COLLABORATIVE DIGITAL TWIN DEVELOPMENT FOR RAILWAY BRAKING AND TRACTION APPLICATIONS

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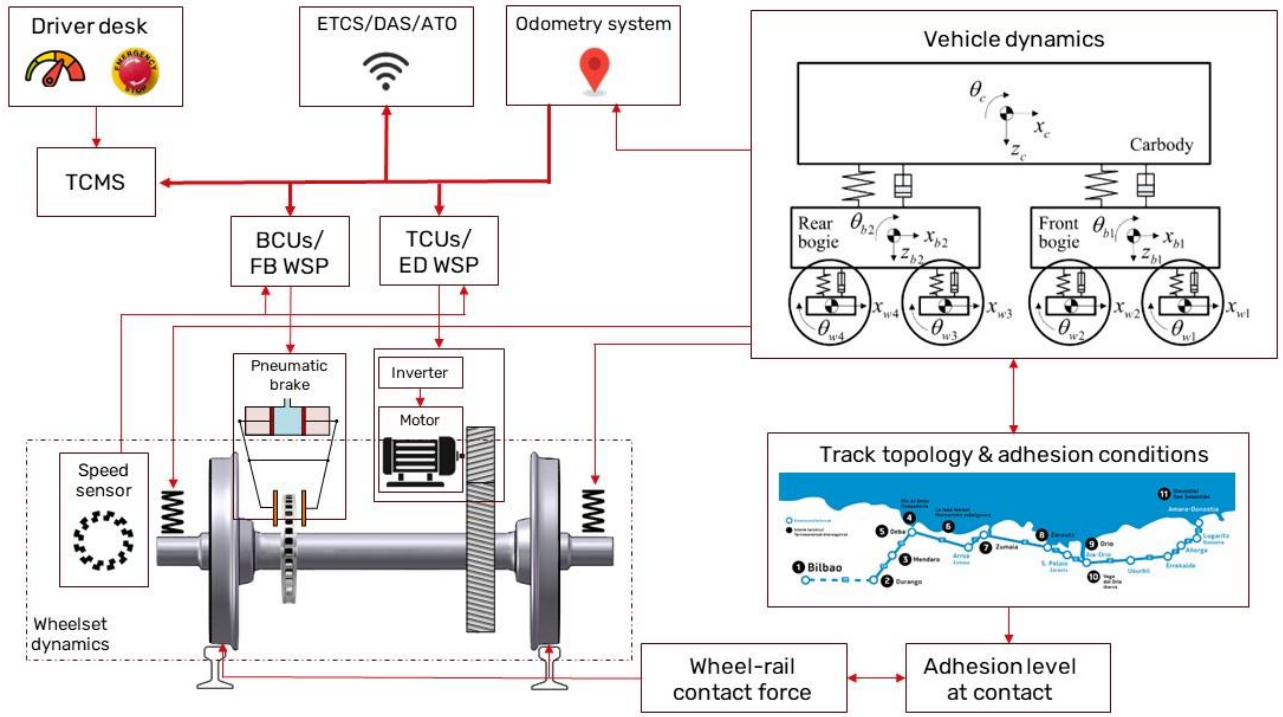
16th International Modelica & FMI Conference 2025

Braking & Traction Use Case

Braking & Traction development of rail vehicles

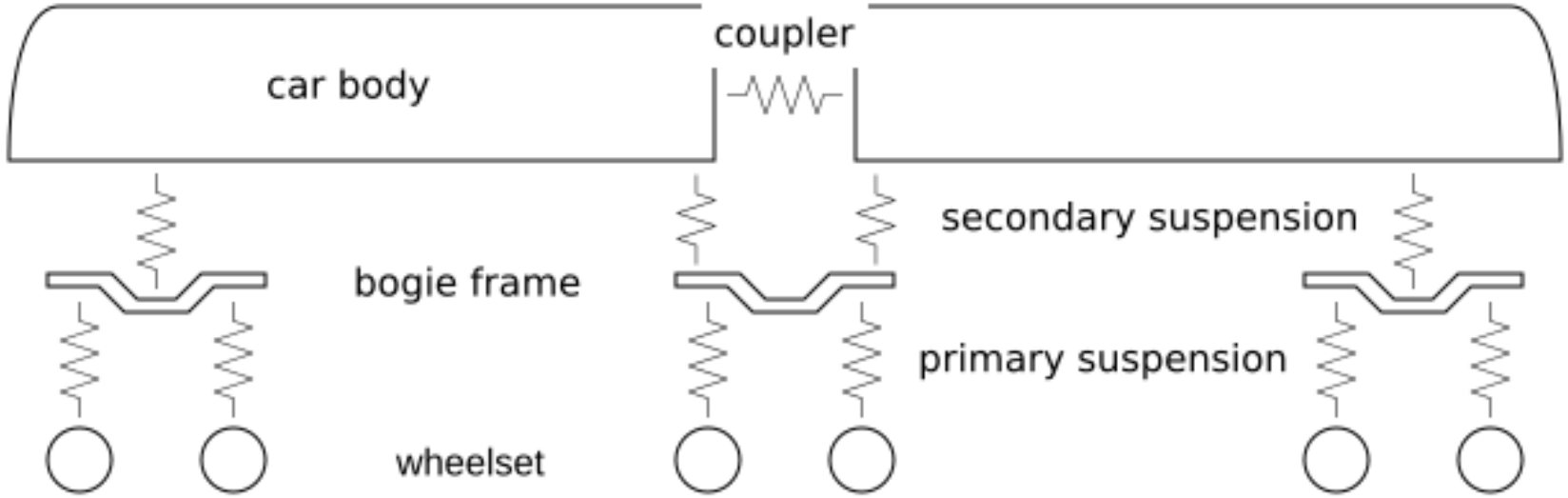
- Synchronised work of multiple subsystems by different providers
- Projects with different architecture and number of components
- Various environmental and topographical conditions

→ Reduce track testing by common Digital Twins with submodels from different suppliers



Vehicle Dynamics MBS-Model

- 2 car multiple unit for passenger transport
- 3 bogies with 2 stage suspension system
- Multi-body system of 11 rigid bodies and 11 spring-damper force elements
- Lateral, roll and yaw motion not relevant → eliminated
- Scaling factors for variable wheel-rail friction conditions
- Velocity-dependent aerodynamic forces
- Track component included
- Modelica/Dymola with DLR Railway Dynamics Library



Tuneable Parameters and Interfaces of Vehicle Dynamics Model

Initial conditions

- Track position
- Vehicle speed

Scenario parameters

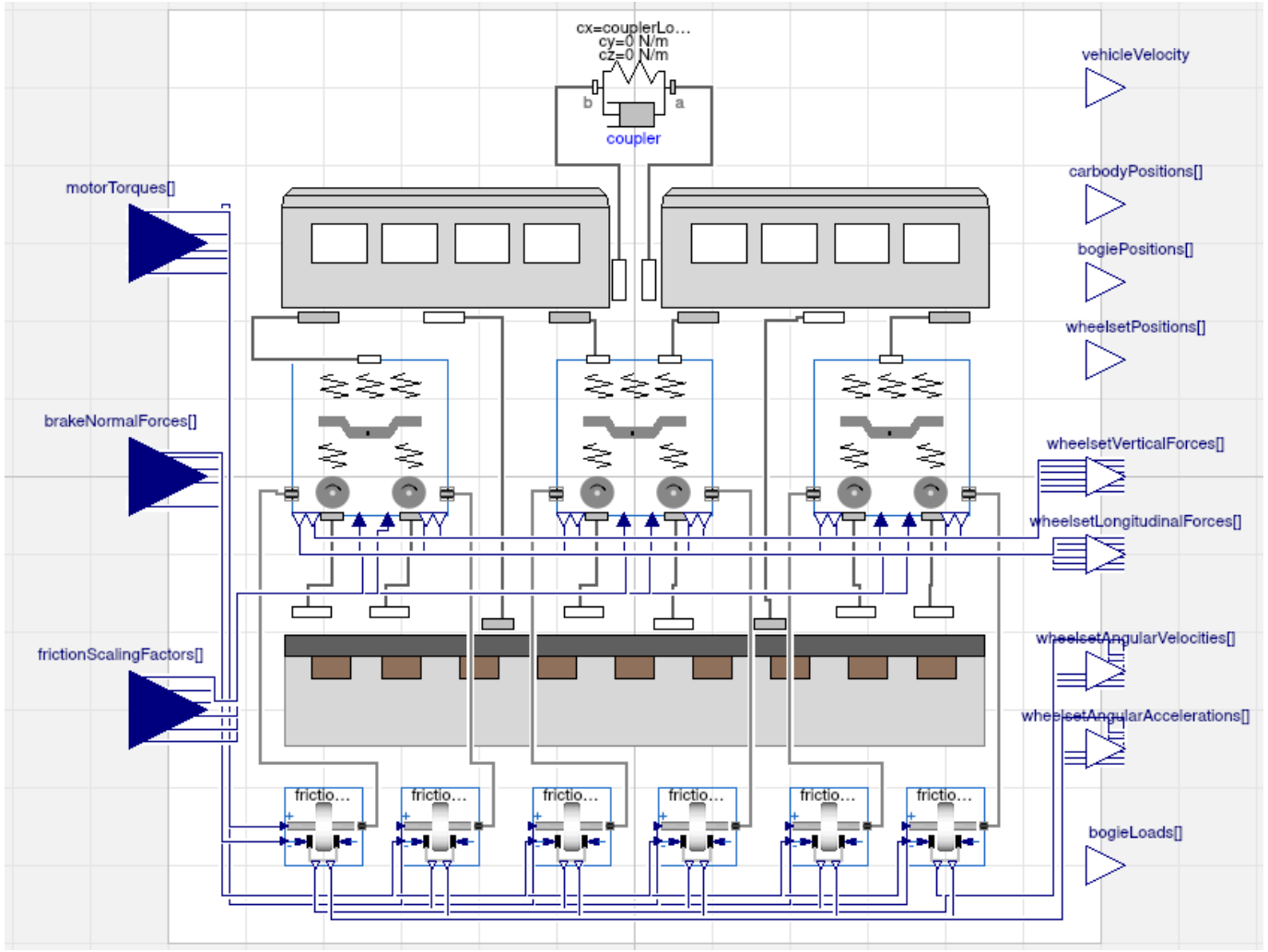
- Track data file
- Car occupancies
- Wheel-rail friction coefficients
- Pad-disc friction coefficients

Design parameters

- Mass properties
- Stiffness and damping values
- Wind resistance coefficients

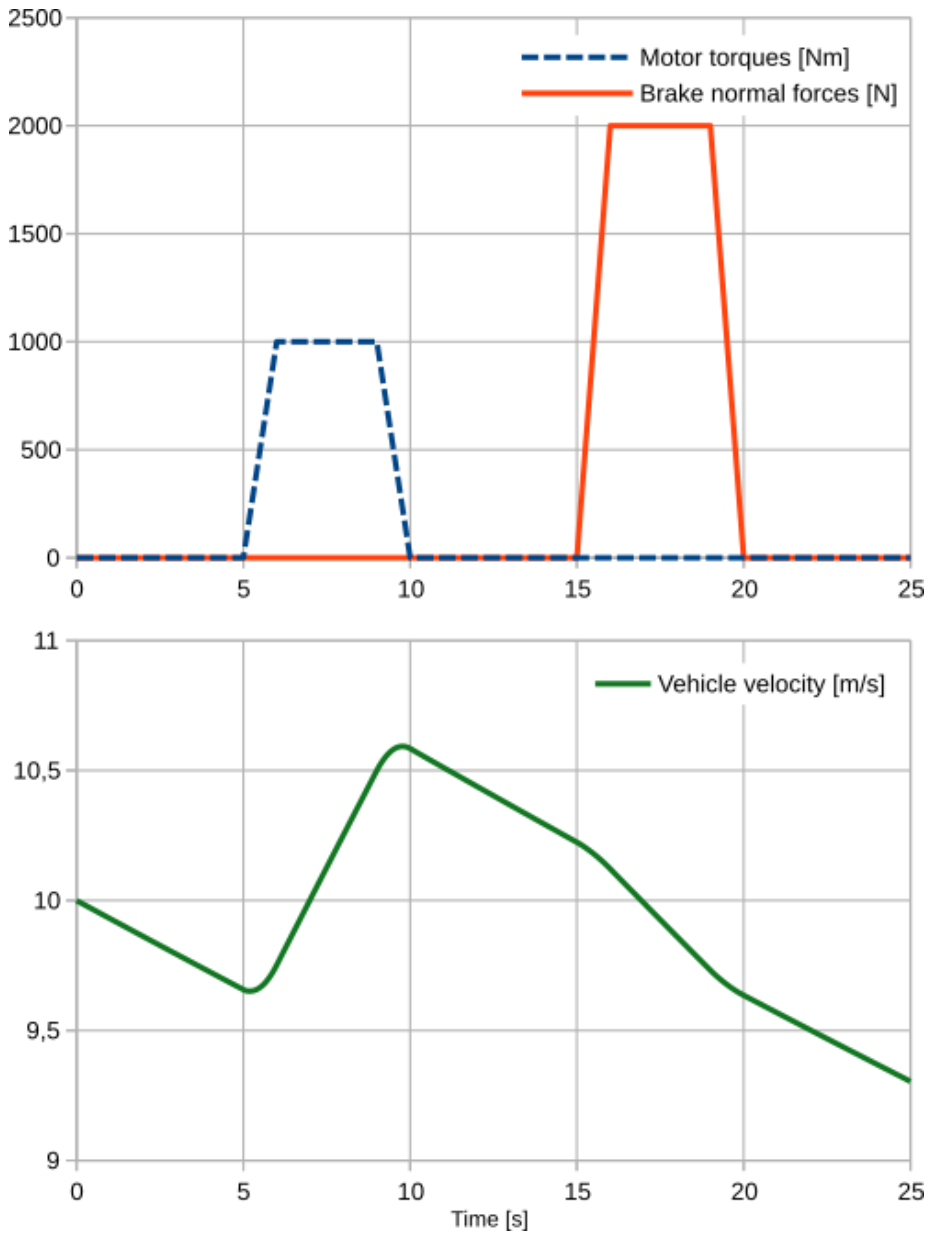
Input signals

Output signals



Simple Test Scenario for Vehicle Dynamics Model

- Initial velocity 10 m/s
- Low deceleration by air resistance
- Acceleration by motor torques
- Increased deceleration by brakes



Control Units and Architecture

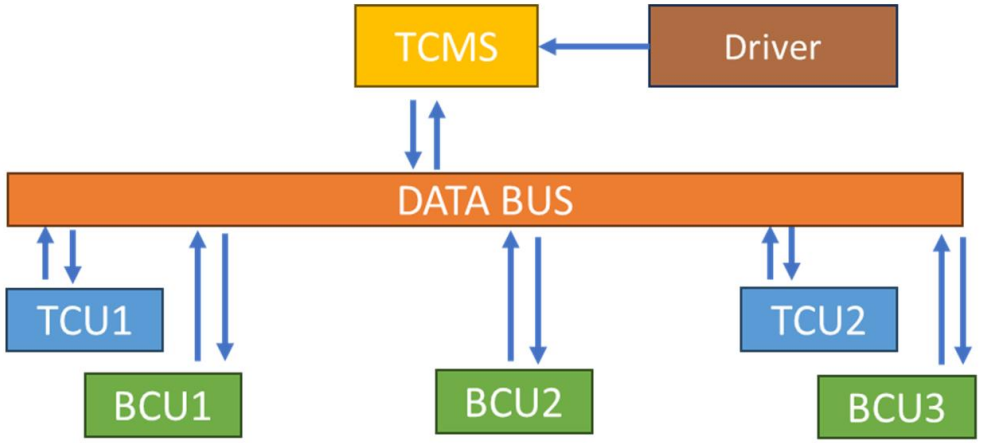
Main functionality

- Implement braking and traction as determined by driver
- Share braking efforts among electrodynamic and friction brakes (blending)
- Wheel-rail slide/slip protection (WSP)

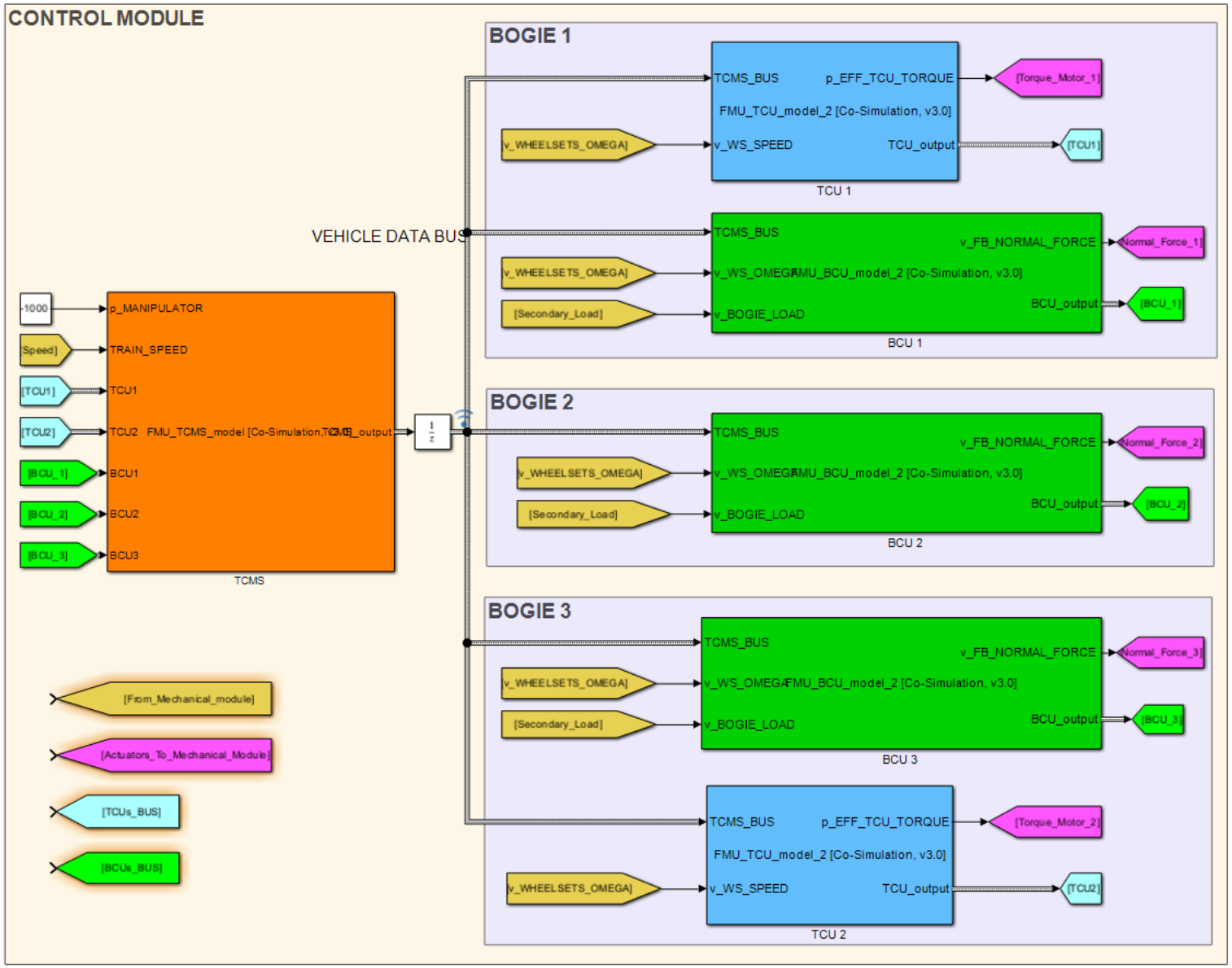
Basic control units

- Traction Control Unit (TCU)
  - Electric motor traction and braking control
  - Electrodynamic WSP
- Brake Control Unit (BCU)
  - Friction brake control
  - Friction brake WSP
- Train Control Management System (TCMS)
  - Train logic and electronics backbone
  - Communication via vehicle data bus

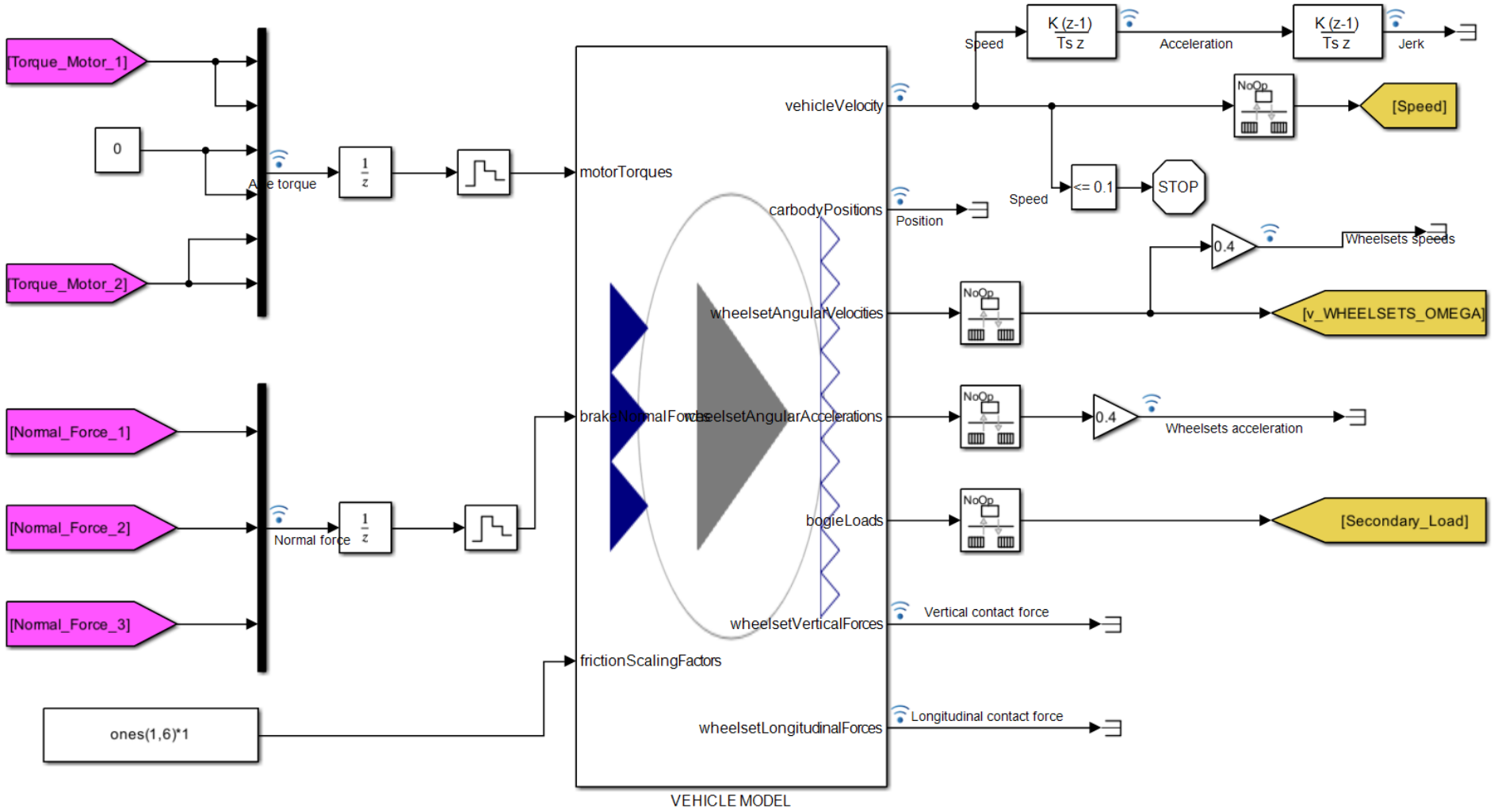
Separate Matlab/Simulink models/FMUs



Control Model



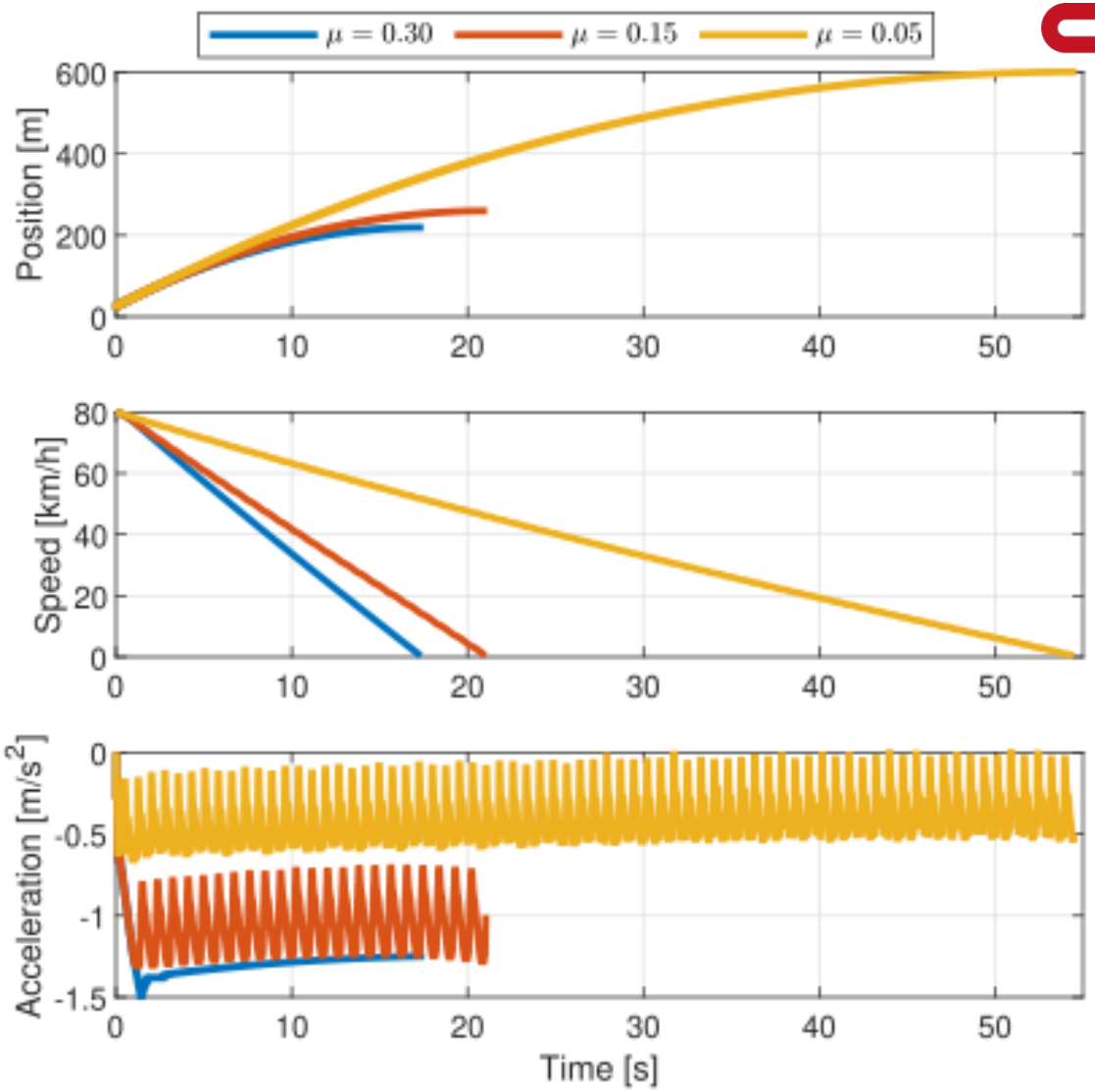
Interface Vehicle Dynamics – Control



Simulation and Verification

Scenario: Service braking operation
from 80 km/h to standstill
at 3 different adhesion conditions

Condition	Friction coefficient	Braking distance
Dry	0.30	220 m
Wet	0.15	260 m
Contamined	0.05	600 m



Braking Control Effort Results

Blending strategy for optimal energy recovery

- Maximise usage of electrodynamic brakes
- Avoid usage of friction brakes as far as possible

Dry conditions

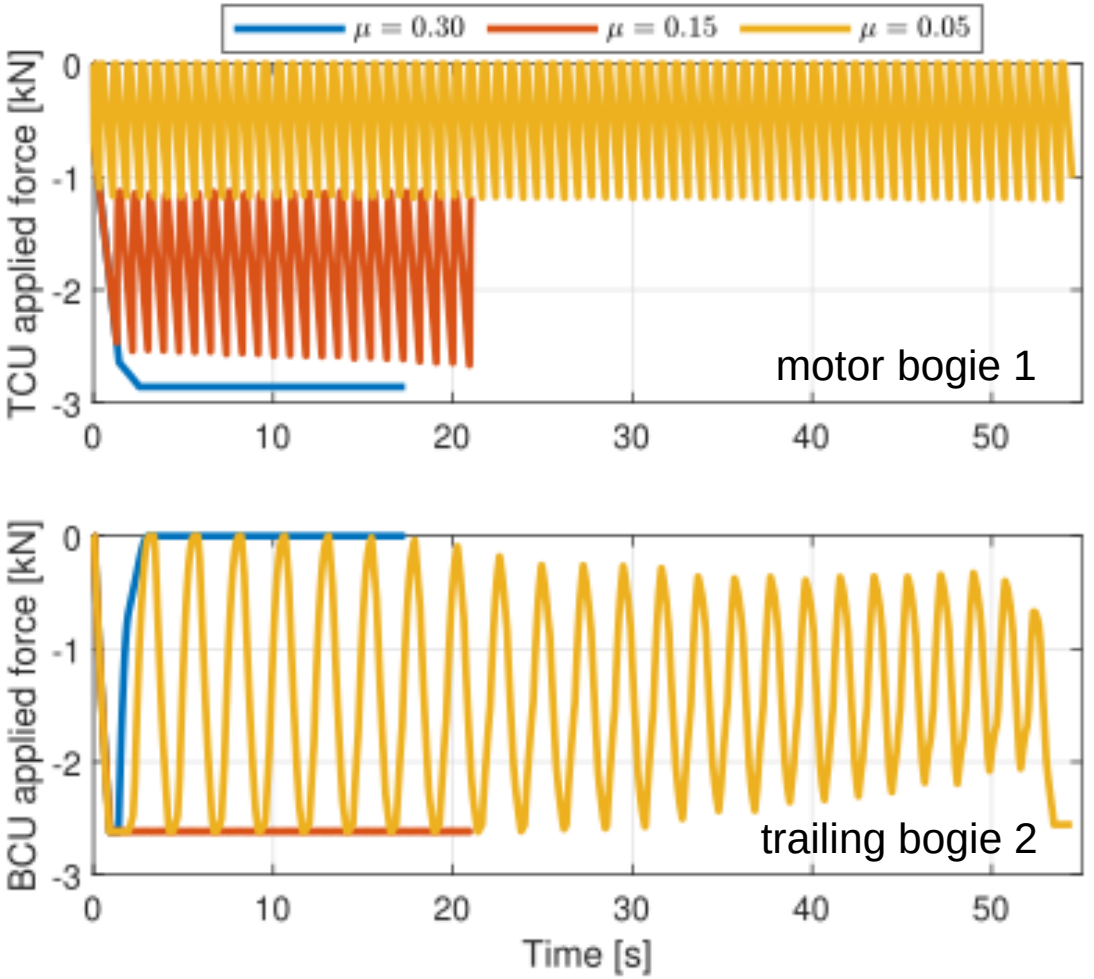
- TCUs/electrodynamic brake only

Wet conditions

- TCUs with WSP enabled
- BCU compensates deceleration deficit

Contamined conditions

- WSP limits effort of TCUs and BCU



Digital Twin Context

Improved operation

Digital Twin model

→ estimate current friction conditions
→ reduce minimal allowed distance between trains
→ increase line capacity

Monitoring

Digital Twin model

→ compare real world and digital twin sensor outputs
→ identify anomalies using AI
→ avoid damage, optimise maintenance intervals

→ **Improved economic efficiency and reliability of rail transport**