VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD

Bus line simulations

eBus Troms

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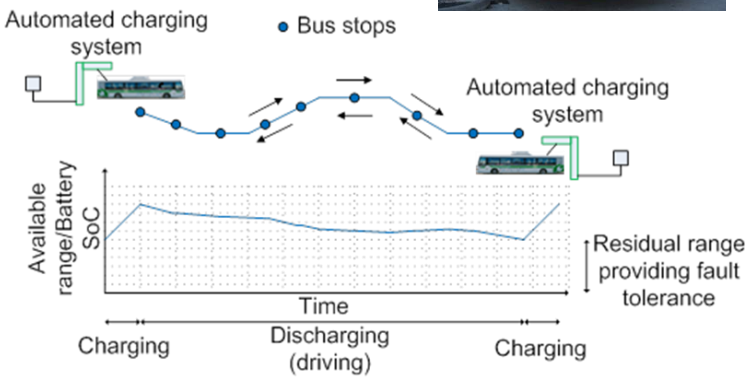
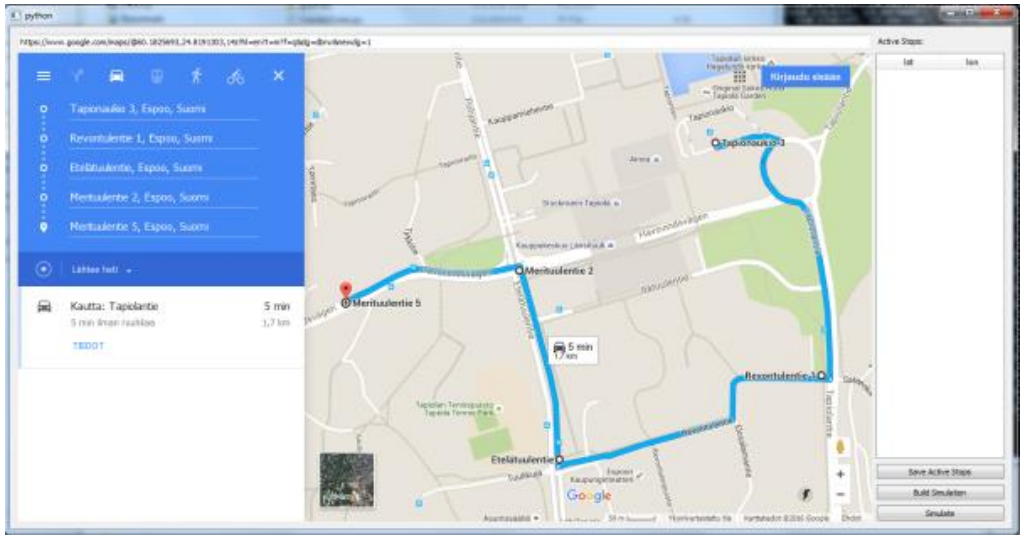
Main challenges in introducing electric buses in cities

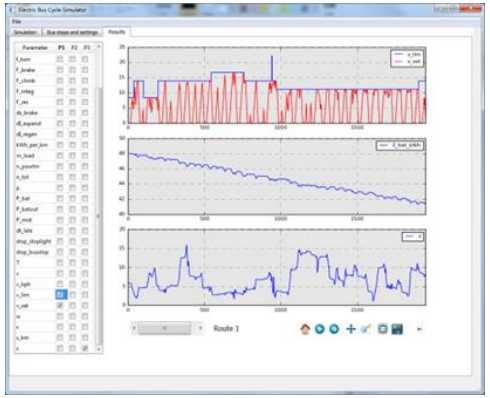
- What is the cost of electric bus systems?
- Which bus lines to electrify?
- How to secure the reliability of the system?
- Where to place and how to dimension charging infrastructure?
- What are the operational (energy) margins and flexibility?
- How to prepare for disturbances?
- What happens in winter conditions?
- How to scale up (roll-out phase)?

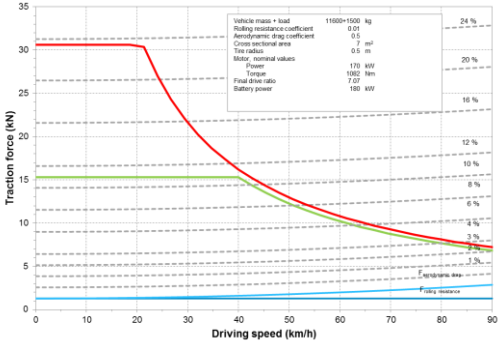


Our solution: GIS-based tool for the design of electric bus systems

- Combining open-source input with specific expertise
- Utilises existing data from environment, road network and public transportation system registers, schedules etc.
  - Any city, line or duty
- Electric bus database
  - Efficiency maps of components
  - Environmental conditions and energy use
  - Power curves in charging
- Validation by comparing to data collected from real operation







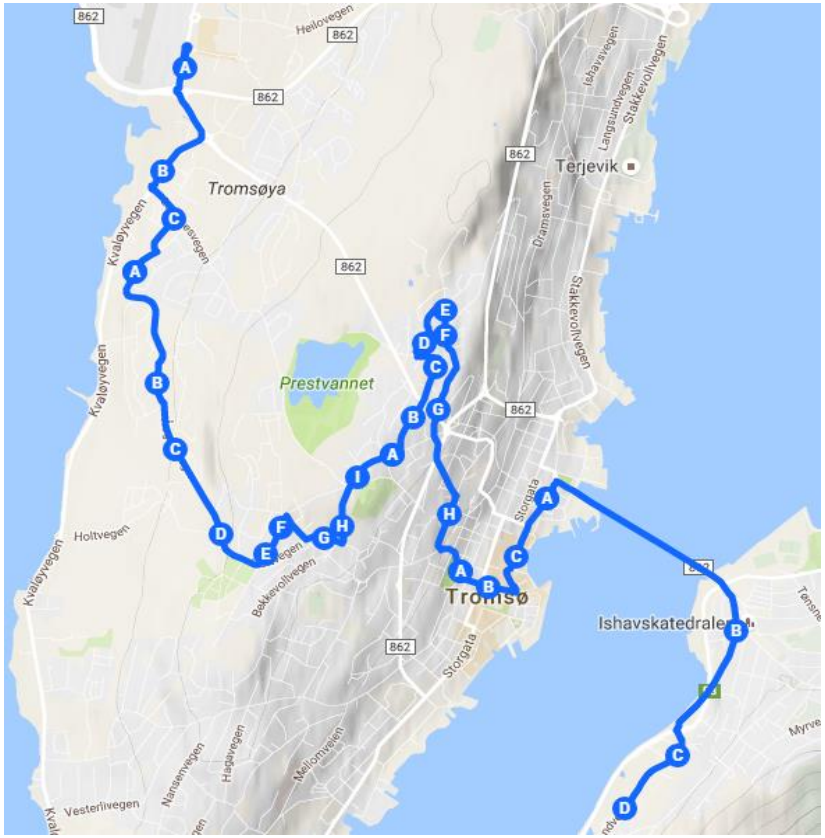
Analysis workflow

- Construction of bus lines using geographical data
- Selection of bus parameters
  - Special requirements: steep hills, snow chains, slippery roads
- Validation of speed profile
- Simulations line by line in varying conditions
- Sensitivity analysis

Construction of bus lines

- Lines 26, 32, 33 – 34, 37 and 40 analysed
- Bus lines constructed based on data from open sources (OpenStreetMap, Google Maps, HERE Maps)
- Bus line data include: elevation, bus stops, speed limits, crossings
- Bus line data does not include pedestrian crossings and stop lights
- Elevation data was filtered in order to obtain a smooth and realistic profile

Bus line 26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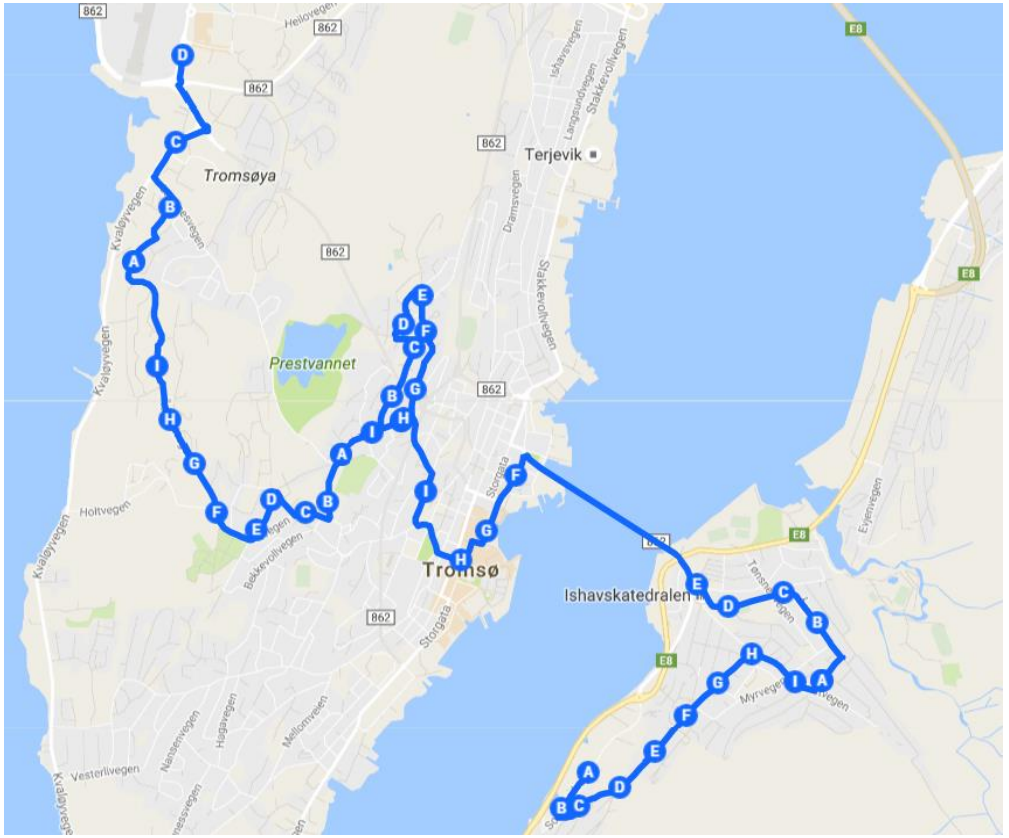
Terjevik
Prestvannet
Tromsø
Ishavskatedralen
Storgata
Holtvegen
Kvaløyvegen
Bekkevollvegen
Stakkevollvegen
Vesterlivegen
862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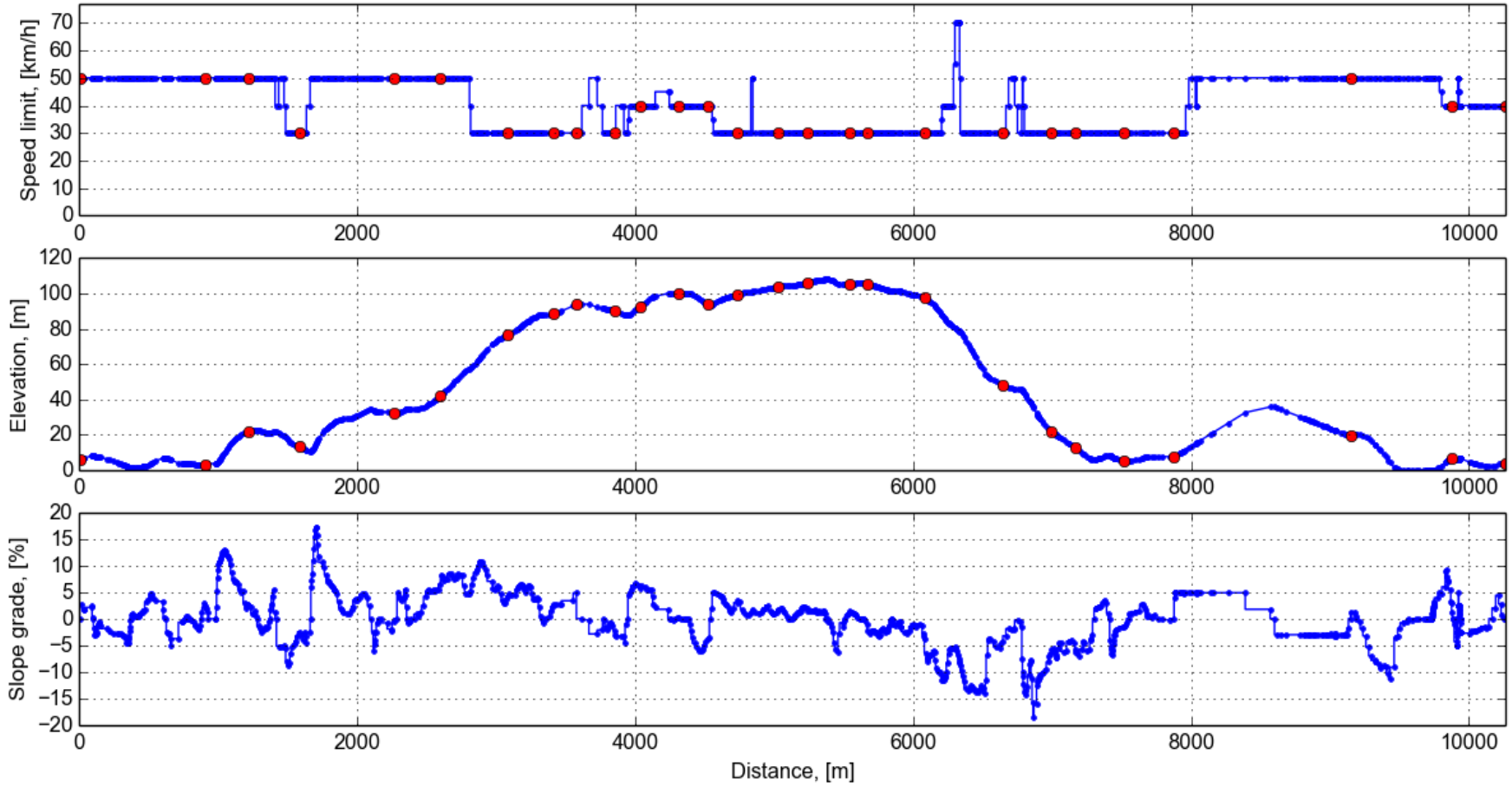
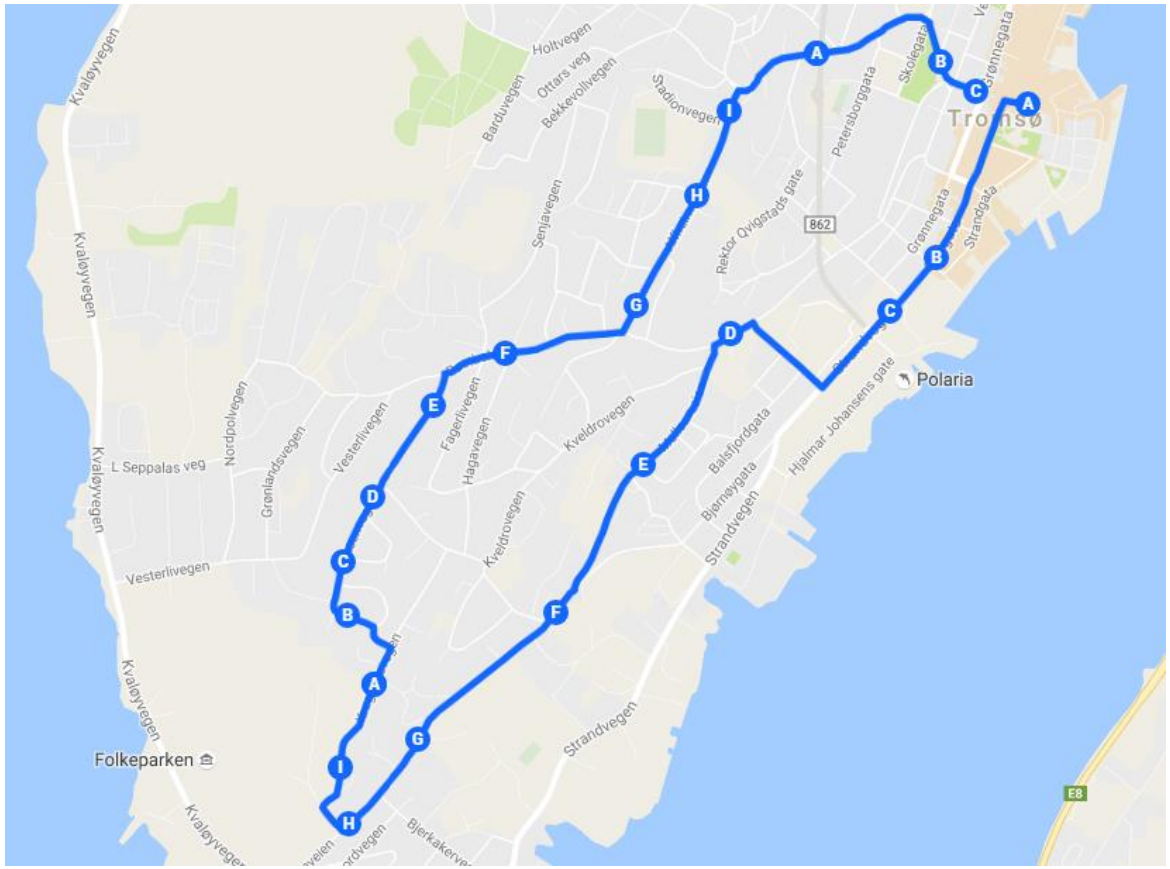
Terjevik
Prestvannet
Tromsø
Ishavskatedralen
Storgata
Holtvegen
Kvaløyvegen
Bekkevollvegen
Stakkevollvegen
Vesterlivegen
862
E8

Bus line 26 (part one)



Bus line 37


Kvaløyvegen
Holtvegen
Ottars veg
Bekkevollvegen
Barduvegen
Stadionvegen
Senjavegen
Rektor Qvigstads gate
Petersborgata
Skolegata
Grønnegata
Strandgata
862
Tromsø
Polaria
Hjalmar Johansens gate
Balsfjordgata
Bjørnøygata
Strandvegen
Kveldrovegen
Fagerlivegen
Hagavegen
Vesterlivegen
Nordpolvegen
Grønlandsvegen
L Seppalas veg
Folkeparken
E8
A
B
C
D
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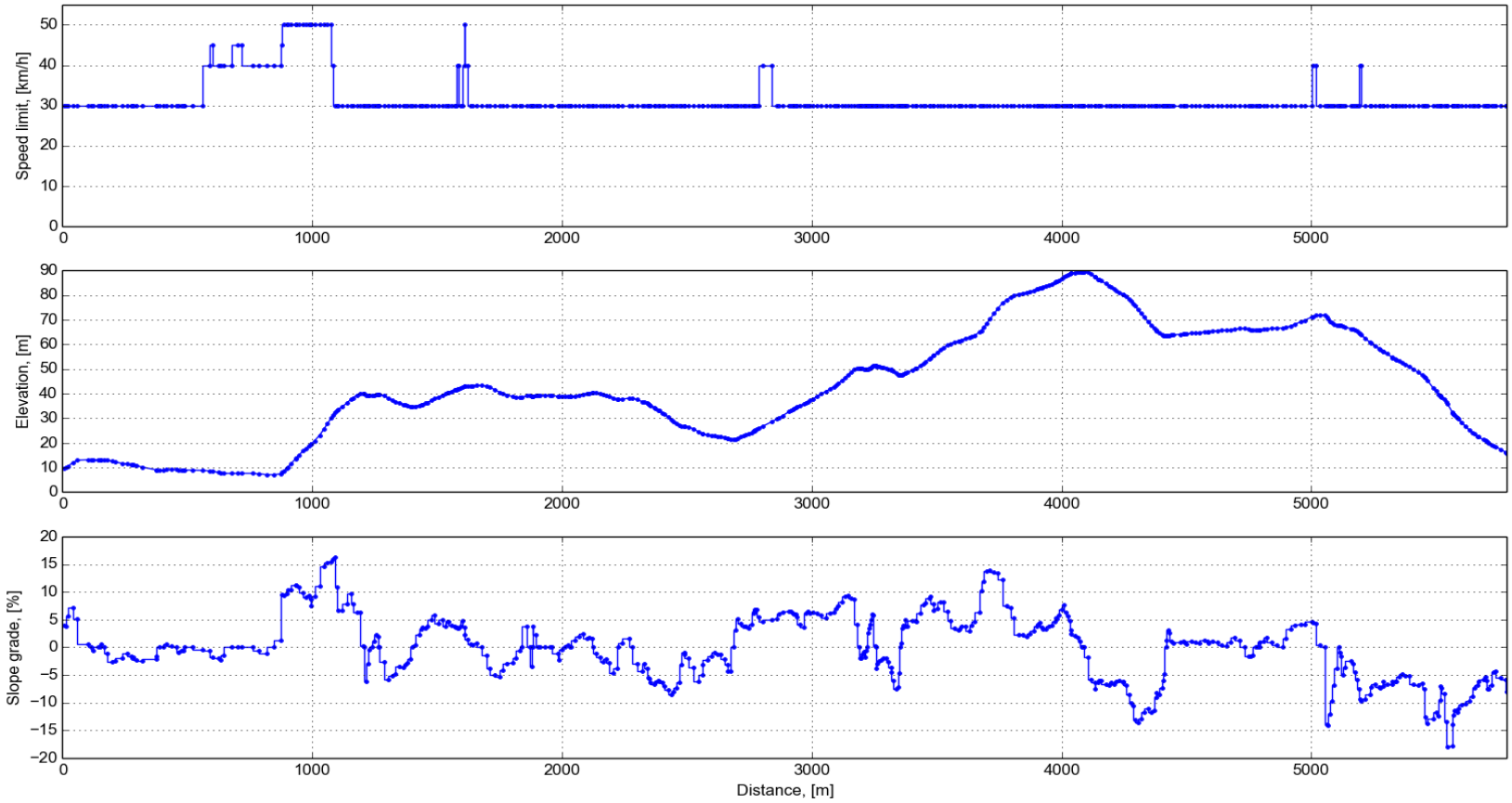
H
I

Bus line 37

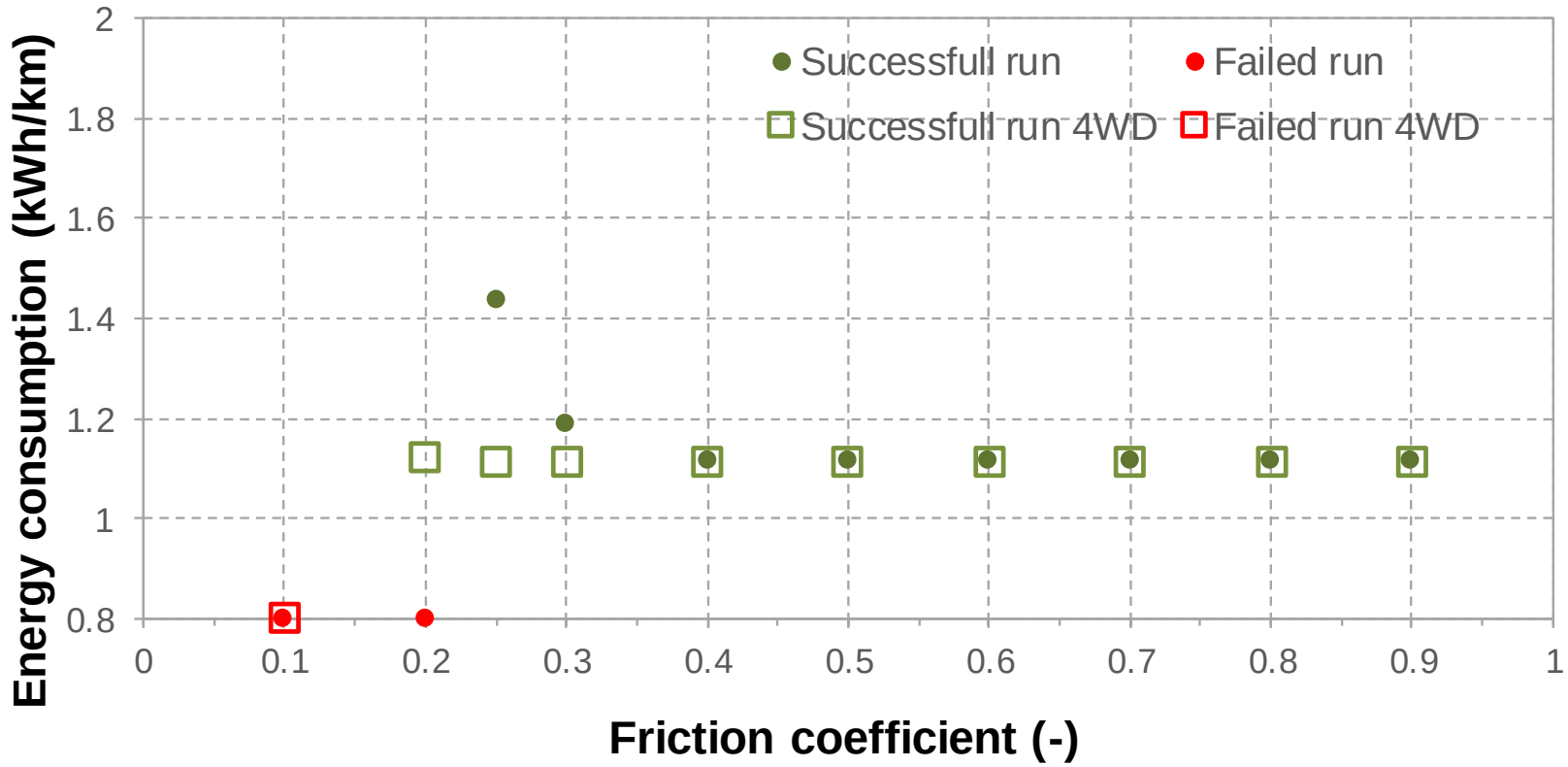

Speed limit, [km/h]
0
10
20
30
40
50
0
1000
2000
3000
4000
5000
Elevation, [m]
0
10
20
30
40
50
60
70
80
90
0
1000
2000
3000
4000
5000
Slope grade, [%]
−20
−15
−10
−5
0
5
10
15
20
0
1000
2000
3000
4000
5000
Distance, [m]

Bus models

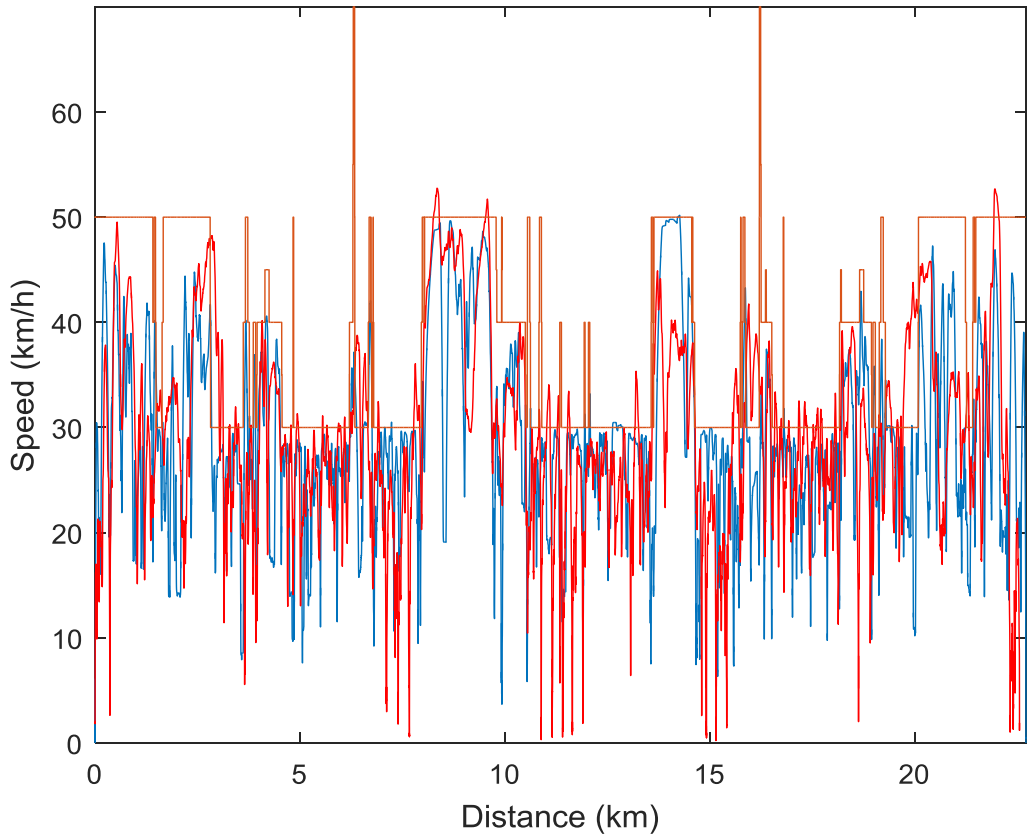
- Two 12 m long buses were analyzed: depot charged bus (charging night time) and opportunity charged bus (charging at end bus stops)

Bus type	Opportunity charged	Depot charged
Chassis weight (kg)	10000	10000
Battery capacity (kWh)	80	250
Bus mass (kg)	11600	15000
Maximum speed (km/h)	75	70

Comparison with four-wheel drive bus



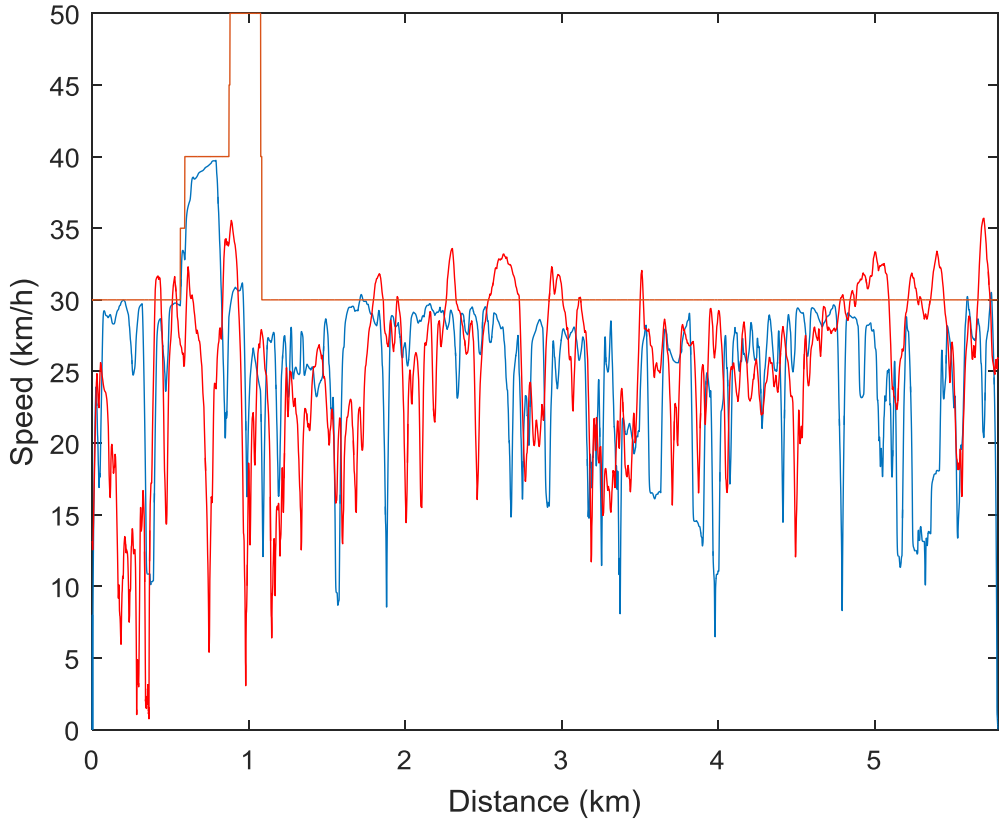
Simulation speed profile validation, bus line 26



- Measured speed (red curve)

- Simulated speed (blue curve)

Simulation speed profile validation, bus line 37



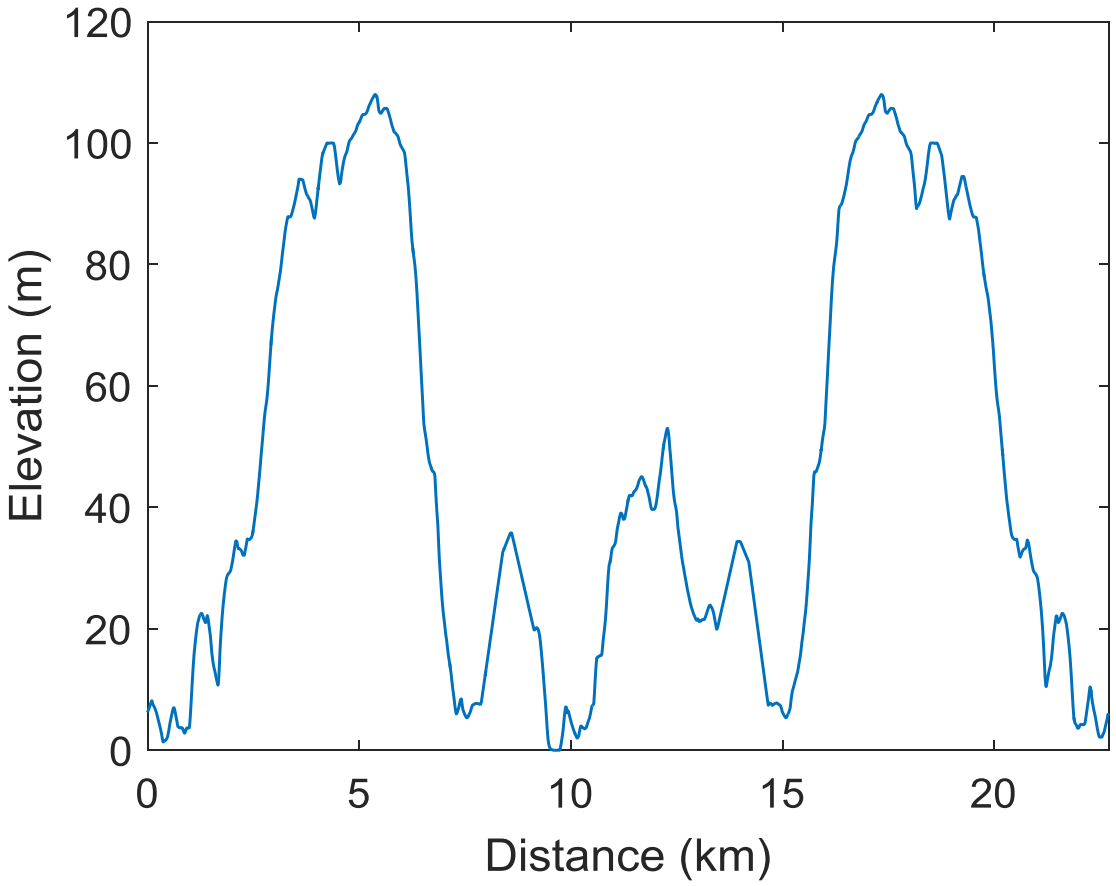
- Measured speed (red curve)

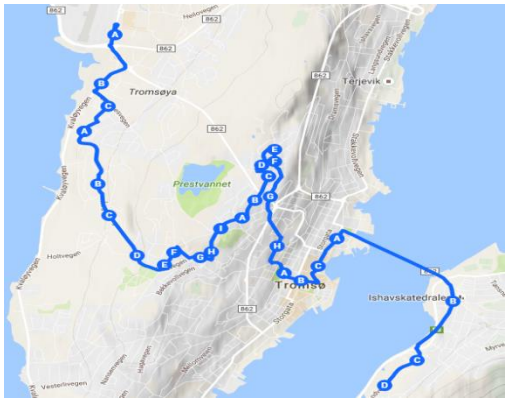
- Simulated speed (blue curve)

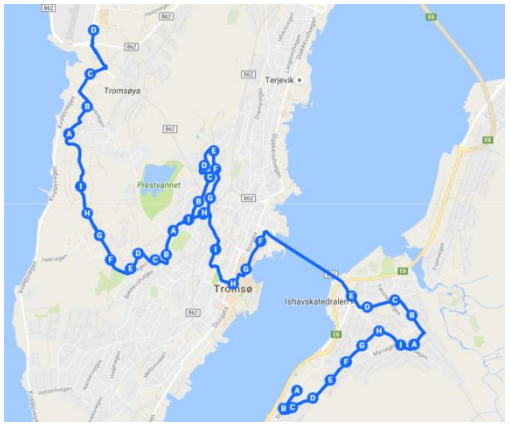
Simulations

- Simulations were performed on each bus line in different conditions
- The passenger load was varied from 0 – 90 passengers, corresponding to 0 – 6120 kg
- Stopping frequency was varied from half of bus stops to all bus stops
- Traffic incidents were modelled by random variations in the speed profile
- All cases were simulated both with and without snow chains

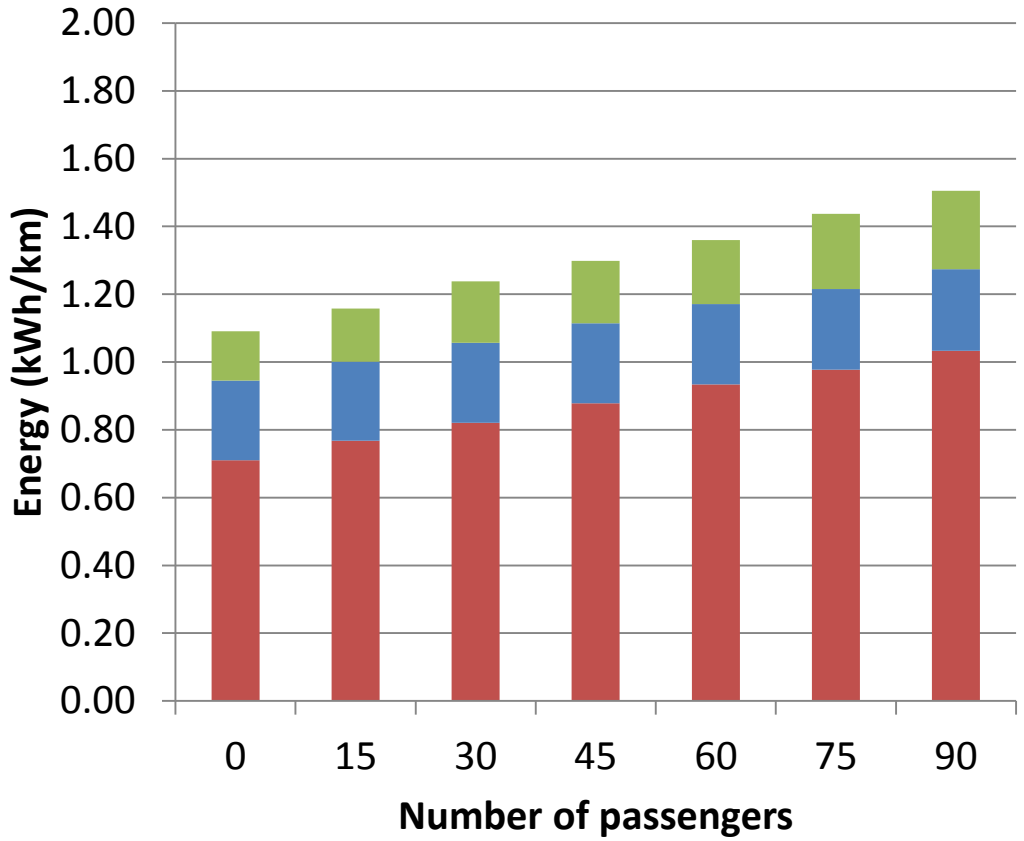
Elevation curve, line 26

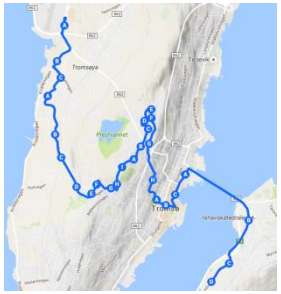


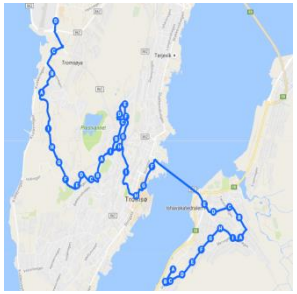




Simulation results on line 26, opportunity charged bus





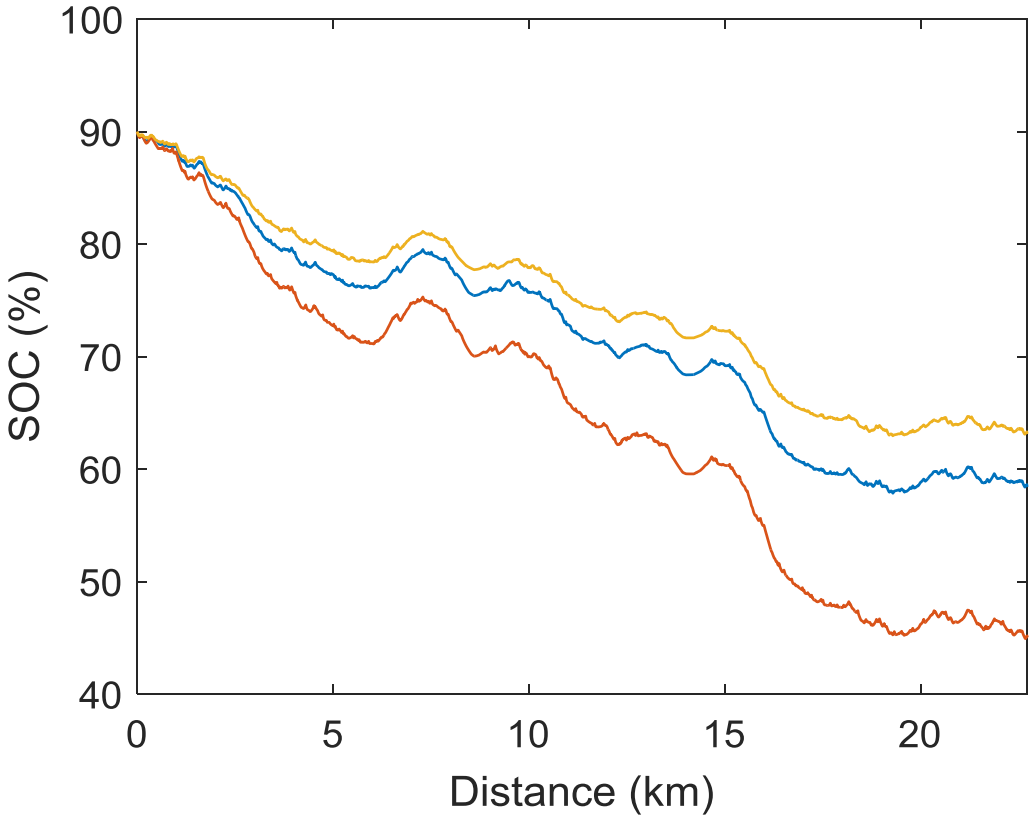


Energy due to snow chains

Auxiliary systems and HVAC

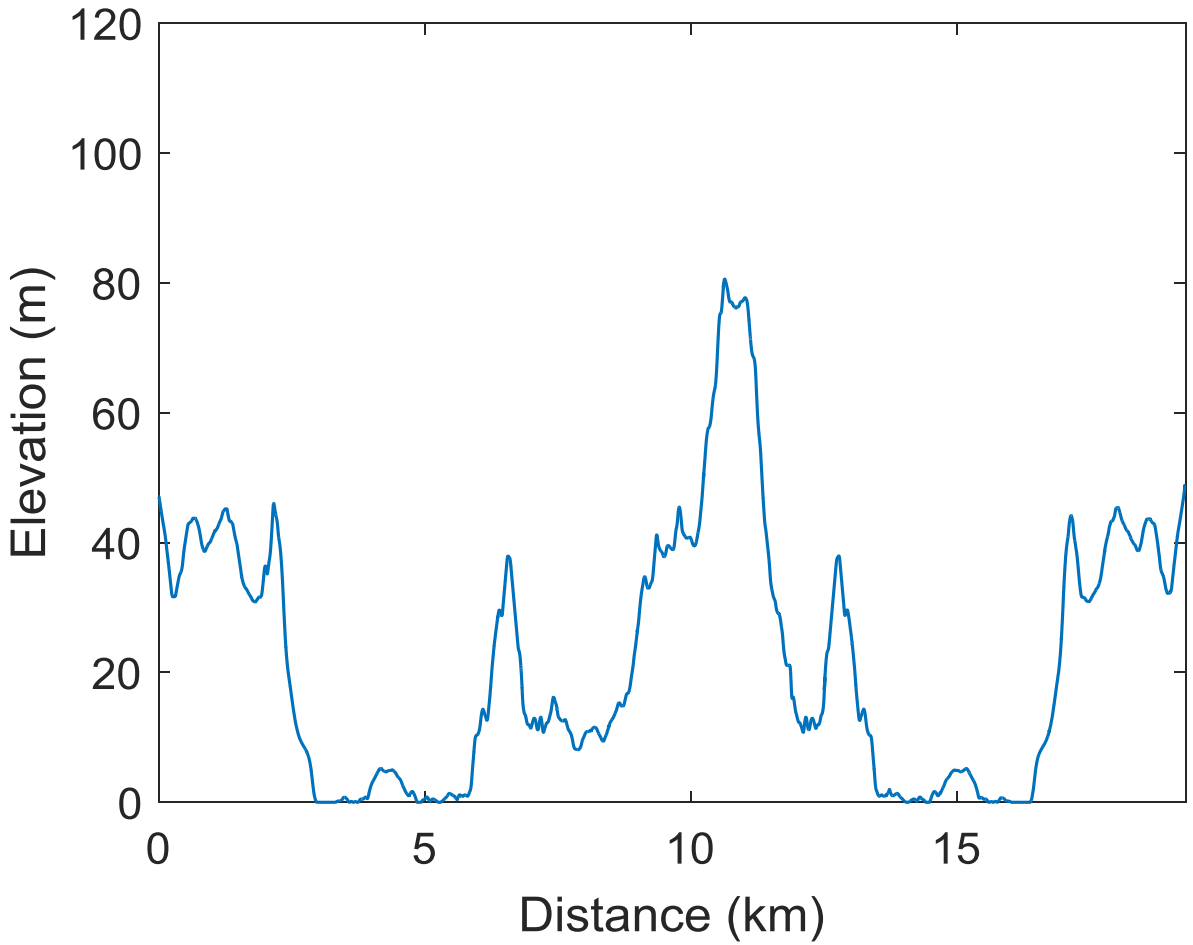
Energy for driving

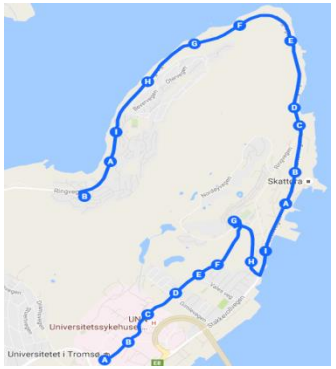
Battery state of charge on line 26, opportunity charged bus

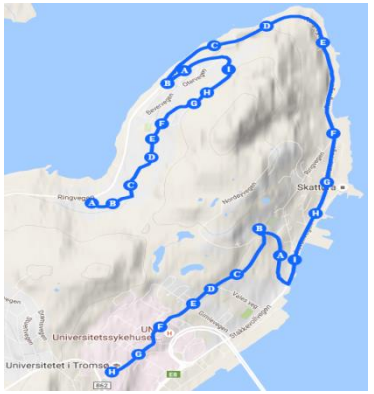


- Yellow curve: good weather, empty bus
- Blue curve: good weather, 45 passengers
- Red curve: snow chains, 90 passengers

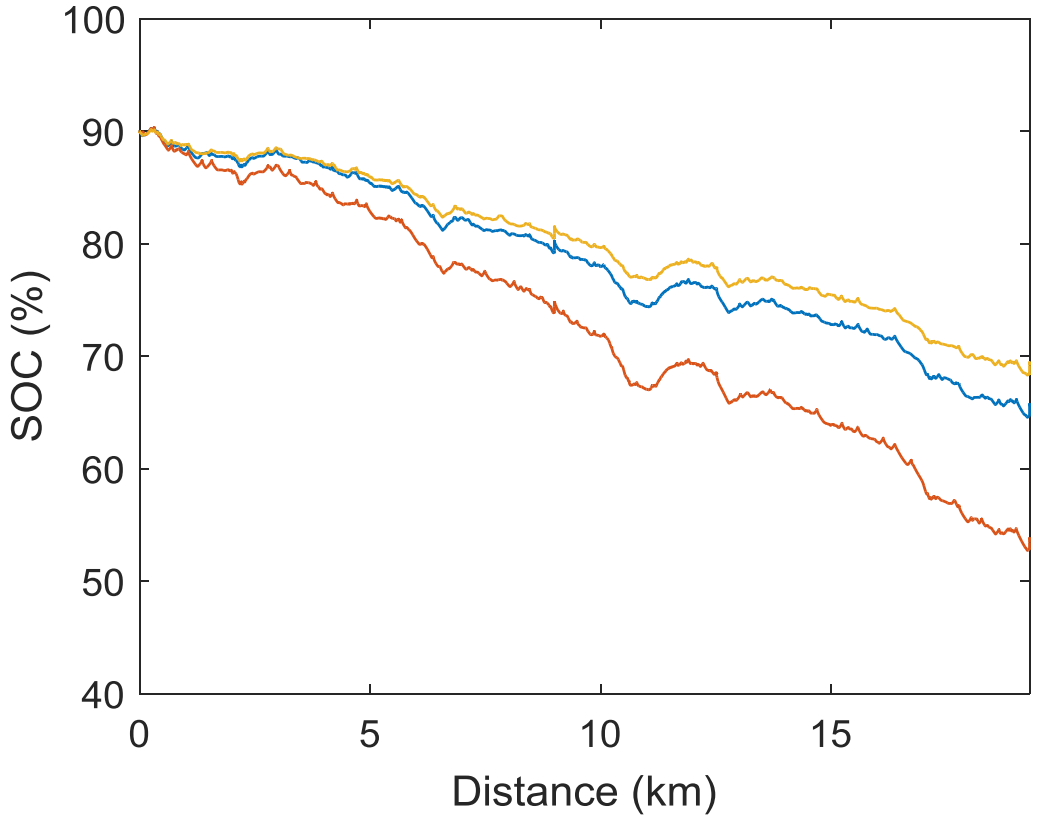
Elevation curve, line 32





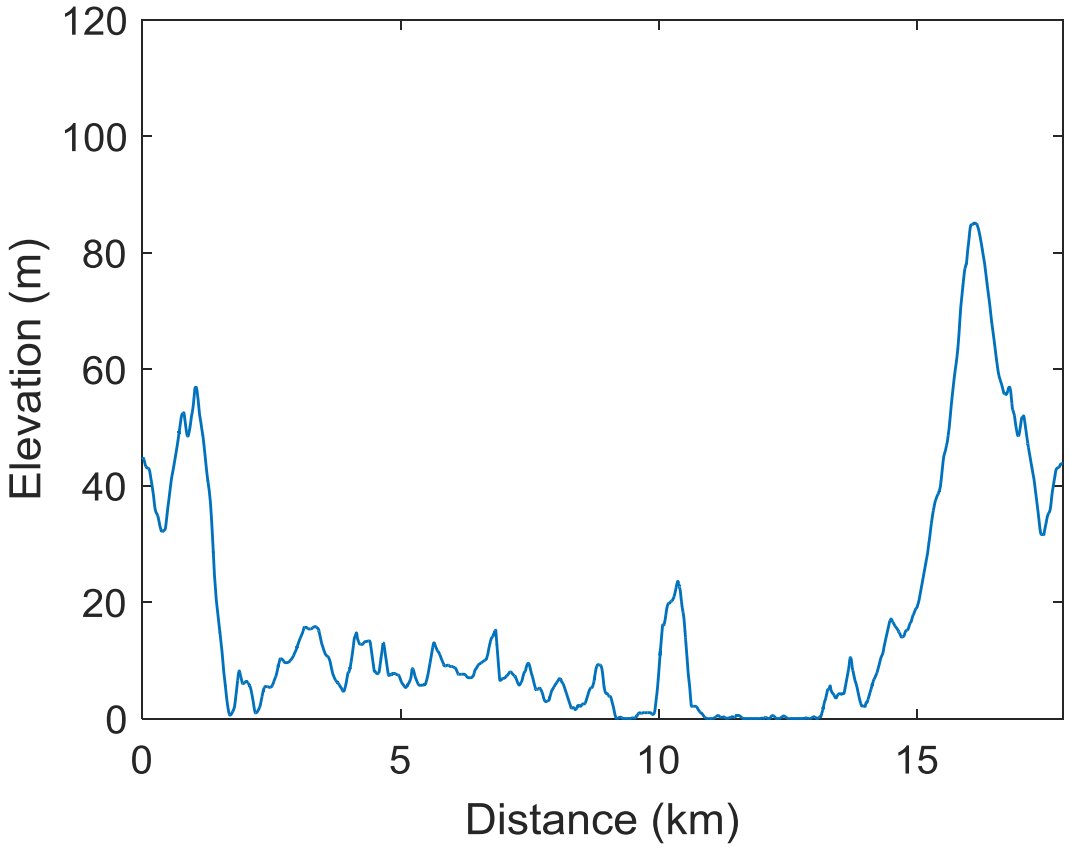


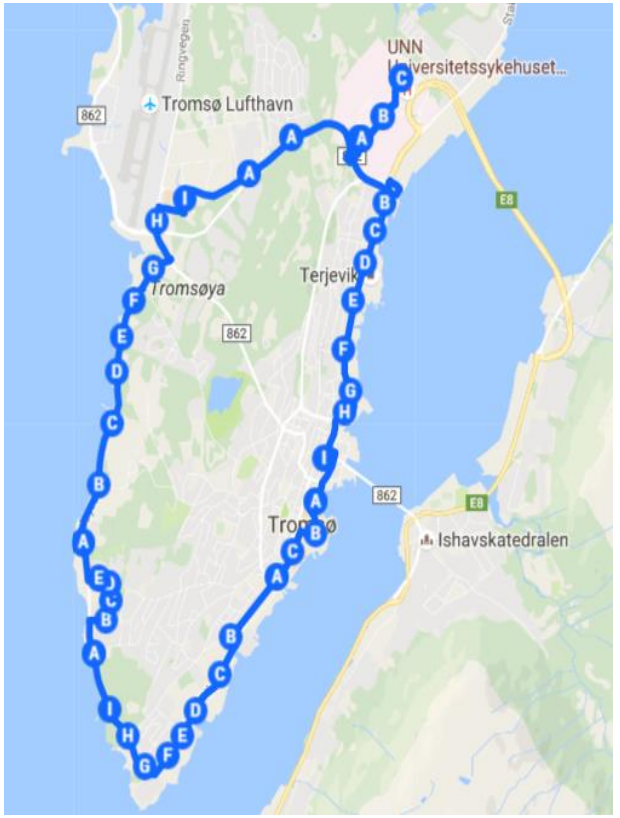
Battery state of charge, line 32



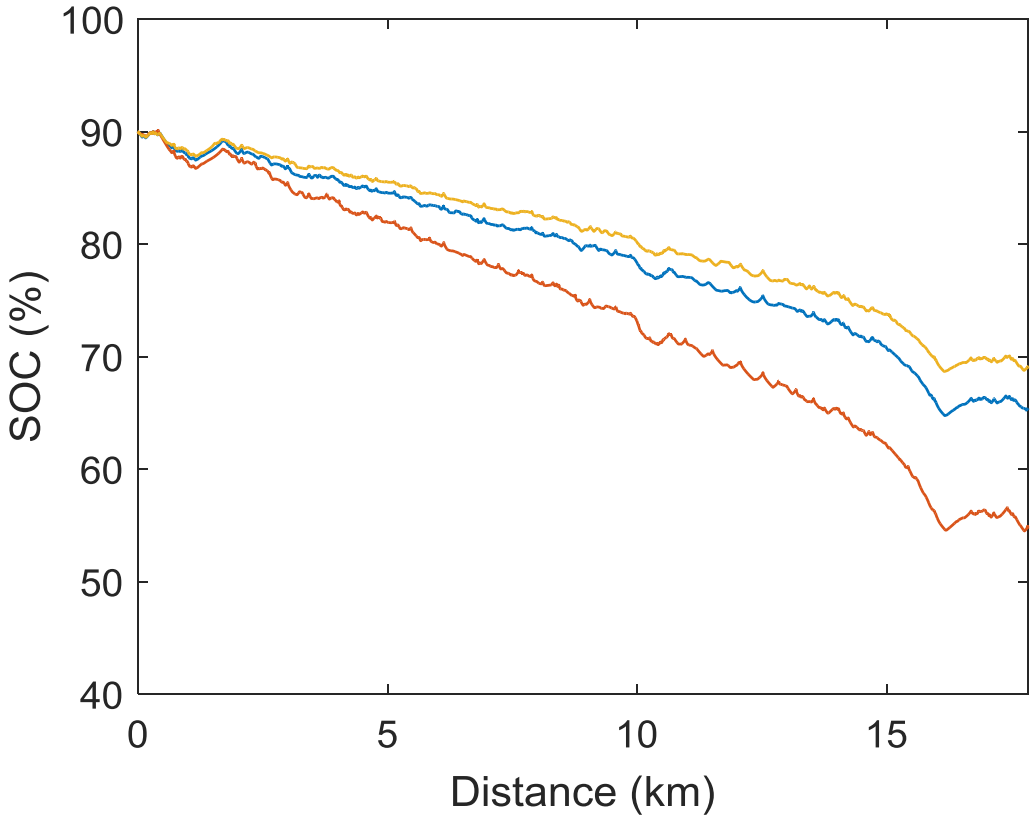
- Yellow curve: good weather, empty bus
- Blue curve: good weather, 45 passengers
- Red curve: snow chains, 90 passengers

Elevation curve, line 33



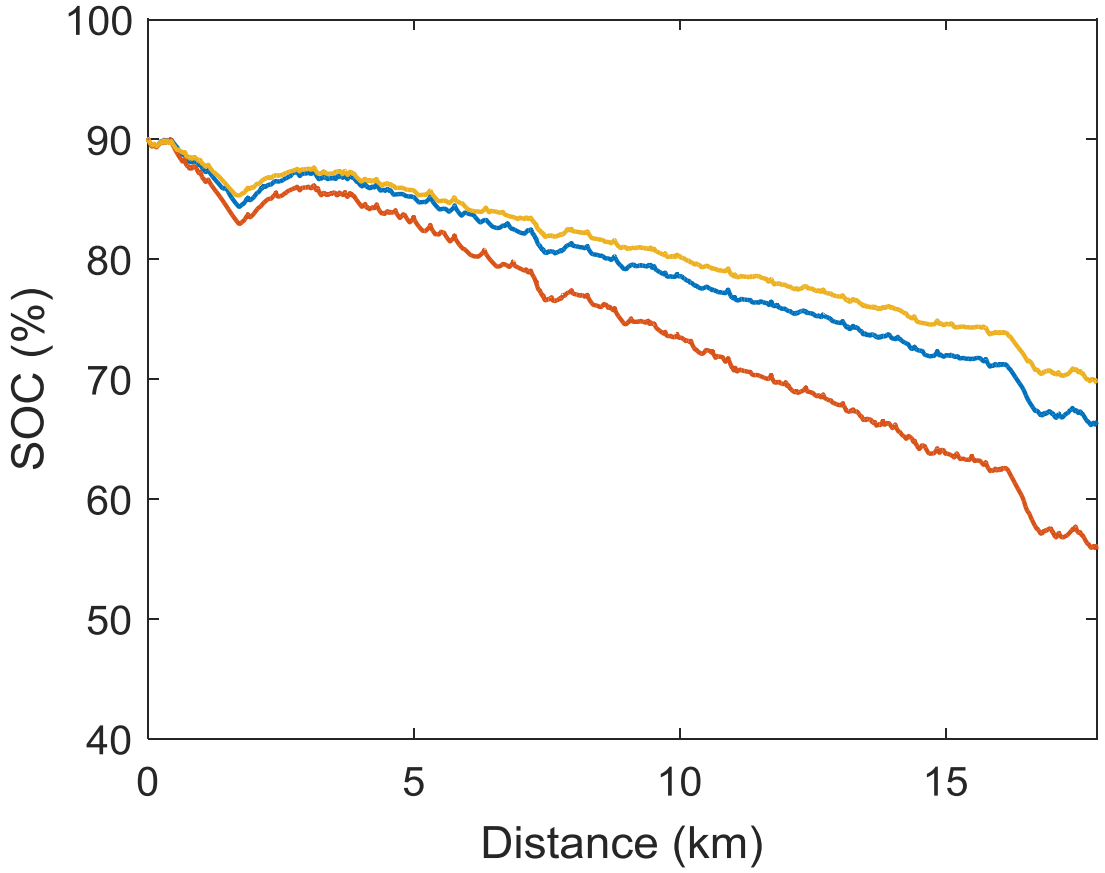


Battery state of charge, line 33



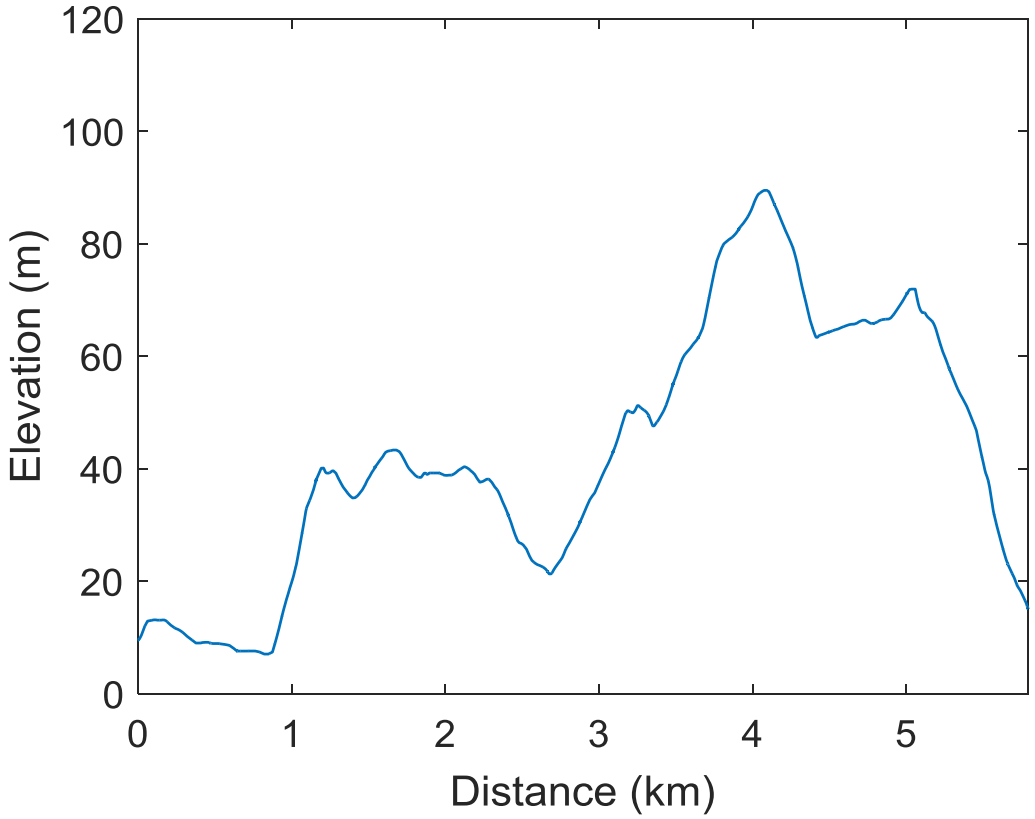
- Yellow curve: good weather, empty bus
- Blue curve: good weather, 45 passengers
- Red curve: snow chains, 90 passengers

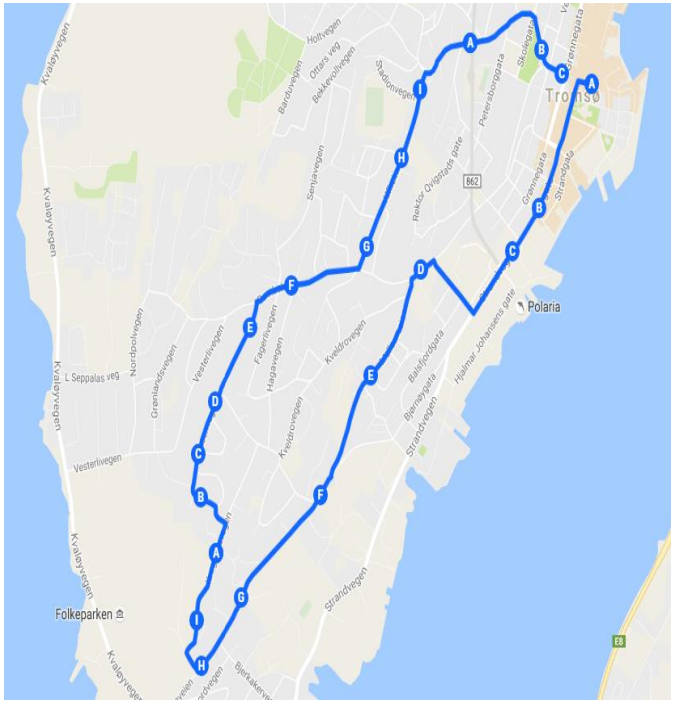
Battery state of charge, line 34



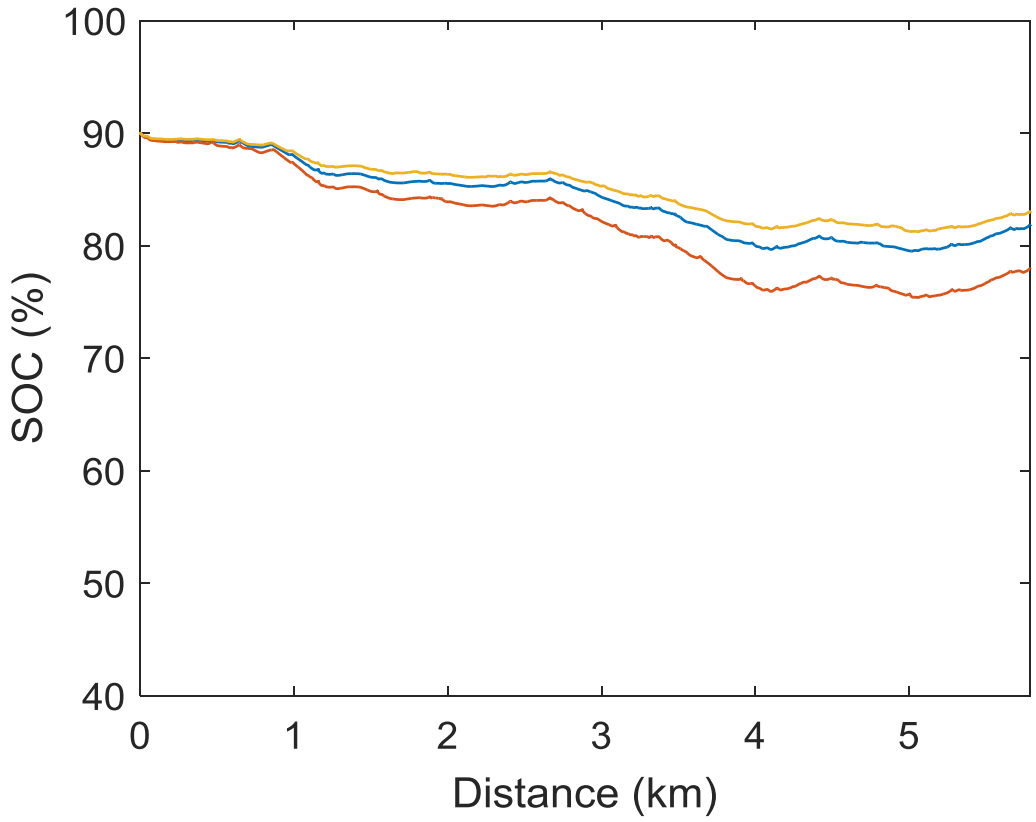
- Yellow curve: good weather, empty bus
- Blue curve: good weather, 45 passengers
- Red curve: snow chains, 90 passengers

Elevation curve, line 37



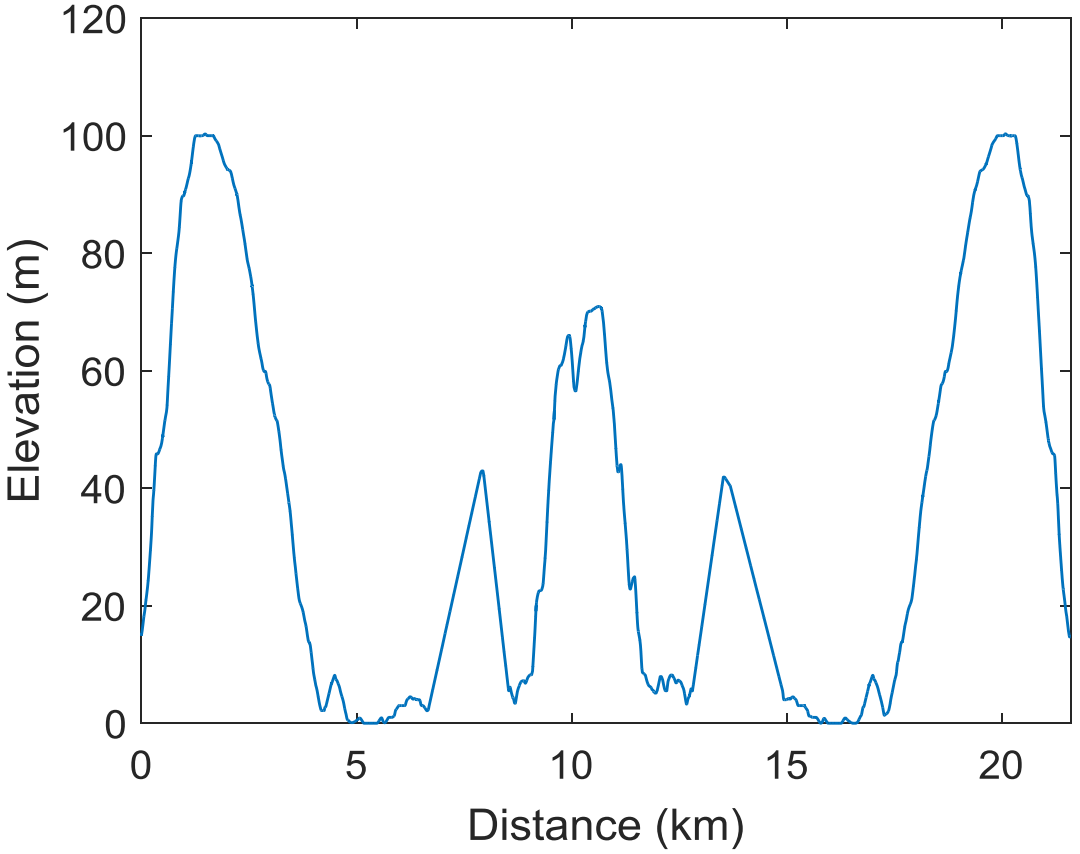


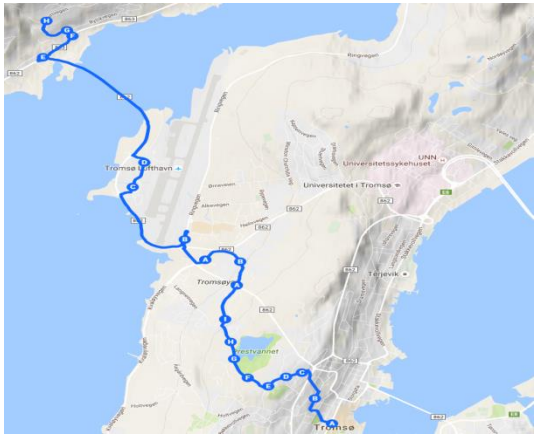
Battery state of charge, line 37

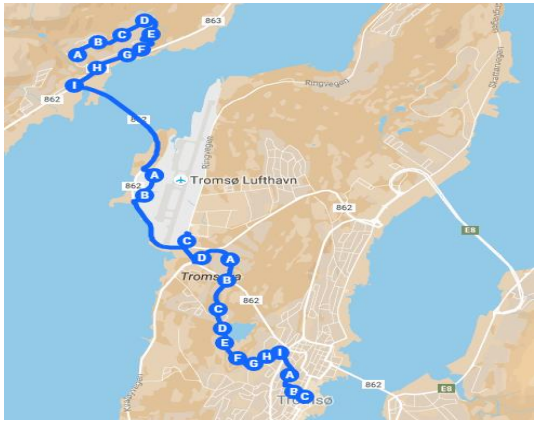


- Yellow curve: good weather, empty bus
- Blue curve: good weather, 45 passengers
- Red curve: snow chains, 90 passengers

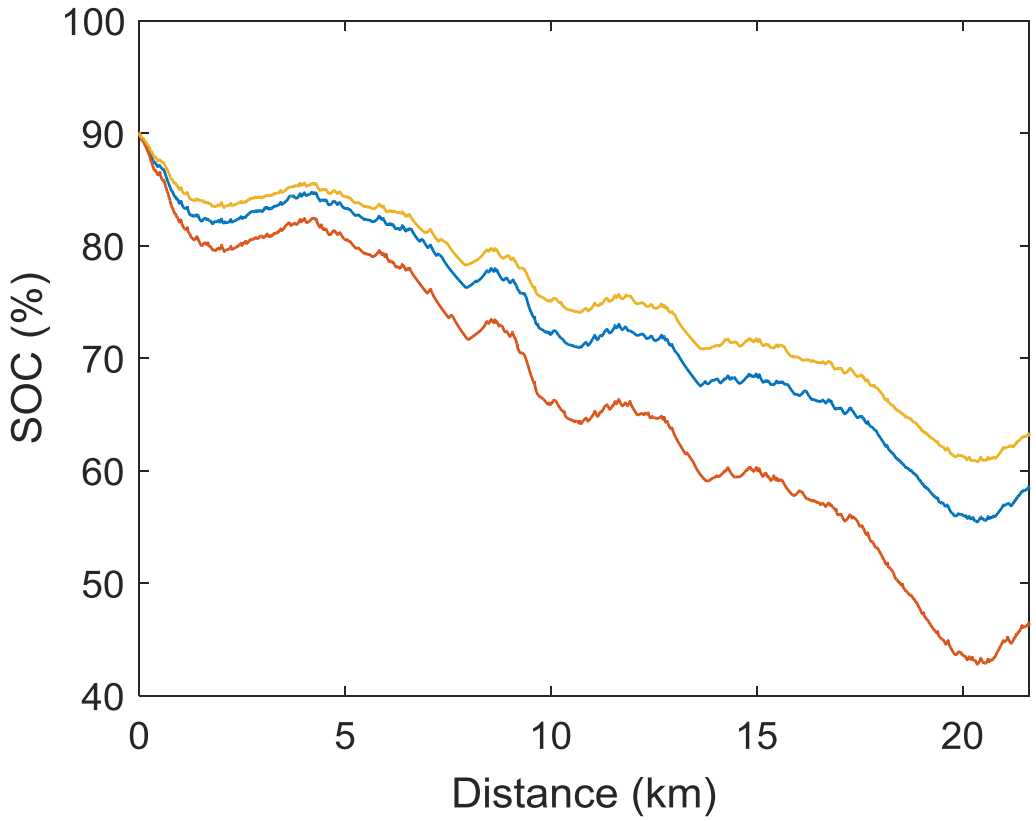
Elevation curve, line 40





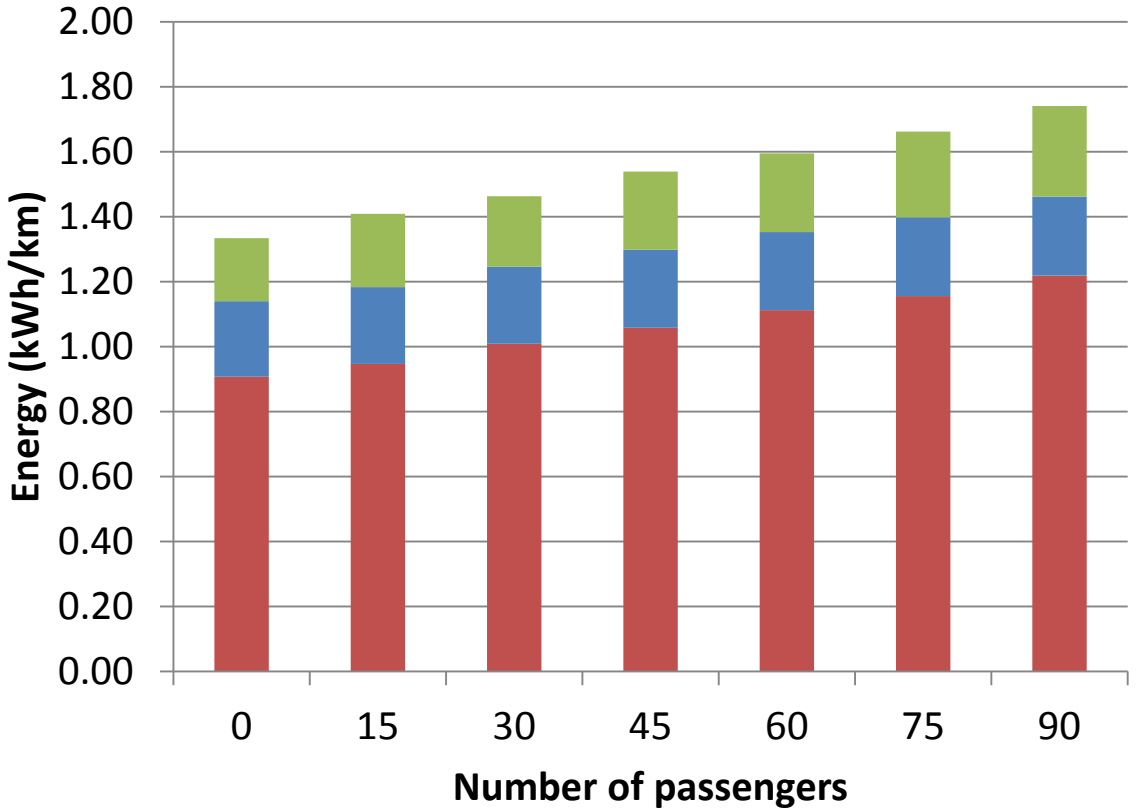


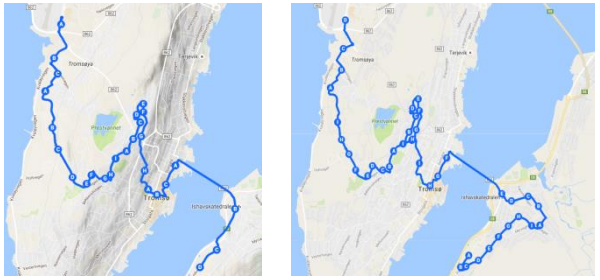
Battery state of charge, line 40



- Yellow curve: good weather, empty bus
- Blue curve: good weather, 45 passengers
- Red curve: snow chains, 90 passengers

Simulation results on line 26, depot charged bus





Energy due to snow chains

Auxiliary systems and HVAC

Energy for driving

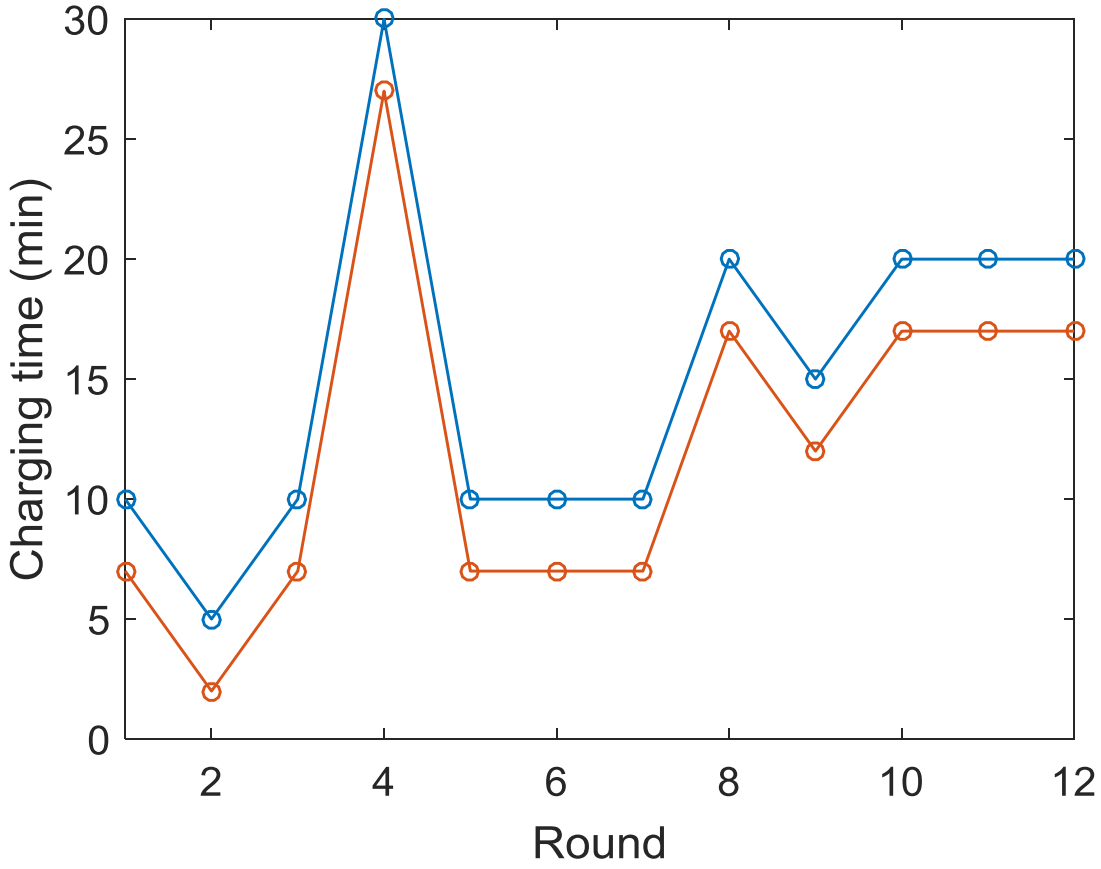
Total energy consumption of depot charged and opportunity charged buses

Line	Opportunity charged bus (kWh/km)	Depot charged bus (kWh/km)
26	0.95 – 1.59	1.14 – 1.84
32	0.86 – 1.50	1.06 – 1.76
33	0.94 – 1.58	1.14 – 1.84
34	0.91 – 1.54	1.10 – 1.78
37	0.98 – 1.68	1.18 – 1.94
40	1.00 – 1.62	1.23 – 1.88

Simulation results, depot charged bus

Line	Total energy consumption (kWh/km)	Maximum range (km)	Maximum number of round trips	Typical number of round trips, diesel buses
26	1.14 – 1.84	136 – 219	5 – 8	12
32	1.06 – 1.76	141 – 234	7 – 12	14
33	1.14 – 1.84	135 – 220	7 – 12	18
34	1.10 – 1.78	140 – 227	7 – 12	18
37	1.18 – 1.94	129 – 212	22 – 36	34
40	1.23 – 1.88	133 – 202	6 – 9	16

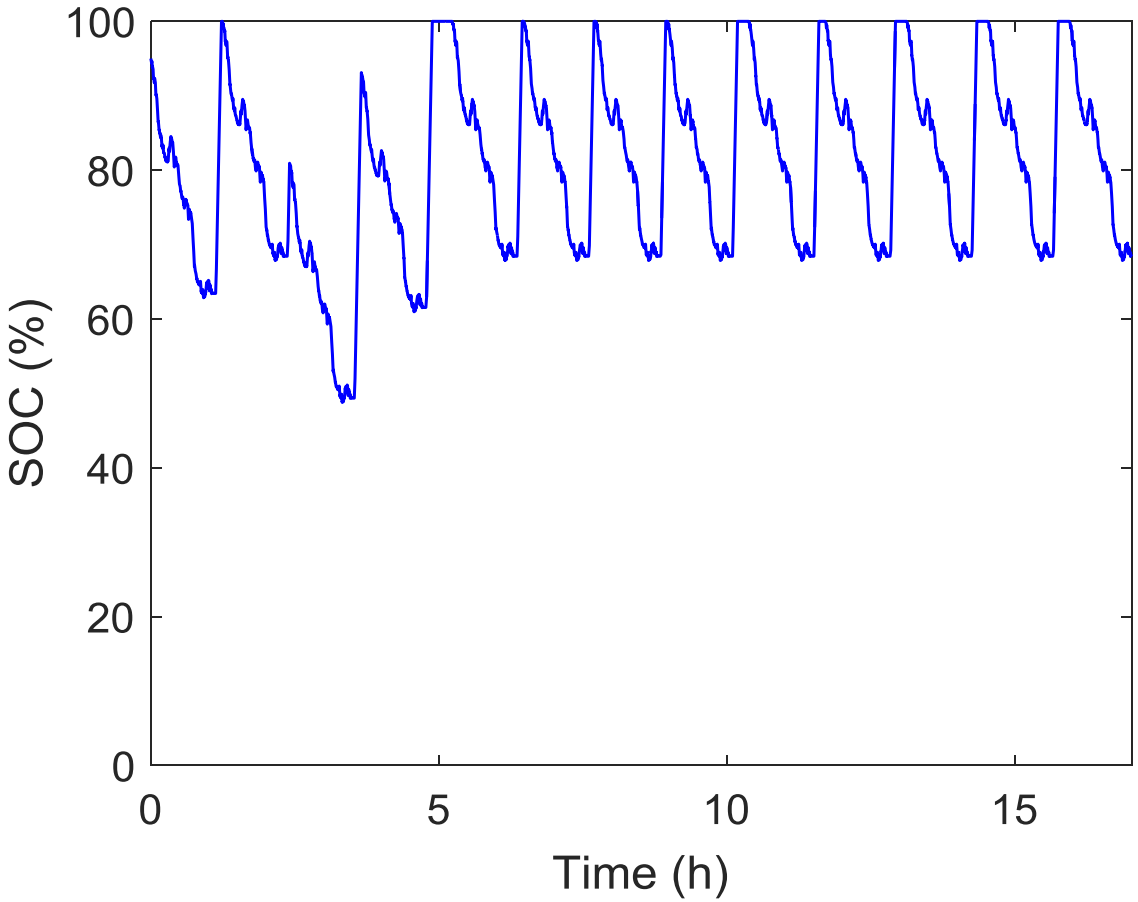
Sensitivity study – charging time available on line 26

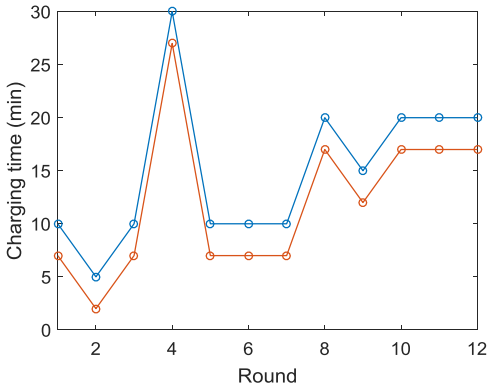


Maximum time at end bus stop (blue curve)

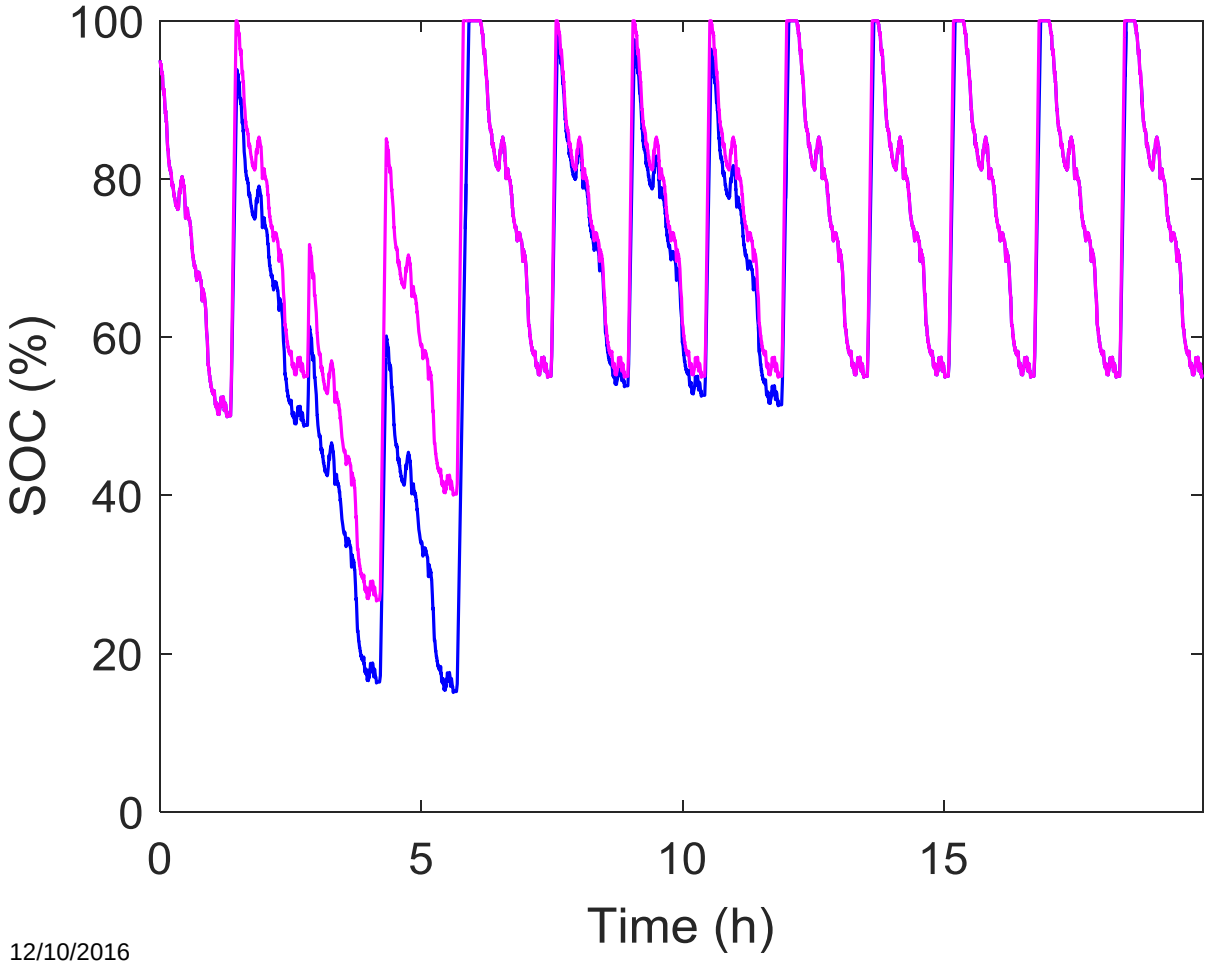
Time available for charging with 3 min delay (red curve)

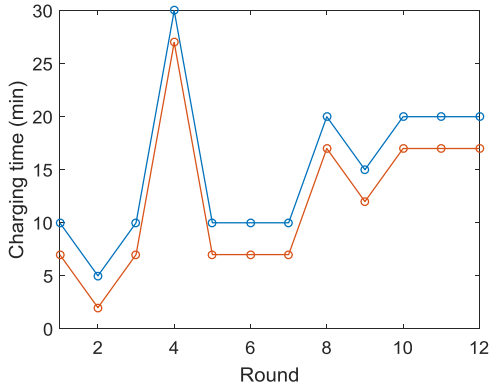
Sensitivity analysis – one day on line 26 in good weather



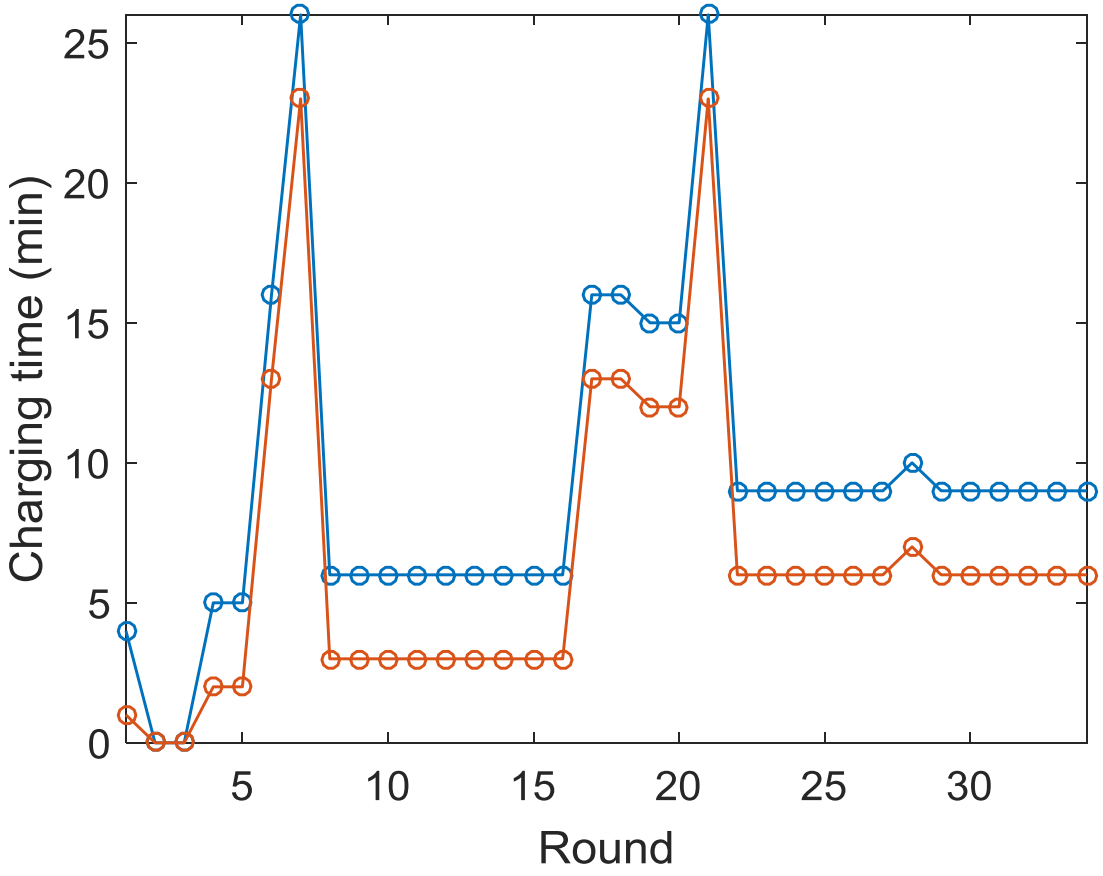


Sensitivity analysis – one day on line 26 in extreme conditions





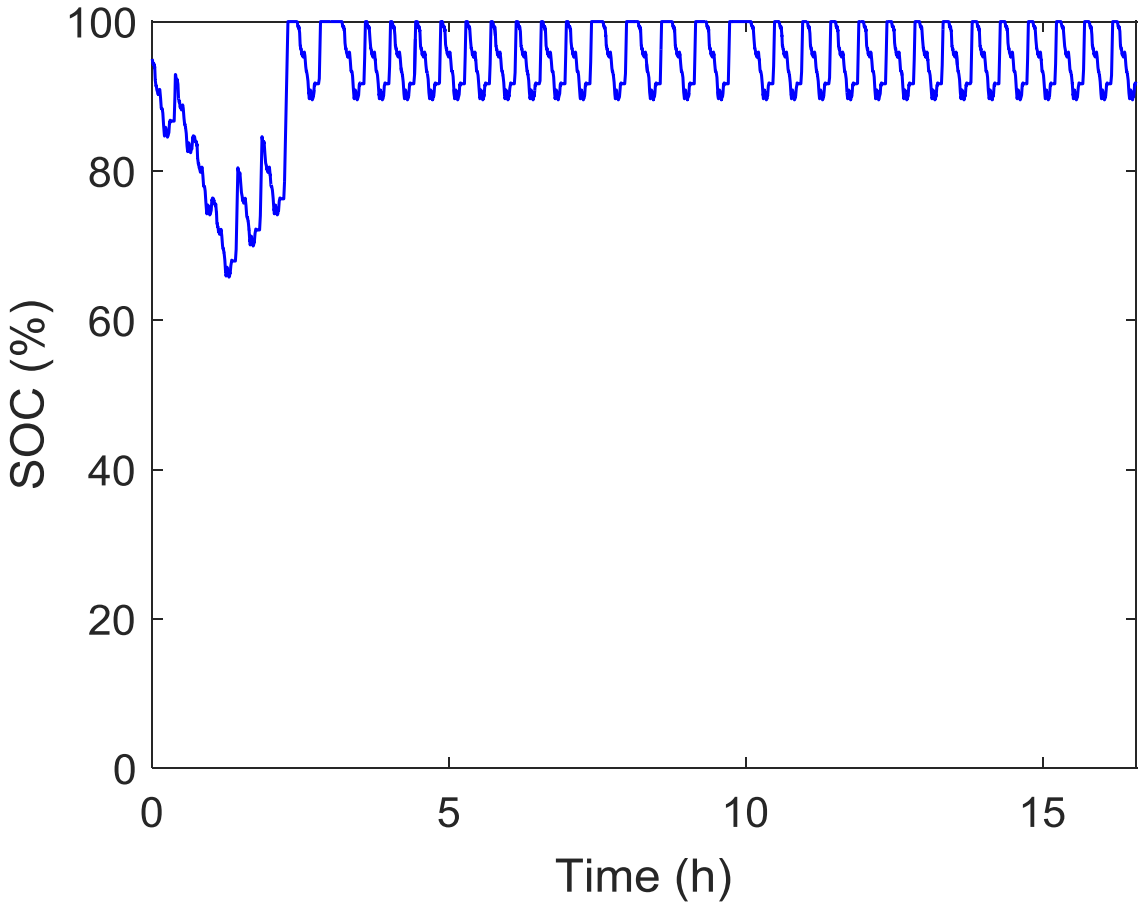
Sensitivity analysis – charging time available on line 37

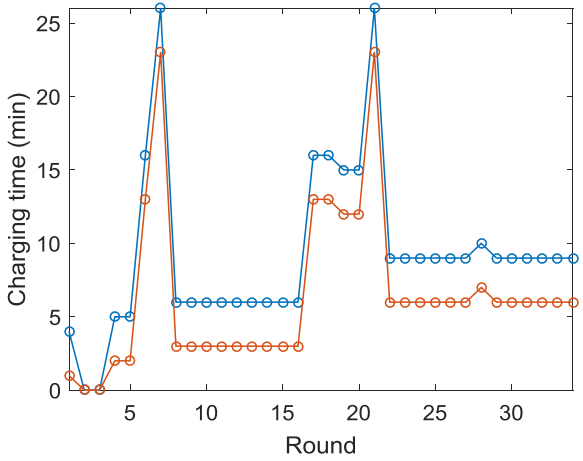


Maximum time at end bus stop (blue curve)

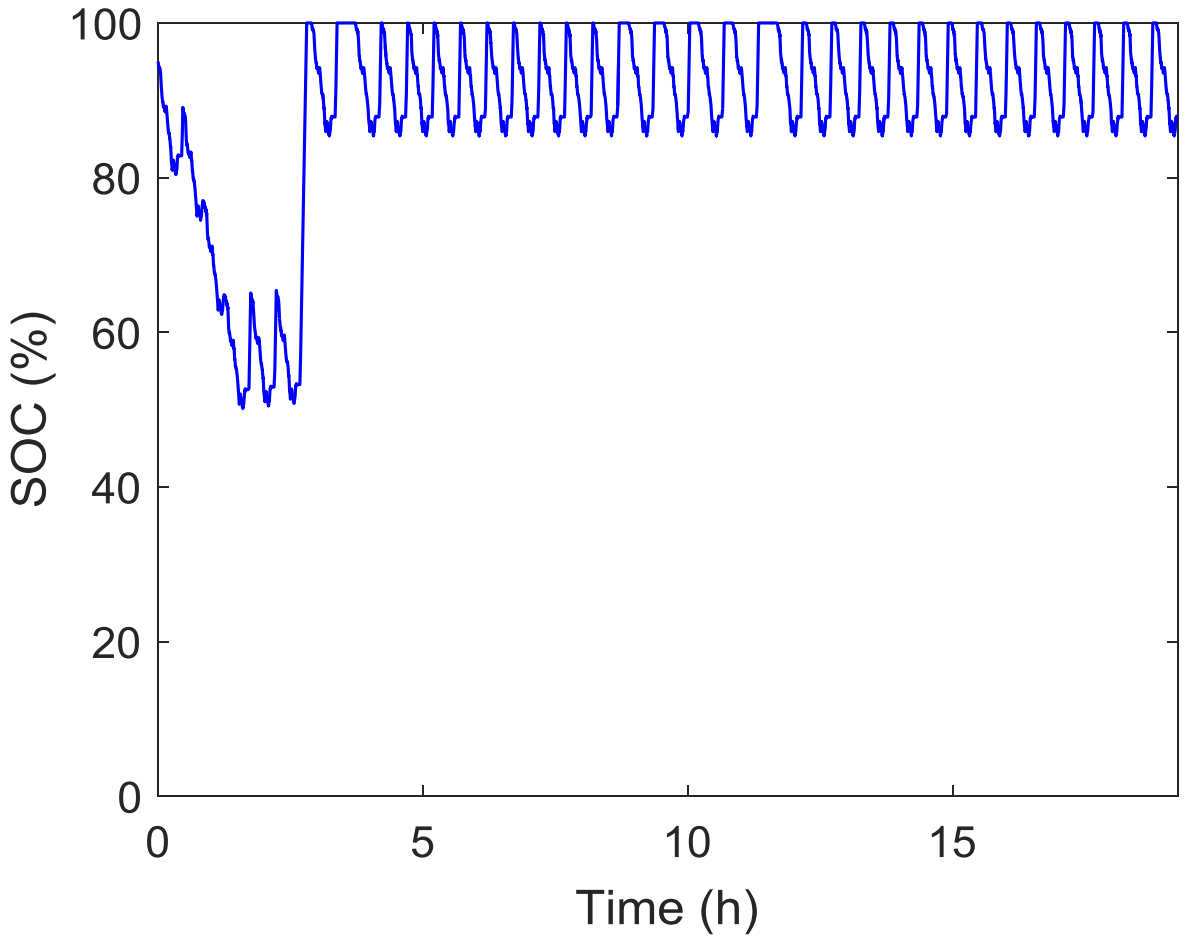
Time available for charging with 3 min delay (red curve)

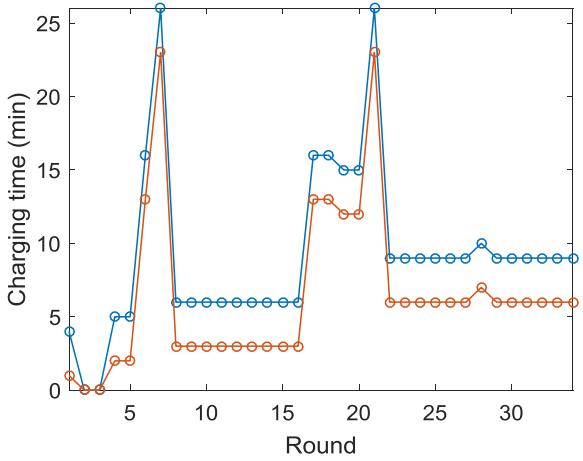
Sensitivity analysis – one day on line 37 in good weather



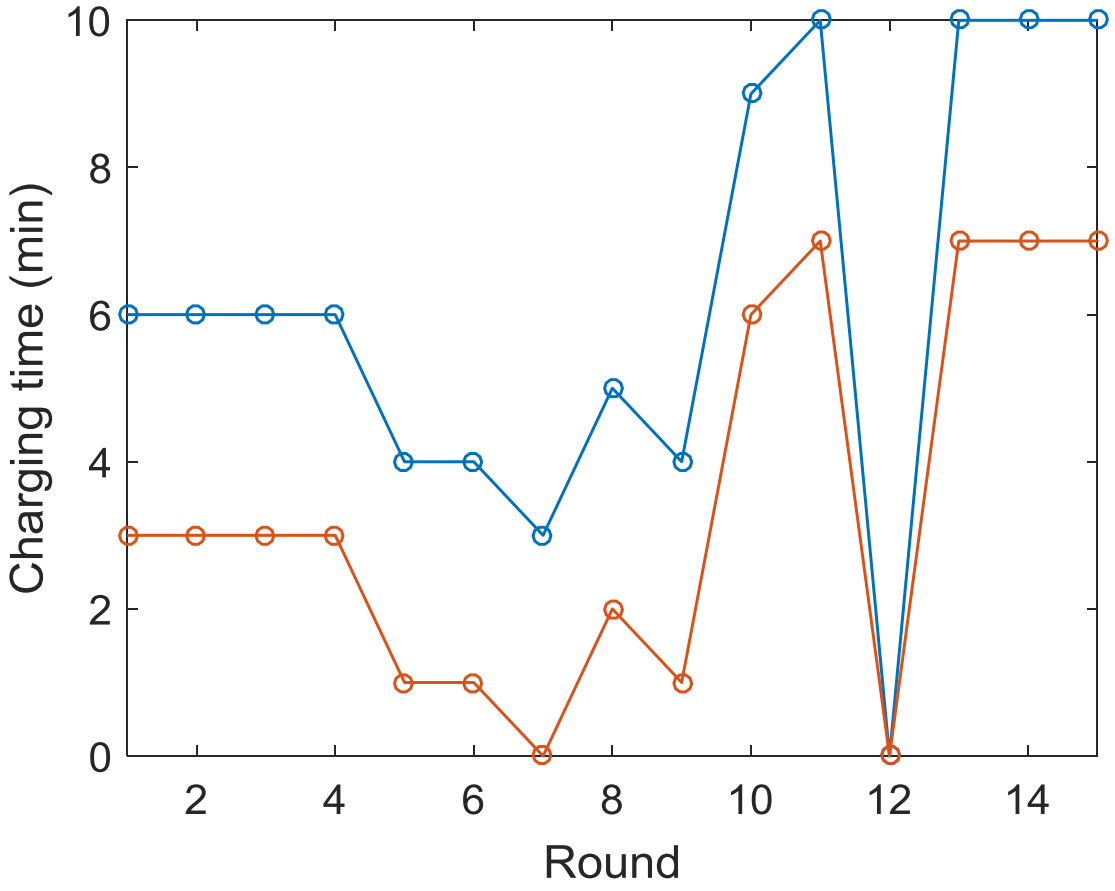


Sensitivity analysis – one day on line 37 in extreme conditions





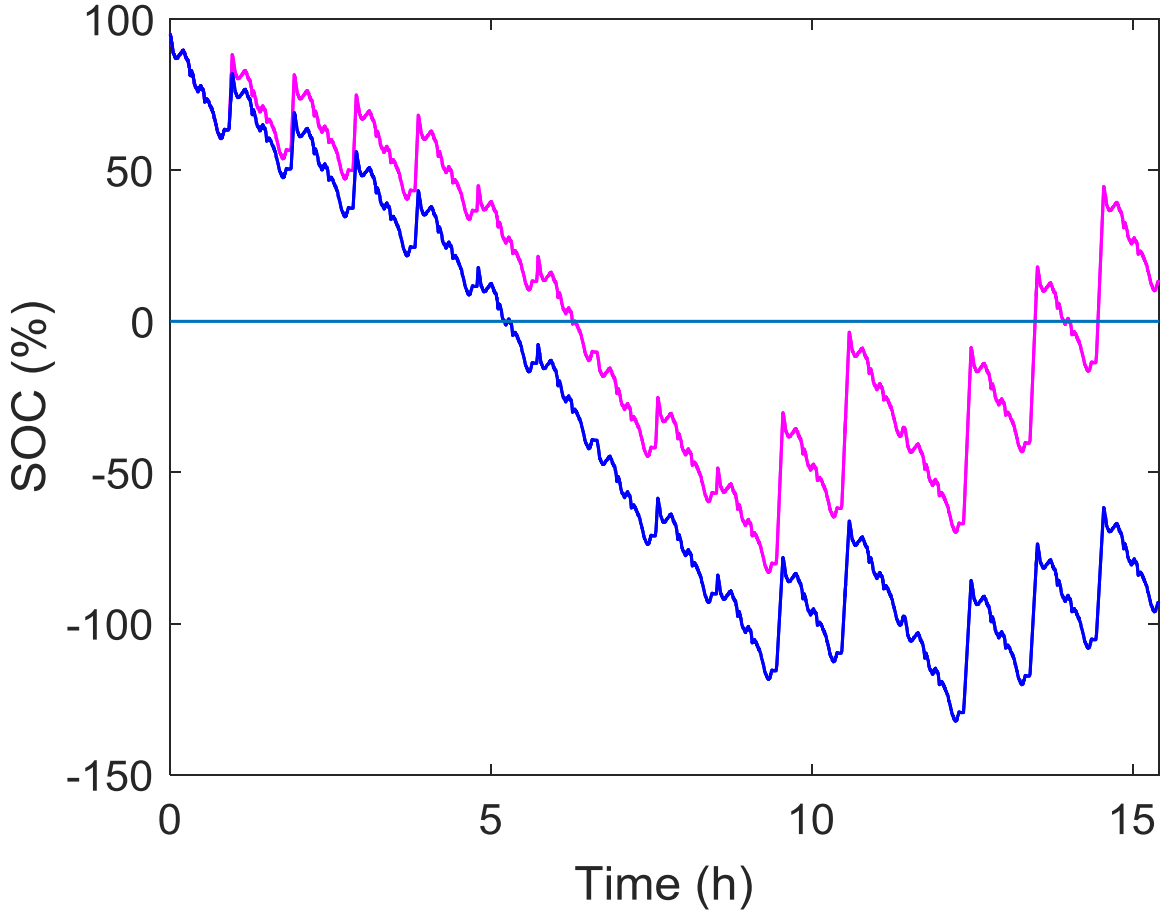
Sensitivity analysis – charging time available on line 40

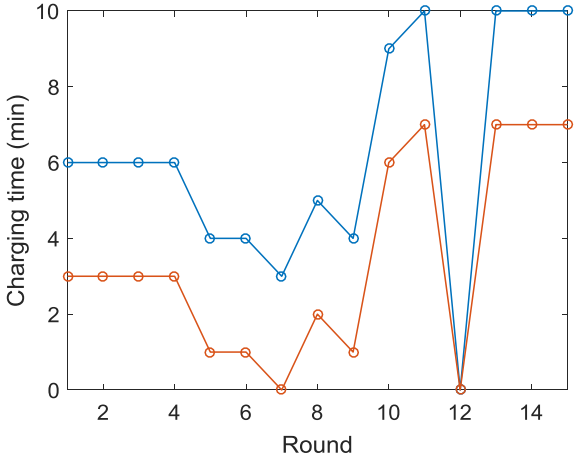


Maximum time at end bus stop (blue curve)

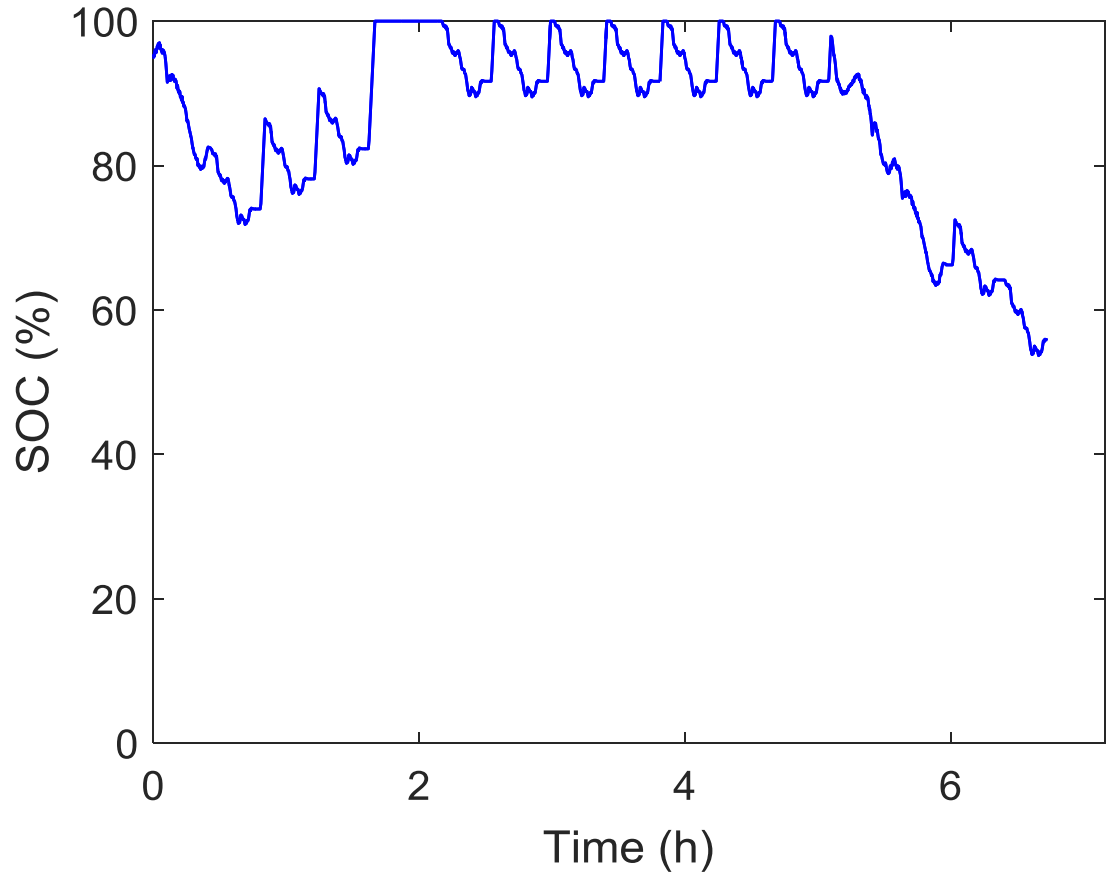
Time available for charging with 3 min delay (red curve)

Sensitivity analysis – one day on line 40 in good weather

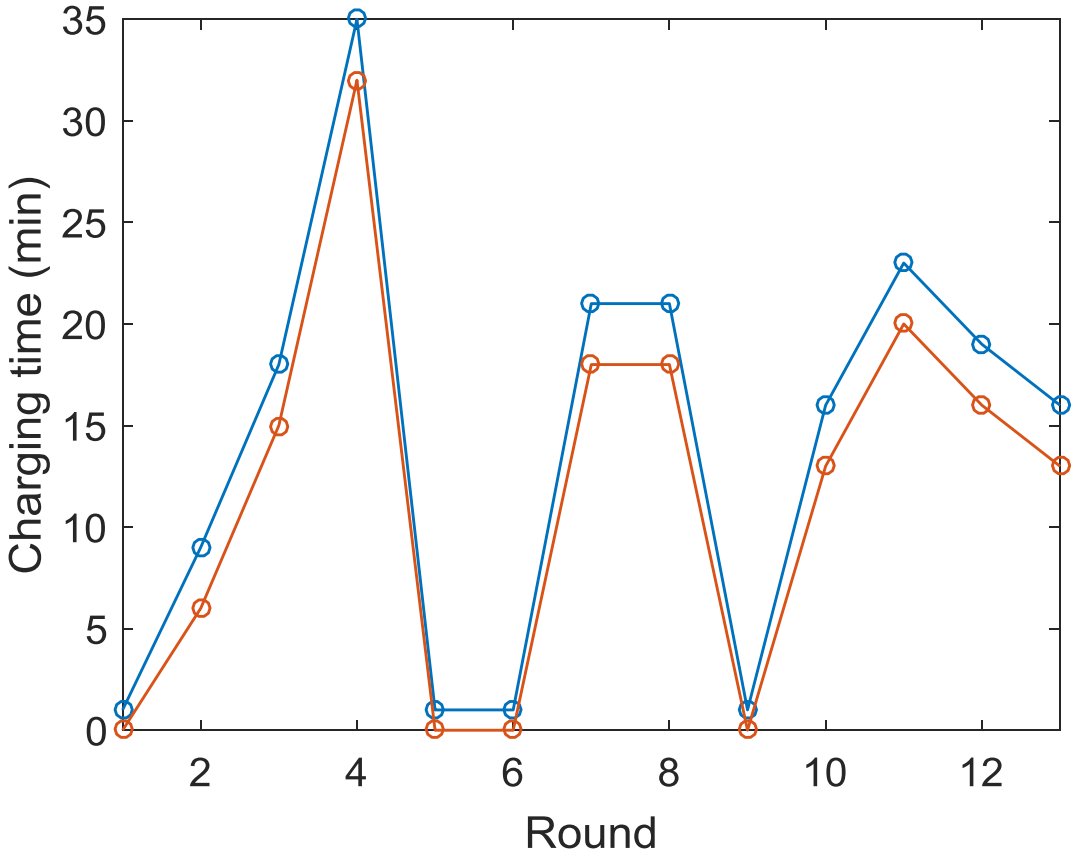




Sensitivity analysis - combination of line 37 and line 40



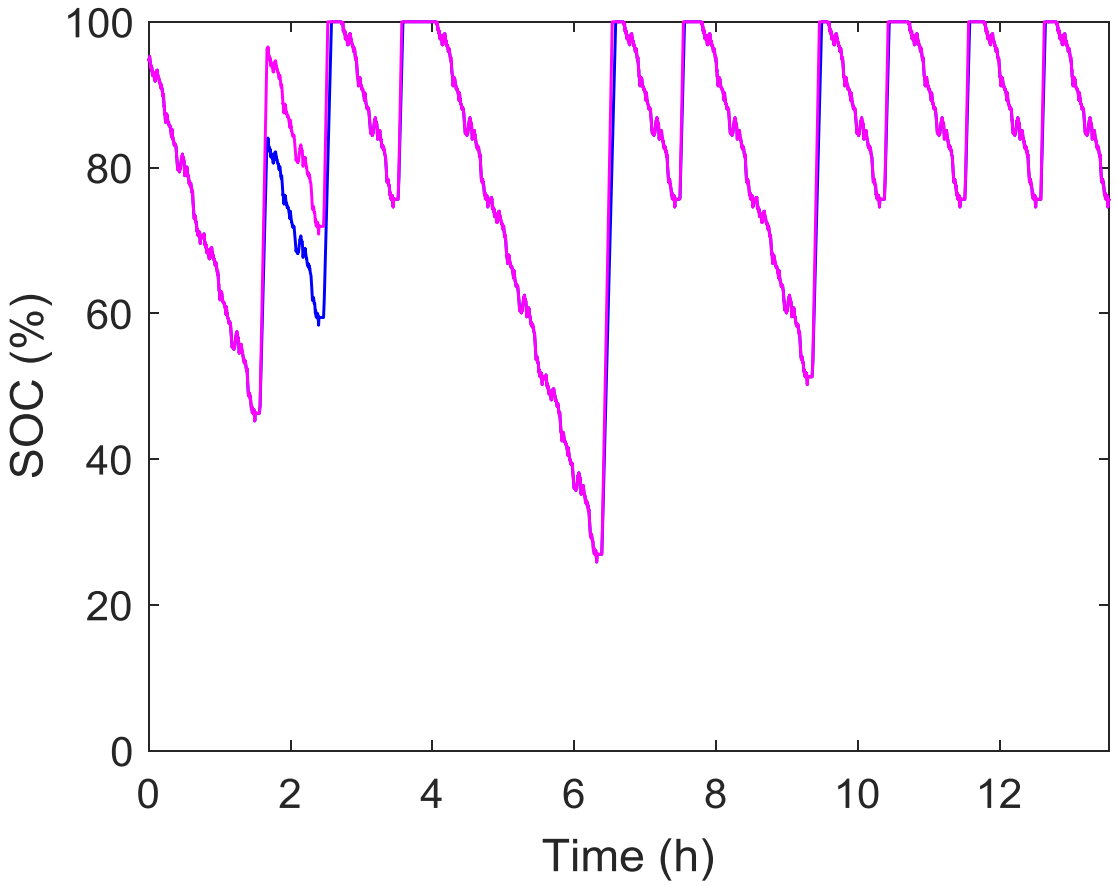
Sensitivity analysis – charging time available on line 32

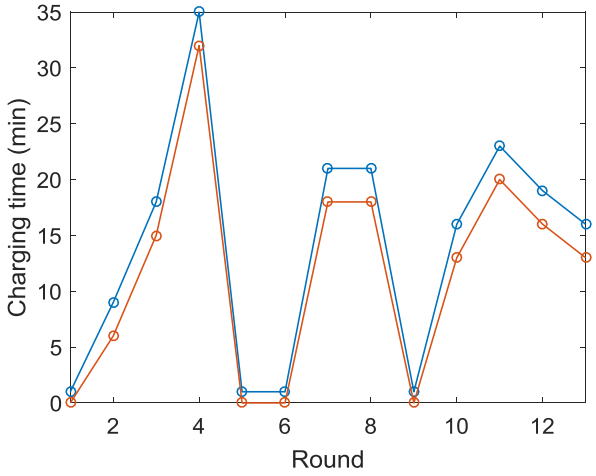


Maximum time at end bus stop (blue curve)

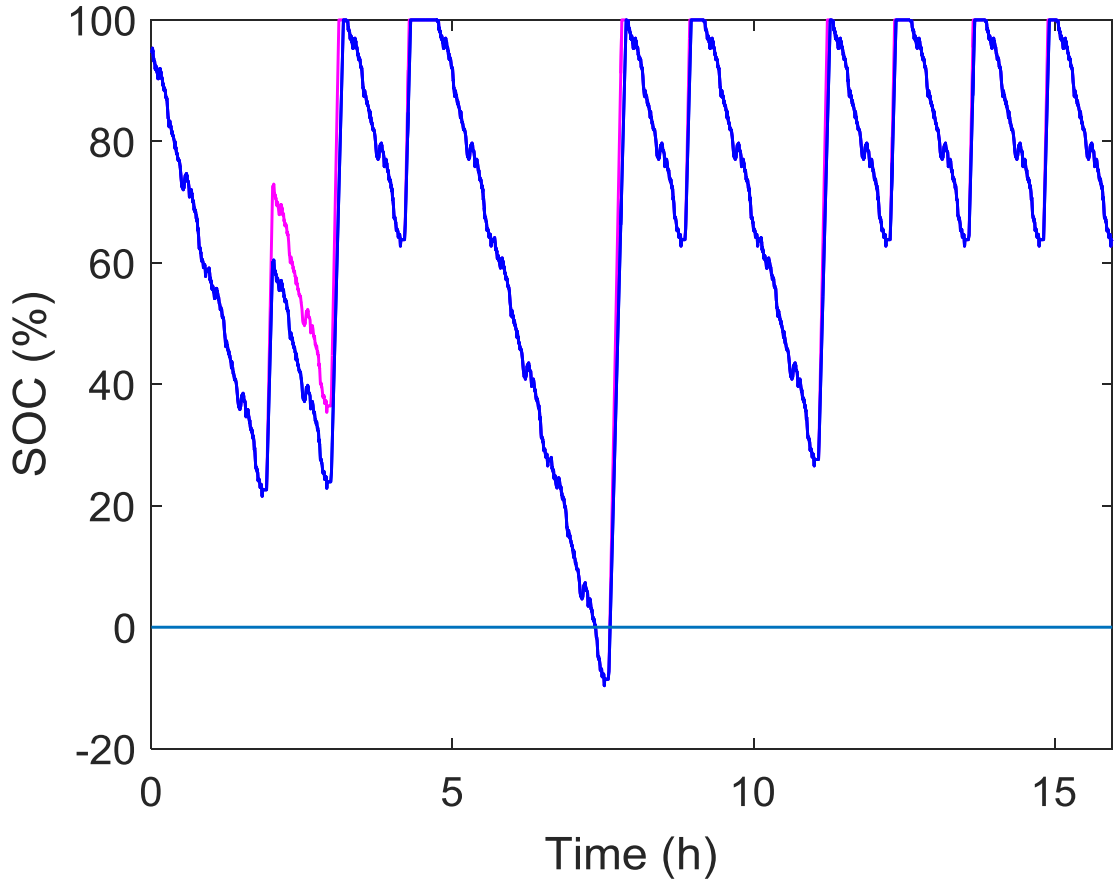
Time available for charging with 3 min delay (red curve)

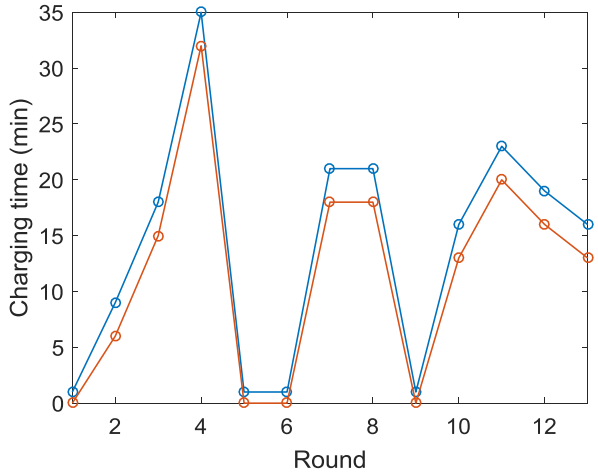
Sensitivity analysis – one day on line 32 in good weather



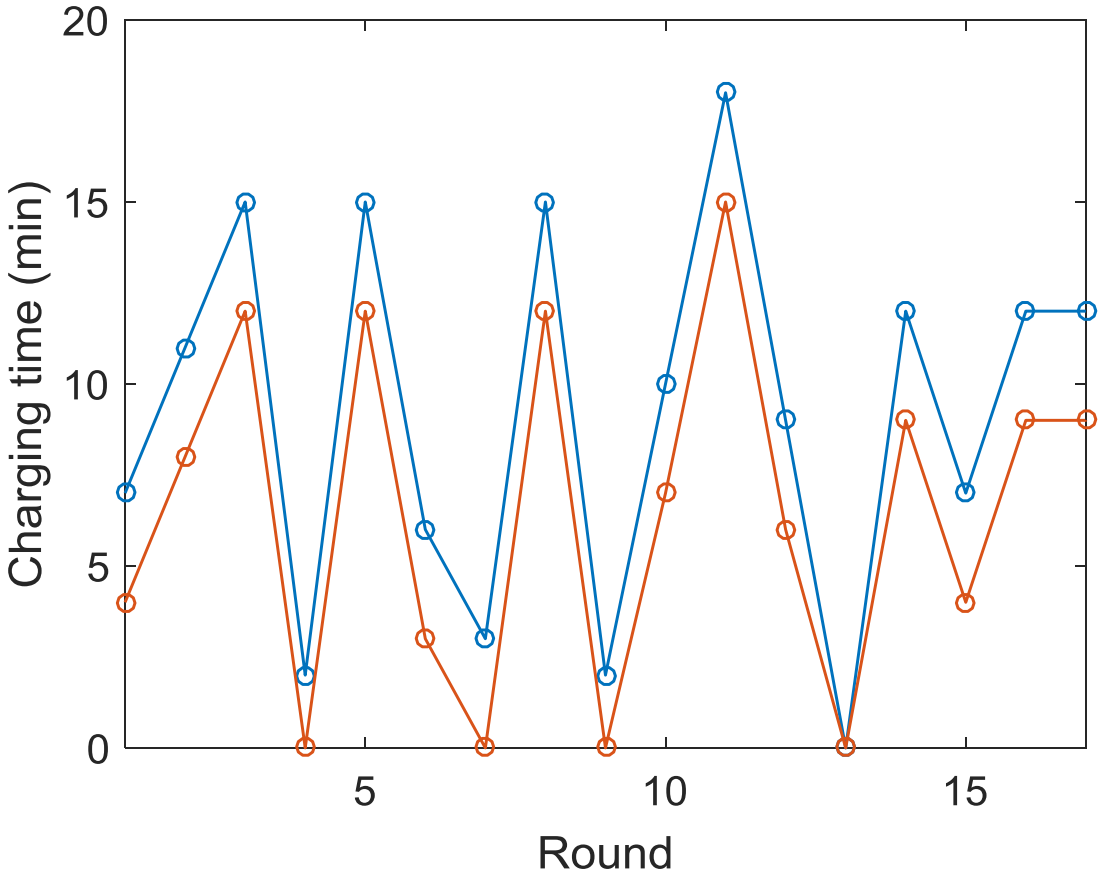


Sensitivity analysis – one day on line 32 in extreme conditions





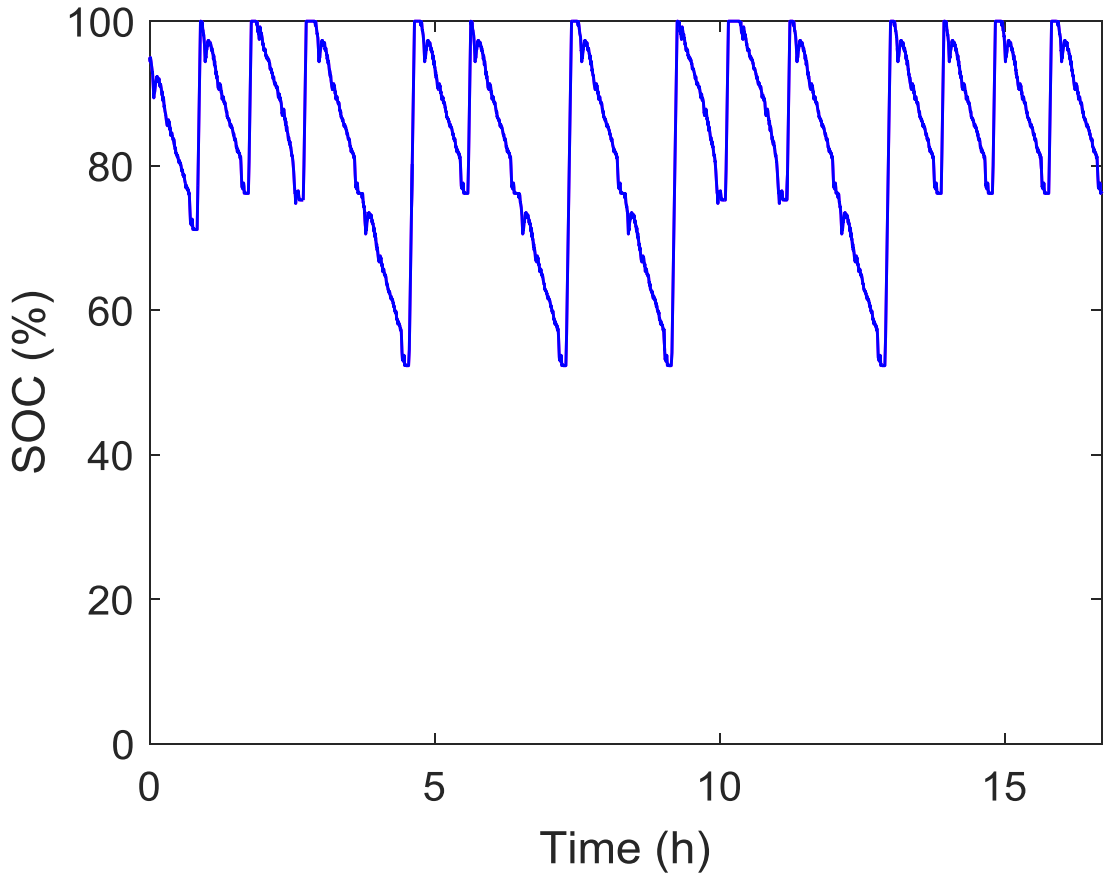
Sensitivity analysis – charging time available on lines 33 and 34

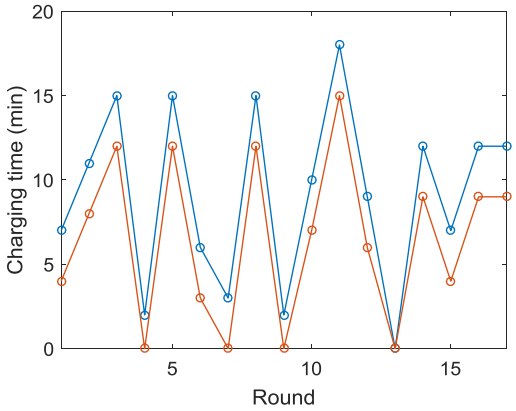


Maximum time at end bus stop (blue curve)

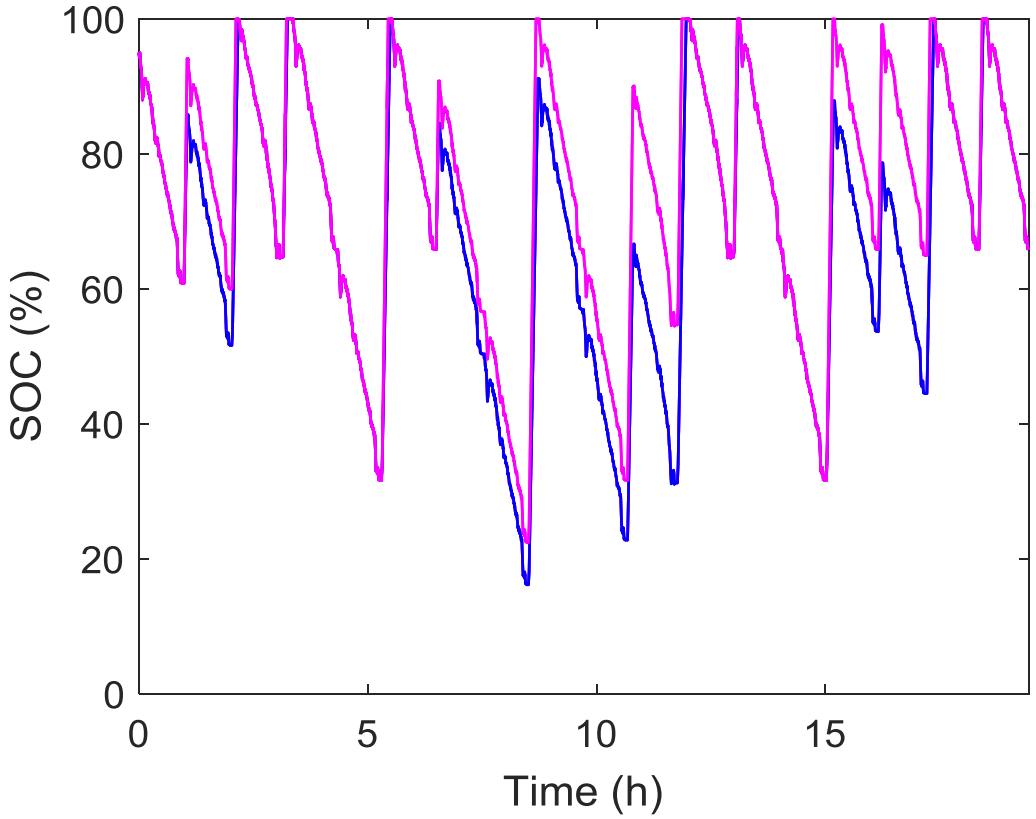
Time available for charging with 3 min delay (red curve)

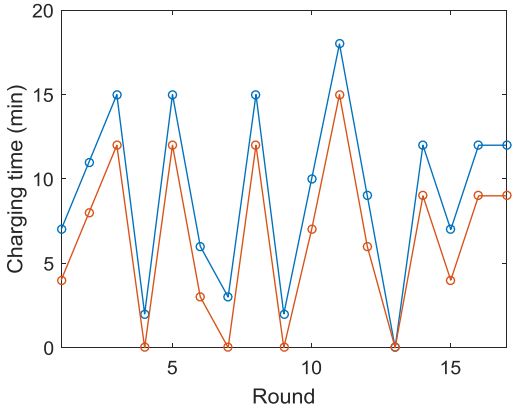
Sensitivity analysis – one day on lines 33 and 34 in good weather





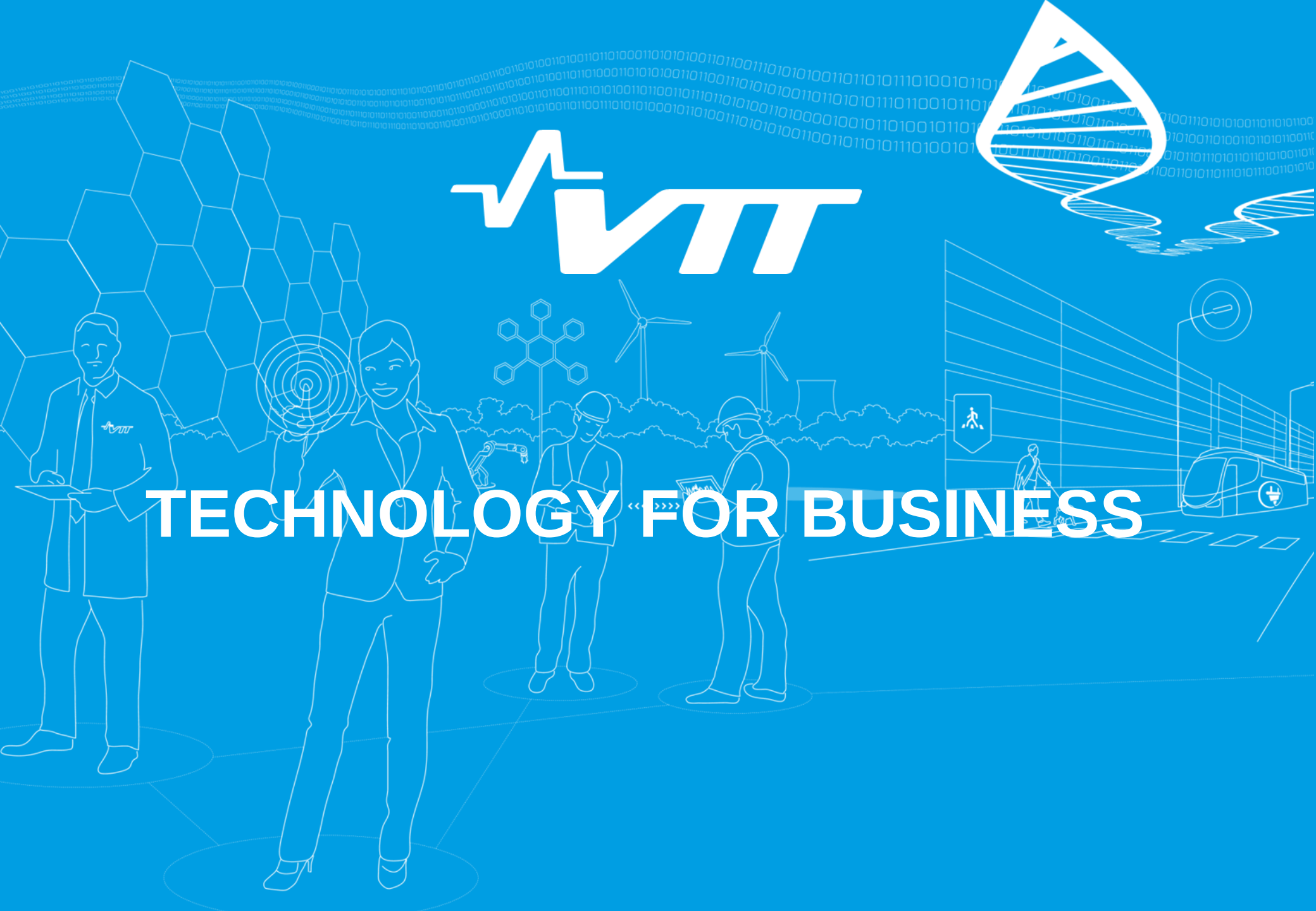
Sensitivity analysis – one day on lines 33 and 34 in extreme conditions





Summary of simulation results and sensitivity analysis

- Opportunity charged bus
  - Line 37 seems to be the easiest as it is very short – not necessary to charge after every round trip
  - Line 26 works well most of the time, but the battery might become almost completely discharged in extreme conditions
  - Line 40 is long and demanding, the time at the end bus stop is currently too short for charging
  - Line 32 works most of the time, but charging time might be too short in extreme weather conditions
  - Lines 33 and 34 works well most of the time, but the battery might become almost completely discharged in extreme conditions
- Depot charged bus
  - The performance is not comparable to diesel buses on any line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