Exploring Human Behaviour in Cyber-Physical Systems with Multi-modelling and Co-simulation

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Overview

Introduction
- Ergonomics modelling
- Multi-modelling and co-simulation

Case Study 1: Operator Loading in UAV Search
- Multi-model
- Results

Case Study 2: Driver Behaviour in Urban Rail
- Multi-model
- Results

Summary and Future Work

Thanks to Rail Safety and Standard Board (RSSB), project "Digital Environment for Collaborative Intelligent De-carbonisation" (DECIDe, COF-IPS-06)

Ergonomics

The study of people's efficiency in their working environment

- Application of psychological and physiological principles
- Improve safety, comfort, productivity; reduce error

Ergonomic models are often a simplified theory of behaviour

- **Fitts' Law**: the time taken to reach a target is a ratio of the distance to and size of the target
- **Yerkes-Dodson** arousal model: poorer performance occurs as both the lowest and highest levels of demand

Ergonomics tools are also increasingly being used

- Siemens' **Jack** tool models human capabilities and range of motion in a 3D virtual environment

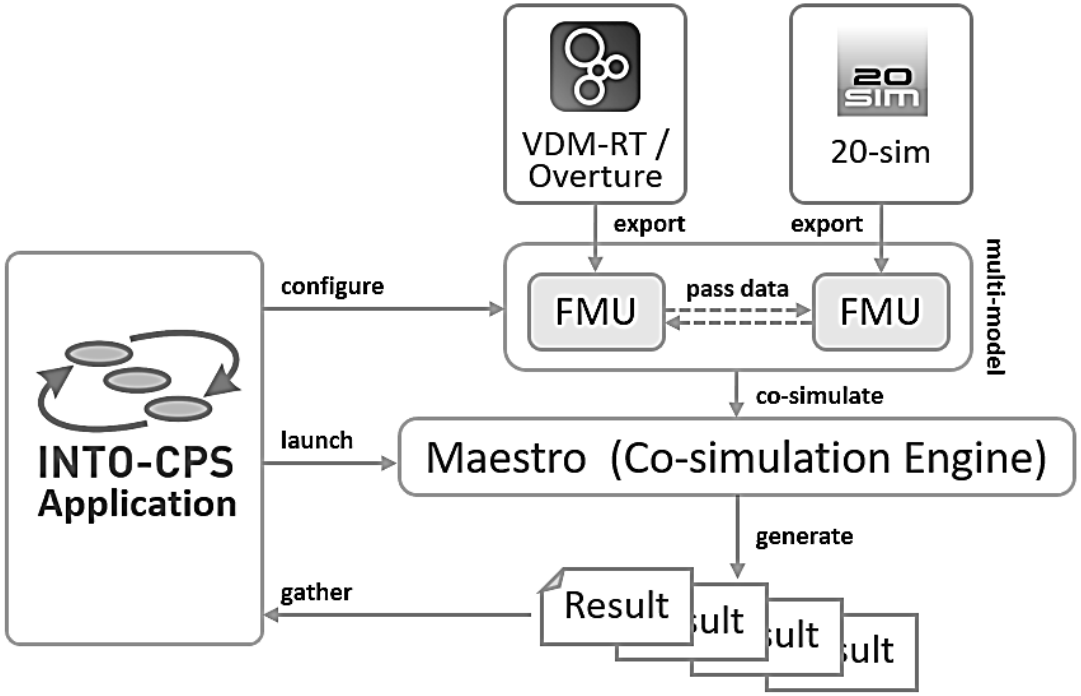
Multi-modelling

Combining models from a range of disciplines

- Allow disciplines to collaborate and interact
- Analysis through co-simulation
- Permit design space exploration

Incorporate ergonomics models in cyber-physical systems

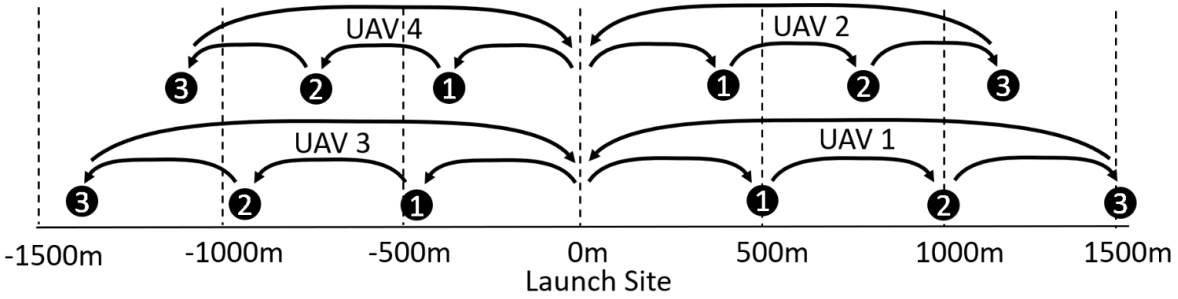
- To study the effect of human behaviour
- To explore the effect of cyber-physical design on humans

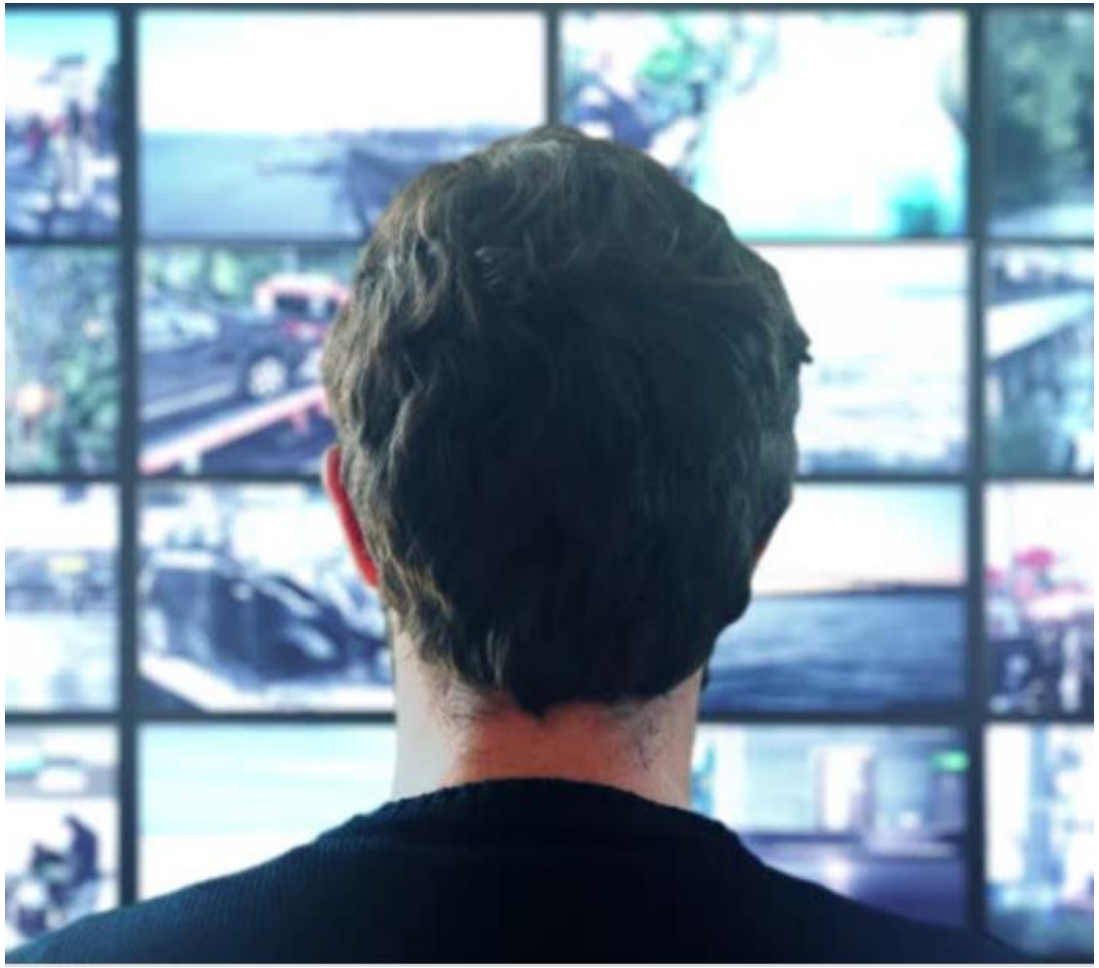


Operator Loading in UAV Search

Drones are increasingly suggested for inspection of dangerous areas such as railway lines

- Four UAVs visiting waypoints along a railway line
- Relaying images back to a single operator
- Await signal to move on



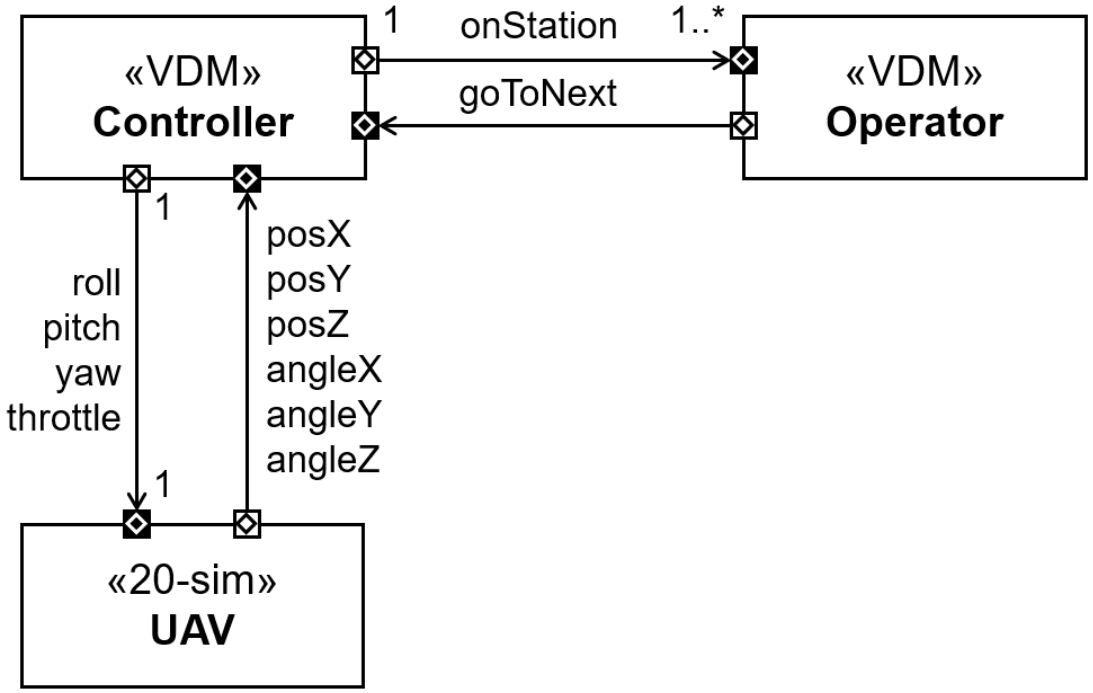


Multi-model

Continuous-time UAV model in 20-sim
- High-fidelity dynamics
- Crosswinds

Controller model in VDM/Overture
- Loop controller (PID)
- Supervisory waypoint controller
- Modal control (take-off, searching, waiting, return-to-base)

Operator model in VDM/Overture
- Respond to UAVs waiting to be checked
- Signal UAVs to move to next waypoint



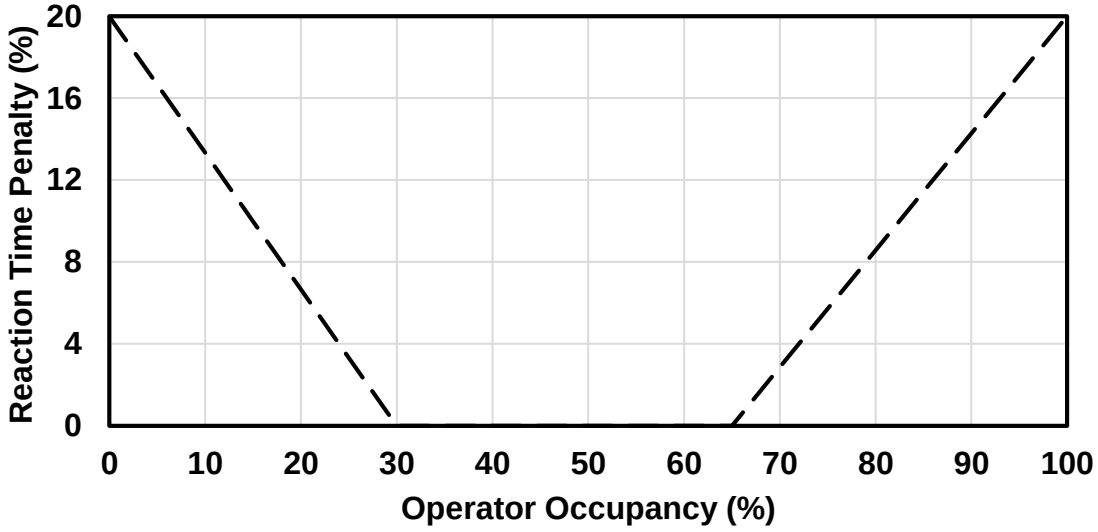
Operator Model

Task activity (duration = TA = 28 seconds)
- Realise UAV requires attention (duration = T_{SA})
- Check images (duration = T_{dec}
- Signal UAV to move on (duration = T_{int})

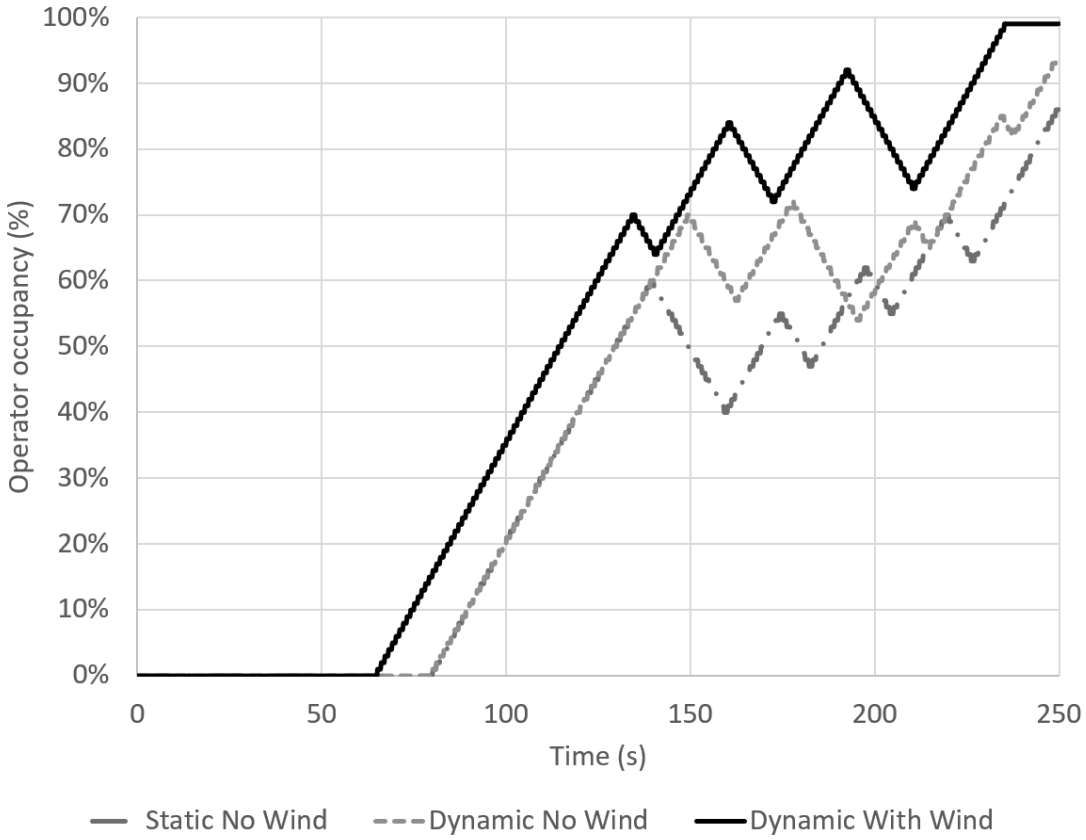
Operator occupancy
- Operator cannot interact while occupied with another UAV
- Rolling window of occupancy (window = 100 seconds)

Task switching
- Operator attends the UAV that has been waiting longest

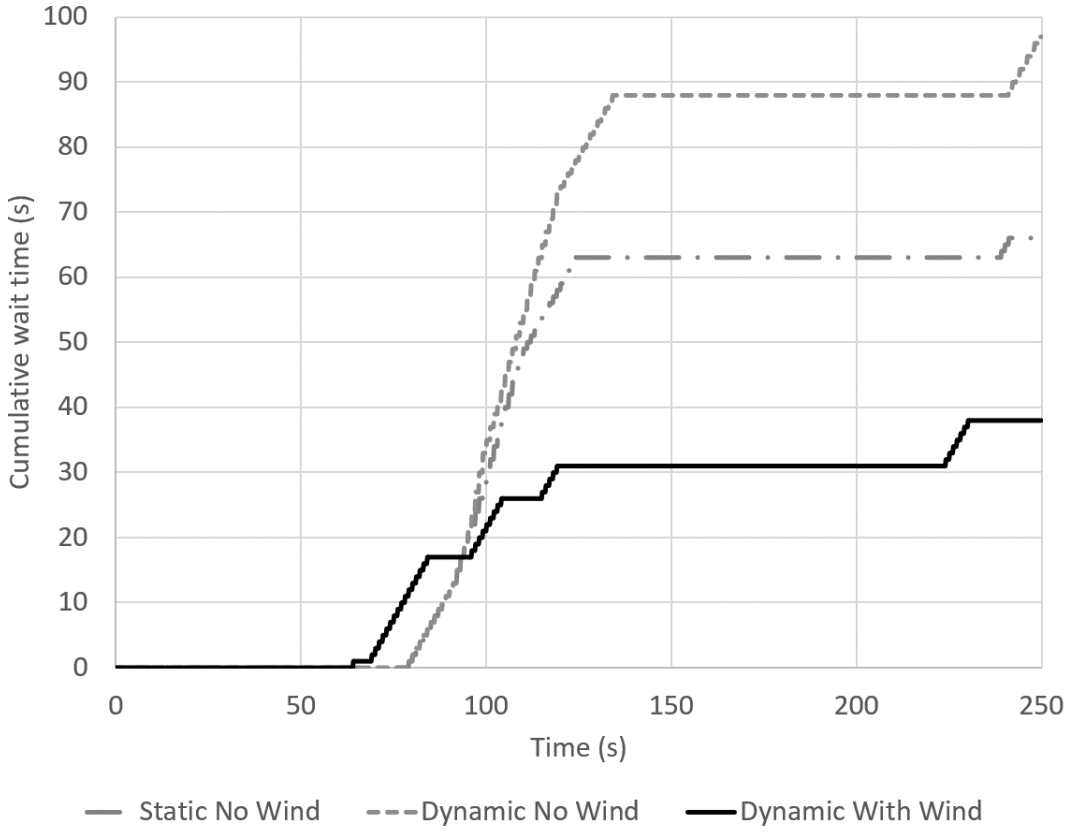
Dynamic performance
- Penalty for bored or overloaded operator (increase in T_{SA})
- Yerkes-Dodson arousal model: boredom below 30% occupancy, overloaded above 70% occupancy



Results

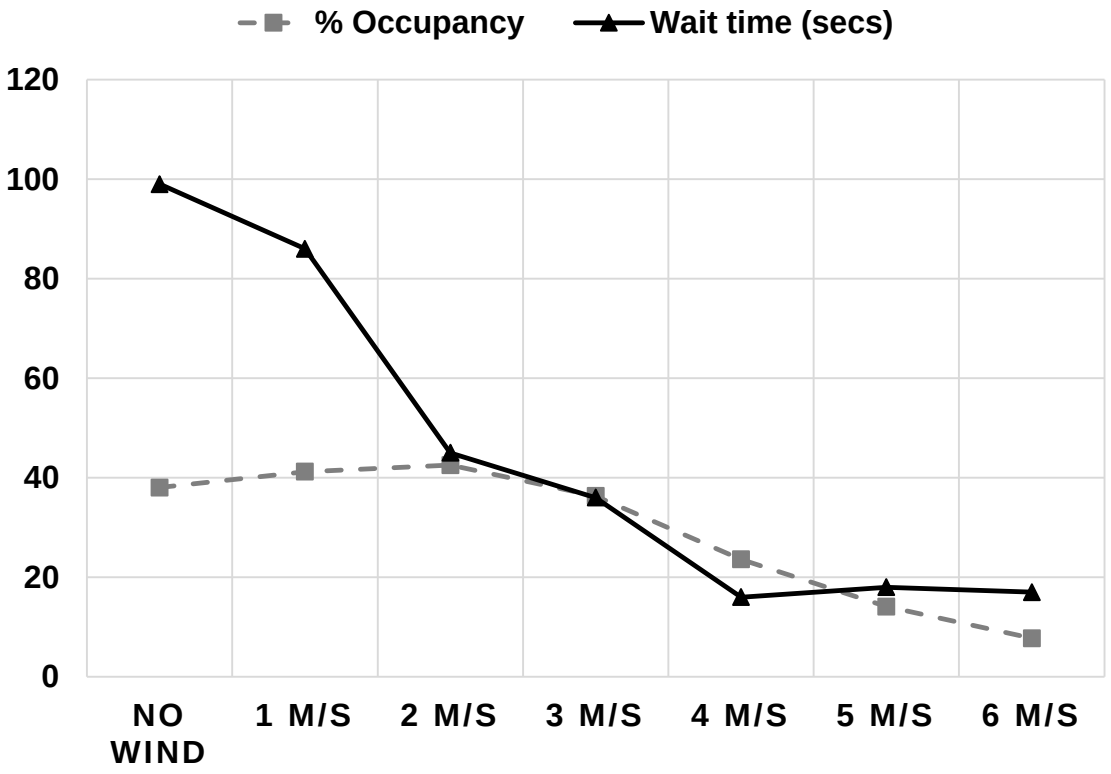


(a) Operator occupancy (%) over time (s)



(b) Cumulative wait time (s) over time (s)

Results

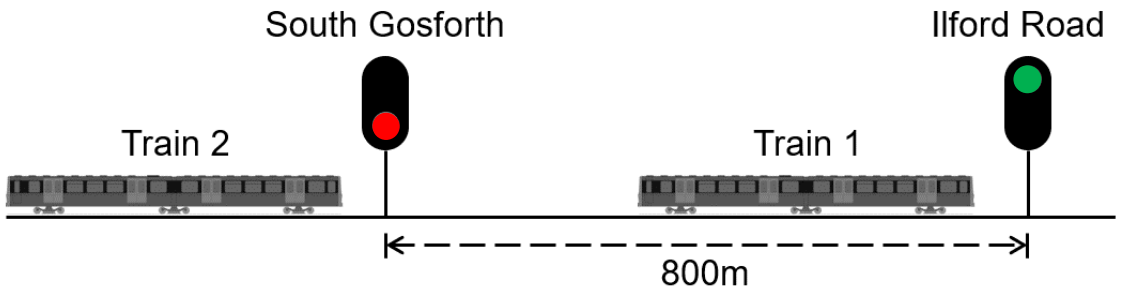


(c) Average occupancy (%) and cumulative wait time (s) over a range of windspeeds

Driver Behaviour in Urban Rail

Driving style has a significant effect on energy use

- Existing work on driving style and energy (Powell & Palacín, 2015)
- Funding for decarbonisation from Rail Systems Safety Board (RSSB)
- Potential for FMI as an enabler for railway "marketplace"



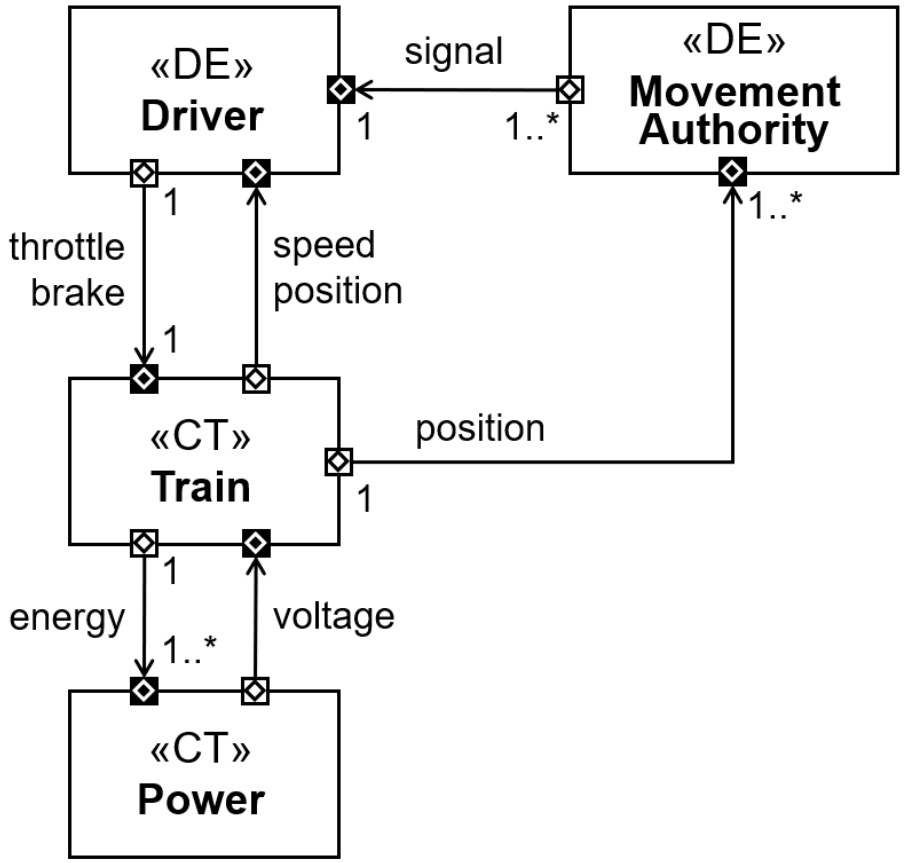
Multi-model

Movement Authority in VDM/Overture
- Two-aspect signalling (stop and go)
- Passes next signal to Driver model

Driver in VDM/Overture
- Drives the train based on signal received from Movement Authority
- Aggressive mode uses full throttle and full brake
- Defensive mode uses half throttle and half brake

Train in 20-sim
- High-fidelity train based on real traction data
- Heavy (40 tons) and light versions (35 tons)
- Regenerative braking option (30% recovery)

Power model in 20-sim
- Provides voltage to each train
- Calculates cumulative energy usage
- Simple: no voltage drop or line losses



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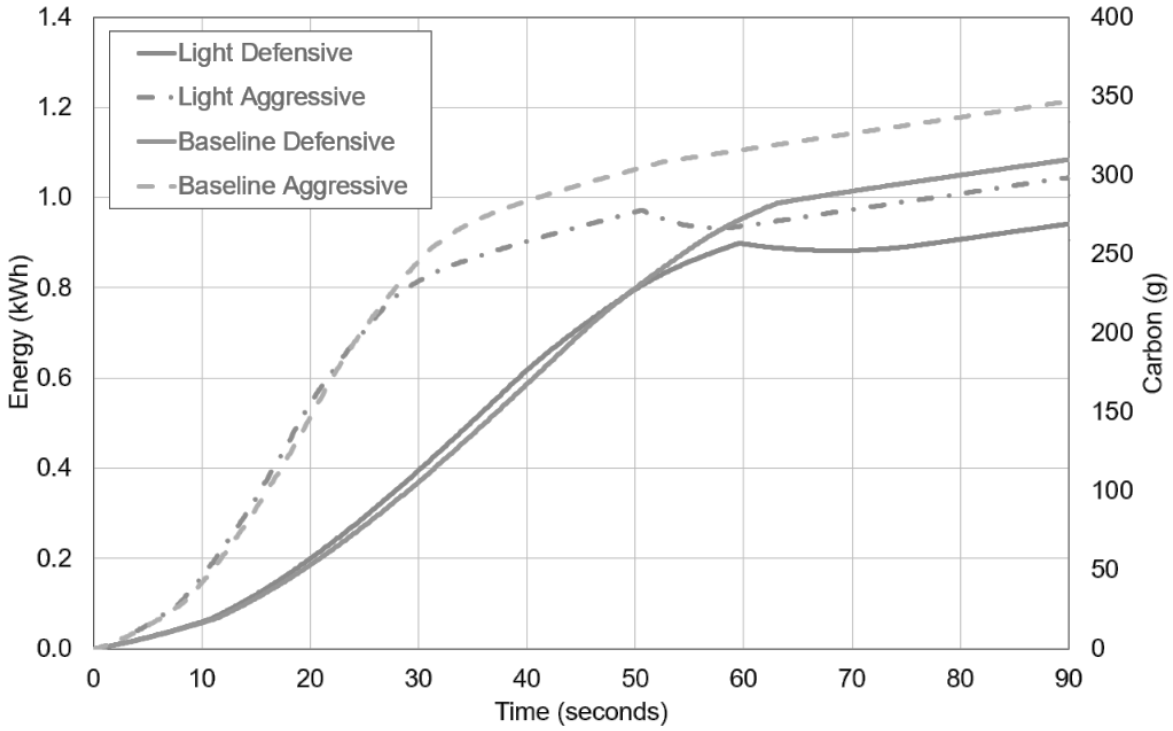
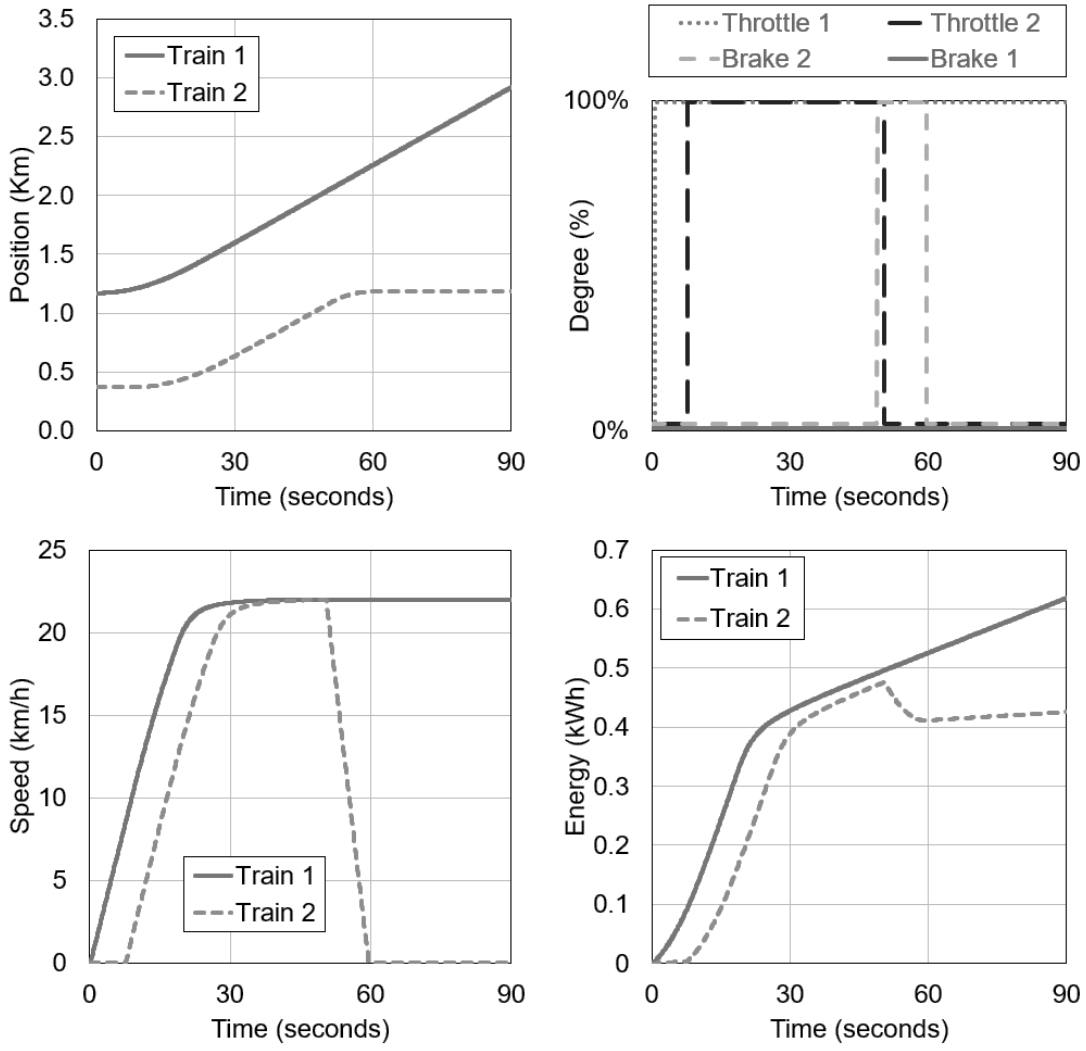
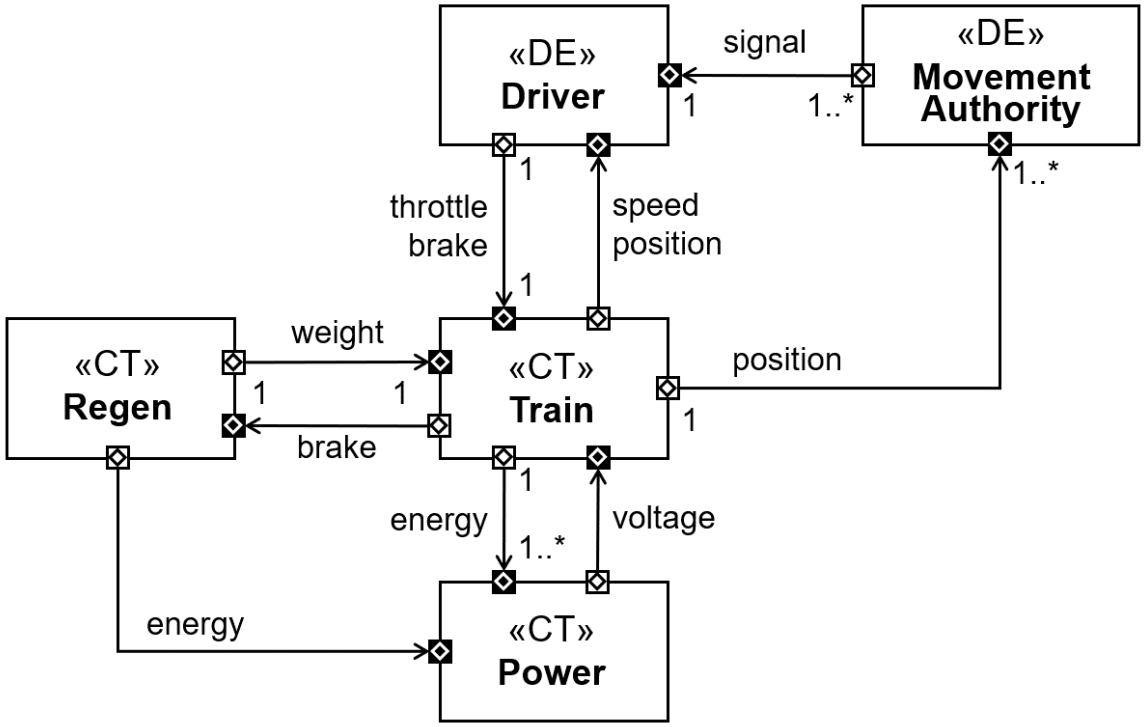


(a) Energy (kWh) and carbon (g) used against time (s) for four scenarios

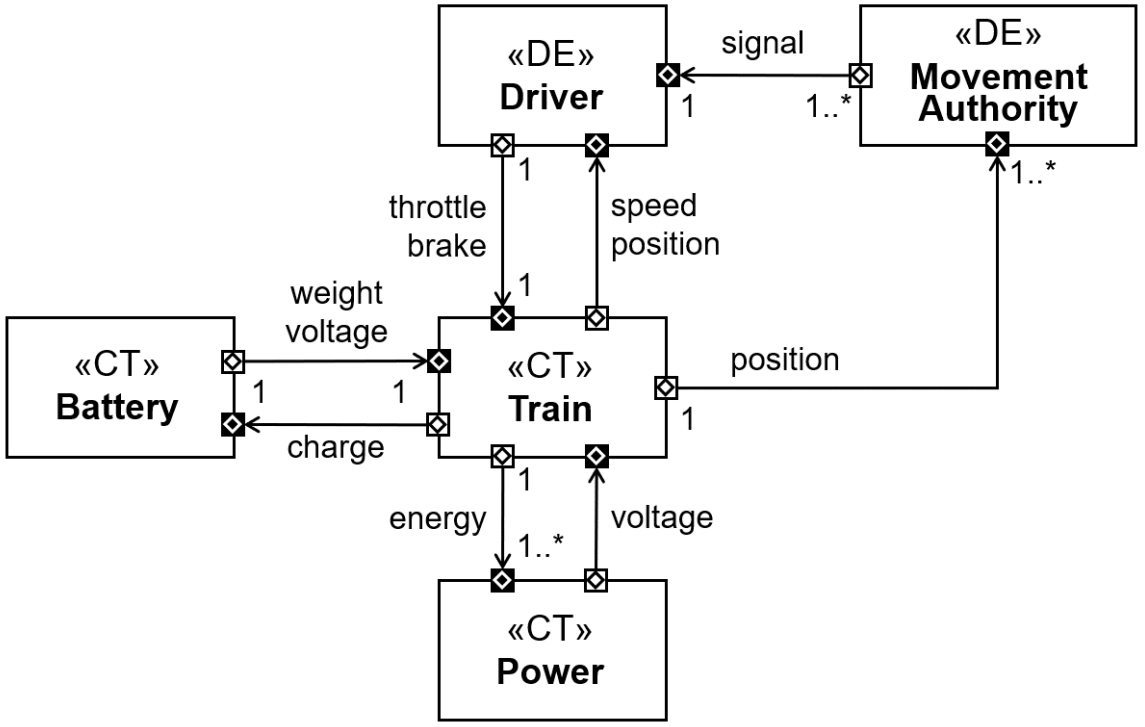


(b) Train positions, driver outputs, energy consumption, and train speeds for a single scenario (baseline driver and lightweight train)

Preparing for Third-Party Models / Marketplace Demonstrator



(a) Regenerative braking unit broken out into FMU



(b) Alternative scenario with an on-board battery

Summary and Future Work

Summary
- Applied ergonomics in two case studies using multi-modelling
- Two cases studies in the rail domain
- Collaboration with experts in rail and psychology

Future work on UAV searching
- Working with search and rescue (S&R) teams and researchers
- Need for guidelines on off-the-shelf UAVs in civilian S&R

Future work on railway
- Moving to mainline train and three-aspect signals
- More sophisticated driver models
- Demonstrate FMI with third-party models (e.g. battery, power)

Future work with ergonomics colleagues
- Siemens' Jack model in smart manufacturing multi-model
- Example: how long will a reconfiguration take to achieve?

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