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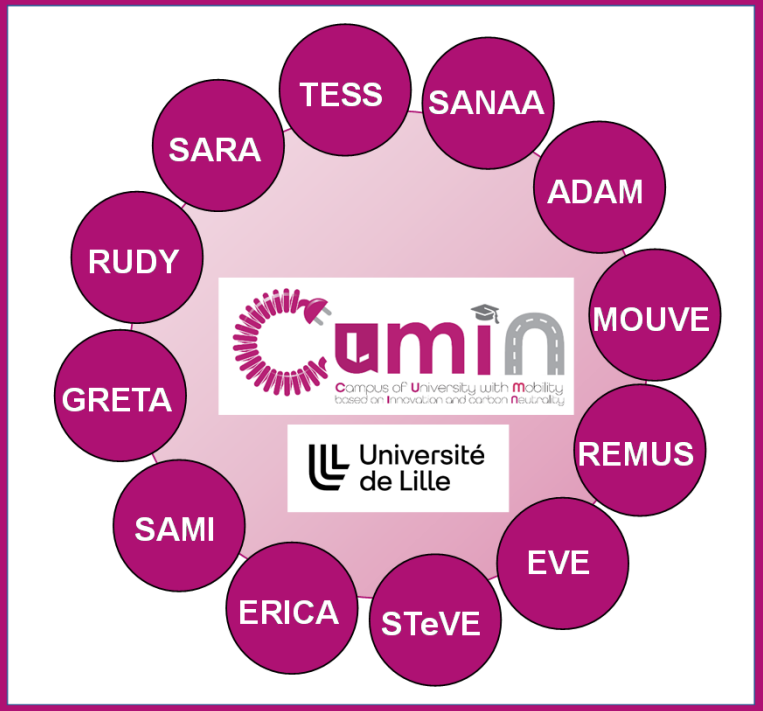

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Regenerative braking of new subways

Ryan O. Berriel[1], Alain Bouscayrol[1], Philippe Delarue[1], Clément Mayet[2] and Charles Brocart[3]

[1]L2EP, Université de Lille
[2] SATIE, Le CNAM, ENS Paris-Sanclay
[3]Metropole Européenne de Lille

Outline

1. Introduction
2. Subway Model and Simulation
3. Hardware-in-the-Loop platform
4. Conclusion

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CUMIN - REMUS

1. Introduction

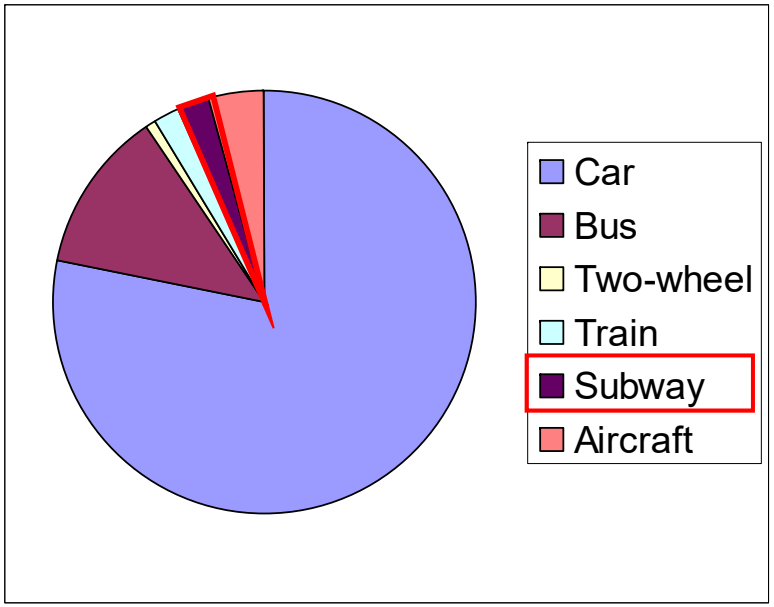
Motivation

Mobility

- Demand for mobility in even more populated cities and emerging economies.

Rail transportation advantages

- High speed
- Punctuality
- Low GHG emission
- Low energy consumption per passenger-kilometer

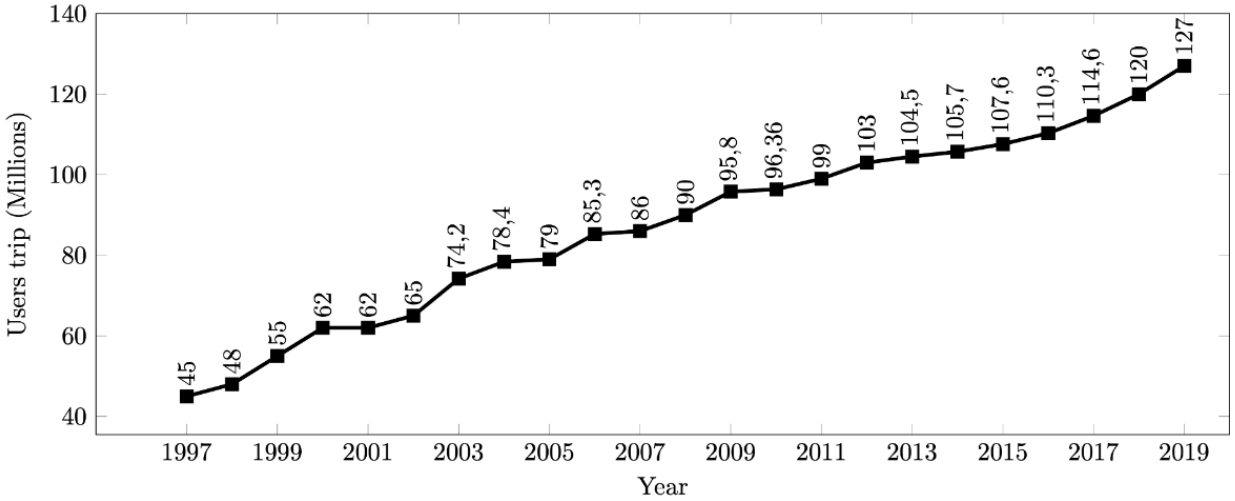


Mobility GHG emissions ULille

Lille Subway System

In Lille

- Consumption of 70 GWh was registered (2019)

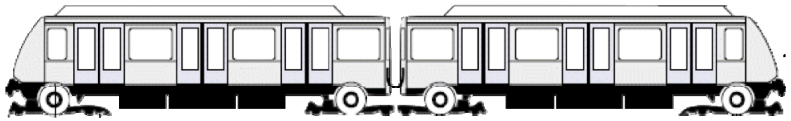


NMR Alstom

Crescent subway utilization

Substitution of the vehicle of line 1 of Lille subway system

- Vehicle Alstom NMR (Nouveau Matériel Roulant)



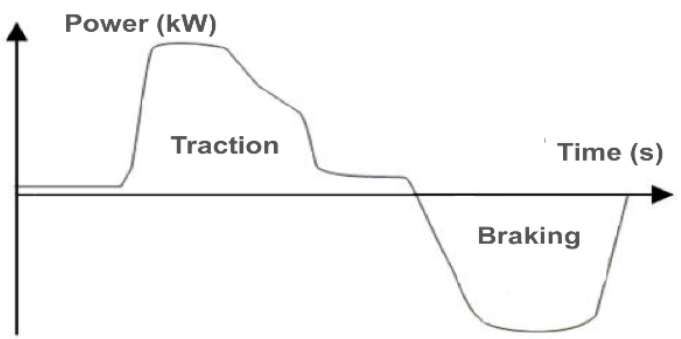
Actual vehicle

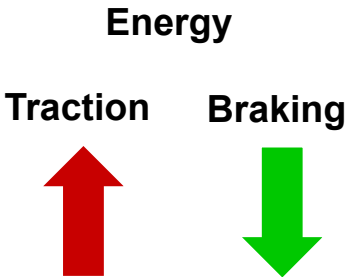
New vehicle

REMUS Objective

Traction subsystem

- subway systems are electrified
- regenerative braking capability
- part of braking energy to next subway
- **part of braking energy wasted**





REMUS objective:

- recover braking energy to charge EV by wasted energy
- demonstration for “Cité Scientifique” station on the campus

Expected outputs:

- Flexible simulation tools for analysis of energy flow
- Development of innovative solutions and management
- Pre-validation on experimental platform

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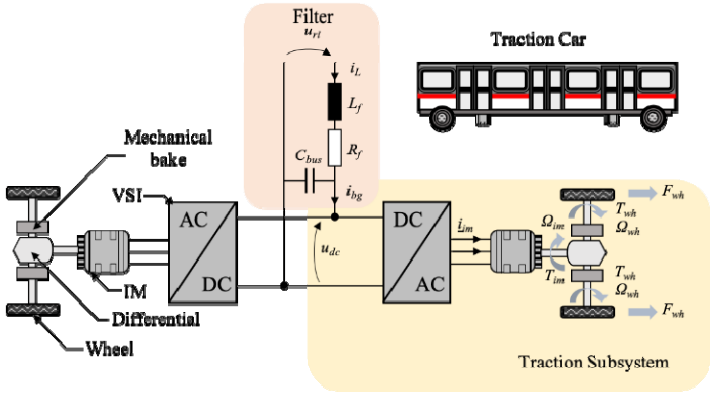
2. Subway Model and Simulation

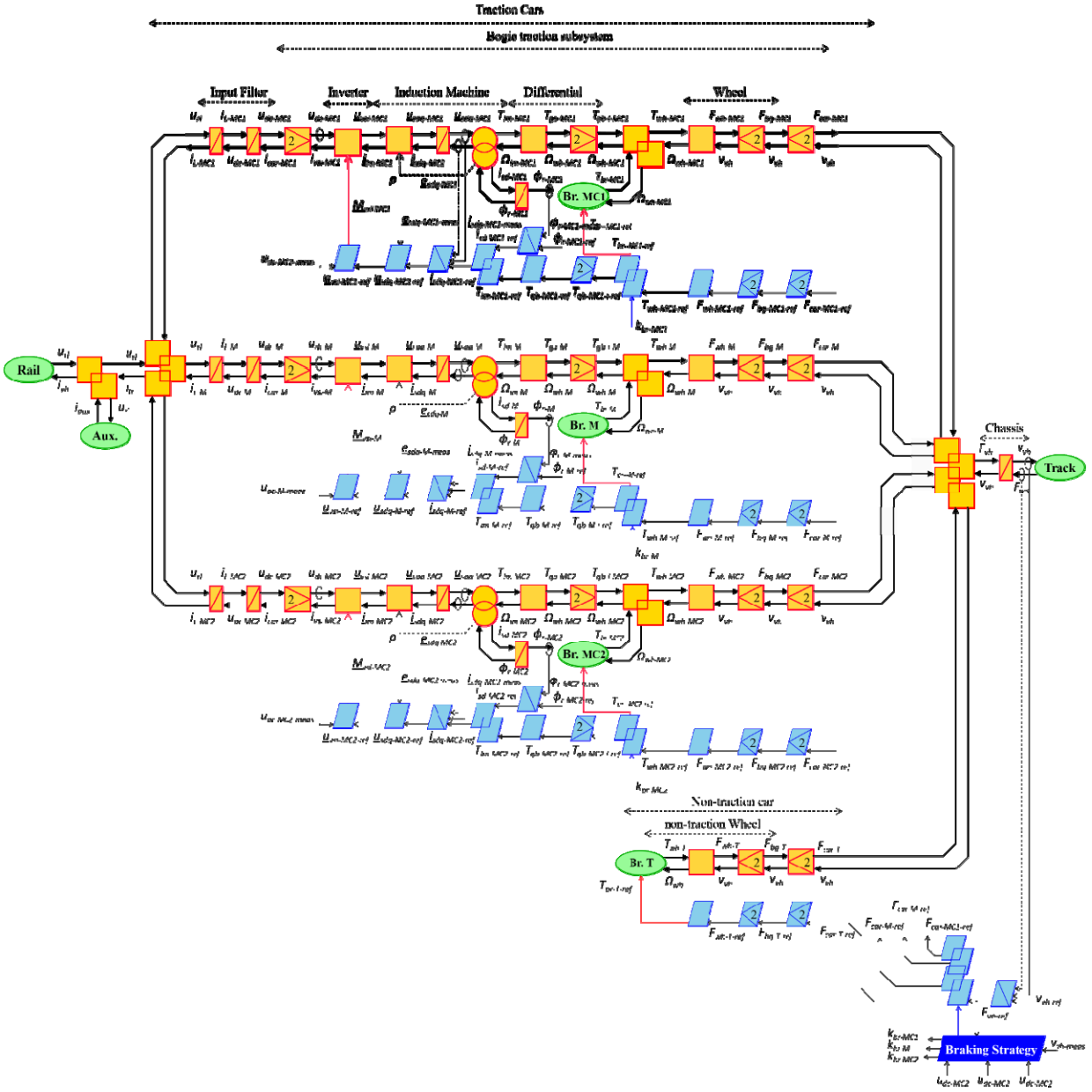
Subway Modelling

Traction Subsystem

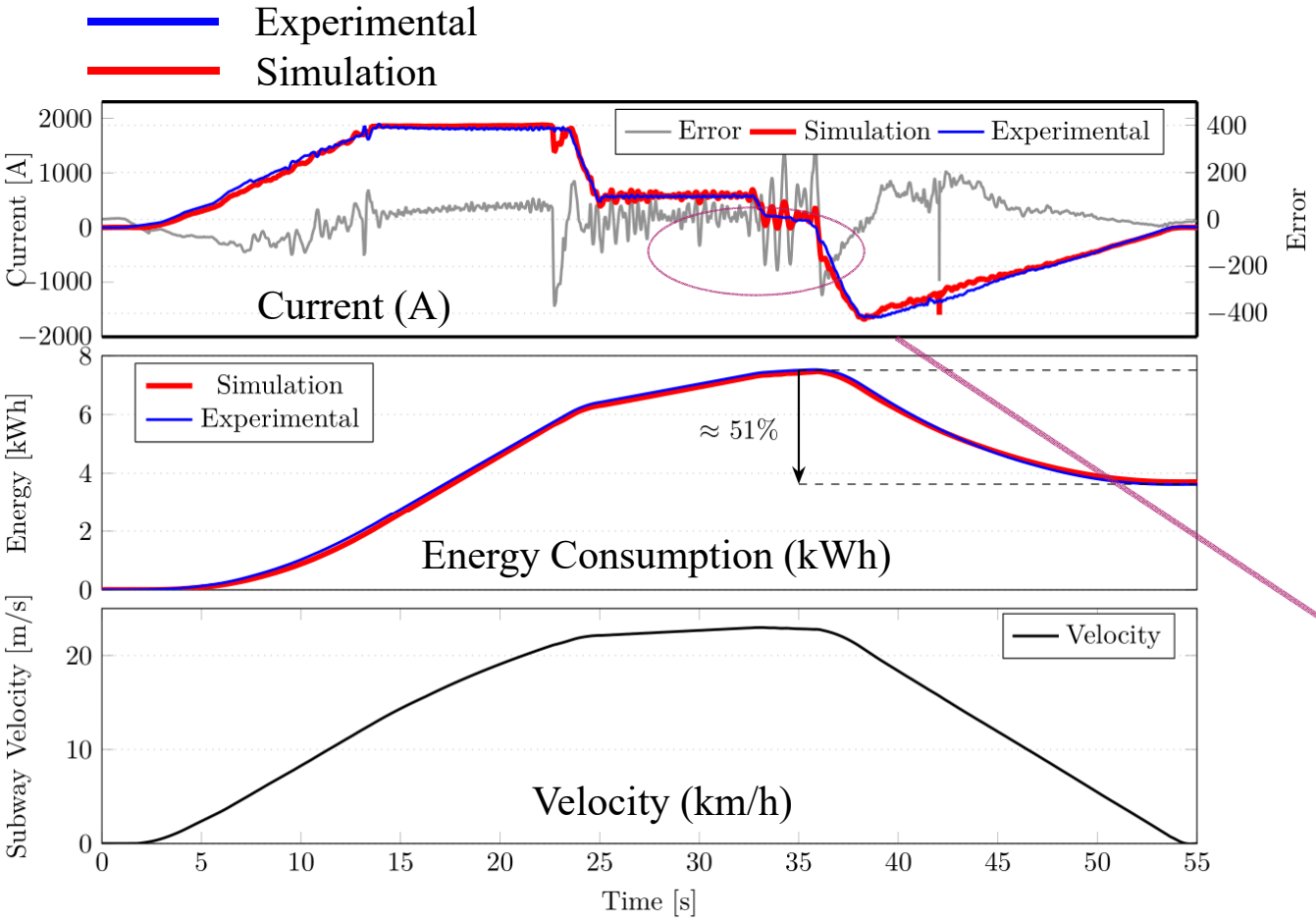


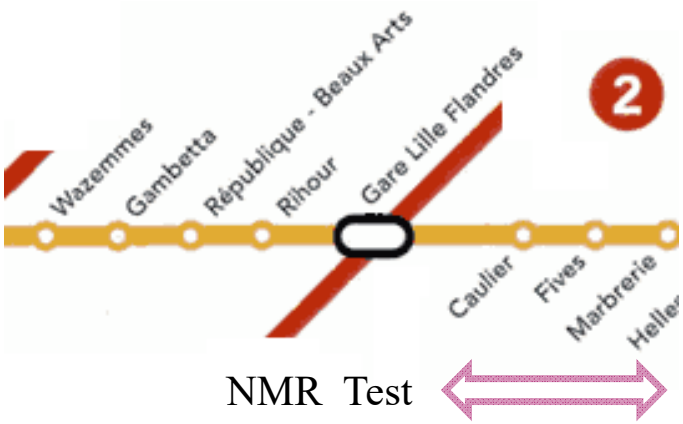
Complete Dynamical Model

- More complex solution



Model Validation





NMR Test

- Energy recovery phase
- 2.1% difference in energy consumption
- **Validation of the simulation tool**

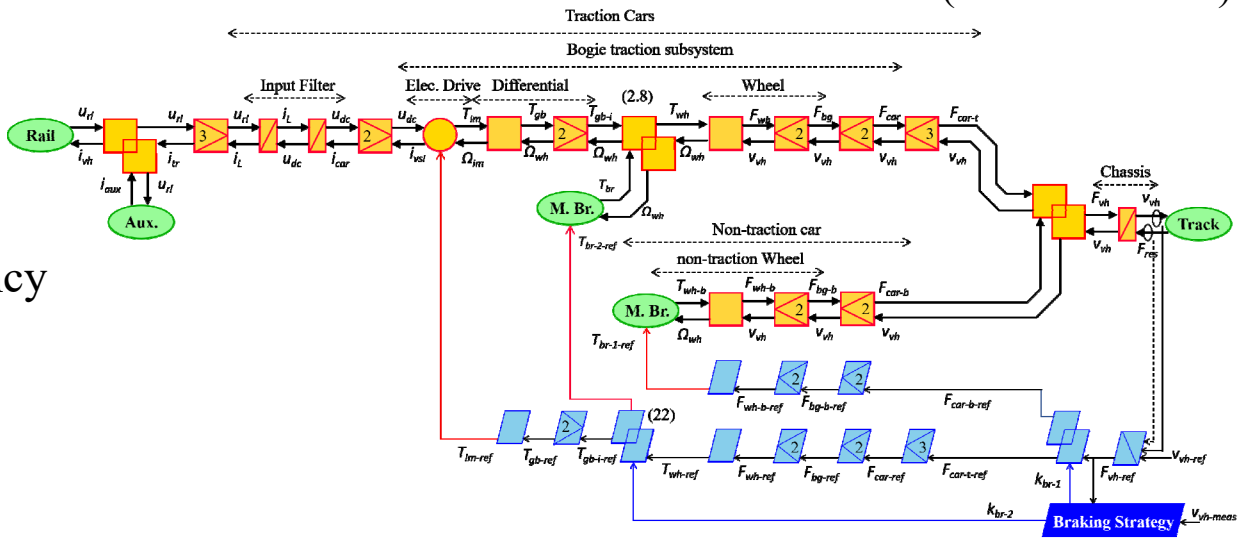
System Modelling

Model Simplification

Model is simplified to improve simulation efficiency

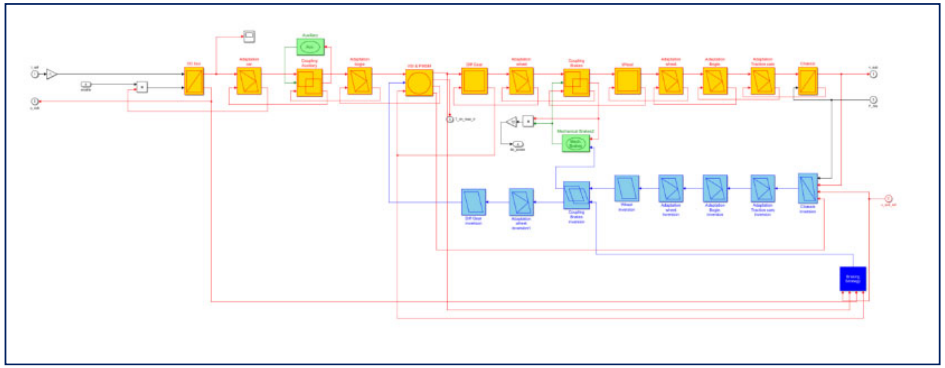
- Reduce computational cost

(O. Berriel 2021)

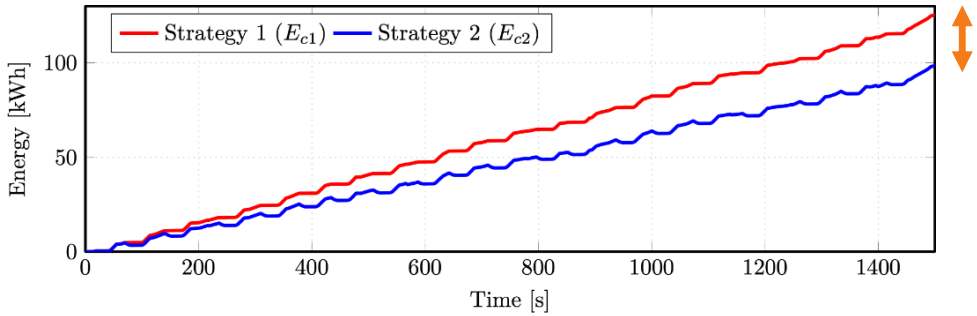


Pure mechanical vs Full regenerative braking

21 % of energy at maximum can be saved

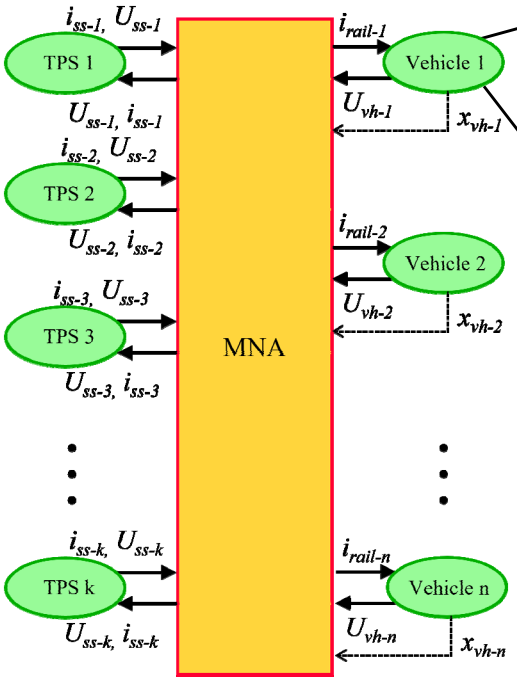


Simulation tool

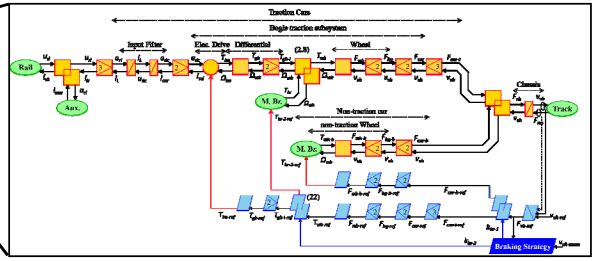


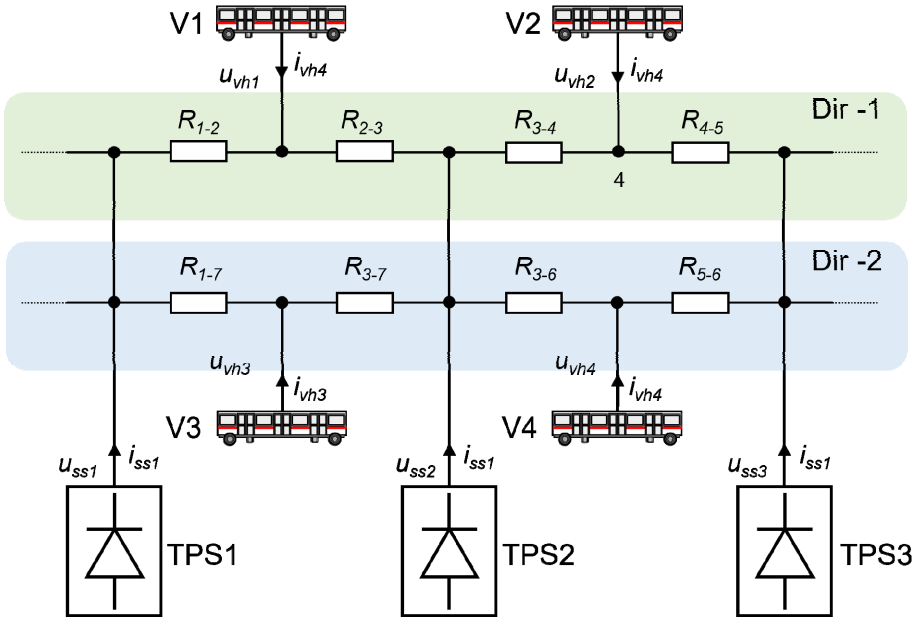
(O. Berriel 2020)

Carrousel Modelling



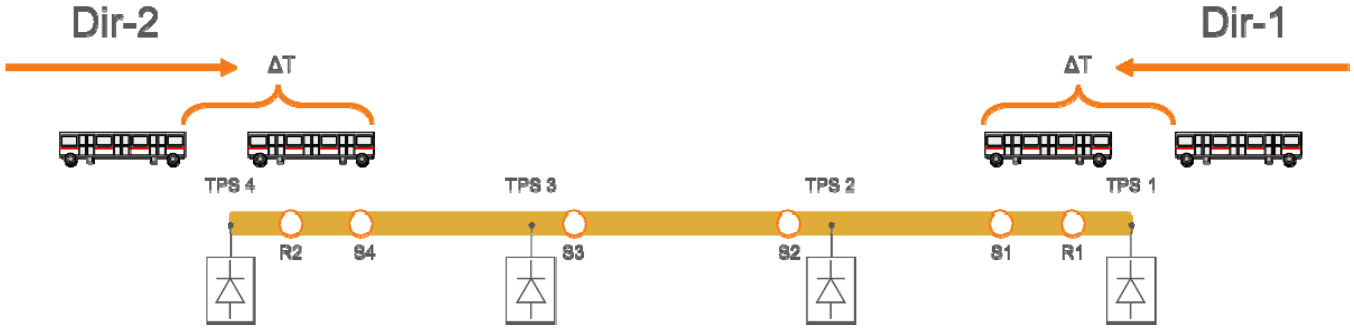
Vehicle model



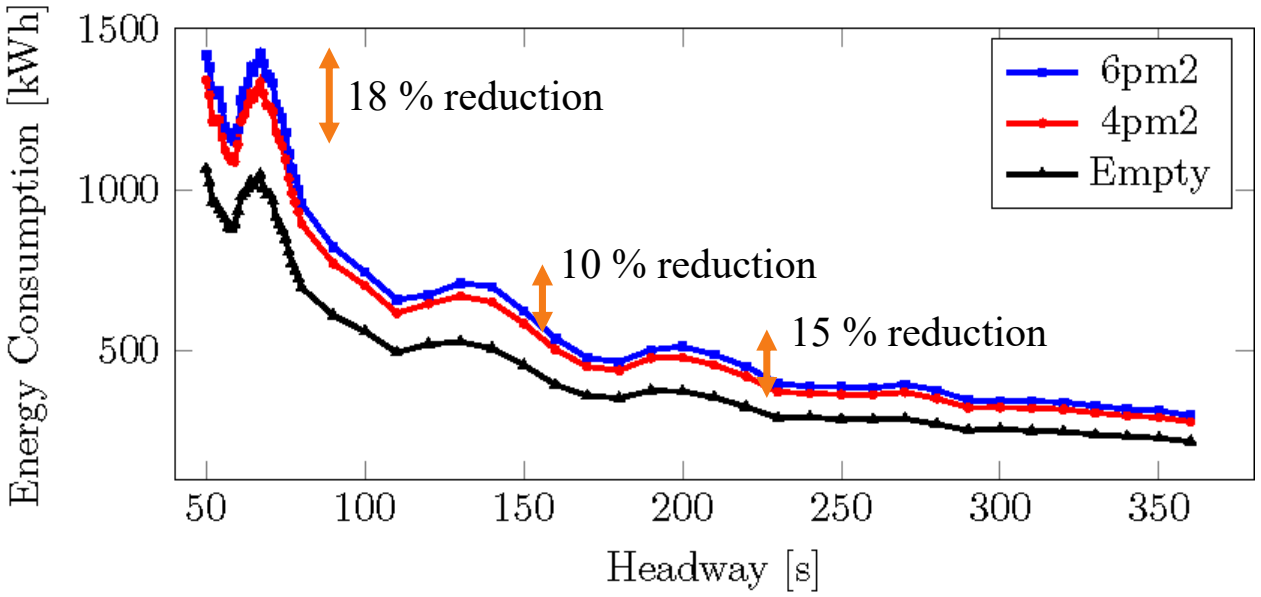


ΔT – Headway

- Between 50s and 360s
- Simulation time of 25min



Carrousel Modelling



Occupancy rate

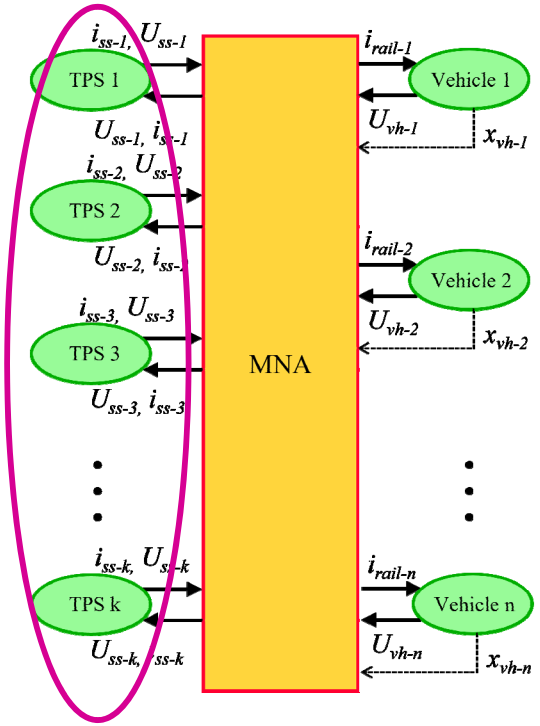
- More passengers -> More Mass -> More consumption

Tendency

- Shorter interval -> More vehicles -> More consumption
- A tendency, but not a rule

Global energy consumption

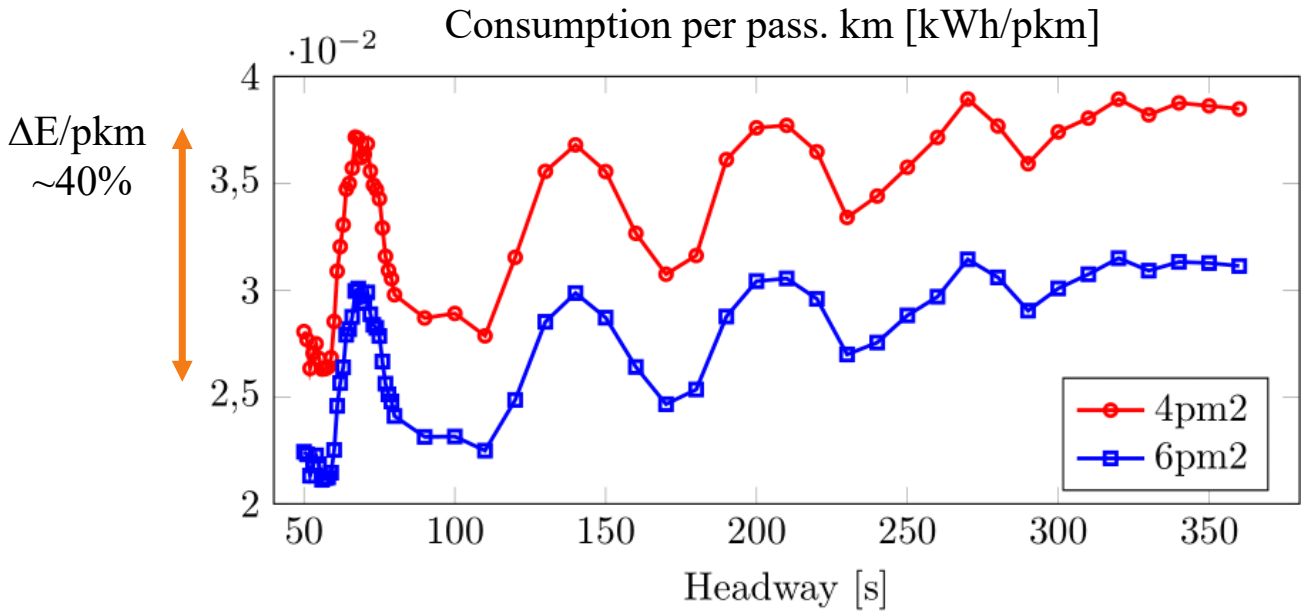
- Consumption on Substation level



Carrousel Modelling

Subway line

- Function: move passengers on a certain path
- Energetic analysis: Energy to move a passenger in one kilometer



To satisfy a certain demand, some **intervals should be prioritized**

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3. Hardware-in-the-Loop platform

Previous existing platform

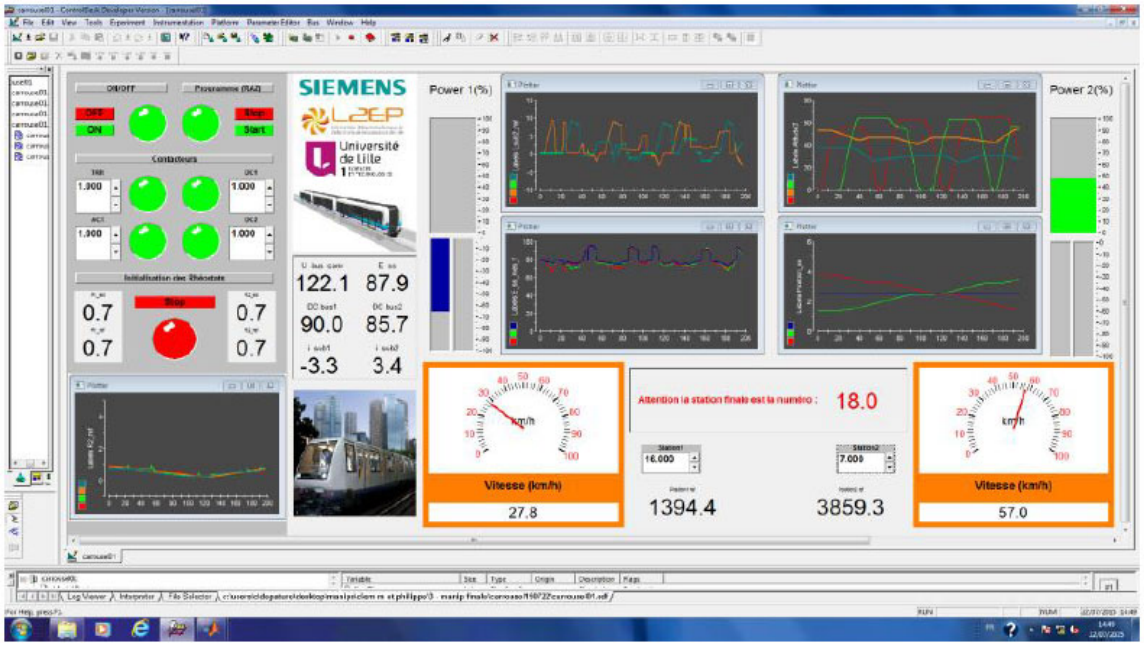
dSPACE

(Mayet, 2017)

Real-time simulation

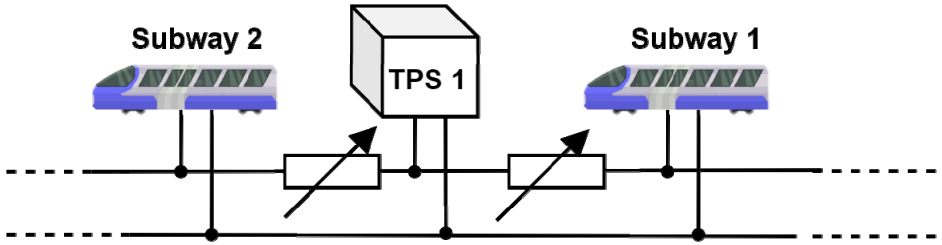
- Experimental test environment before real implementation

- Reduced scale
- Real time simulation
- Voltage scale – 10
- Current scale – 100



Previous platform

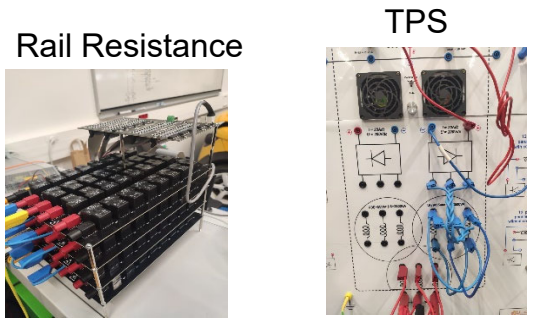
- Limited to 2 vehicles
- Single rail direction

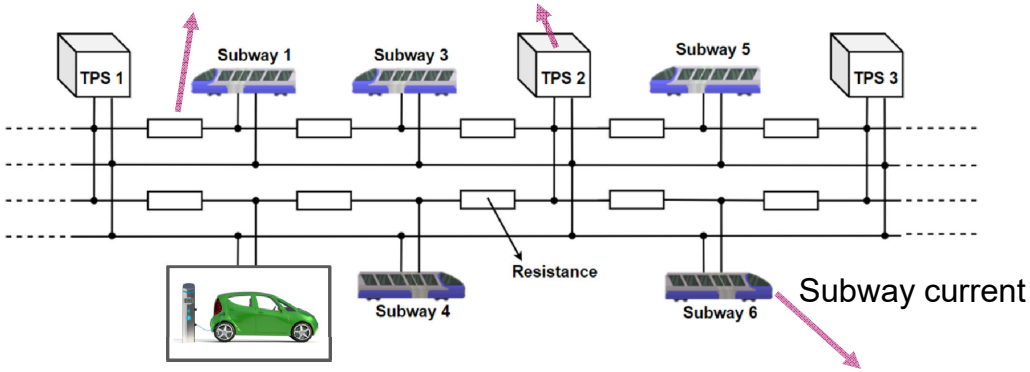


New platform design

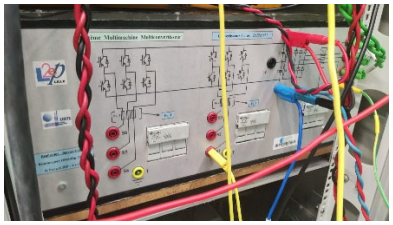
Multi-train topology (Extended platform)

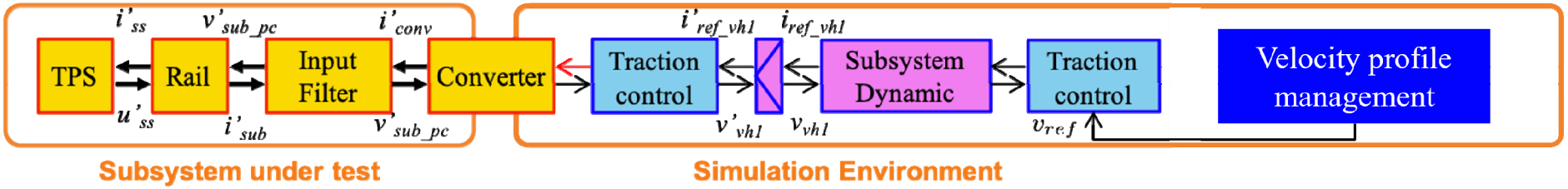
- Equivalent resistance seen by the train according to its position relative to the TPSs
- Set of resistances and relays





New topologies and concepts pre-validation



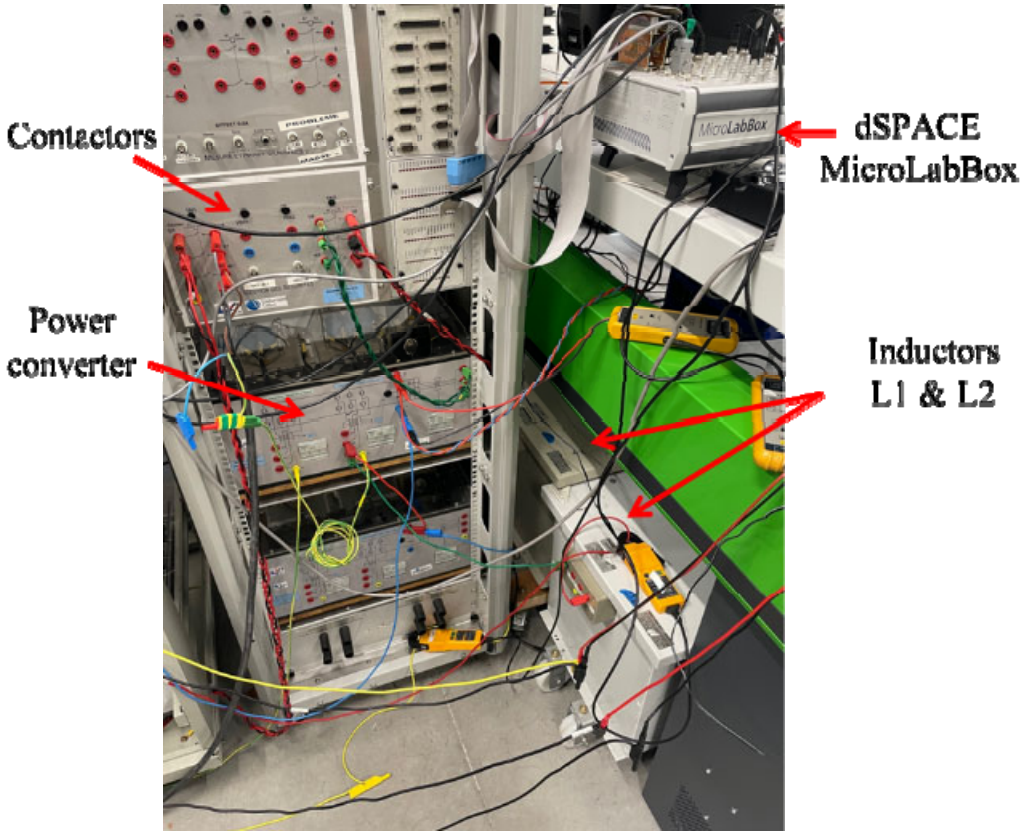


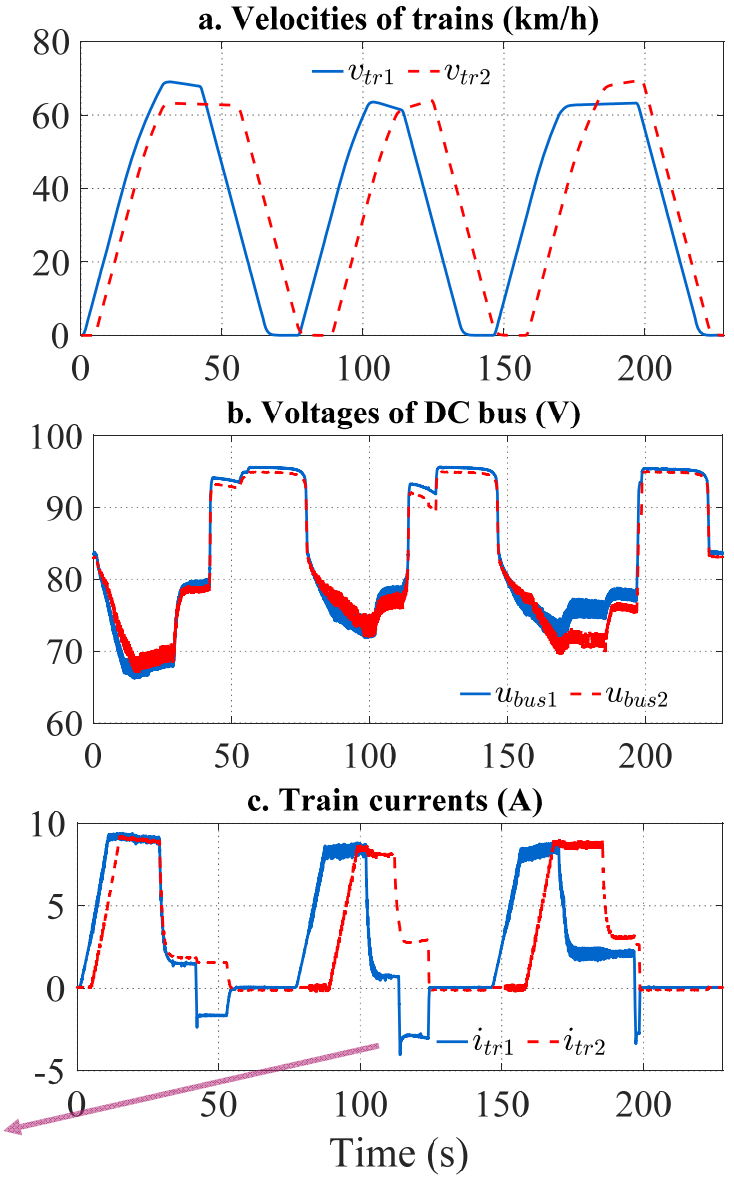
HiL concept

HiL Simulation results

First Test New platform

- Simulations with 2 trains and 1 TPS





Energy exchange between vehicles

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4. Conclusion

Conclusion

Mono-train

- Model of traction subsystem
- Model validation by experimental results - Energy error < 2%
- Recovery of Braking energy up to 21%

Multi-train

- Model of carrousel
- Study of the impact of headway Global Δenergy +/- 18% of reduction

- Management strategy for reduction of consumption ?
- Braking strategy for energy recovery ?
- Supply of EV charging station ?

HiL platform

- Demonstrator at reduced power (extended version for multi-train)
- Experimental pre-validation of new energy management ?
- Experimental pre-validation of new charging station ?

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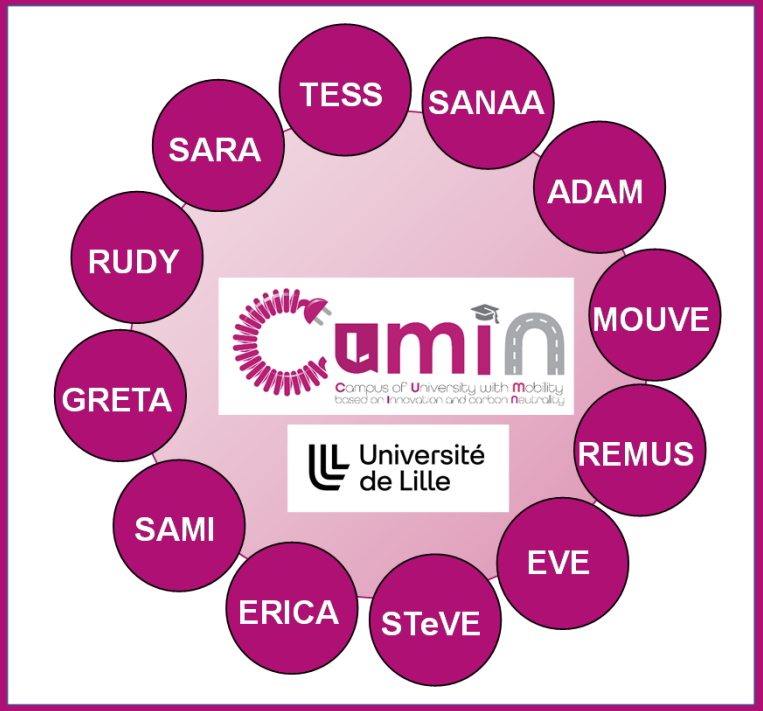

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an exciting living lab
towards eco-cities!

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[O.Berriel 2020] R. O. Berriel, A. Bouscayrol, P. Delarue and C. Brocart, "Mechanical Braking Strategy Impact on Energy Consumption of a Subway," **2020 IEEE Vehicle Power and Propulsion Conference (VPPC)**, 2020, pp. 1-5, doi: 10.1109/VPPC49601.2020.9330984.