Developing a Large-Scale Microscopic Model of Electric Public Bus Operation and Charging

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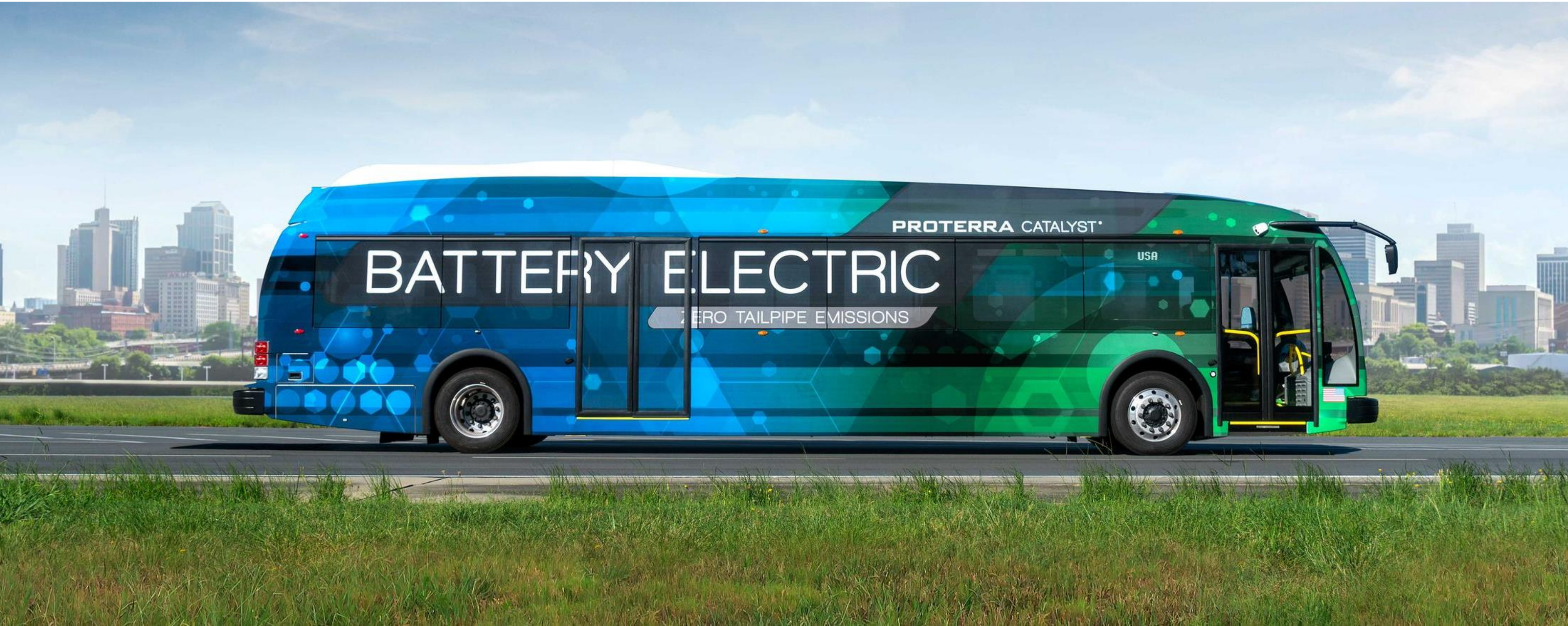
Outline

- Motivation
- Model description
- Preliminary results and Outlook

The electrification of mobility – Electric buses



The electrification of mobility – Electric buses

Deployment of electric buses will be much faster than that of electric cars:

- 84 % of global sales for municipal buses to be electric by 2030

- 80 % of the global municipal bus fleet to be electric by 2040

(According to the Bloomberg New Energy Finance EV Outlook 2018)

→ Singapore procuring 60 electric buses for 2020

The electrification of public transport

*“What are the requirements and the impact of electrifying public transport at **city-scale**?”*

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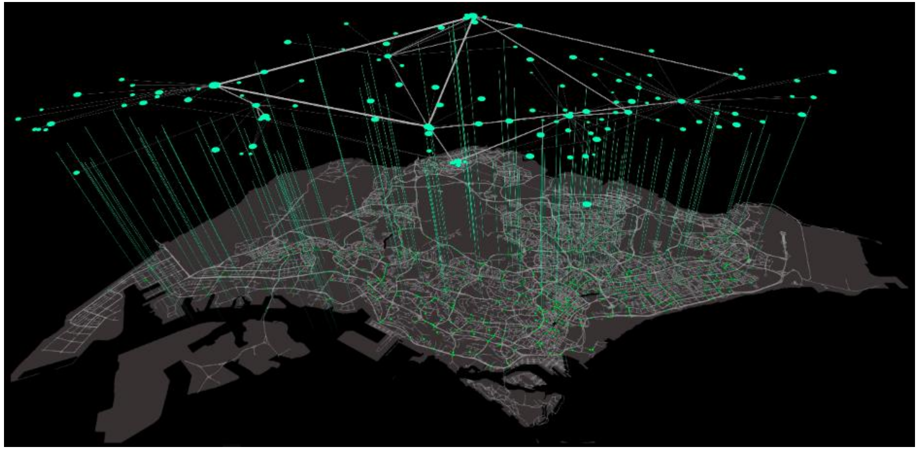
The electrification of public transport – Challenges

Network effect

Studying individual bus routes and simply aggregating results does not lead to good model of the system as a whole

- Infrastructure is shared
- Geographical coupling and interdependencies



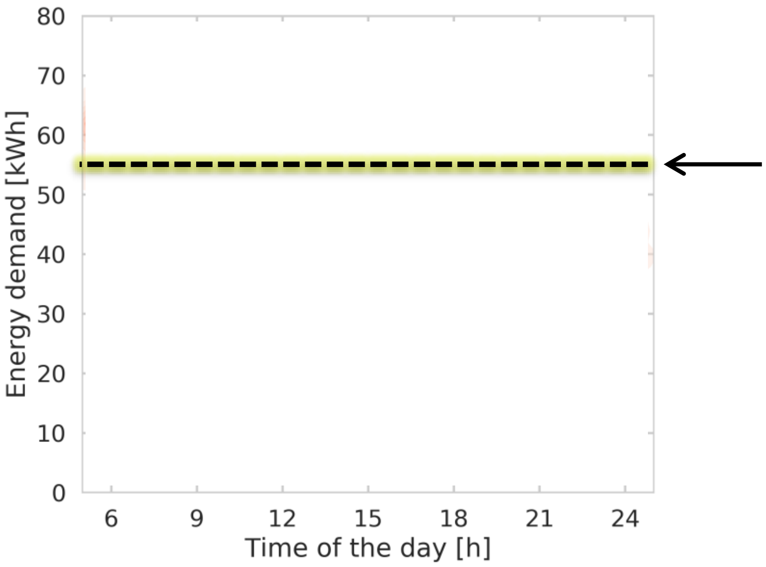
The electrification of public transport – Challenges

Heterogeneity of real-world situations

Using only aggregate values (average value of X, Y, …) does not accurately represent the variety of real-world situations

- Statistical distribution can significantly vary depending on the chosen bus route

“Bus line X requires on average 55 kWh per trip…”



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The electrification of public transport – Challenges

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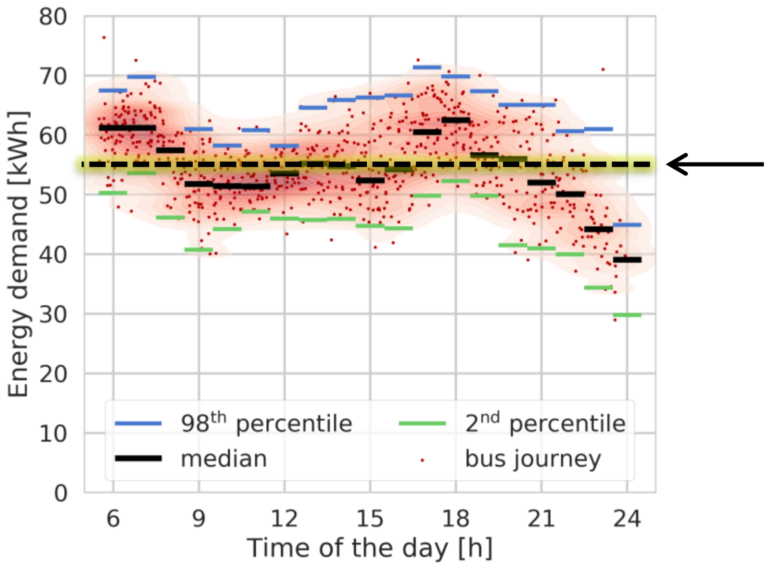
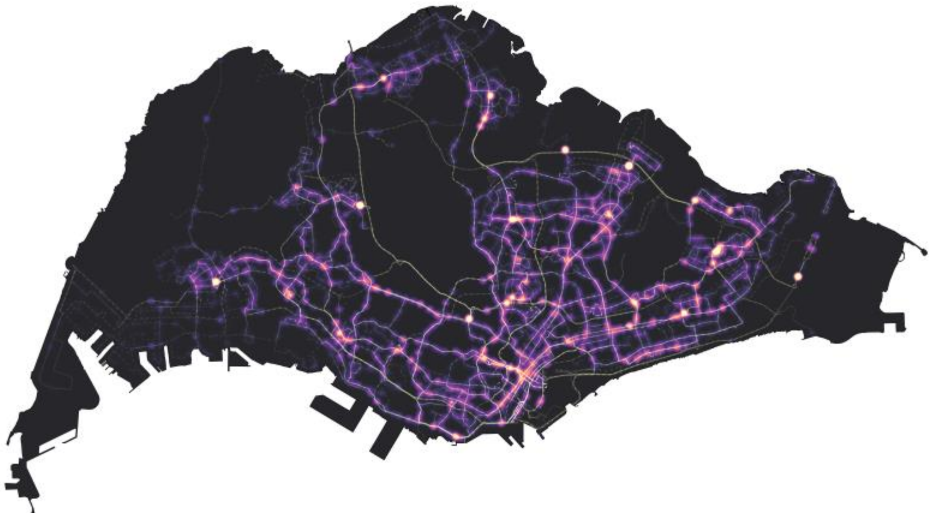


The electrification of public transport – Towards a city-scale model

Motivation:

Study the impact of public road transport electrification at city-scale

Unlike simplified models considering only few bus services, a city-scale model takes into account the network effects arising from infrastructure sharing (chargers, parking spaces, …)



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Existing approaches

- Using average energy demand per unit of distance or time
- Use of a standard driving cycle taken from literature

\+ easy to scale up

\- does not take local bus route characteristics into account

\- does not give detailed results

- High-resolution measurements of driving profiles

\+ takes local bus route characteristics into account

\+ gives detailed results

\- time-consuming

\- hard to scale up

City-scale model of electric bus energy demand

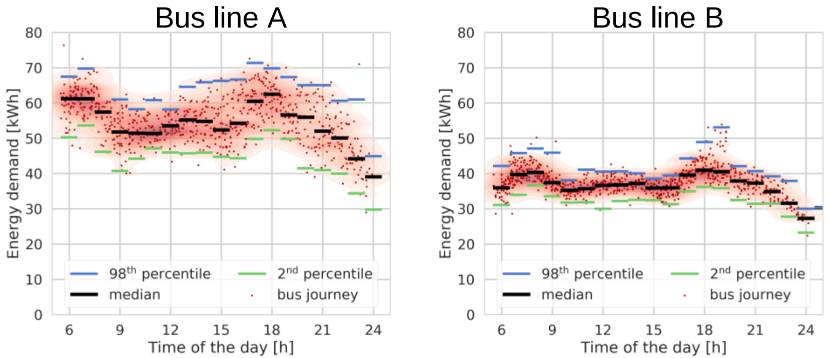
Previous work:

Energy demand analysis from real-world data

- Passenger fare data (tap-in and tap-out of the fare card in bus) used to derive time of arrival and departure at each bus stop for all bus routes in Singapore.

- Simplified driving profile model to calculate energy demand for each vehicle

Variation over the course of a day of the energy required for a terminus-to-terminus trip for two different bus lines



M. Gallet, T. Massier, and T. Hamacher, "*Estimation of the energy demand of electric buses based on real-world data for large-scale public transport networks*" Applied Energy, vol. 230, pp. 344–356, 2018.
DOI: 10.1016/j.apenergy.2018.08.086
(Download: https://zr.k.vu/GalletEtAl2018)

City-scale model of electric bus operation and charging in CityMoS

City-scale model of electric bus operation and charging in CityMoS

TUMCREATE has developed the City Mobility Simulator (CityMoS),

a holistic city mobility simulation platform which features:

- Agent-based, time-stepped, city-scale mobility simulator
- Easy-to-use with an interactive 3D environment
- Includes many participants of the transport system
- Parallelised & high performance
- Time-scales from minutes up to multiple days
- Can be coupled with other simulators

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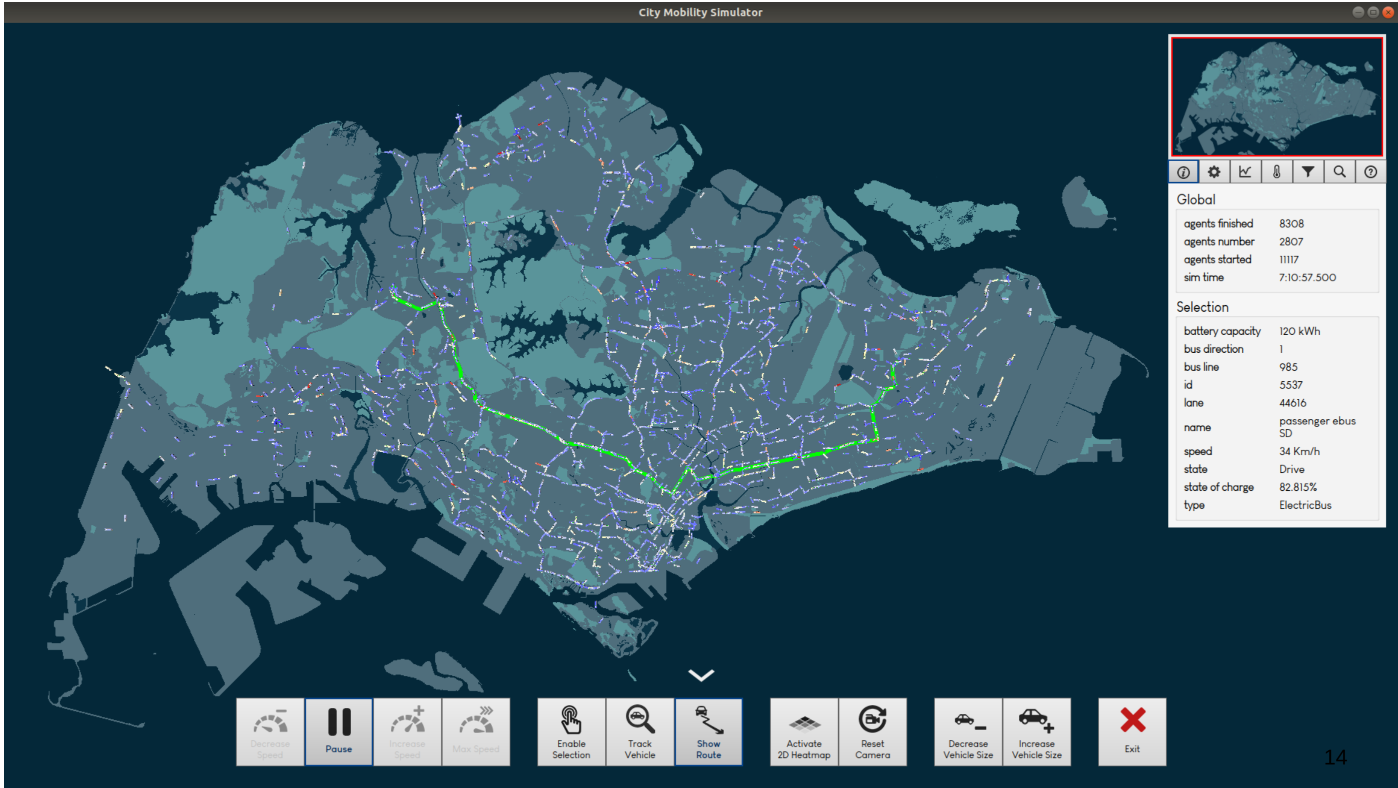
City-scale model of electric bus operation and charging in CityMoS

City-scale, agent-based transport simulation

All bus services of Singapore

Detailed modeling of vehicle and charging infrastructure

Simulate many days of bus operation



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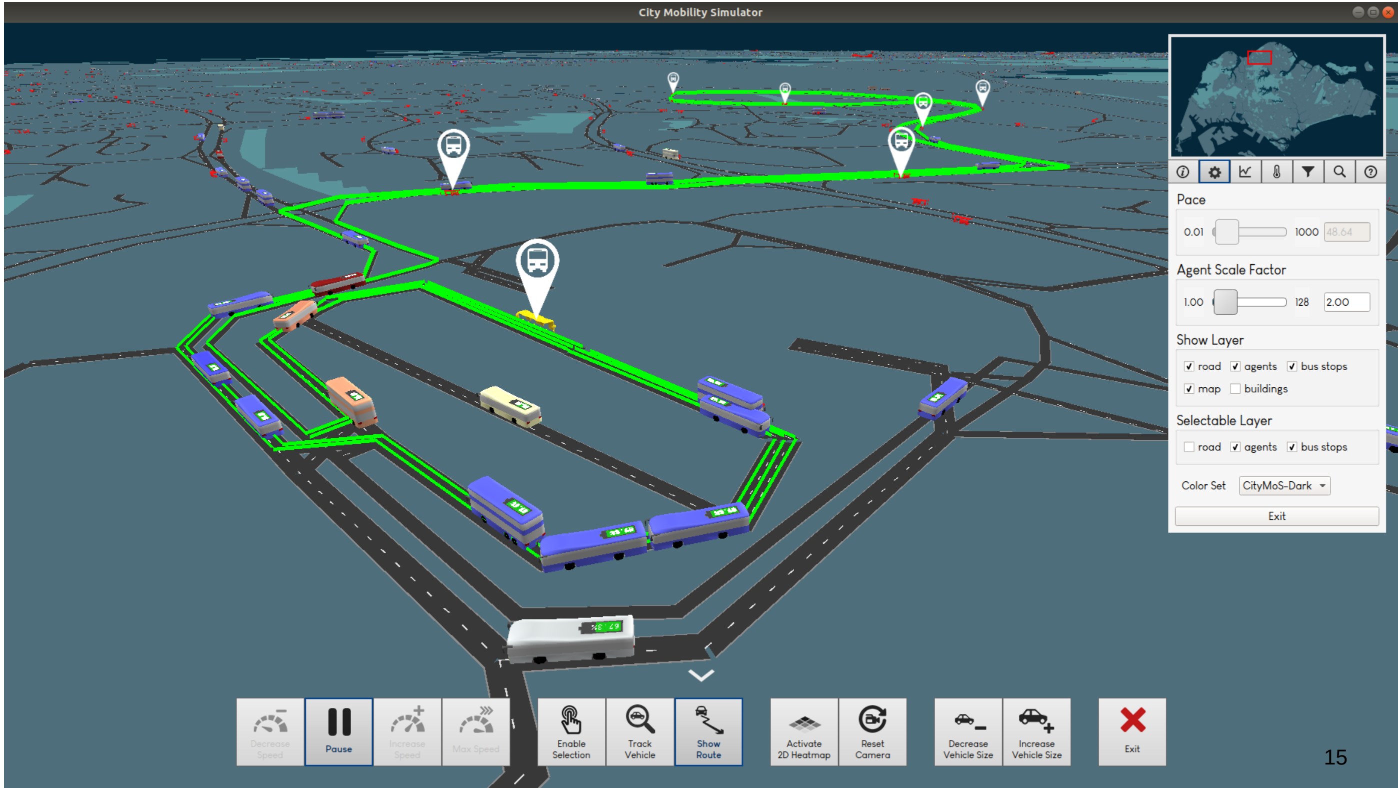
City-scale model of electric bus operation and charging in CityMoS

Agent-based model

Each bus has its own battery and powertrain

Energy consumption computed from acceleration and velocity

Auxiliary energy consumption such as aircon taken into account



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City-scale model of electric bus operation and charging in CityMoS

Singapore bus lines

Entire bus network with bus routes, stops, termini and depots.

Headway for each bus line from LTA DataMall
(for peak and off-peak departure frequencies)

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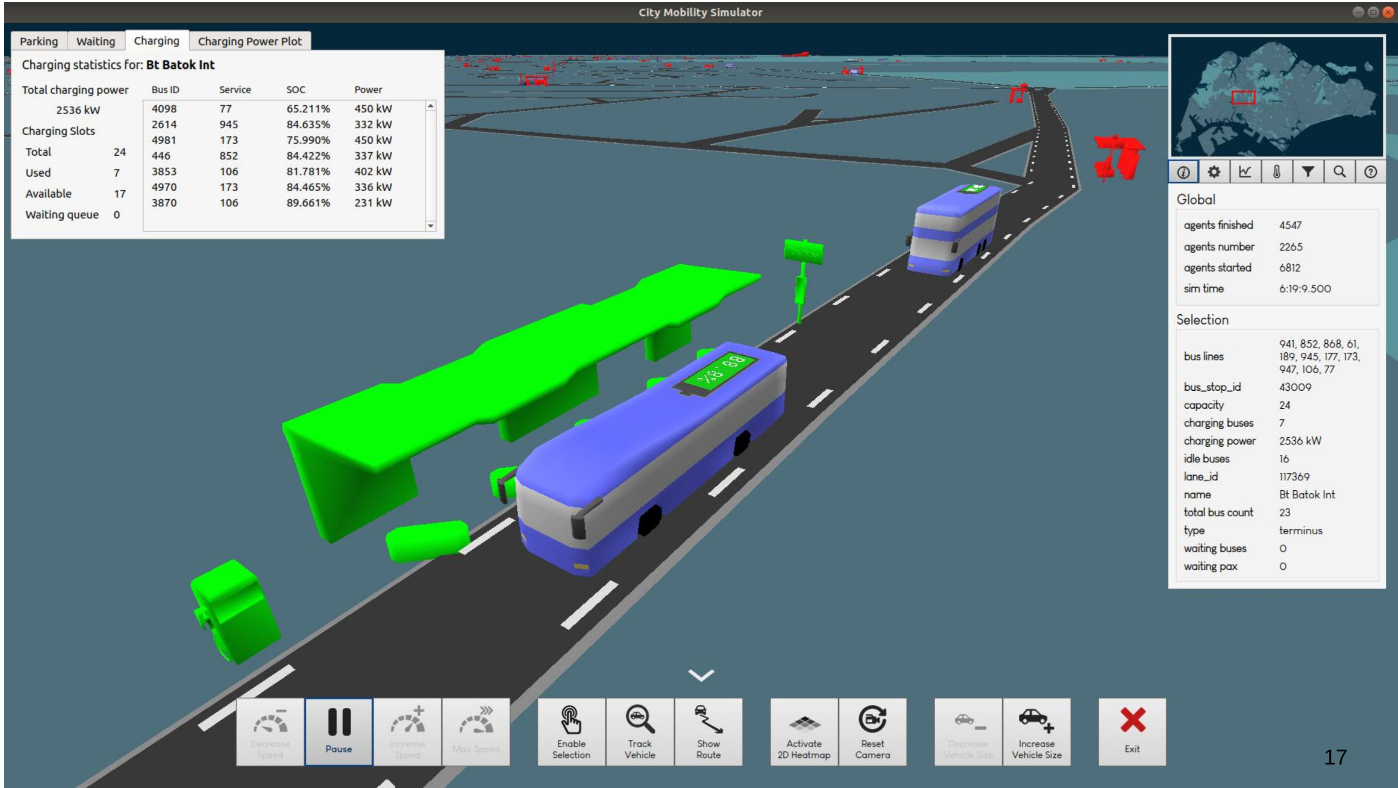
City-scale model of electric bus operation and charging in CityMoS

End station charging

Termini are equipped with charging stations and a given number of chargers.

Different waiting queue strategies can be studied.

Charging power reduced at high state of charge (SOC) levels of batteries.

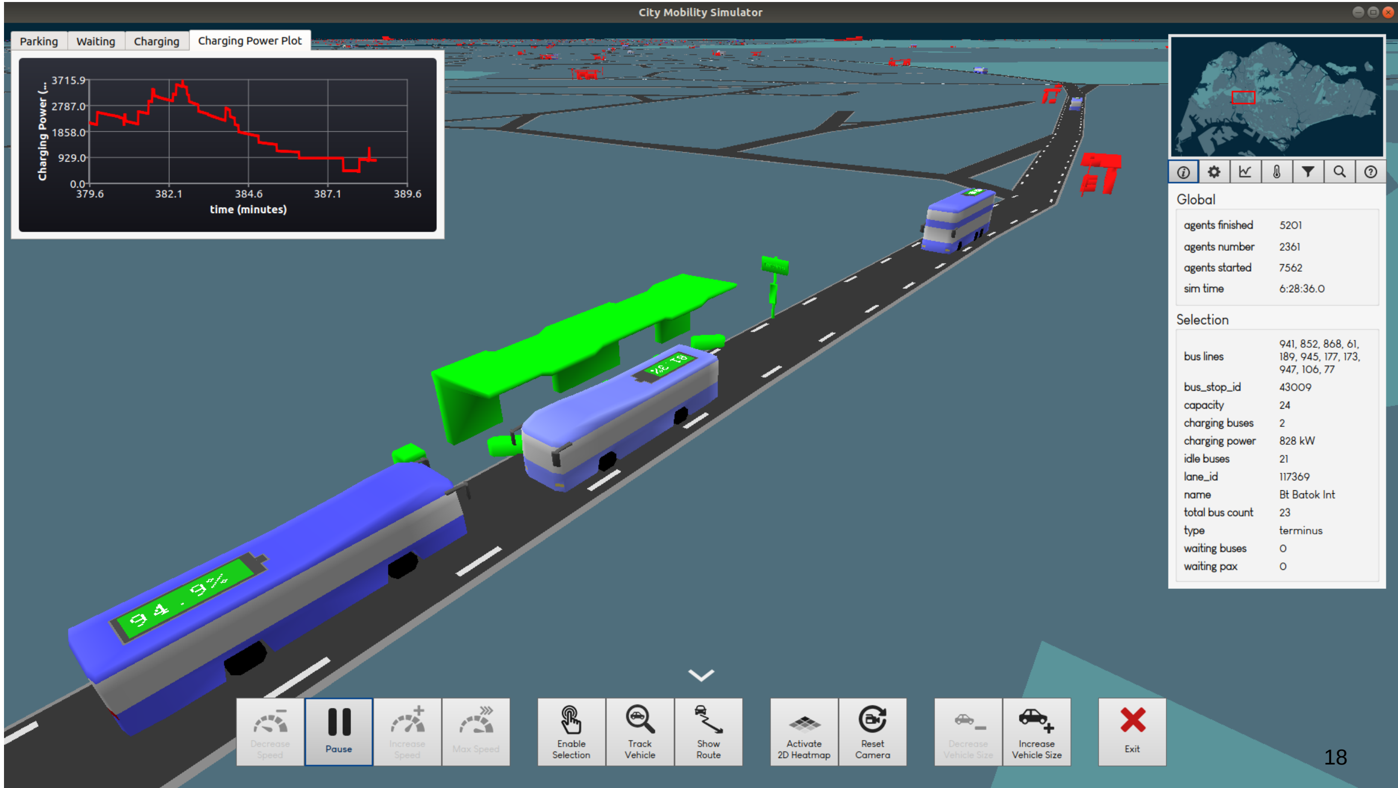


City-scale model of electric bus operation and charging in CityMoS

Charging power

Detailed charging power curve for each charging station.

Can be used for studying the impact on the electric grid.



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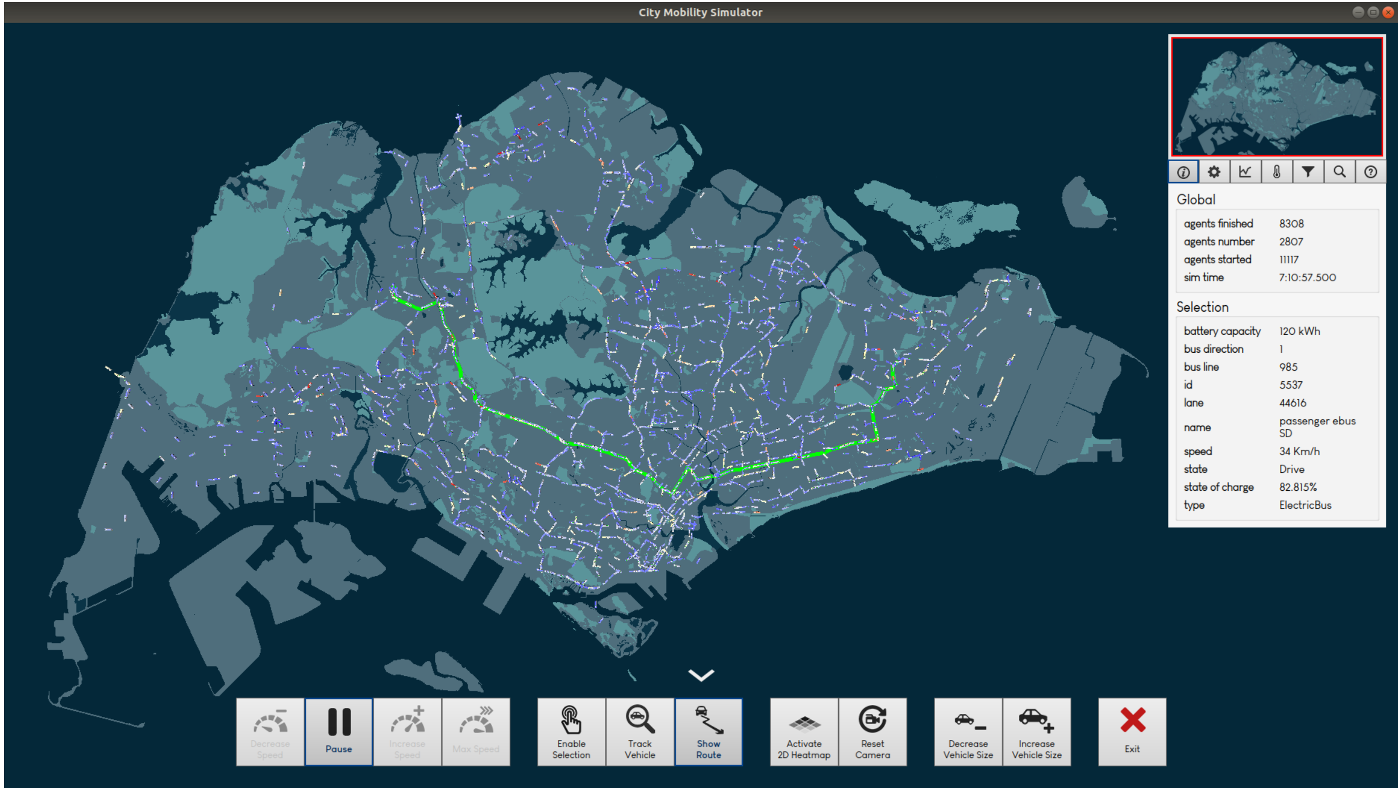
City-scale model of electric bus operation and charging in CityMoS

YouTube video
(duration 5:25 min)

https://zr.k.vu/citymos-bus-demo-1



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Outcomes – Exploration of various electrification scenarios

The flexibility of the model facilitates simulating different scenarios with varying parameters:

Bus model
- Single decker
- Double decker
- Articulated bus

Battery model
- Battery capacity
- *Battery type (LFP / NMC / LTO)*

Charging strategy
- Opportunistic at termini
- *Overnight at depot*
- *At bus stops*

Charging power
- Very fast
- Fast
- Slow

Bus infrastructure and operation
- Bus lines / termini / depots
- Location of chargers
- Departure headway

Percentage of fleet electrification

0% → 100%

Waiting queue priority

FIFO LIFO RANDOM

HSOC LSOC

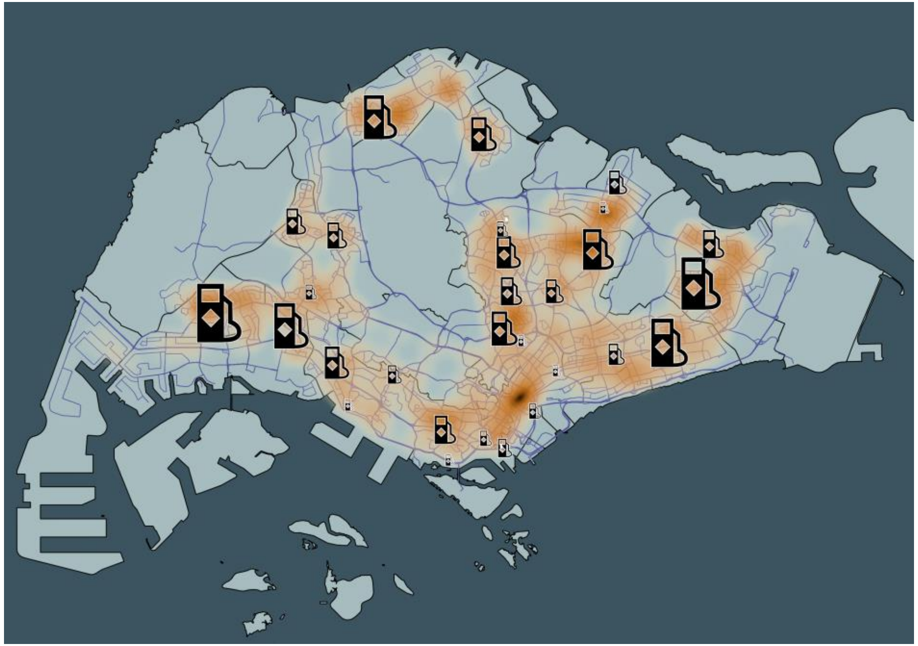
Outcomes – Feasibility analysis for various scenarios

To make the operation of electric bus feasible over many days:

- *How many chargers are required?*
- *What is the minimum size of the battery?*
- *What charging strategy should be used?*
- *…*

Different bus routes will have different requirements

- *Which bus routes are easier or harder to electrify?*



Illustrative representation of the number of chargers required at termini for electric buses.

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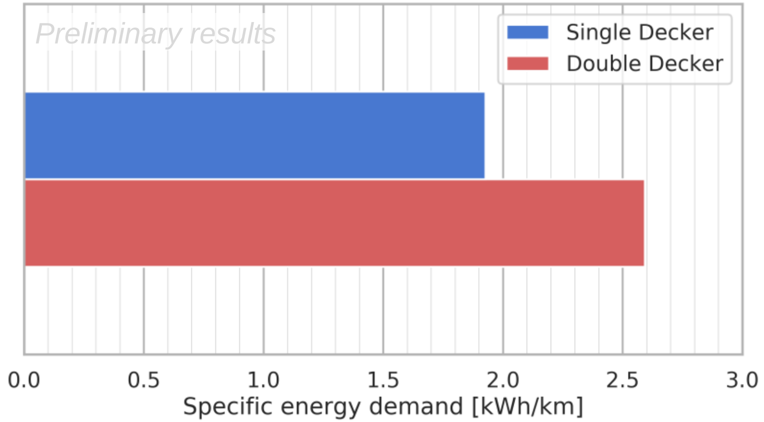
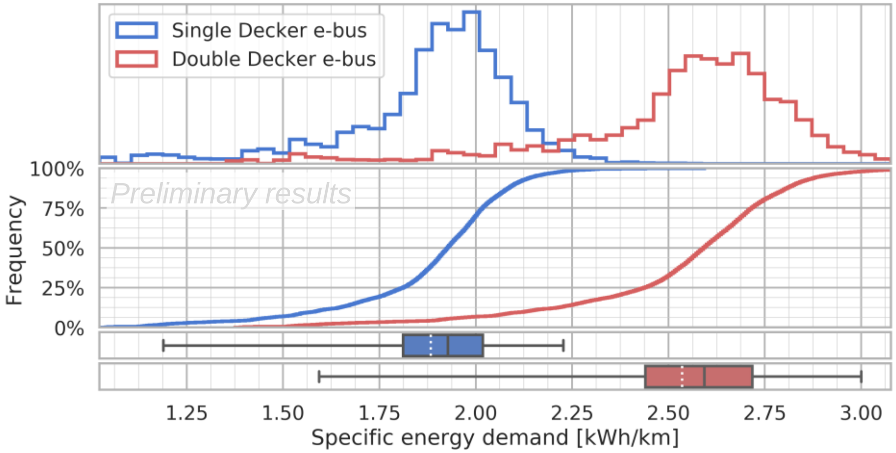
Preliminary results from CityMoS simulation – Specific energy demand

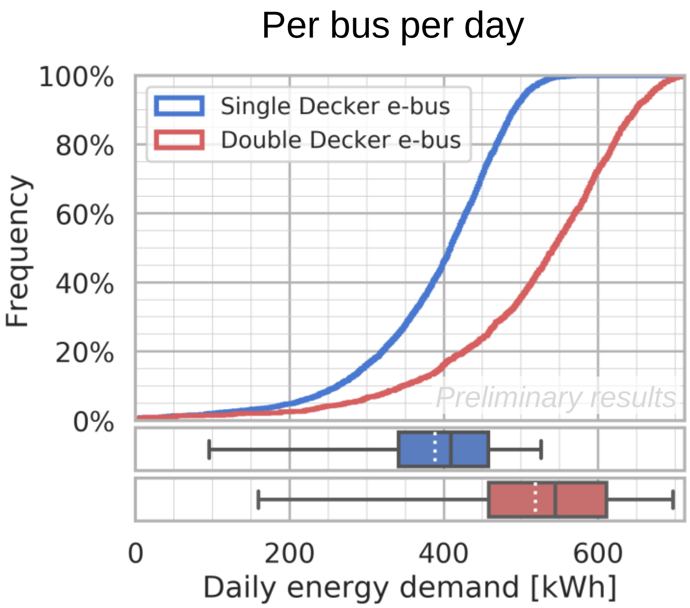
Median specific energy demand per trip

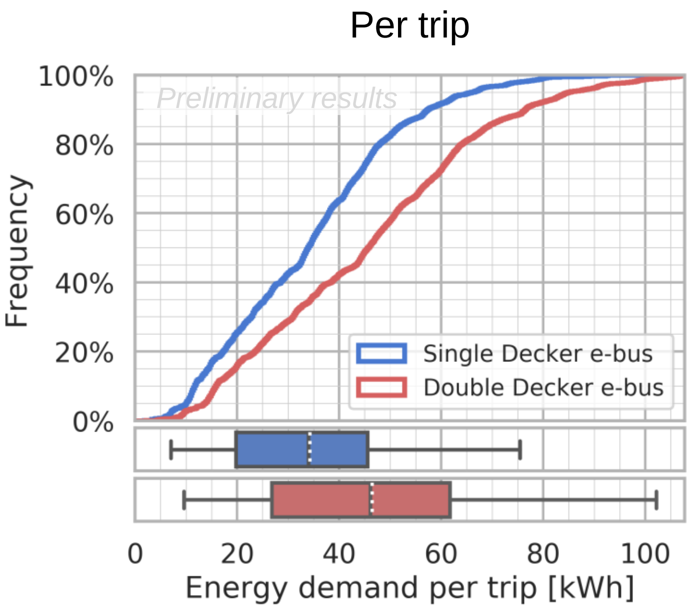


Distribution of the specific energy demand per trip



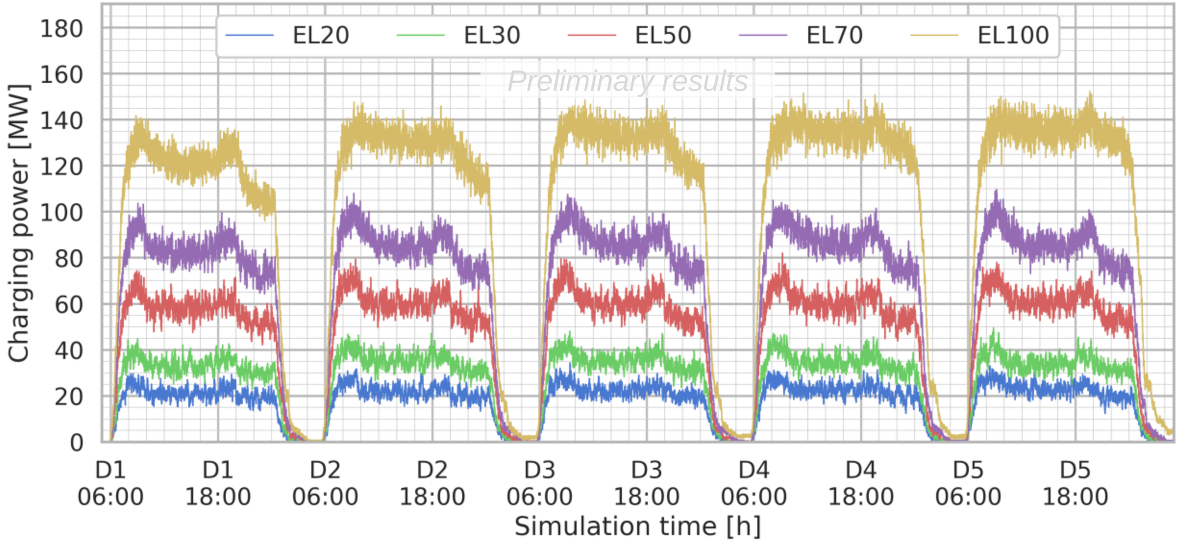
Preliminary results from CityMoS simulation – Absolute energy demand





Preliminary results – Scenario variation for different levels of electrification

Aggregated charging power over Singapore
(instantaneous)



For scenario 100% electrification:

Peak power:
~140 MW
(~2% of current SG power peak)

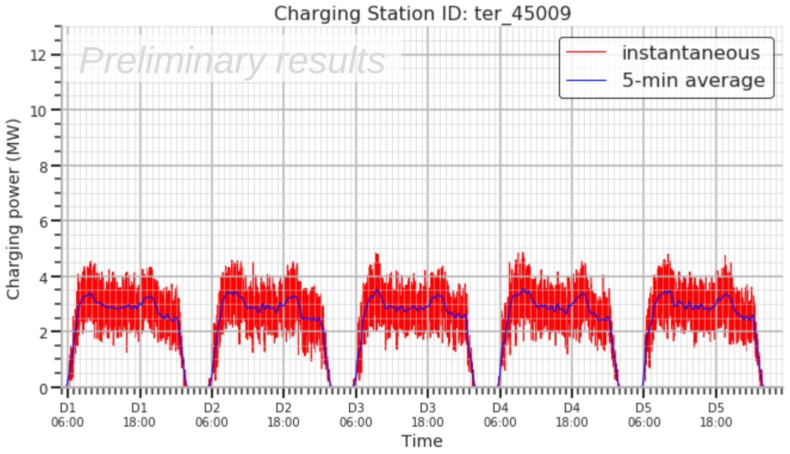
Short-term fluctuations:
~20 MW

(assumptions: electric buses always seek to charge if they are idle at terminus and a charger is available)

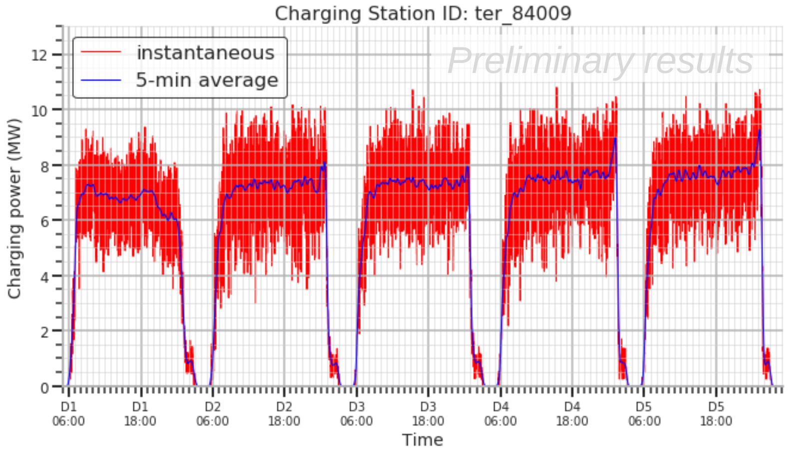
Preliminary results: Aggregated charging power demand for at bus termini

Fluctuations at the terminus level are more important relative to the installed absolute power than when aggregated at city-level → Impact on local grid?

Bukit Panjang



Bedok



(scenario 100% electrification)

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Thank You

Please contact Marc Gallet (marc.gallet@tum-create.edu.sg) for further questions

Presentation, publications and videos available at https://marc-gallet.fr