Framework for Considering Electrification of Bus Routes: Demonstration Experiment Using Osaka University Inter-Campus Shuttle Bus*

7 May 2024

Katsuya Sakai

Mobility System Joint Research Chair,

Graduate School of Eng., Osaka University

*Katsuya Sakai and Yutaka Ota, IEEJ Journal of Industry Applications, 144(7), July 2024 (in Japanese)

e-Mobility Digital Twin by Osaka University

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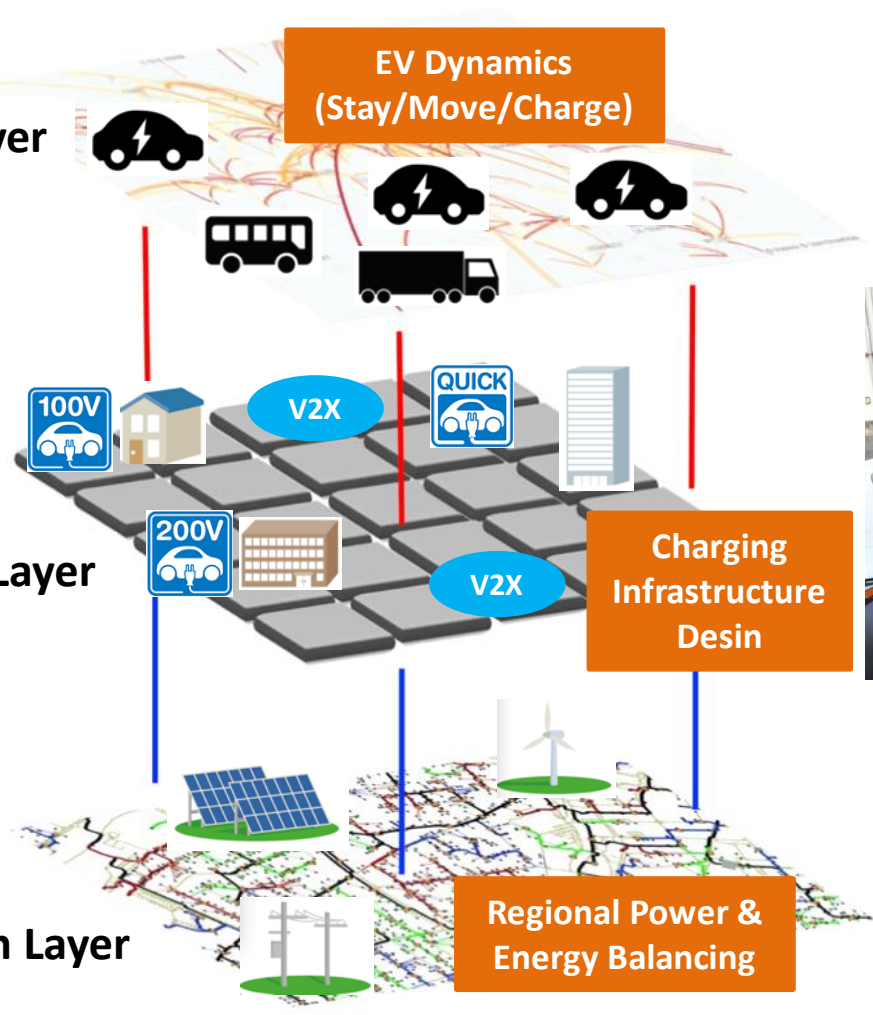
Future Scenarios
(Population/Stocks)
(Carbon Neutrality Target)

Stationary Infrastructure
(Electric Power/Road Network)
(House/Building/Chargers)

Flow Data
(People/Logistics/Vehicle)
(Climate/Power & Energy)



Prof. Ota

Assoc. Prof.
Yoshizawa

Data-driven, Stock and Flow estimated, Geographic Simulation Platform

[Y.Ota, S.Yoshizawa, K.Sakai, Y.Ueda, M.Takashima, K.Kagawa, and A.Iwata, "e-Mobility and Energy Coupled Simulation for Designing Carbon Neutral Cities and Communities", IATSS Research (2023/6)]

Osaka University Inter-campus Shuttle Bus

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- Osaka University has three campuses.
- 80 bus services are operated every school day.
- From October 2021, an electric bus was introduced.
- We have conducted demonstration experiment of considering electrification of bus routes.

Out-bound

Dec. 22, 2020 created

Bus #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Toyonaka		7:40	8:05	8:15	8:20	8:50	9:20	9:40	9:50	10:00	10:30	11:00	11:15	11:40	12:05	12:10	12:25	12:40	12:45	13:05	13:30	14:20	14:35	14:45	14:50
Minoh	7:45	8:00	↓	↓	8:40	9:10	↓	10:00	↓	10:20	10:50	↓	11:35	↓	↓	12:30	12:45	13:00	↓	↓	13:50	↓	↓	15:05	↓
Convention	8:00		8:30	8:40	8:55	9:25	9:45	10:15	10:15		11:05	11:25	11:50	12:05	12:30	12:45			13:10	13:30	14:05	14:45	15:00		15:15
Dept. of Eng.	8:05		8:35	8:45	9:00	9:30	9:50	10:20	10:20		11:10	11:30	11:55	12:10	12:35	12:50			13:15	13:35	14:10	14:50	15:05		15:20

Bus #	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Toyonaka	15:00	15:20	15:25	15:50	16:10	16:25	16:35	16:50	16:55	17:10	18:05	18:15	18:30	18:45	19:00	19:45	20:10
Minoh	15:20	↓	15:45	↓	↓	↓	16:55	17:10	↓	17:30	↓	18:35	18:50	↓	19:20	20:05	20:30
Convention	15:35	15:45	16:00	16:15	16:35	16:50			17:20	17:45	18:30	18:50		19:10	19:35	20:20	20:45
Dept. of Eng.	15:40	15:50	16:05	16:20	16:40	16:55			17:25	17:50	18:35	18:55		19:15	19:40	20:25	20:50

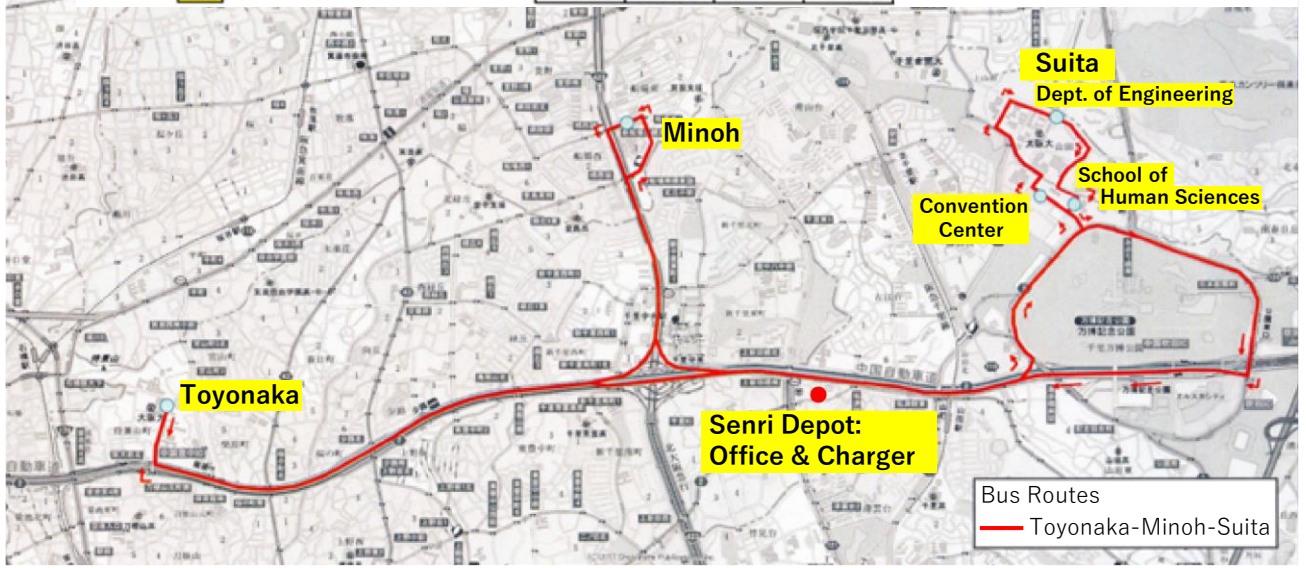
In-bound

Bus #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Dept. of Eng.		8:05	8:50	9:05	9:35	9:50	10:20	10:30	11:15	11:35		12:00	12:10		12:50	13:35	14:15	14:50		15:05	15:20	15:40	15:50	16:05	16:25
Human Sci.		8:10	8:55	9:10	9:40	9:55	10:25	10:35	11:20	11:40		12:05	12:15		12:55	13:40	14:20	14:55		15:10	15:25	15:45	15:55	16:10	16:30
Minoh	8:00	8:30	↓	9:30	10:00	↓	↓	10:55	11:40	↓	12:05	12:25	↓	12:45	↓	14:00	14:40	↓	15:05	15:30	↓	↓	16:15	16:30	↓
Toyonaka	8:20	8:50	9:20	9:50	10:20	10:20	10:50	11:15	12:00	12:05	12:25	12:45	12:40	13:05	13:20	14:20	15:00	15:20	15:25	15:50	15:50	16:10	16:35	16:50	16:55

Bus #	26	27	28	29	30	31	32	33	34	35	36	37	38
Dept. of Eng.	16:40		16:55		17:30	17:50		18:15	18:35		19:00	19:25	20:10
Human Sci.	16:45		17:00		17:35	17:55		18:20	18:40		19:05	19:30	20:15
Minoh	↓	16:55	↓	17:10	17:55	↓	18:25	18:40	↓	18:50	19:25	19:50	20:35
Toyonaka	17:10	17:15	17:25	17:30	18:15	18:20	18:45	19:00	19:05	19:10	19:45	20:10	20:55

00:00 Electric Bus

Depot Dept. 9:20 Depot Arr. 19:25



Objectives

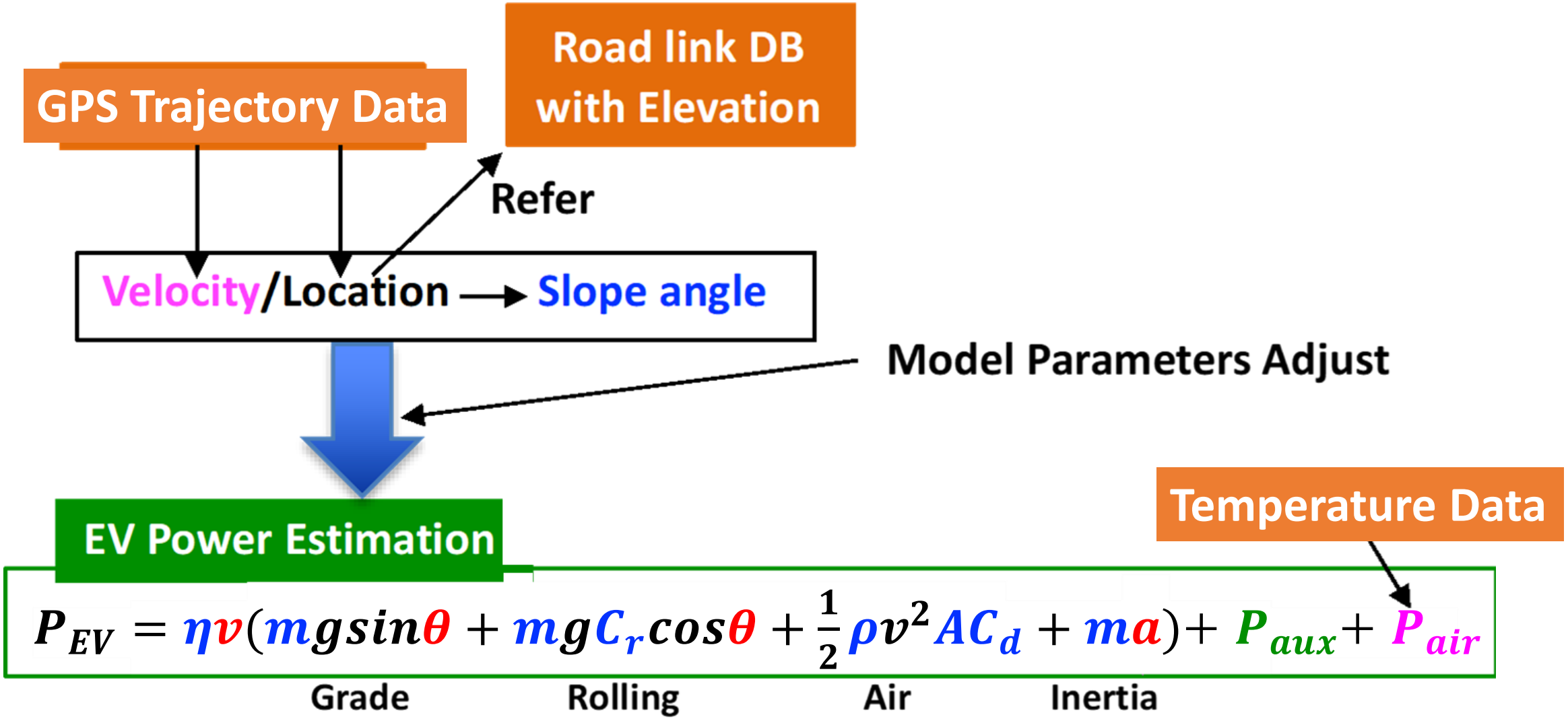
- To understand electric bus power consumption and its fluctuation factors
- To construct framework to consider electrification of bus routes

- We examine the possibility of the bus routes electrification in terms of:
  (1) Driving range
  (2) Charging schedule at bus depot

BYD K8

GPS logger installed at bus front

Kinematic Model to Estimate Power



η: drive system efficiency, v: speed, a: acceleration, ϑ: slope angle, m: vehicle weight, C_r: rolling resistance coefficient, ρ: air density, A: vehicle front area, C_d: air resistance coefficient, P_{aux}: auxiliary power, P_{air}: air conditioning power

Model Parameters and Output Example

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η=0.95

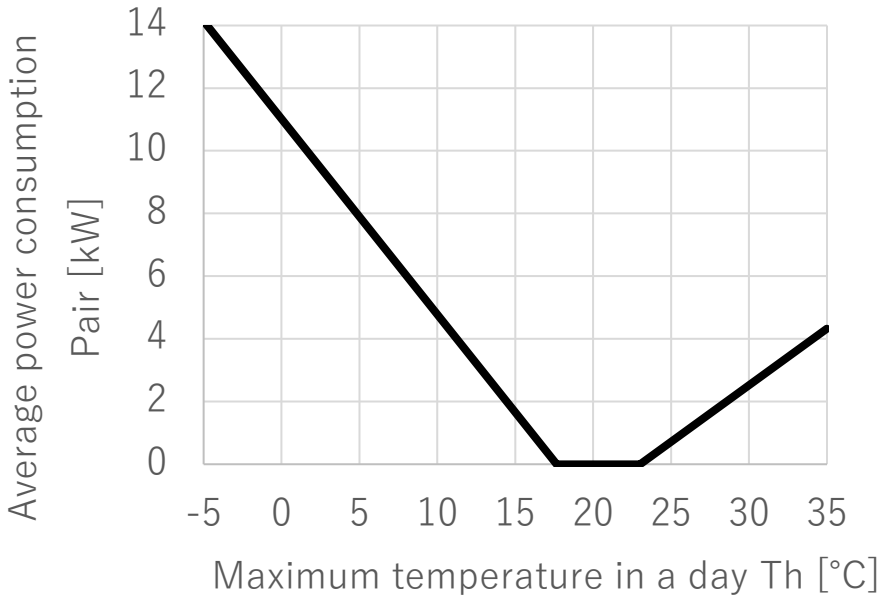
C_r=0.015

C_d=0.7

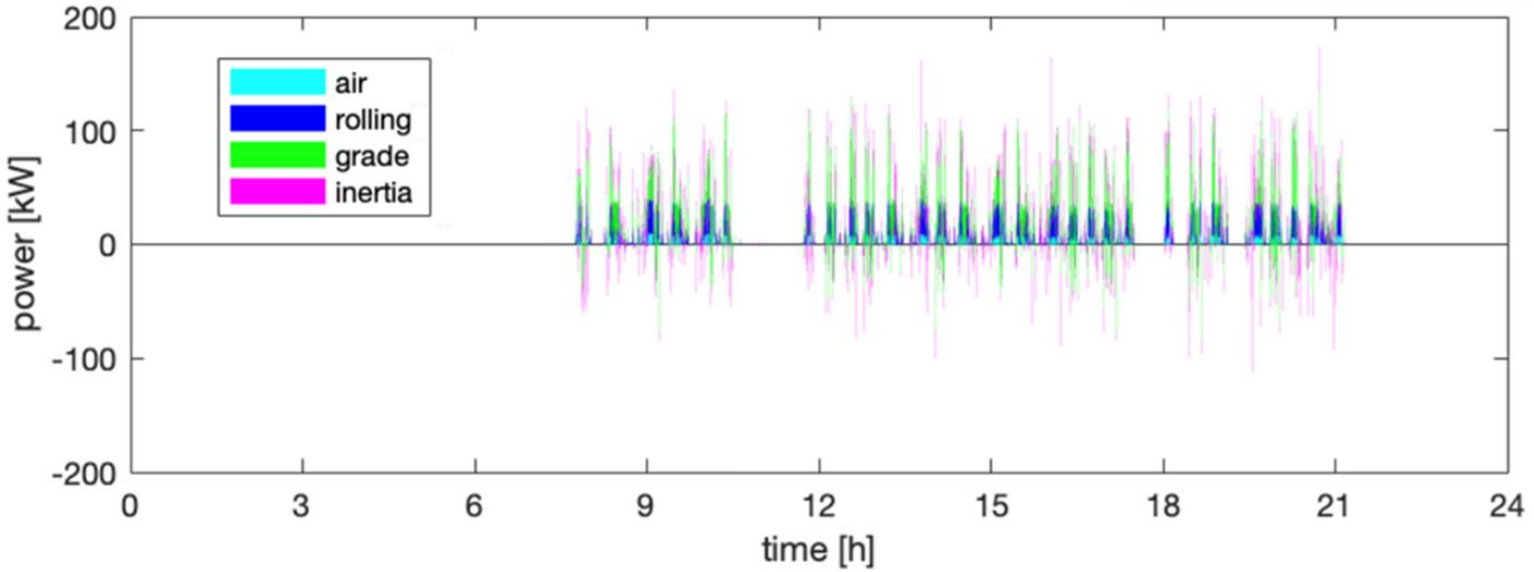
P_{aux}=600 [W]

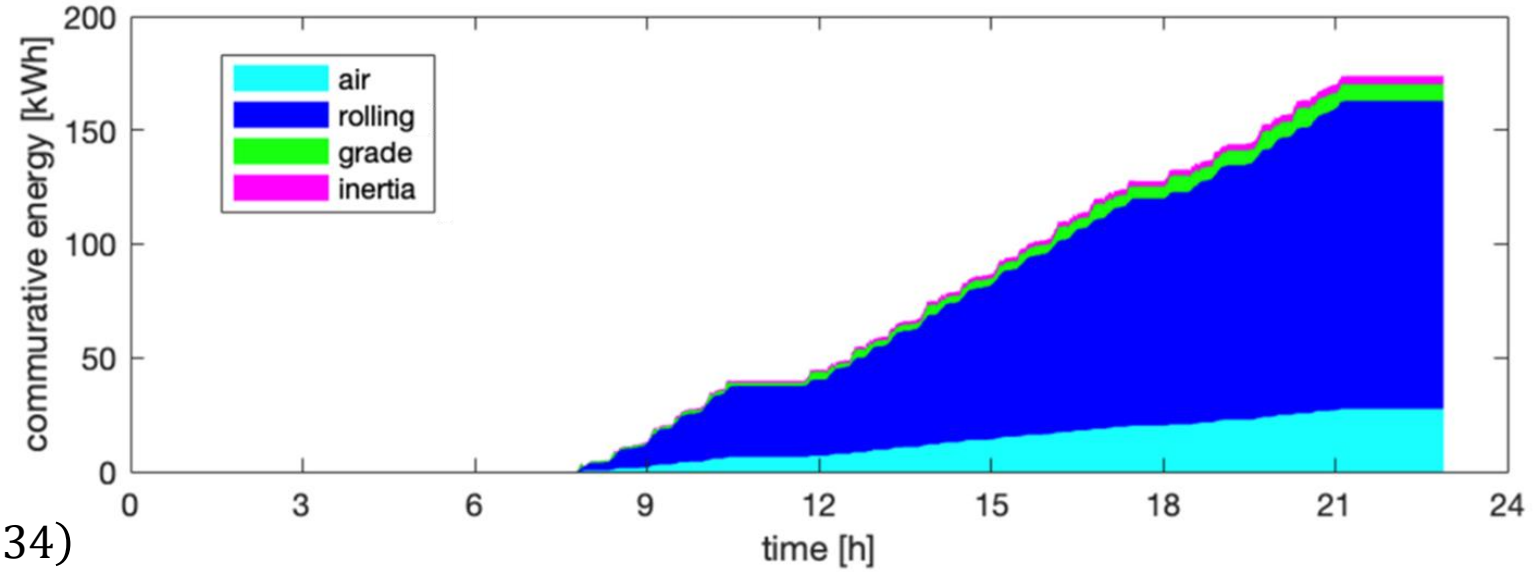
A=2.5×3.36=8.4 m^2

m=11850+55*30=13,500 kg



$$P_{air} = max(-0.63T_h + 11.03, 0, 0.36T_h - 8.34)$$





Estimated vs Actual Energy Consumption a Day

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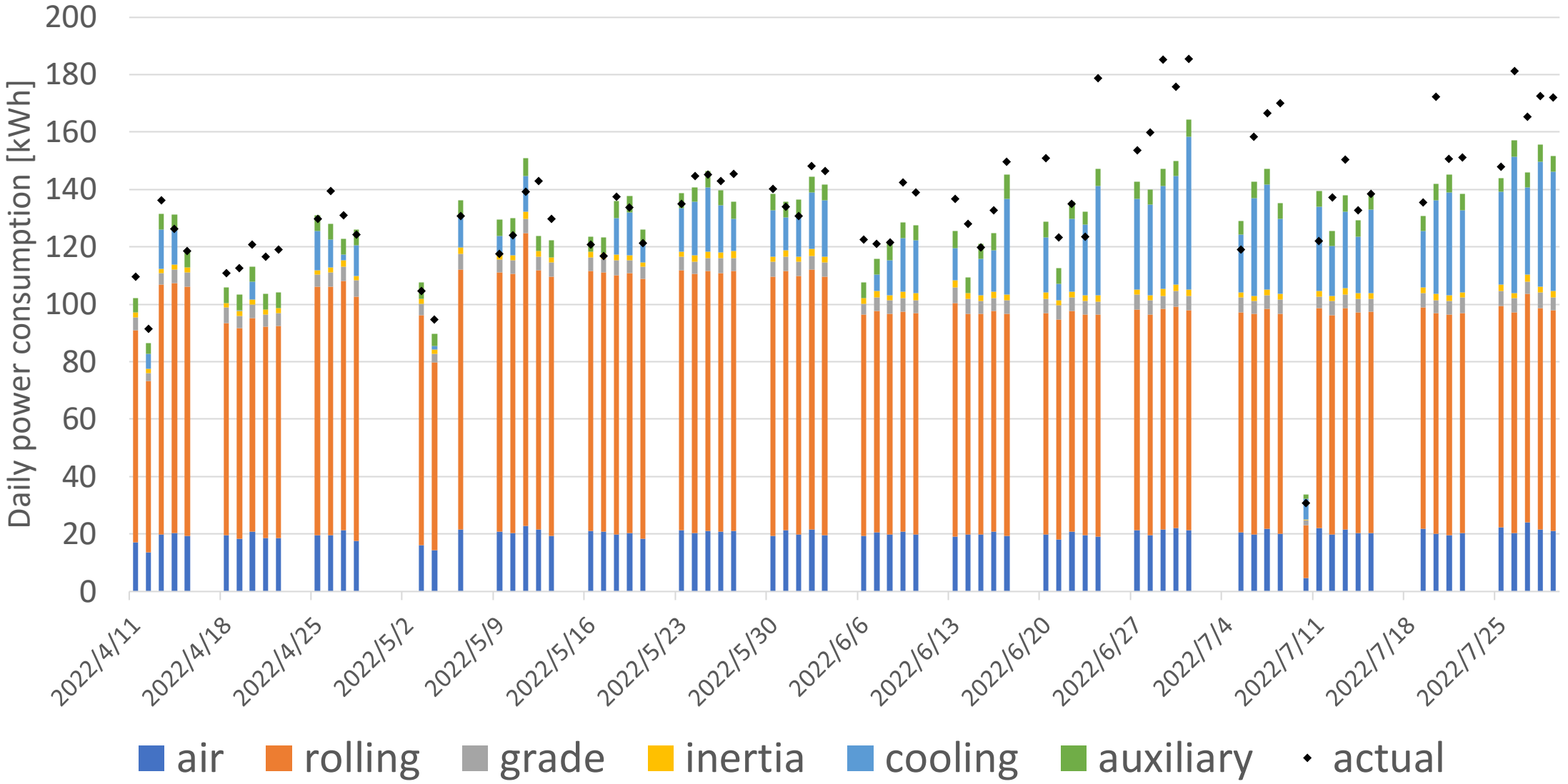
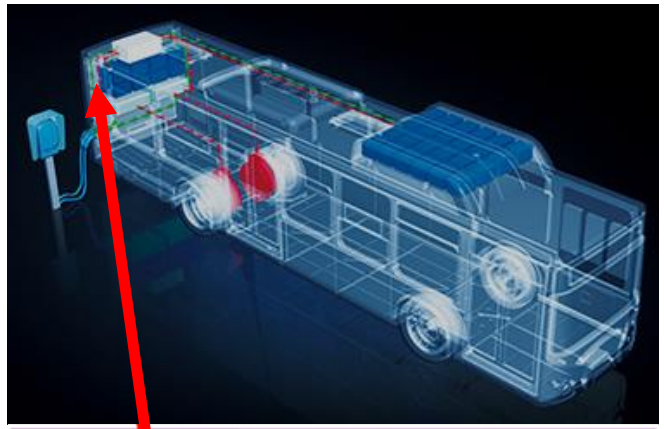
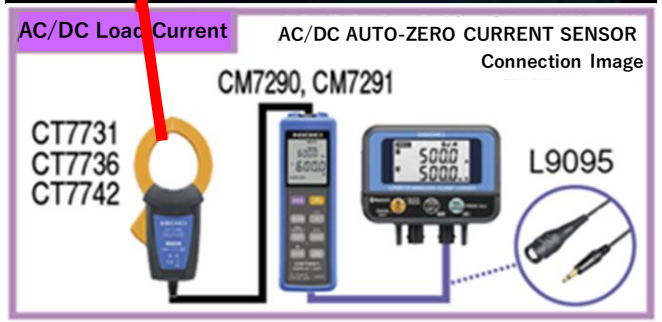
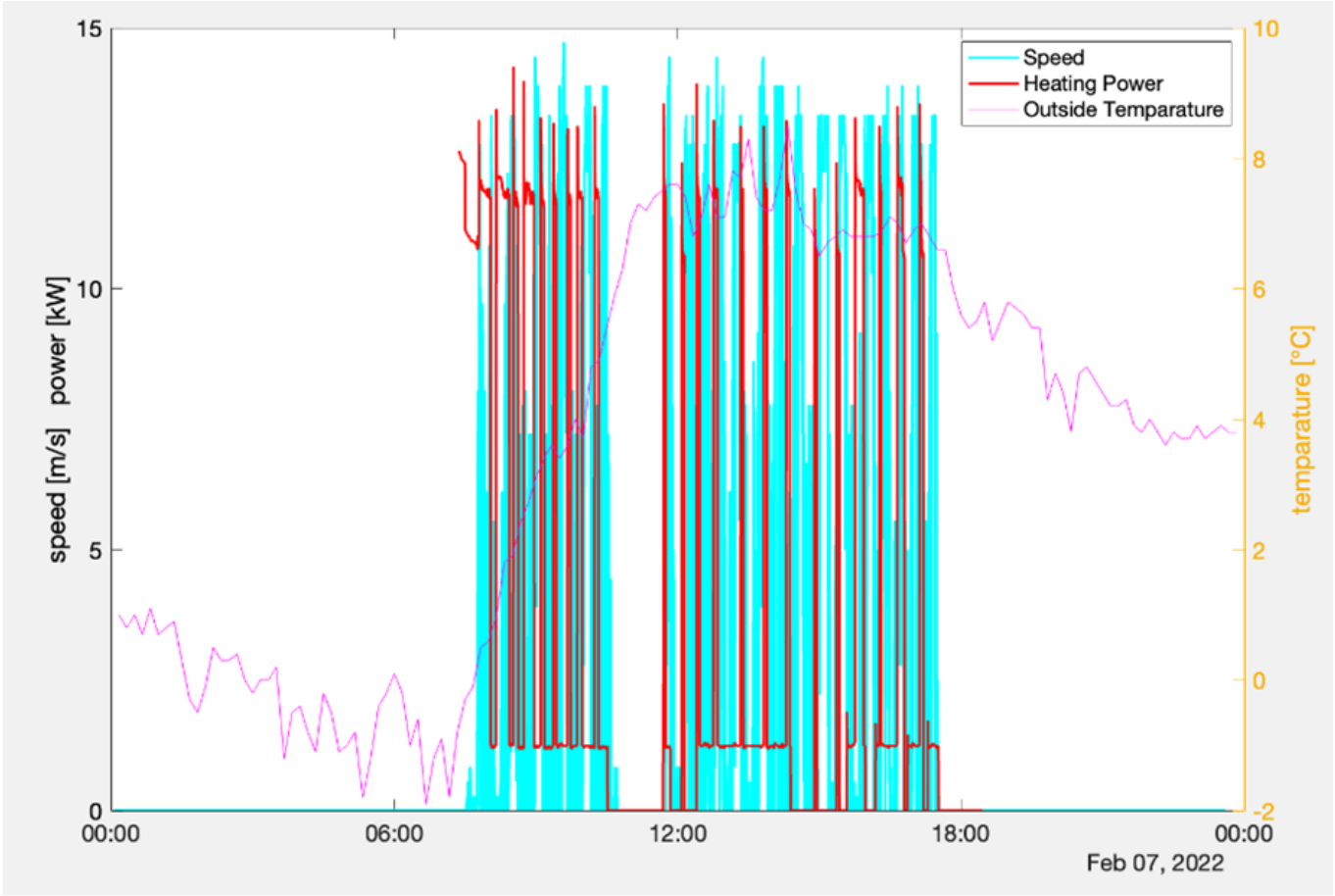


To improve model accuracy...







- Current loggers installed to measure air conditioning energy and total energy consumption
- Heating power on/off behavior could be observed.

Improved Model

Drive system efficiency:

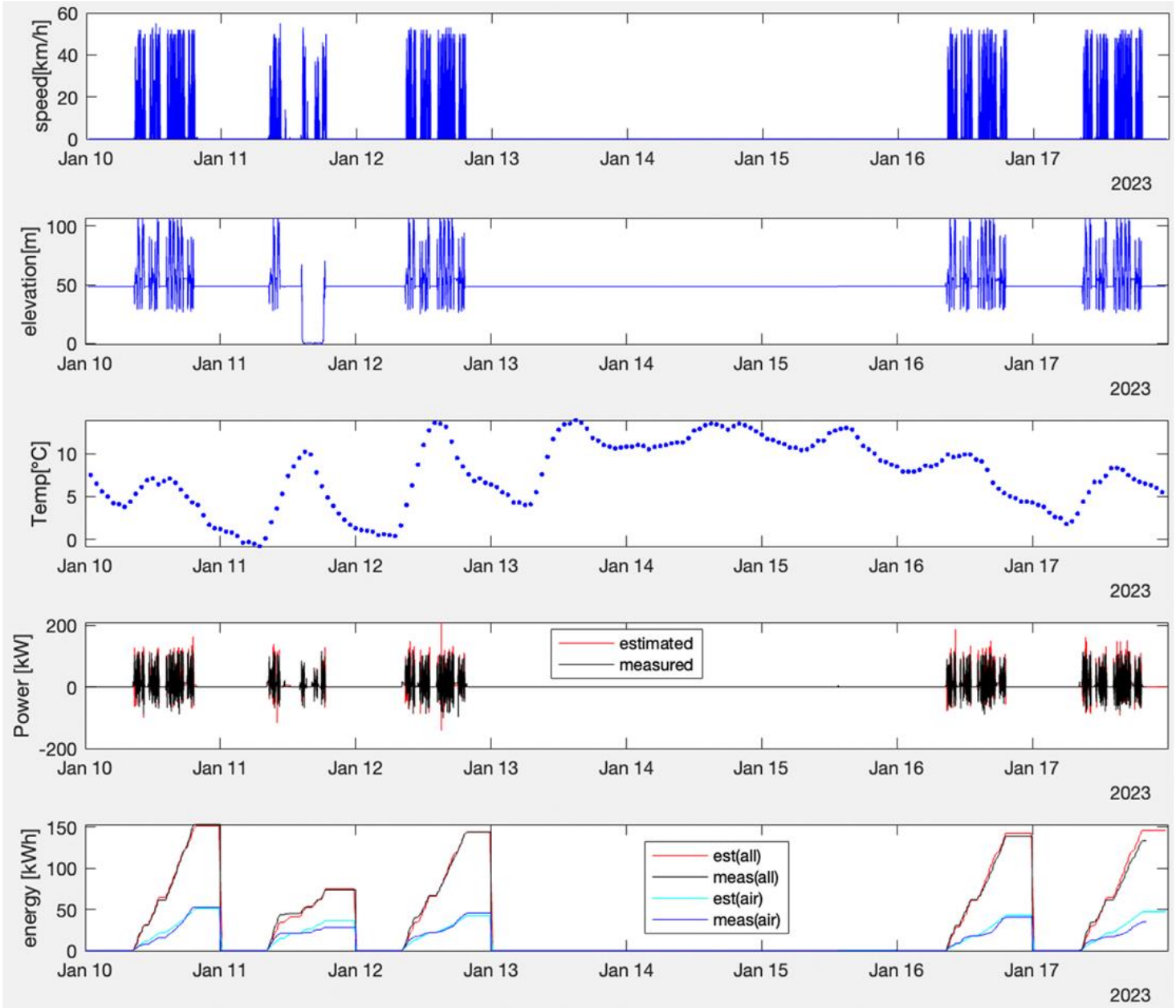
Power η_p=0.95

Regeneration η_r=0.85

Air conditioning:

Heating Pair=7kw-300W/℃

Cooling Pair=200W/℃



Electric Bus Charging Management Model

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Input Data

- GPS Trajectory
- Temperature
- Office Electricity Contract and Equipment
- Chargers number and specs

Estimation Model

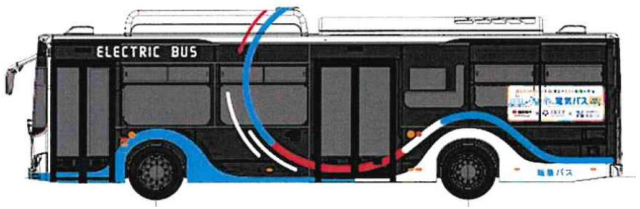
- Driving Power Consumption
- Air Conditioning Power Consumption
- Office Power Demand

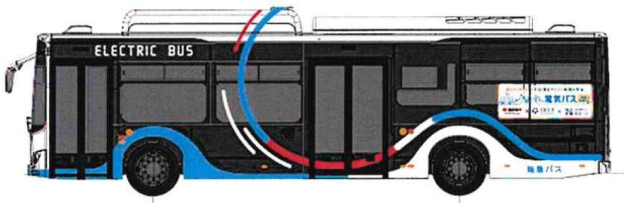
$+ \int$ → Electric Bus Daily Power Consumption

Output Data

Office Power Demand Including Electric Bus Charging Power

Valley Filling Algorithm:
Electric bus charging power is determined as the maximum within the contracted power availability.

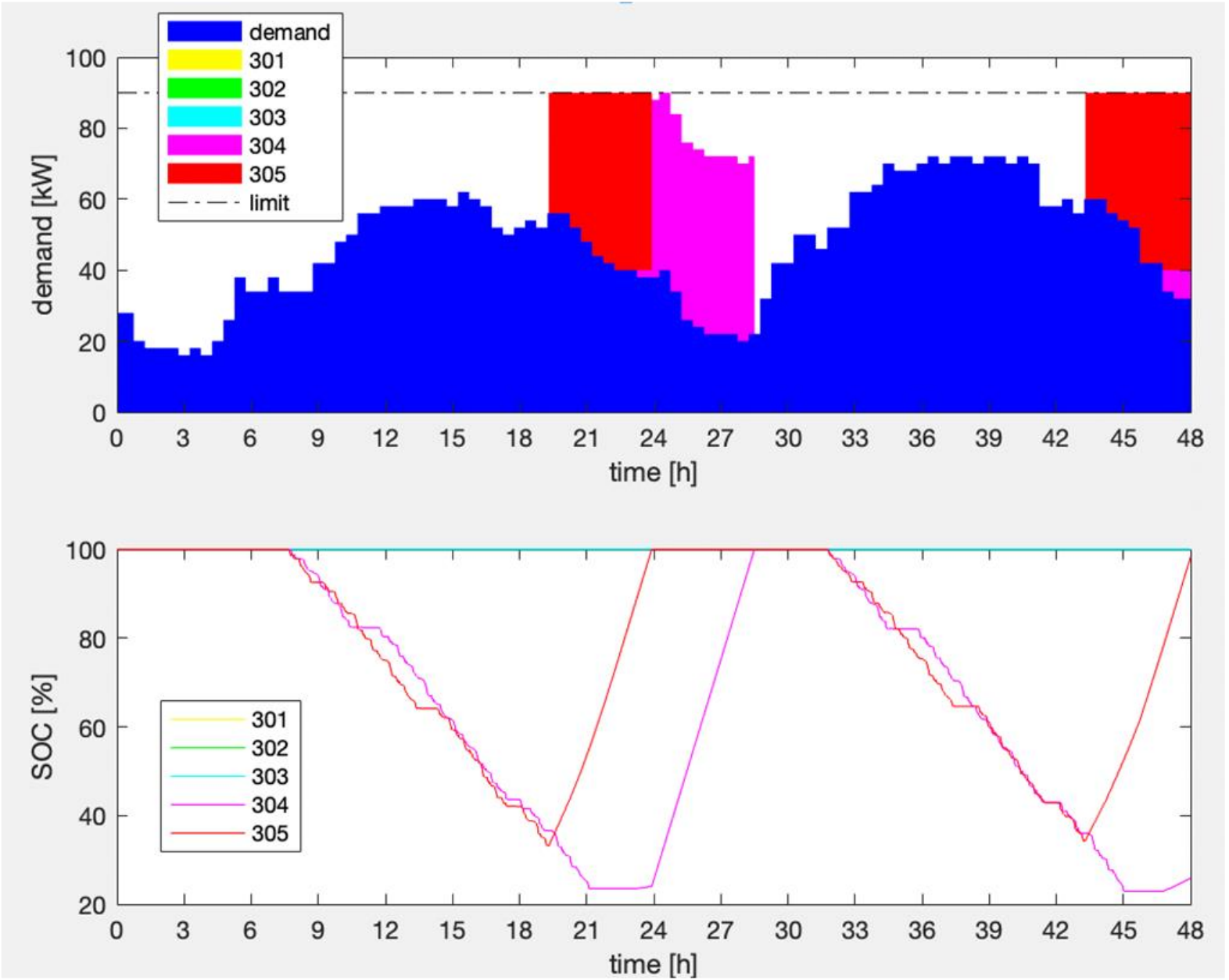




Charging power:
50 kW

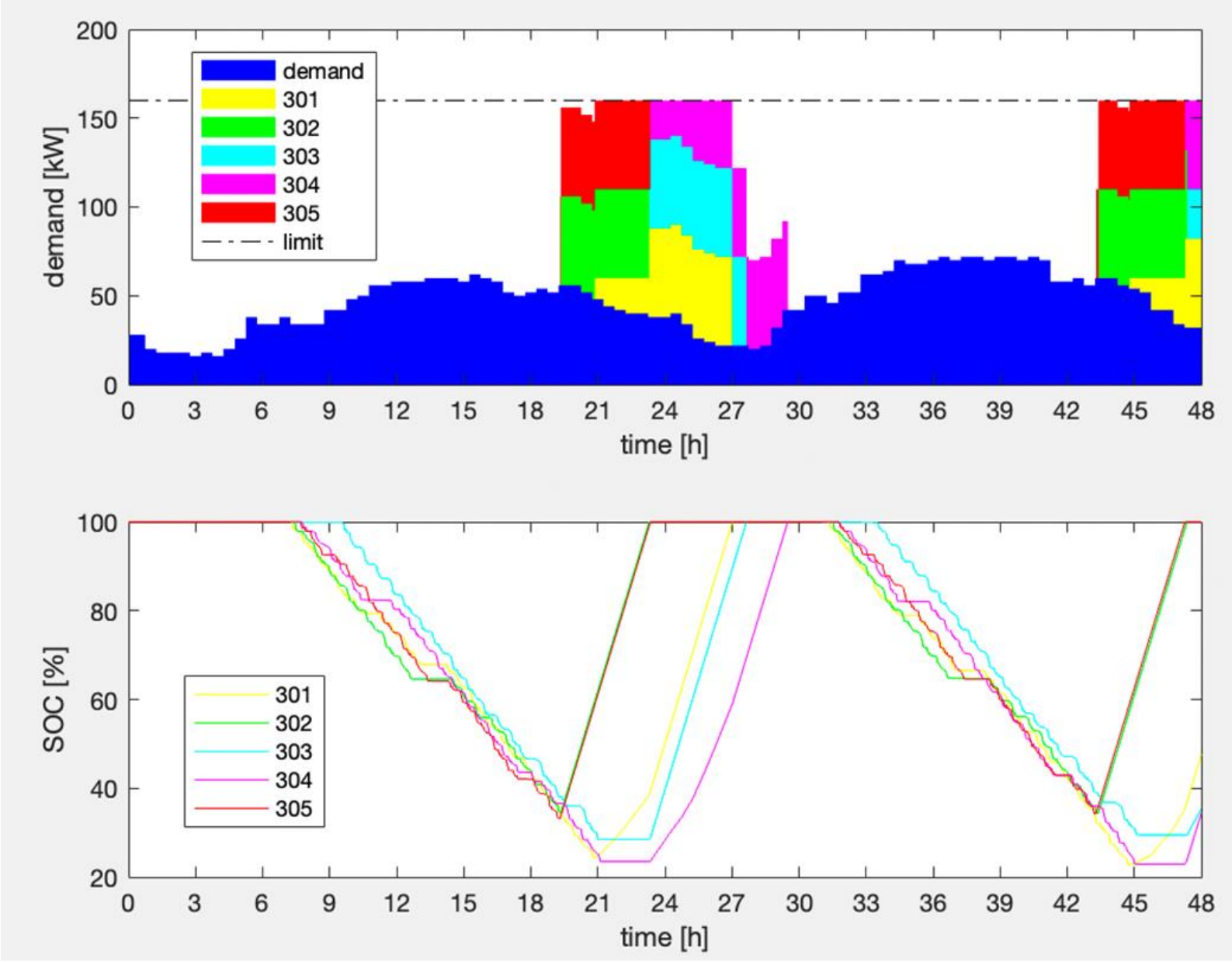
Energy Consumption & Charging Simulation

- Two buses are simulated for two days.
- Contract power is 90 kW.
- Two buses charge is finished at 5am.



Energy Consumption & Charging Simulation

- Case study with assuming all five buses are electrified.
- Contract power is 160 kW.
- All buses charge is finished at 6am.



Summary

- Power consumption estimation simulation
  - Estimating power consumption/regeneration by each factor (rolling/air/ascending/acceleration/auxiliary/cooling/heating) from GPS trajectory data and temperature data

- Simulation of energy management at an e-bus depot
  - Simulation of charge/discharge connected from power consumption estimation simulation

Summary

- Practical steps to consider electrification of bus routes are:

  (1) Installing a GPS sensor on a current bus and driving it to estimate the power consumption of the running and auxiliary parts

  (2) Collecting data on seasonal temperature forecasts

  (3) Simulating change in SOC and estimating the risk of electricity shortage in advance to install electric bus.