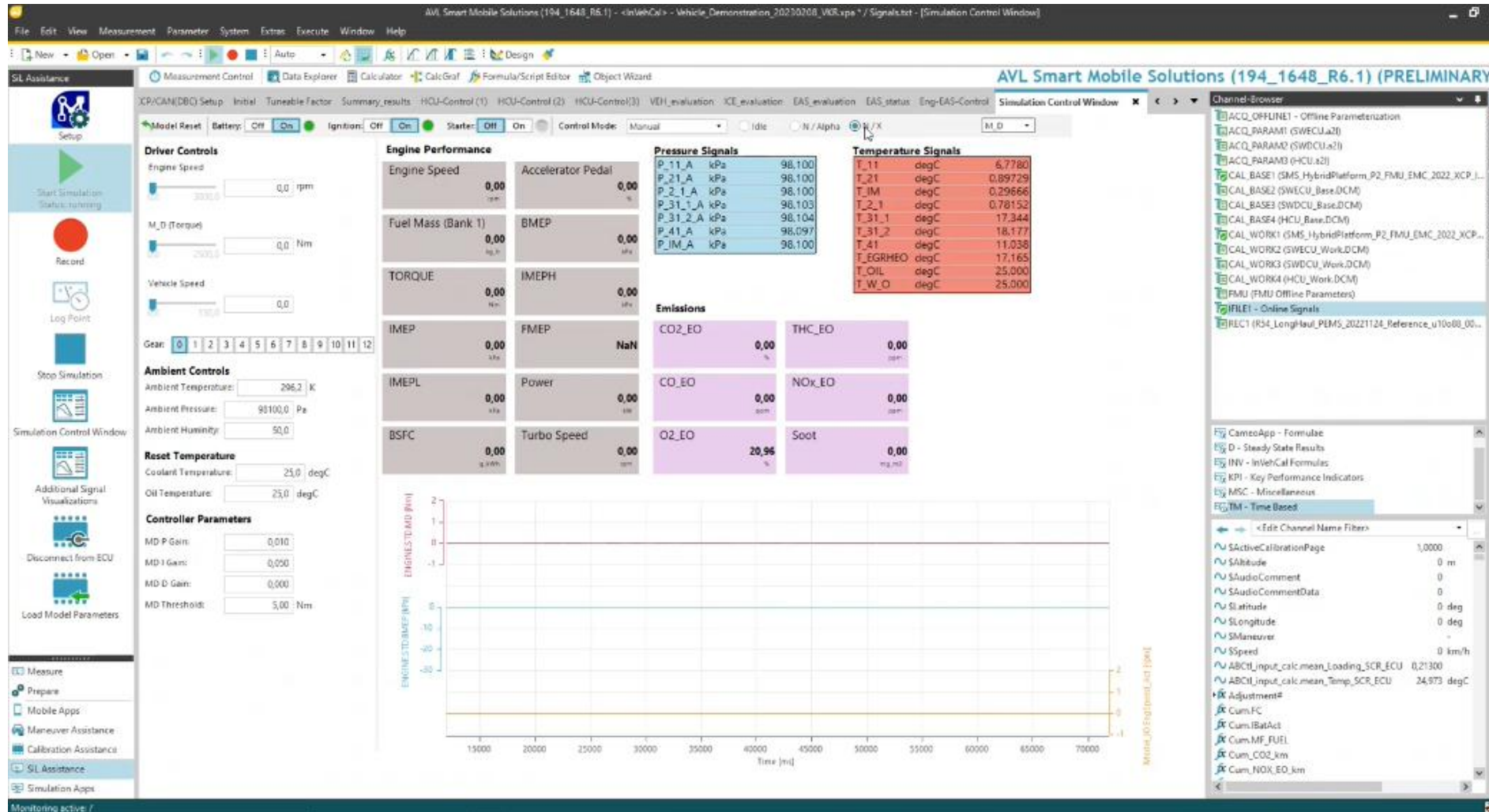
## Initial Parameter Setup





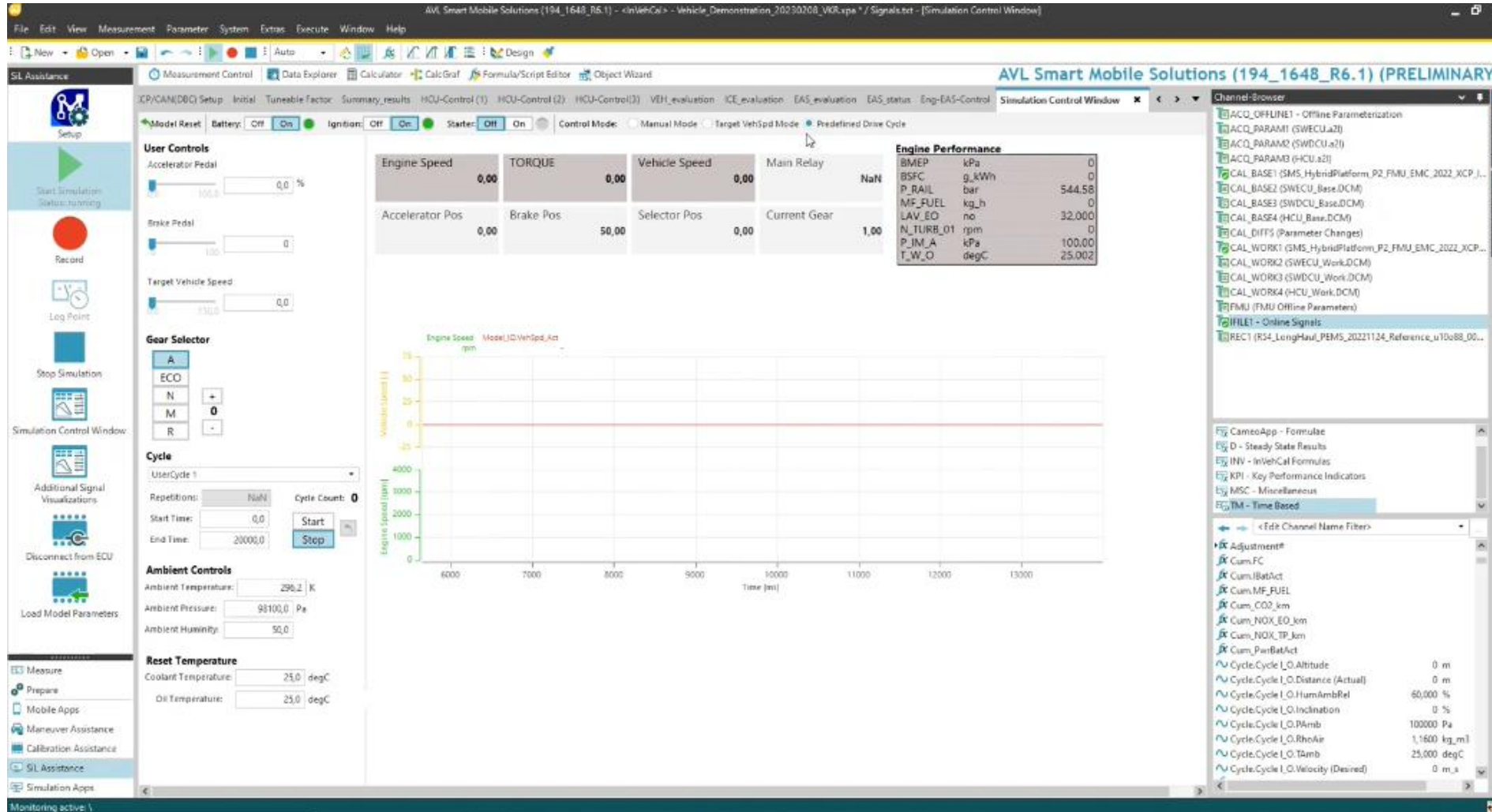
# High Fidelity Digital Prototype

## Main Control Window – Manual Control



# High Fidelity Digital Prototype

## Main Control Window – Cycle Execution

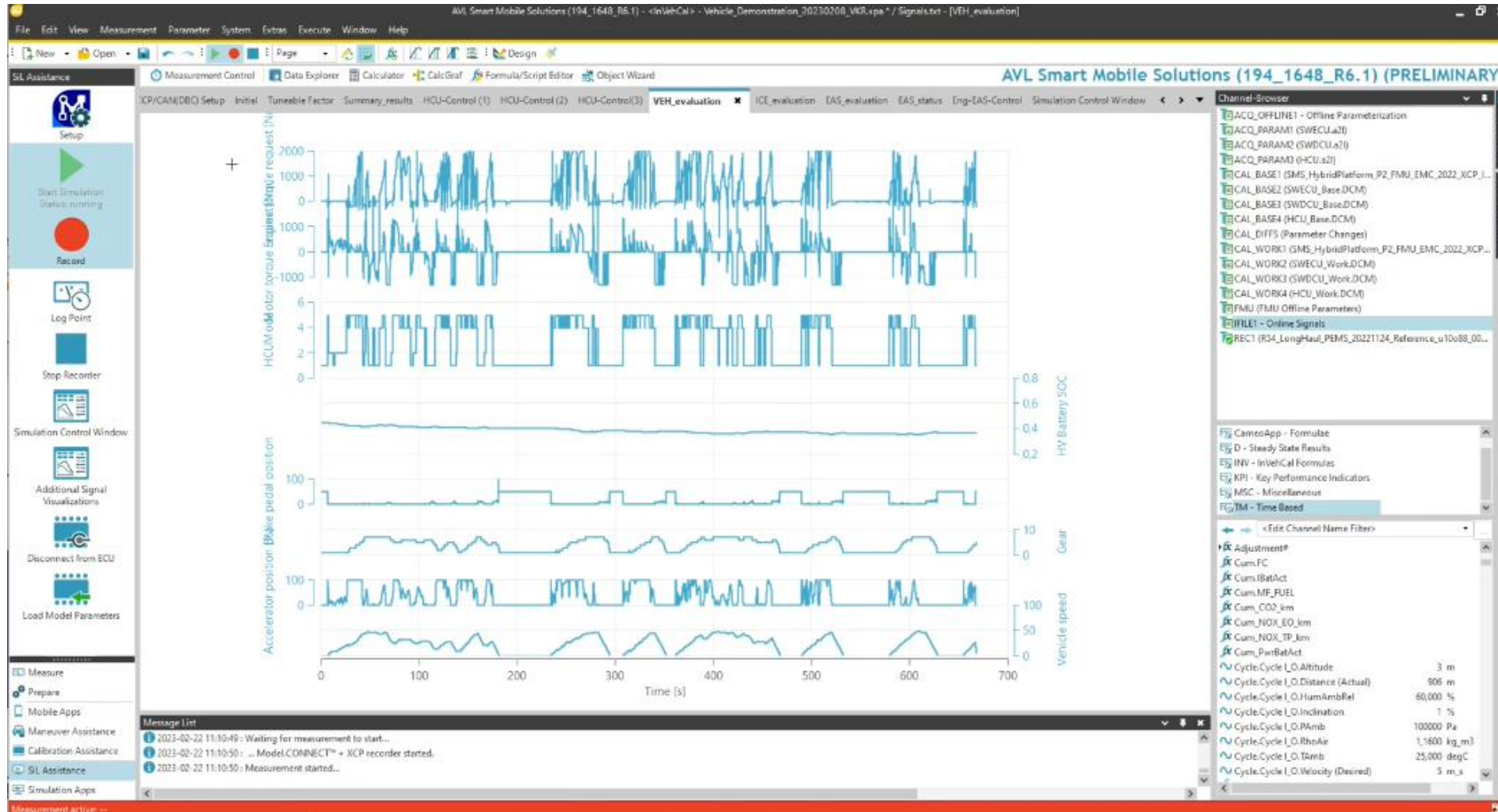






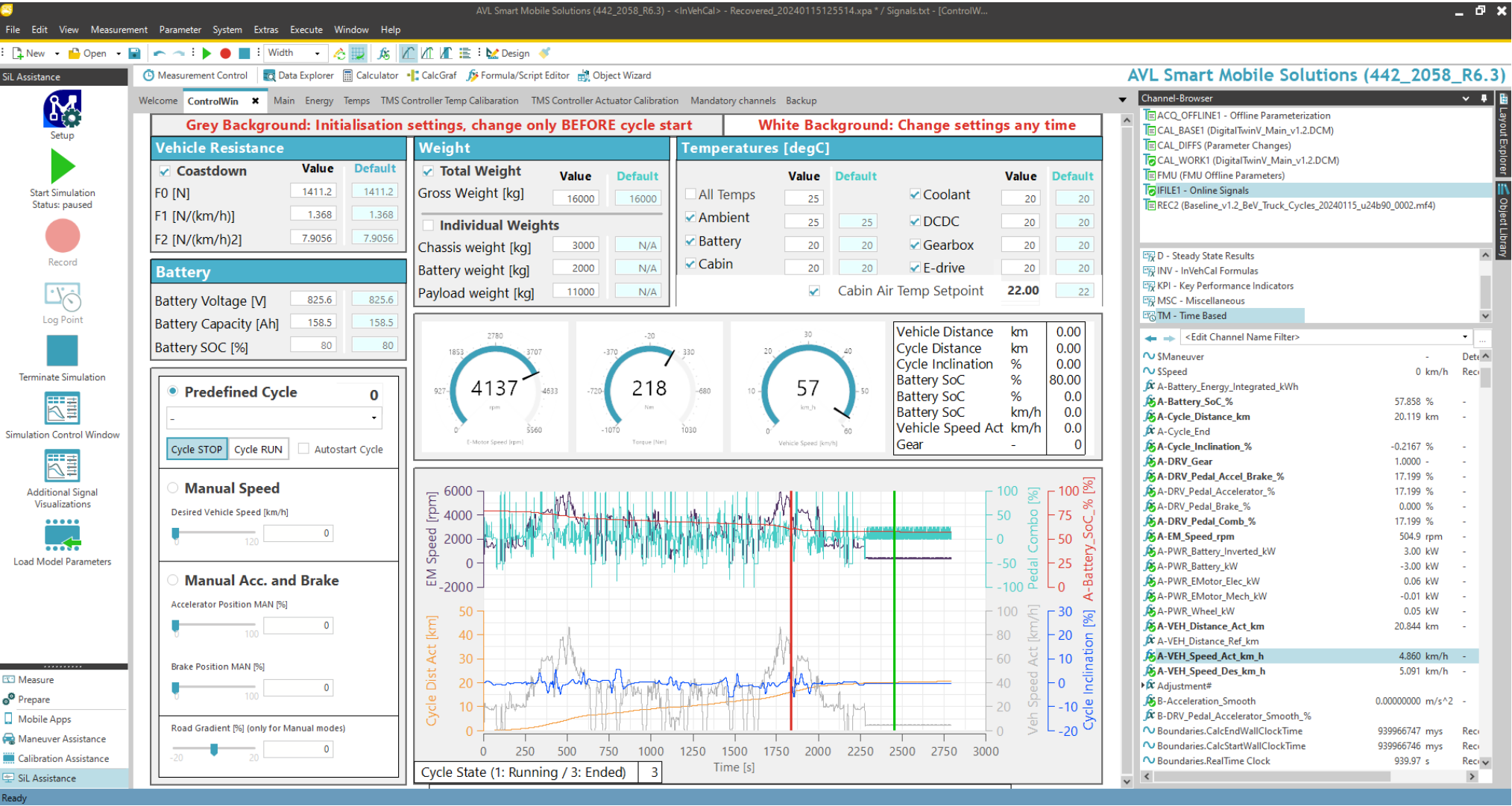
# High Fidelity Digital Prototype

## Post-processing Example



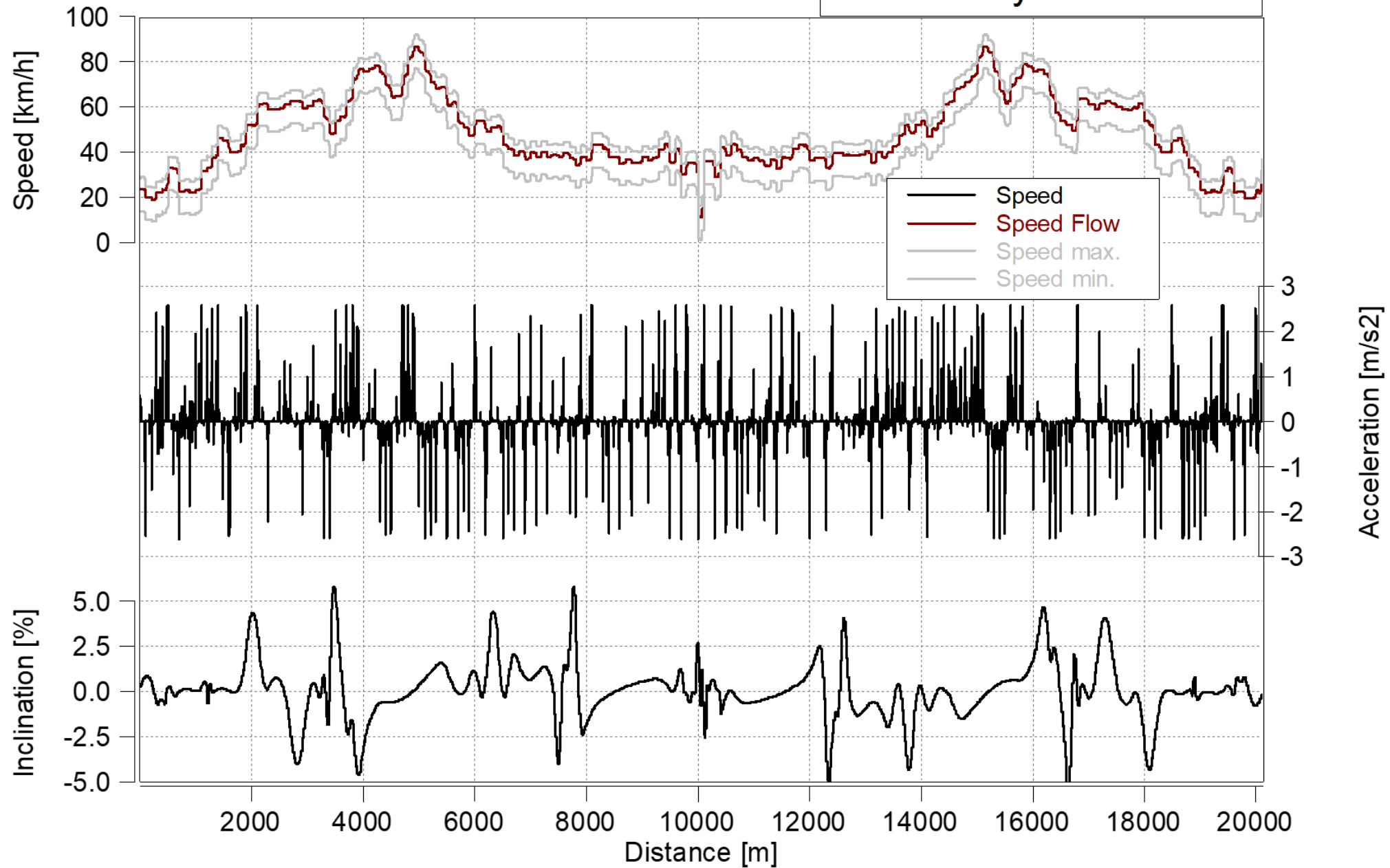
# CAMEO for SiL Interface for NextETRUCK

## Main Control Window

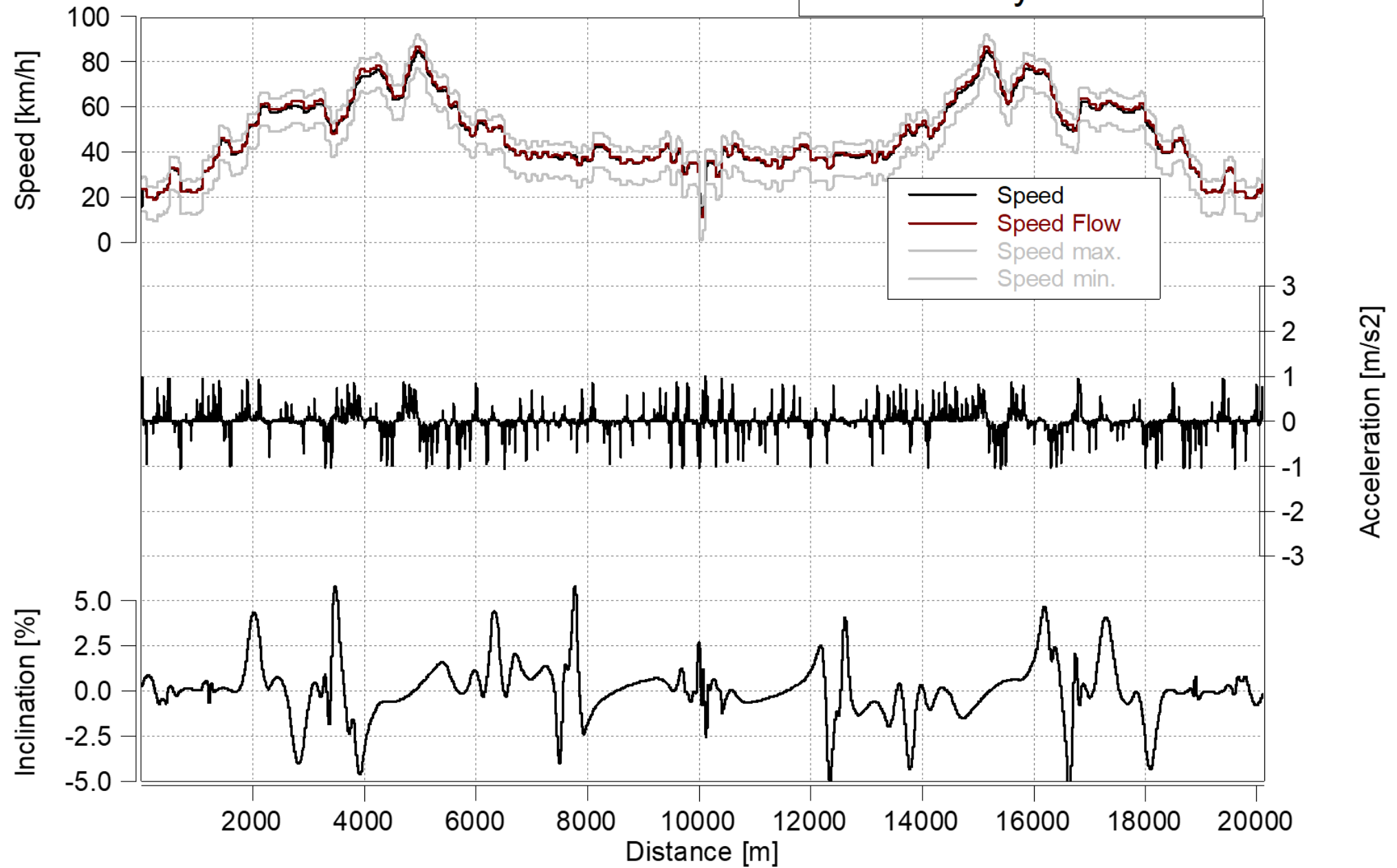




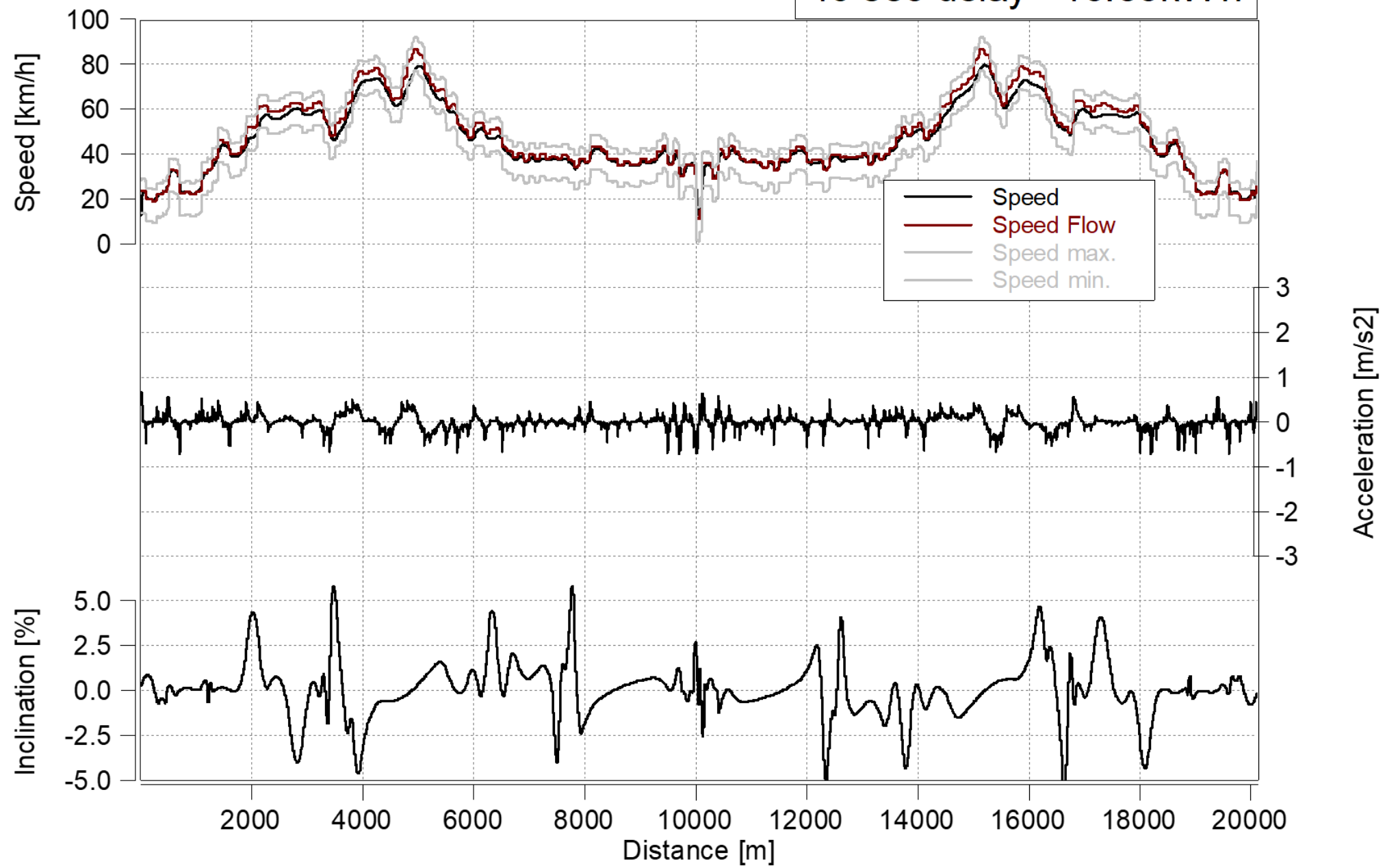
0 sec delay - 17.97kWh



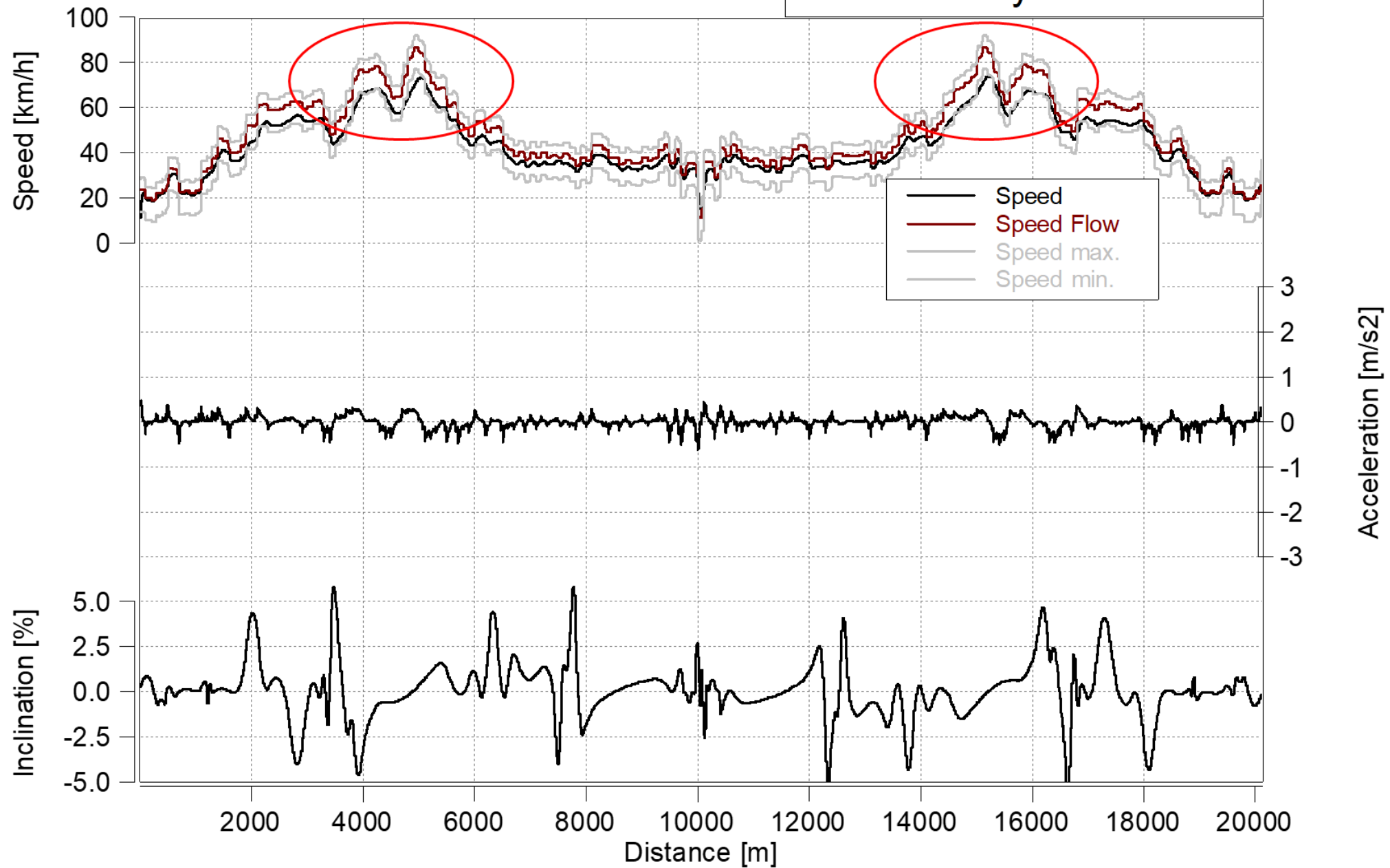
20 sec delay - 17.23kWh



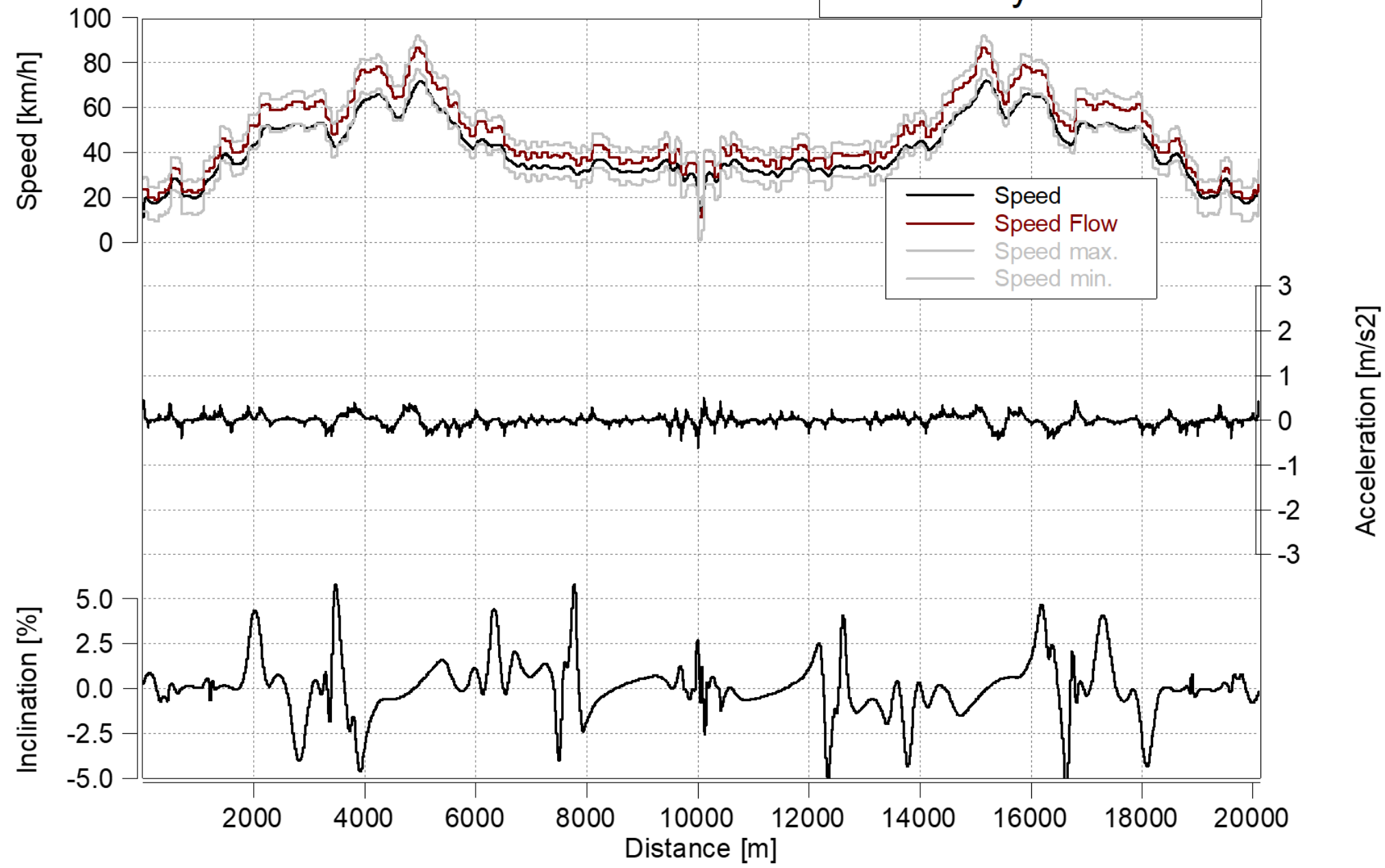
40 sec delay - 16.56kWh

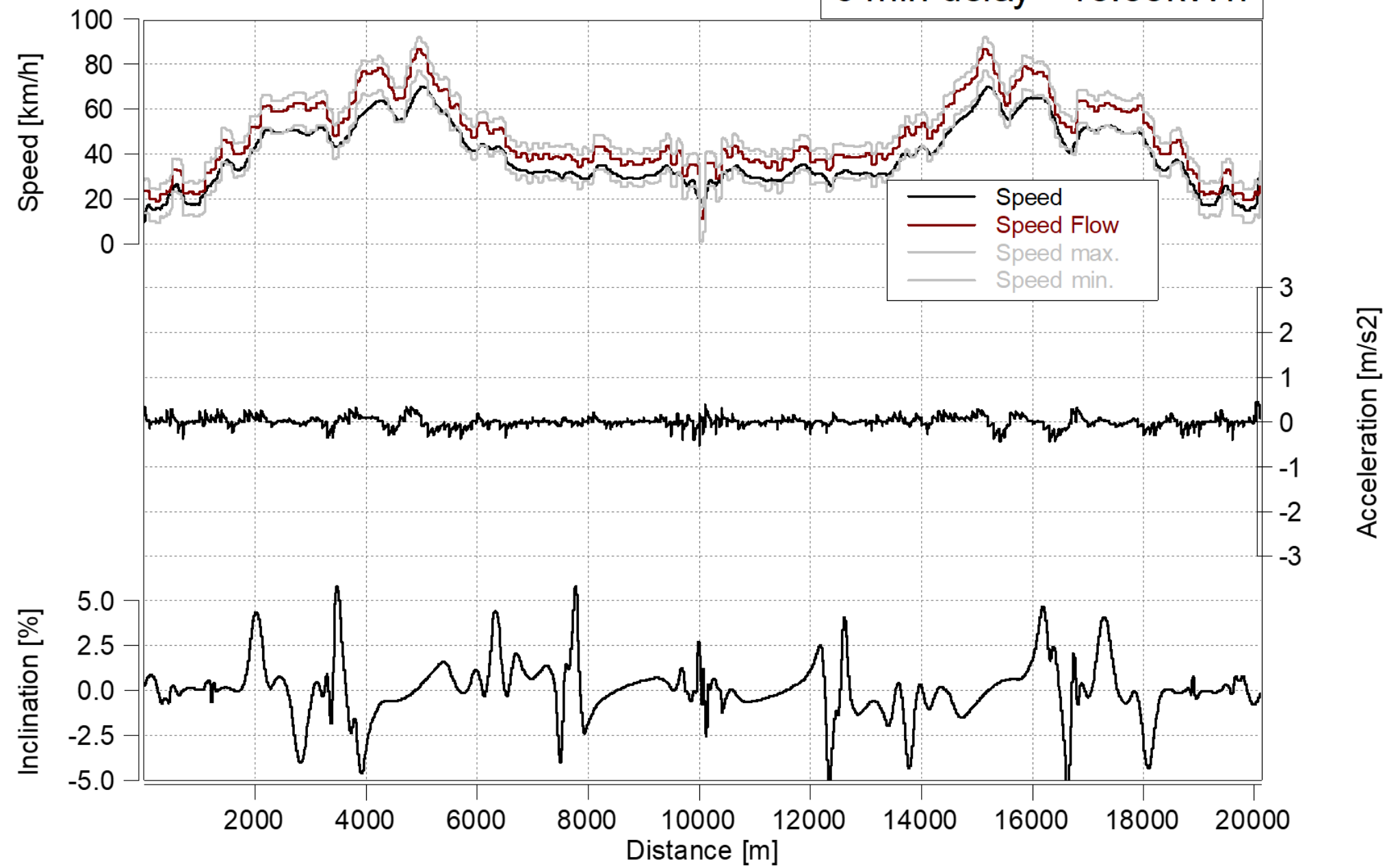


2.5 min delay - 15.84kWh

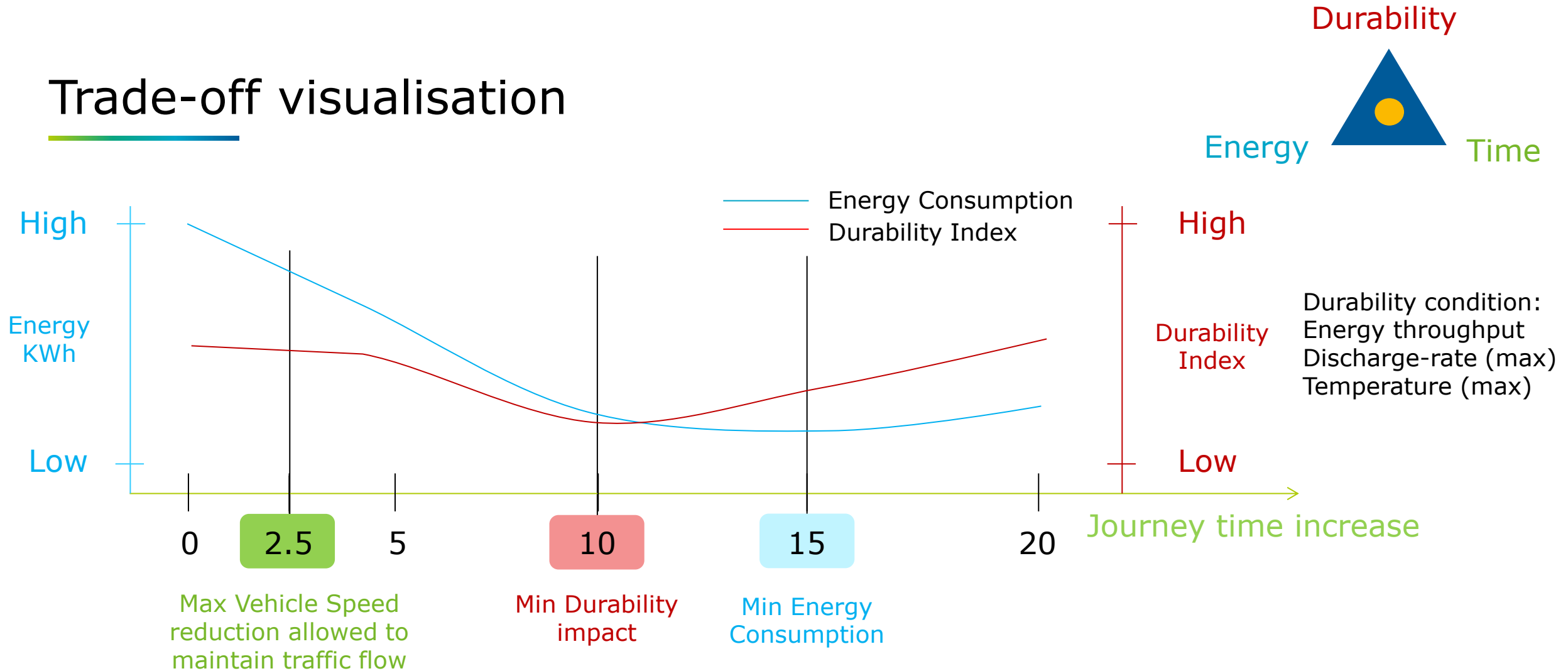


4 min delay - 15.58kWh





# Trade-off visualisation



High fidelity Digital Twin with map API data access

- Predicts speed profiles, durability effects and total energy consumption

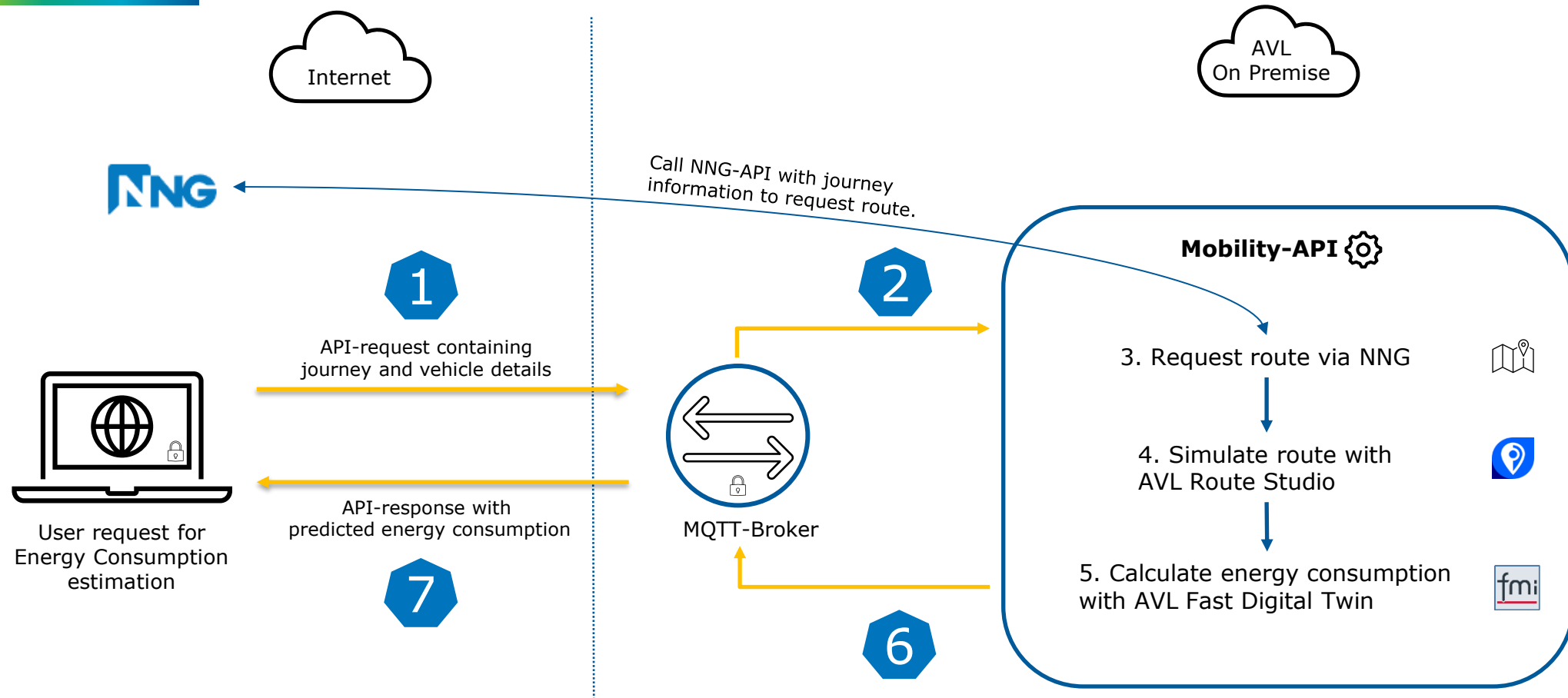


# NextETRUCK Project

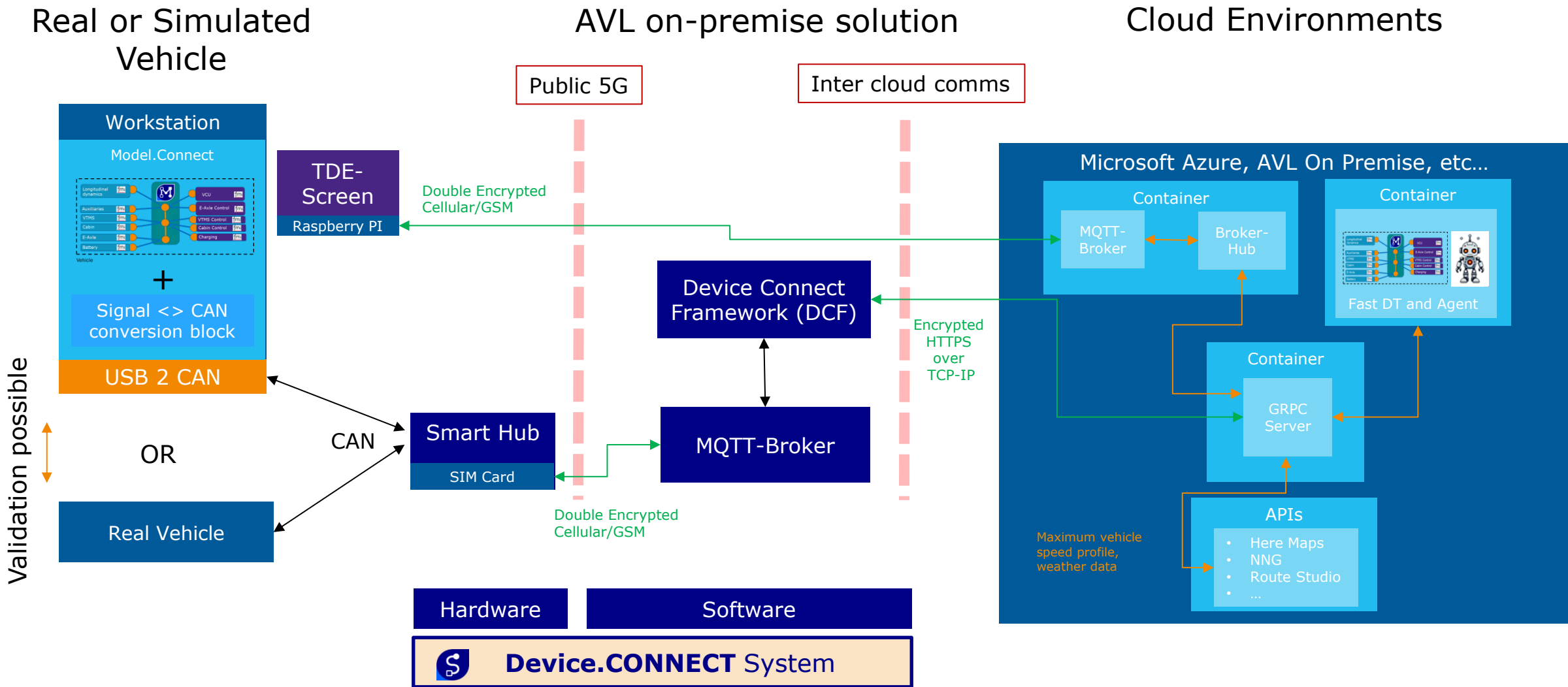
## Secure Bi-Directional Communications System Overview



# Energy Consumption EC DT Usage Workflow



# Secure Data Transfer with the Cloud





# Innovations on NextETRUCK

# Automation on Testbed/From baseline data

- Full Fidelity Digital Prototype creation

## CAMEO on Testbed

Component  
Testbed or  
Manufacturer  
Baseline data

DoE Data

Automate DoE  
Generation and  
Execution

High Fidelity  
Models

Automate  
Map/Curve tuning

Tuned HF Digital  
Prototype

Errors to DoE  
data minimized

CRETA

Parameter Storage

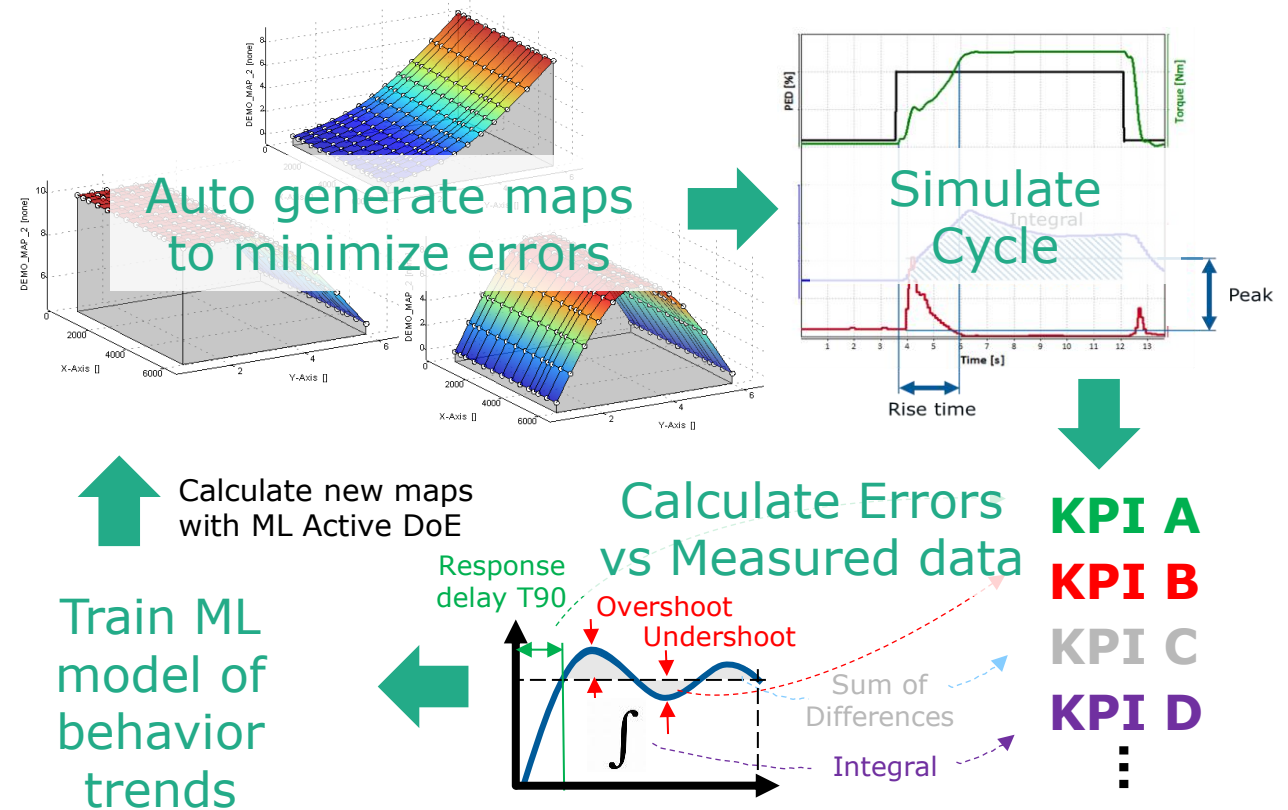
\* Not performed on NextETRUCK project

# Automated High Fidelity DT Tuning

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

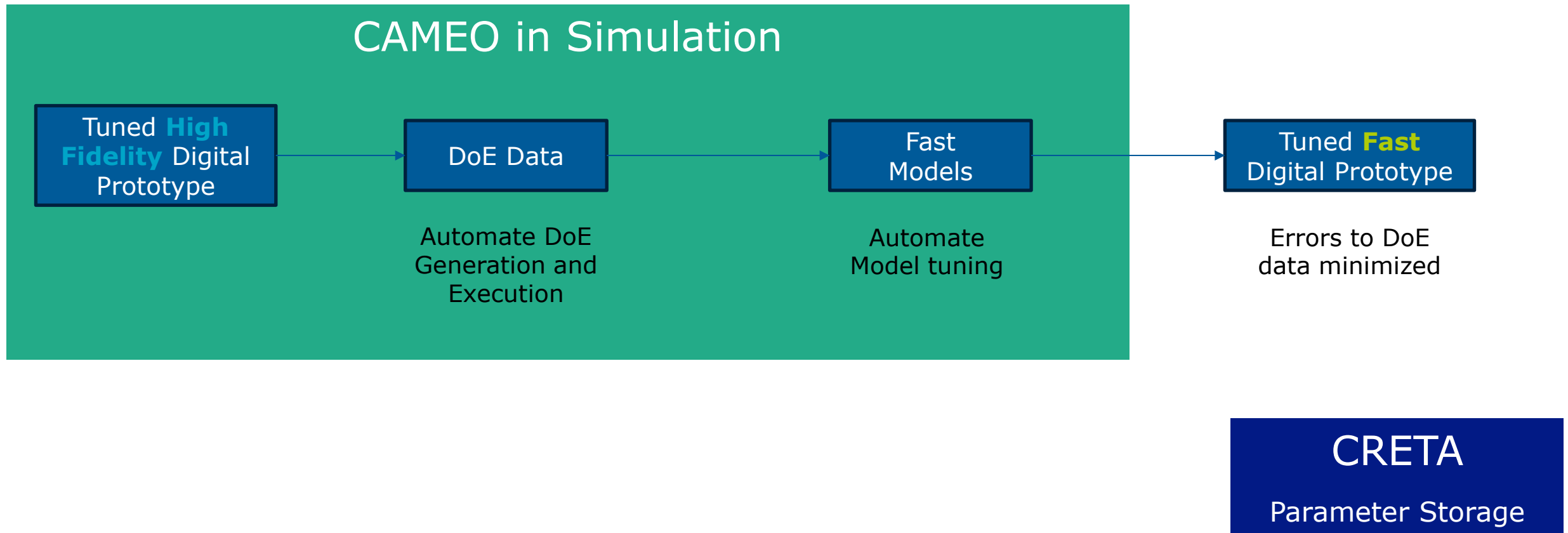
E-motor efficiency map, PID controller map, battery ageing map... etc

- 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

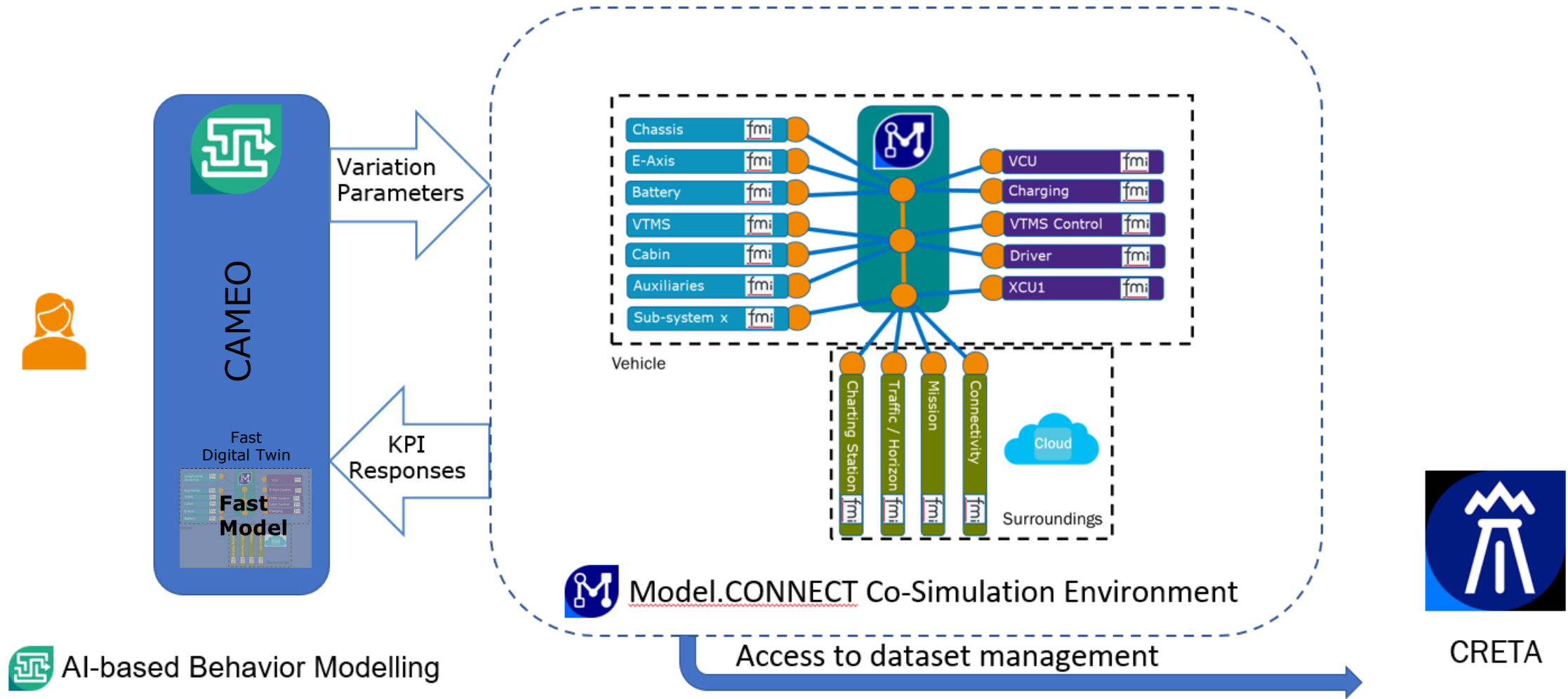


# Automated Fast model tuning (from High Fidelity model)

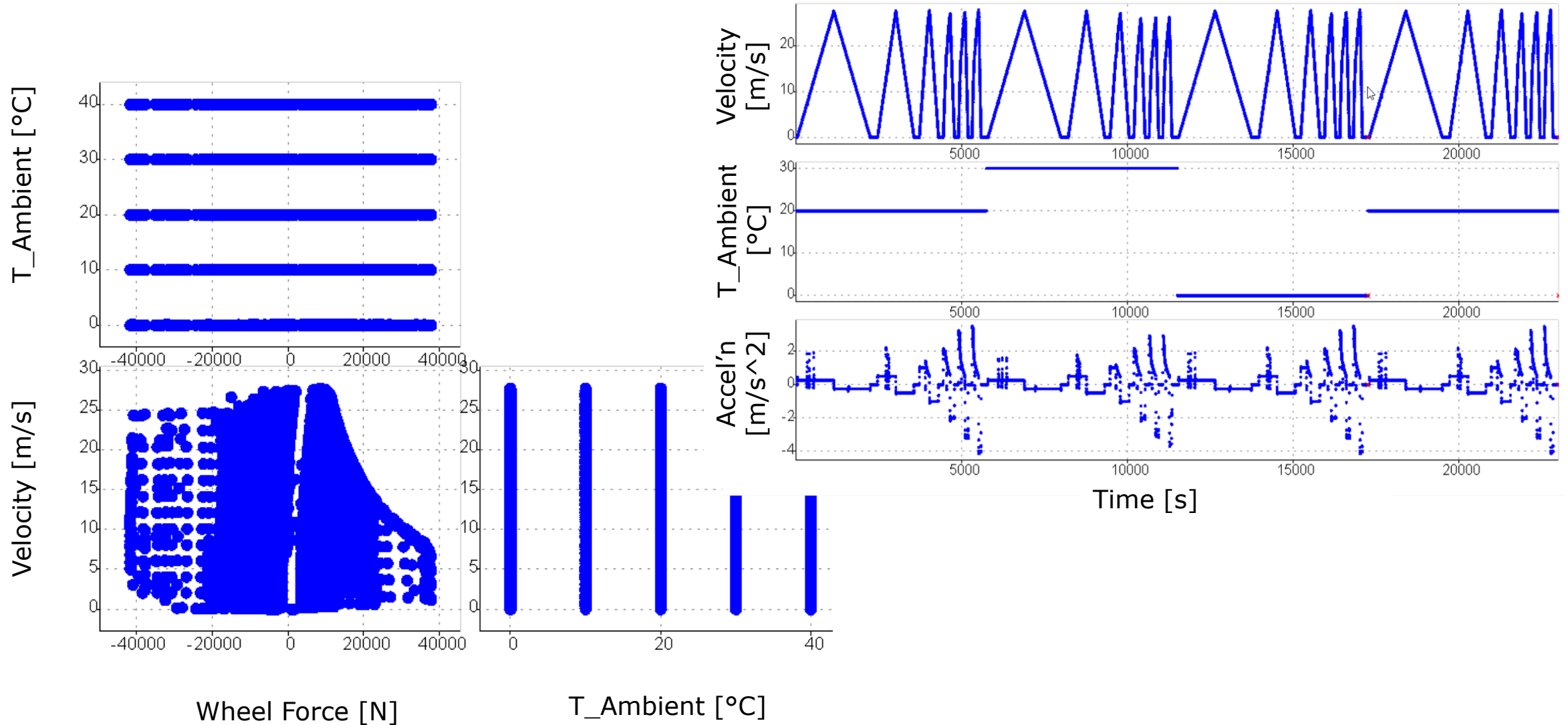
- Fast Digital Prototype creation



# Fast DT of Truck Energy Consumption

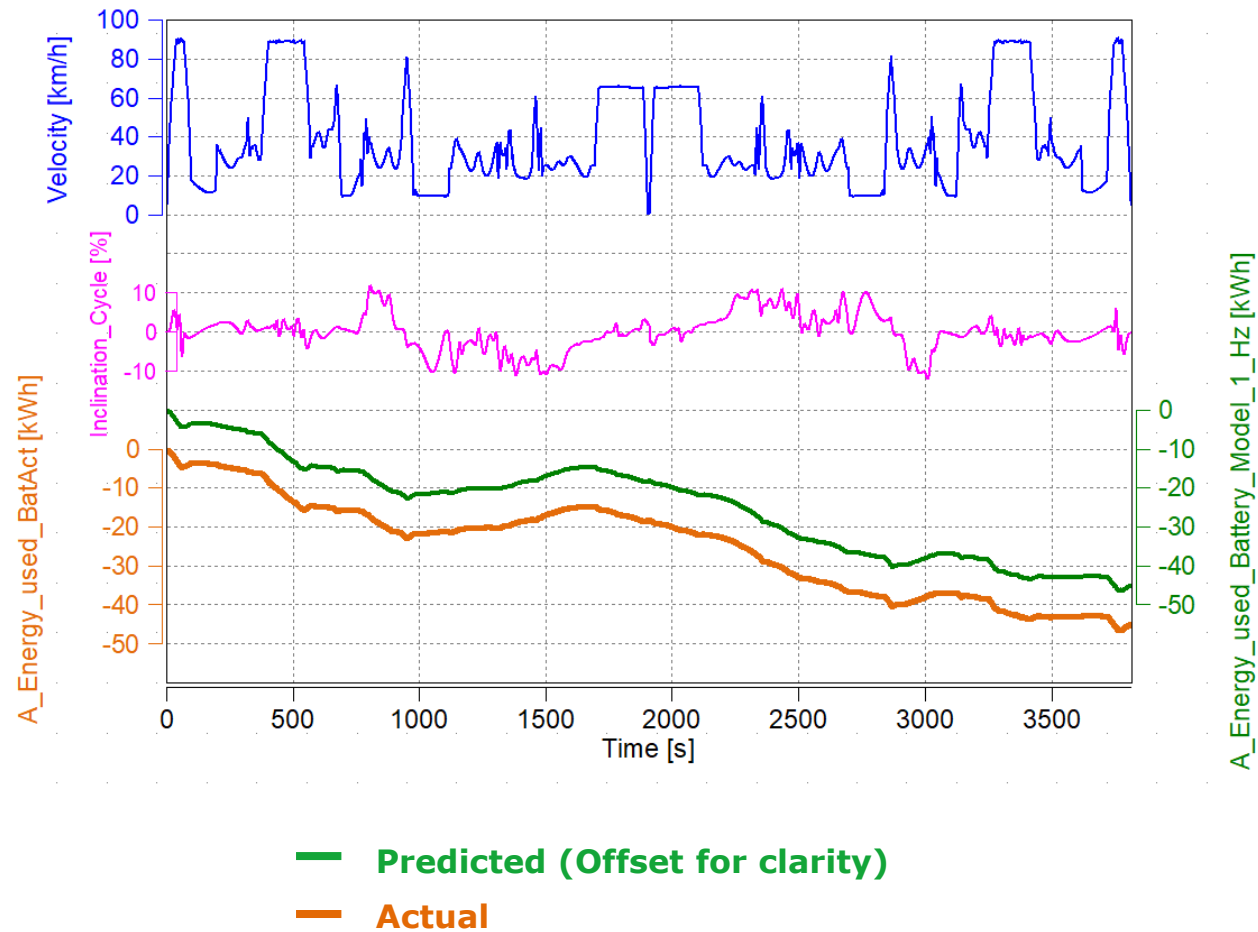


# Variable Acceleration and Speed ramps for EC Characterization

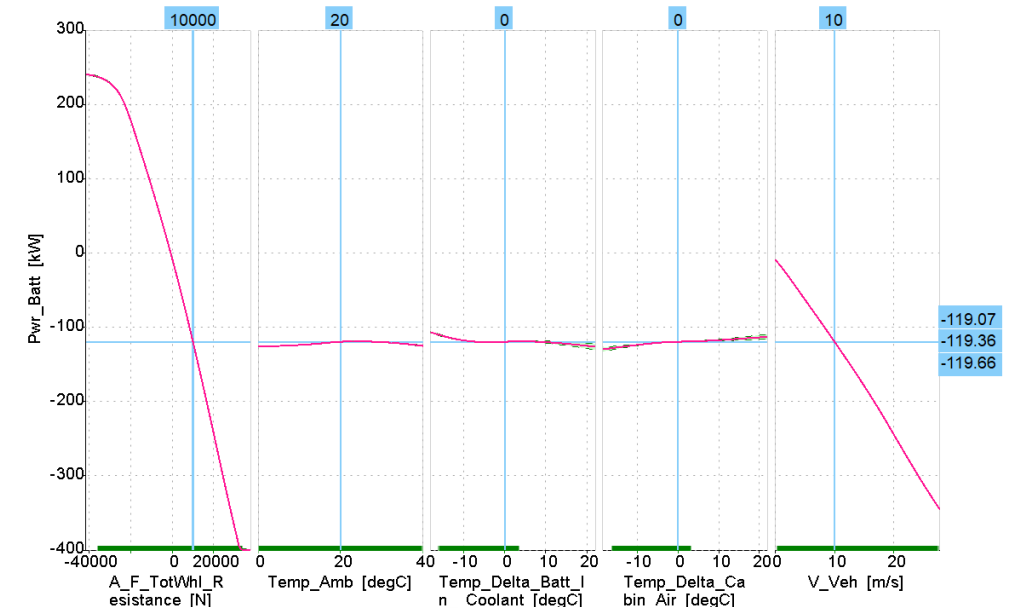




# Range Prediction based on "On-Demand DTs" (ca. 1000x Real-Time)



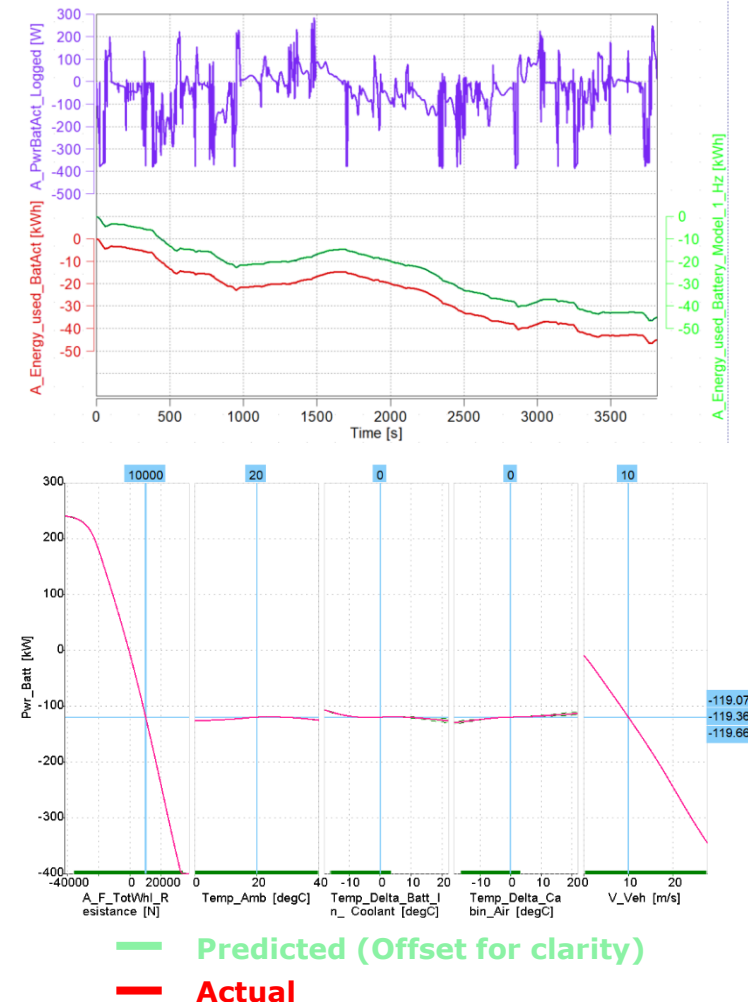
Fast DT Results for Cycle  
Energy Consumption  
<3% Error



# Automated Fast DT Tuning

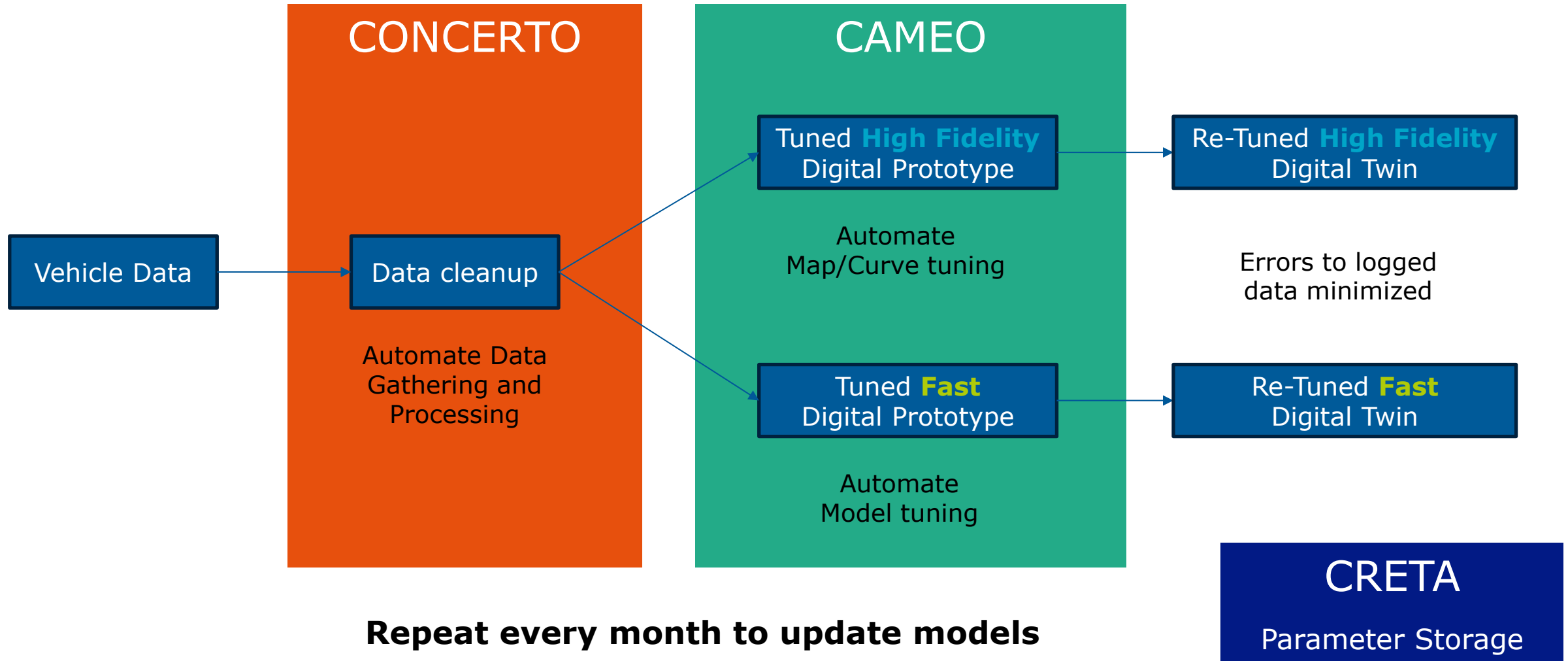
- For fast DT
  - Empirical – Almost no setup necessary
  - Semi-physical – Formula constrained symbolic regression models (Reduced drift, better extrapolation)
    - eg  $F(x,y) = Ax^2 + Bxy + Cy^3 + D$  where A to D can be constants or ML models
- Advantages
  - Built-in Model error prediction
    - 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

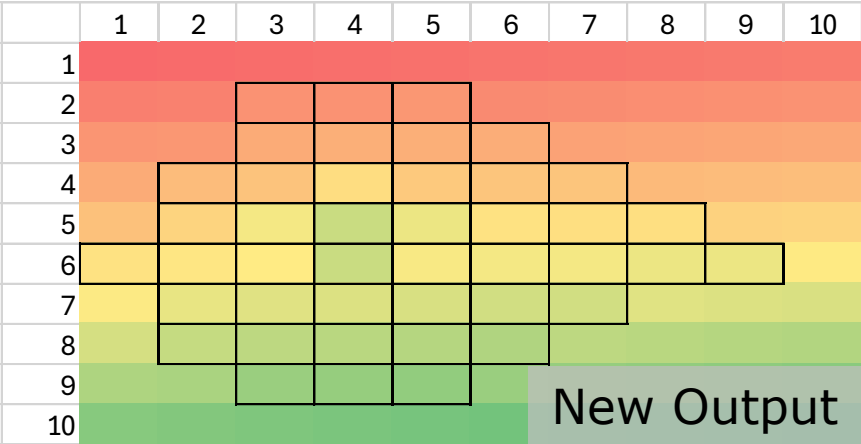
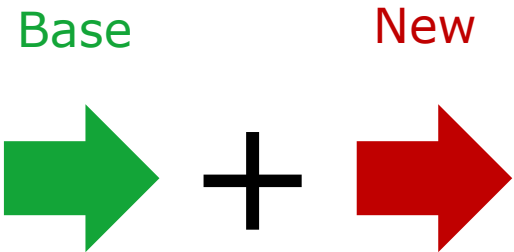
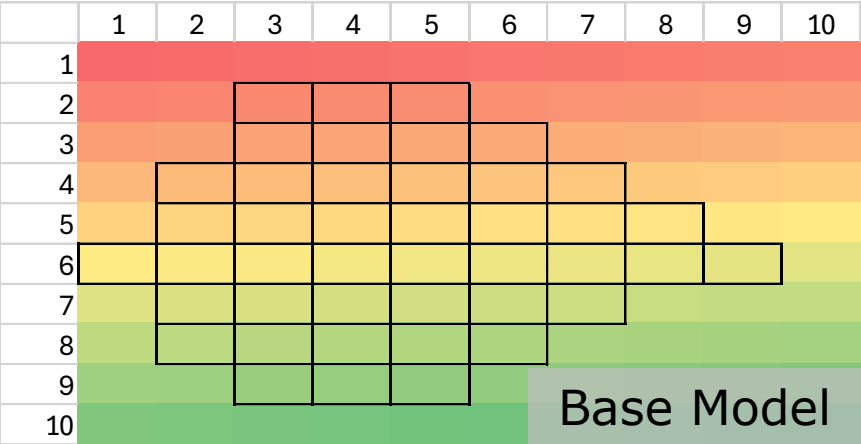
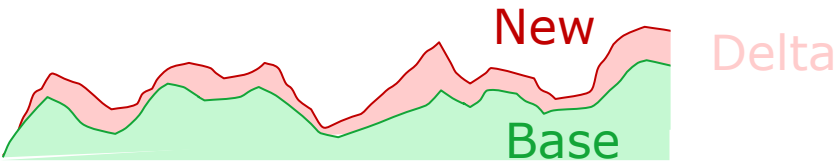


# Automated model tuning (from vehicle data)

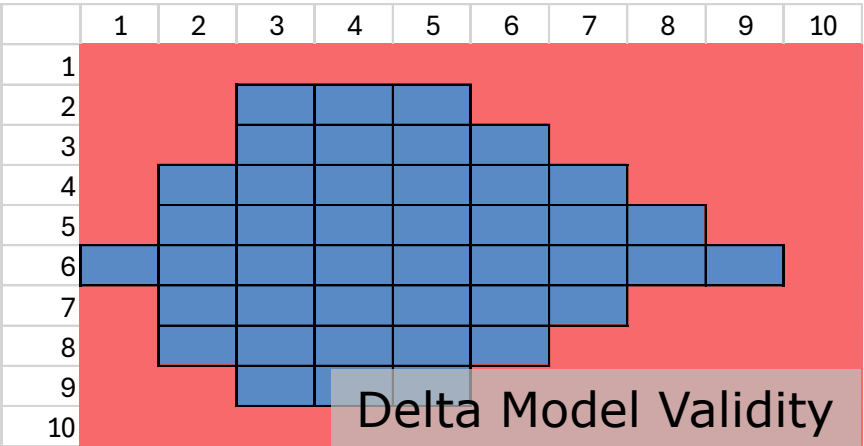
## - Digital Twin creation



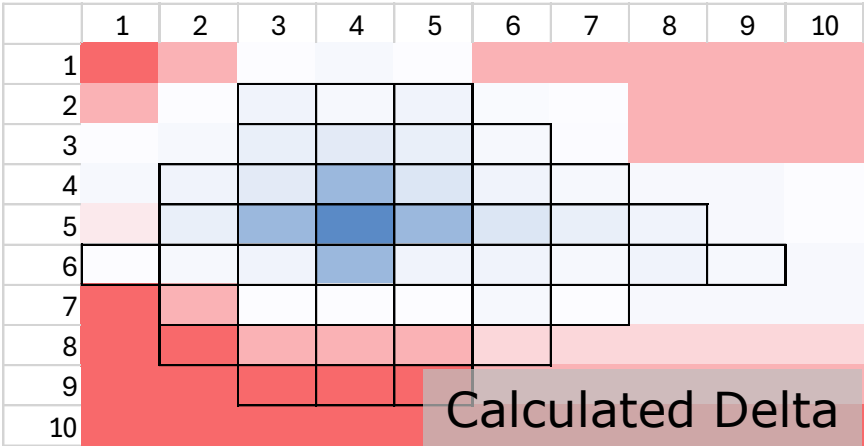
# Model Validity Metric for DT updates



Delta Model

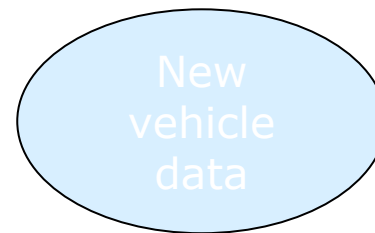
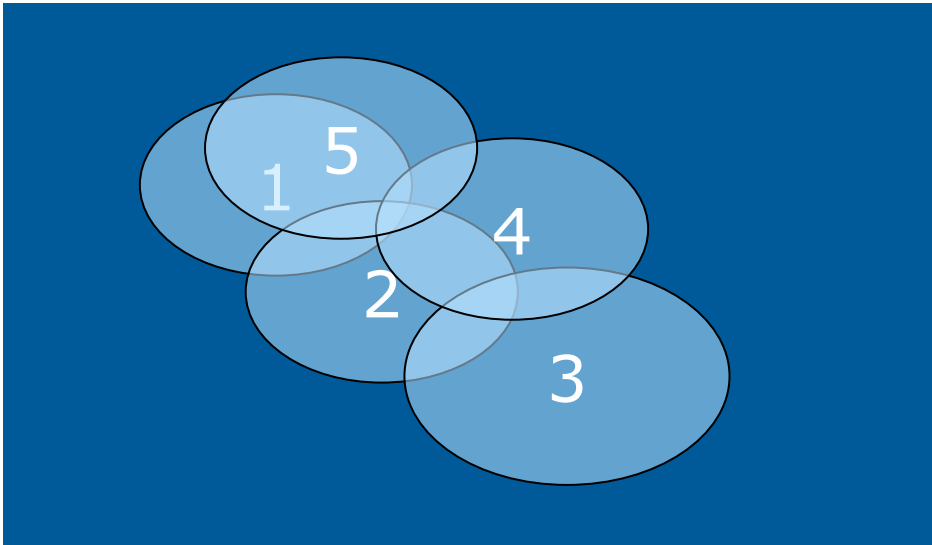


X



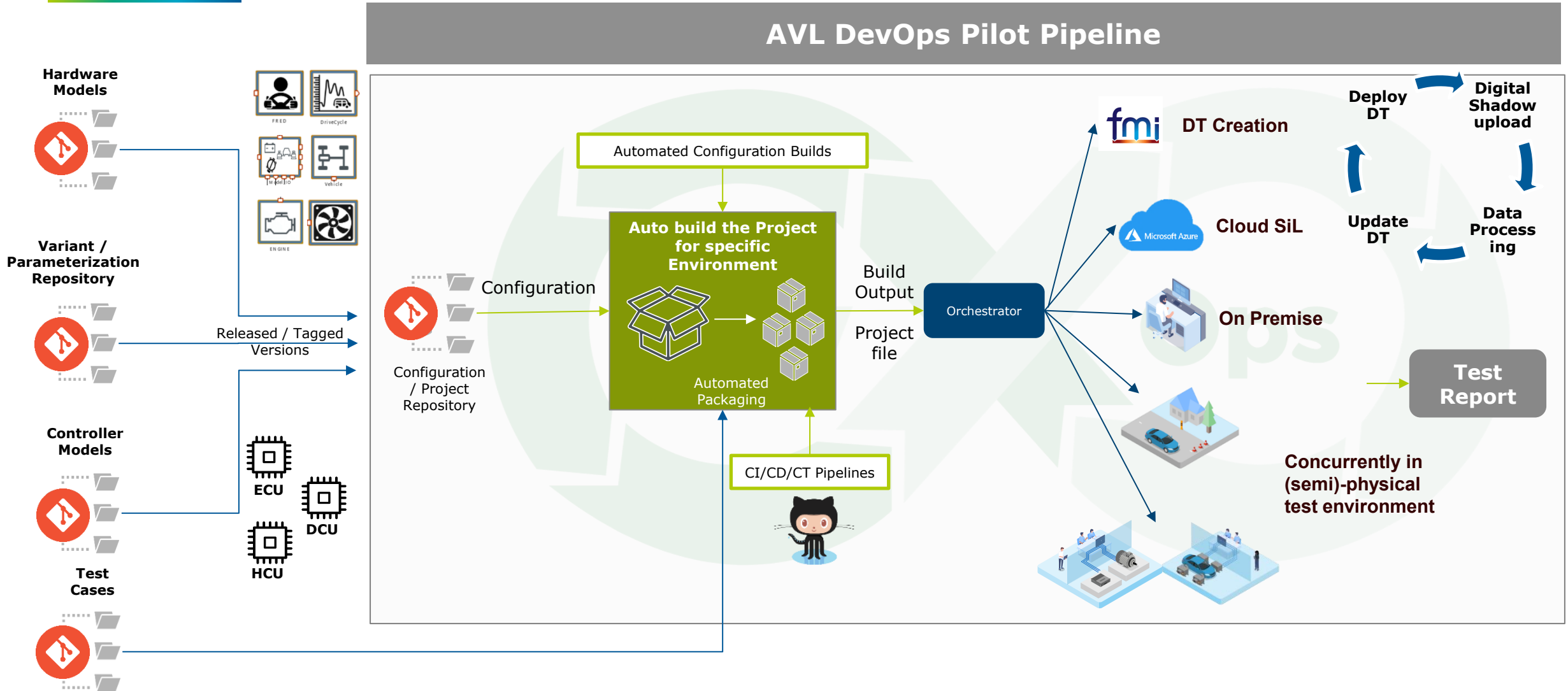
# Exercise (please contribute, you know you want to!)

- 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

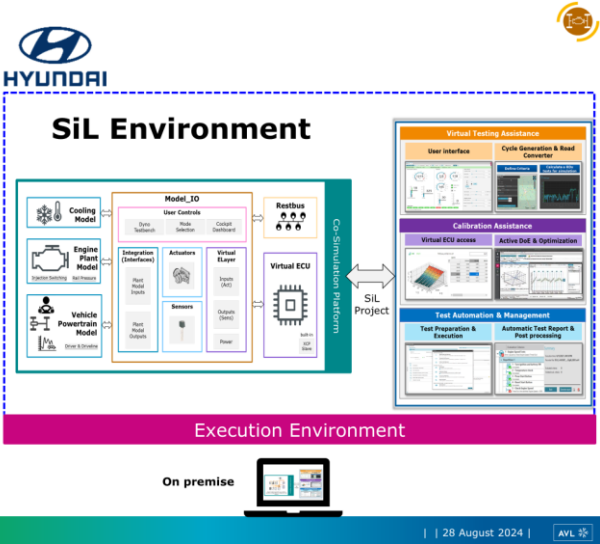
**AVL's value proposition**

- Complete tool chain
- Creation of missing simulation models like Actuators
- SiL Setup
- support with calibration & modelling expertise

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## 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

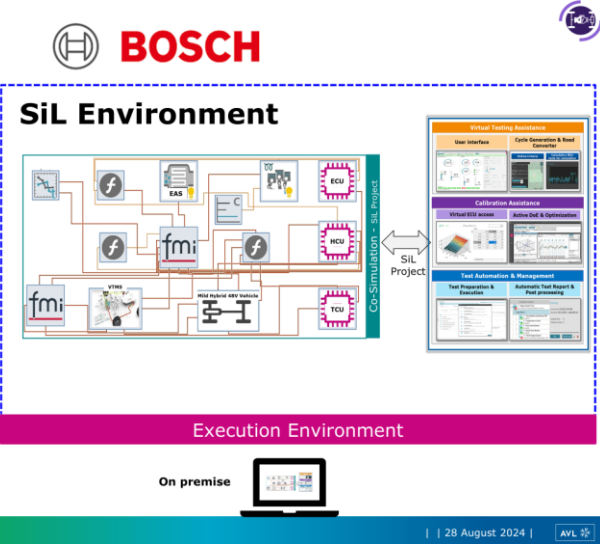
**AVL's value proposition**

- Complete tool chain
- SiL Setup
- support with calibration & modelling expertise

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## 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 Converter & 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

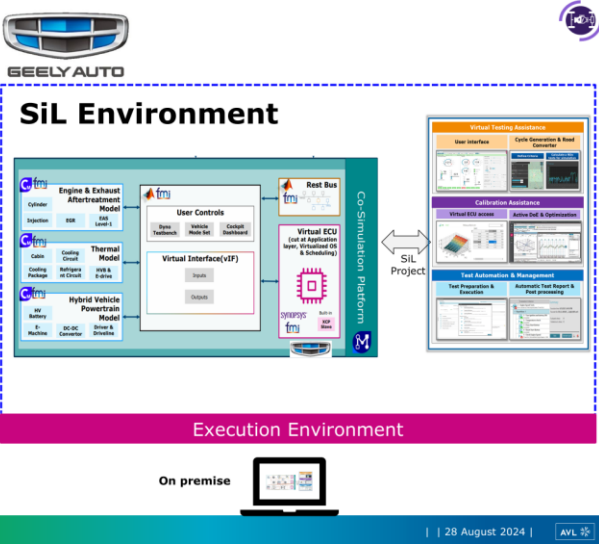
**AVL's value proposition**

- Complete tool chain
- SiL Setup
- support with calibration & modelling expertise

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## 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
- ...

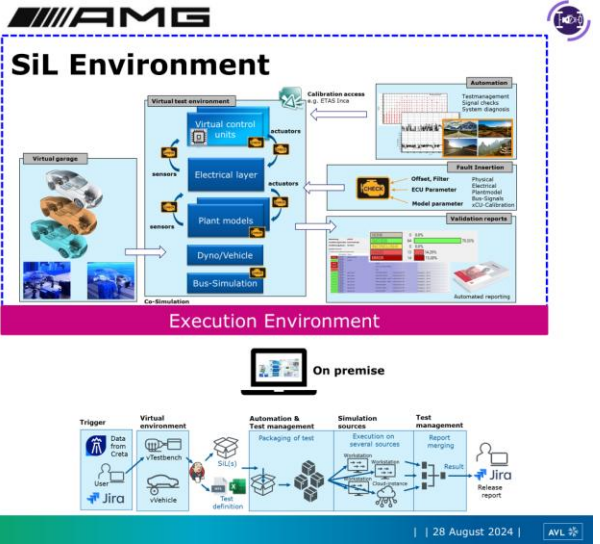
**AVL's value proposition**

- 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

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# Thank you



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Q&A

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