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Anthropolis Chair and Future Cities Lab

Joint Seminar Series 2021-2022

November 24th, 2021

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Resilience assessment of electric based autonomous mobility system and power distribution grid under emergency

Etienne Liu

Outline

- Introduction and Context
- Research Methodology
- Case Study - Results
- Conclusions

Introduction and context

Development in technologies

Electric vehicles:>10 million production,
taking an importance place in market

natural synergies

SAEV

Autonomous driving: L2 (driving assistance)on production
L3 and L4 (partial/conditional driving automation)in research

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Introduction and context

SAEV model

Fleet operation:
· a group of electric autonomous vehicles fully owned by one group
· operated in an area (often considered as an node map)
· main purpose: satisfy the transport demand in this area
· operations: moving passengers, relocating, charging, (wandering)

- SAEV design model: Choosing components to meet transportation demand with low cost
- Charge station model: Choosing parameters of charging station with enough efficiency and low cost
- V2G & grid resilience: Implementing V2G service and evaluate the impact on grid
- etc

Introduction and context

Related work

title	Models included	problem type	Other attributions	Solution method
Lee et al.(2020) Shared autonomous electric vehicle design and operations under uncertainties:a reliability-based design optimization approach	Fleet operation SAEV design Charge station model	SQP problem	RBDO design	Monte-Carlo simulation
Iacobucci et al. (2019) Cascaded model predictive control for shared autonomous electric vehicles systems with V2G capabilities	Fleet operation V2G service	MILP problem	MPC control	Matlab
Chen et al. (2016) Operations of a shared, autonomous, electric vehicle fleet: Implications of vehicle & charging infrastructure decisions	Fleet operation SAEV design Charge station model	Generation of metrics Sensitivity detection	discrete-time agent based model	Financial analysis
Iacobucci et al. (2018) Modeling shared autonomous electric vehicles: Potential for transport and power grid integration	Fleet operation V2G service Charge station model	MILP problem	Economic evaluation break-even price estimation	Matlab

Introduction and context

Resilience of grid:
capacity to resist a sudden change and recover rapidly from a sudden change

Daily usage:
Peak shaving, valley filling

Severe situation:
· resistance: stability of components & back up sources
· recovery: repairment efficiency

Introduction and context

Related work

title	cases included	problem presented	Solution method
Kumaravelan et al.(2020) Modeling Power Grid Recovery and Resilience Post Extreme Weather Events	Daily usage Severe situation	Extreme weather repairment V2G service in normal case V2G for industrial in emergency	Random process Economic analysis
Rahimi et al. (2018) Electric vehicles for improving resilience of distribution systems	V2H service for EVs	NLP problem for minimum peak energy usage and calculation of V2H service duration	Generic algorithm
Cadini et al. (2017) A modeling and simulation framework for the reliability/availability assessment of a power transmission grid subject to cascading failures under extreme weather conditions	Severe situation	Cascaded failure in extreme weather & repairment	Monte-Carlo simulation
Panteli et al. (2017) Power system resilience to extreme weather: fragility modeling, probabilistic impact assessment, and adaptation measures	Severe situation	Probabilistic fragility modeling &measures to improve resilience	RAW indice (the percentage improvement in the resilience indices when each line is considered 100% reliable)

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Introduction and context

Power outage case model:

· A critical building (hospital, factory, etc) at node n meets a power outage
· An energy demand per time step Q_d and a back up generator with energy generation per time step Q_m
· At each time step, an amount of energy Q_{v2b} is discharged to critical building from our fleet
· Q_{v2b} needs to be no more than energy needed, and also has a minimum acceptable delivery rate R_d

This model is a simplification of a model in (Kumaravelan 2020)

Introduction and context

SAEV model

· a group of electric autonomous model fully owned by one group
· operated in an area which is divided into different zones(considered as nodes)
· basic parameters of vehicles are fixed and charging stations are placed in each node with no limitation
· main purpose: satisfy the transport demand in this area
· other pattern controlled: relocation behavior, charging & discharging behavior
· MILP model

This model is mainly based on (Iacobucci 2019)

Introduction and context

General framework

Normal situation

Traditional SAEV with V2G

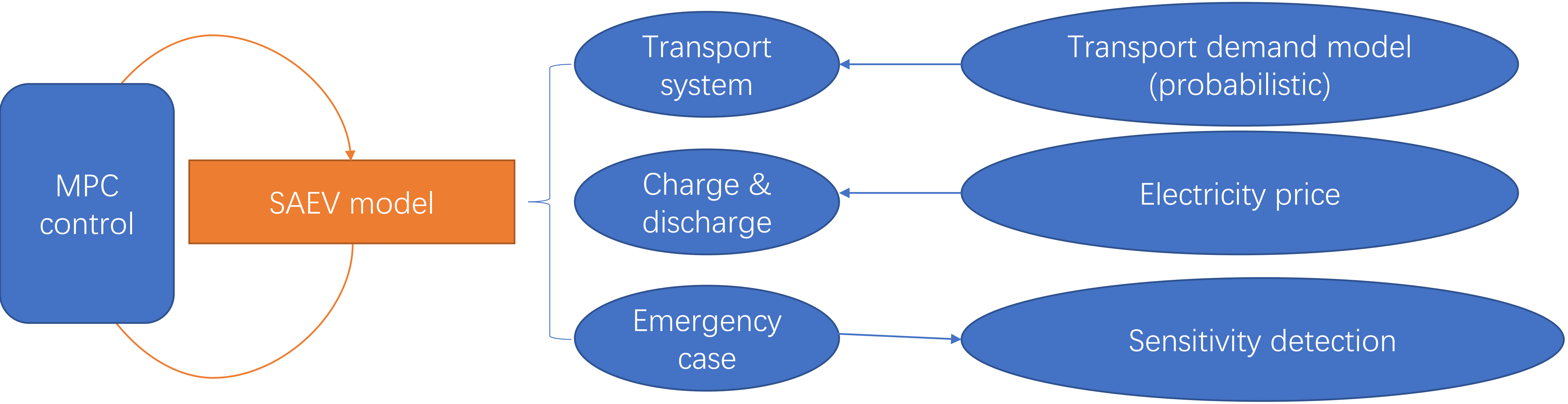
· transport demand
· charging decision
· V2G service

Emergency case

· keep in running service
· support a critical building with a minimum delivery rate

Introduction and context

General framework



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Research Methodology (Model)

variables

$q^k(t)$	the energy stored in the battery of vehicle k
$d_{ij}(t)$	the number of passengers waiting at node i for destination j
$u^k_i(t)$	the parking status of vehicle k (binary)
${}^{Ti}p^k_i(t)$	the remaining travelling time for a moving vehicle (${}^{Ti}p^k_i(n)=1$ if the number of time steps remaining until the vehicle reaches station i is Ti)
$v^k_{ij}(t)$	binary variable denoting if vehicle k is picked up to move passengers from node i to node j
$w^k_{ij}(t)$	binary variable indicating if vehicle k starts relocating from node i to node j
$e^k(t)$	energy charged to vehicle k
$g^k(t)$	energy discharged from vehicle k using V2G services
$v2b^k(t)$	energy discharged from vehicle k during emergency
$Q_{v2b}(t)$	total energy discharged to critical building in time t during emergency

Research Methodology (Model)

Parameters and constants

All the parameters are normalised

$\eta=0.9$	the discharge effiency
$q_{max}=1$	the maximum SOC
$q_{min}=0.2$	the minimum SOC allowed
$\alpha_d=0.01$	the consumption of the energy for vehicle on route(SOC per time interval)
$\alpha_c=0.02$	the charging rate(SOC per time interval)
$\alpha_{v2g}=0.02$	the discharging rate(SOC per time interval)
$\omega=10$	the recycling cost
$\rho_1=0.01$	weight for rebalancing secondary objective
$\rho_2=0.001$	weight for charging secondary objective
$\rho_3=0.015$	weight for final SOC secondary objective
$T_t=10$	optimisation horizon
$K=8$	numbers of the vehicles
$N=11$	numbers of the nodes
$M_e=120$	time period for MPC control

Research Methodology (Model)

Parameters and constants

m[t]	electricity price at time t
c_{ij}[t]	numbers of passengers arrives at node i with destination j at time t
outage[i,t]	binary variable describes when and where a power outage occurs
Q_d=5	energy demand for a critical building in emergency
Q_m=4.8	energy generated by a critical building in emergency
n	node number where power outage occurs
T[i,j]	the numbers of time interval taken for the vehicle to travel from one node to another
R_d	a minimum rate for energy discharge in emergency

Values hidden:

V=20	the speed of the vehicle(km/h)
tau=6	the length for a time interval(minute)
B=50	the battery capacity for a vehicle(kWh)

Notion: most of the values are taken from (Iacobucci 2019) for a test

Research Methodology (Model)

SAEV model

cost functions:

$J_x(t)$:cost function of the waiting time for passengers
$J_u(t)$:cost function of the rebalancing costs in terms of distances travelled by empty vehicles
$J_q(t)$:cost function of the cost of energy transferred between the grid and the SAEVs
$J_r(t)$: cost function which limits the final SOC for each vehicle

$$J_x(t) = \sum_i \sum_j d_{ij}(t)$$

$$J_u(t) = \sum_k \sum_i \sum_j T_{ij}\, w_{ij}^k(t)$$

$$J_q(t) = \sum_k \left(e^k(t) - \eta * g^k(t)\right) * \; m(t) \; + g^k(t)\gamma_{cycle}$$

$$J_r(t) = -\sum_k q^k(Tt - 1)$$

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Research Methodology (Model)

SAEV model

objective function: the minimisation of cost functions

$$\min \sum_{t=0}^{Tt-1} J_x(t)+\rho_1 J_u(t)+\rho_2 J_q(t)+\rho_3 J_r(t)$$

Research Methodology (Model)

SAEV model

Constraint 1: evolution of the number of waiting passengers

$$d_{ij}(t+1) = d_{ij}(t) + c_{ij}(t) - \sum_{k} v_{ij}^{k}(t)$$

Constraint 2: evolution of the parking status

$$u_i^k(t+1)=u_i^k(t)+{}^{0}p_i^k(t)-\sum_{j}(v_{ij}^k(t)+w_{ij}^k(t))$$

Research Methodology (Model)

SAEV model

Constraint 3: evolution of the state of moving vehicles

$$
{}^{T_i}p_i^k(t+1) = \begin{cases} {}^{T_i+1}p_i^k(t) + \sum\limits_{j:T_{ji}-1=T_i} v_{ji}^k(t) + w_{ji}^k(t) & T_i < T_{max} \\ \sum\limits_{j:T_{ji}-1=T_i} v_{ji}^k(t) + w_{ji}^k(t) & T_i = T_{max} \end{cases}
$$

Constraint 4: evolution of the energy stored in the battery

$$
q^k(t+1) = q^k(t) + e^k(t) - g^k(t) - \alpha_d \sum_i \sum_{T_i=0}^{T_{max}} {}^{T_i}p_i^k\,(t+1)
$$

Research Methodology (Model)

SAEV model

Constraint 5 : a vehicle k is either travelling or parked in every time step

$$\sum_{i} u_i^k(t) + \sum_{i} \sum_{T_i}^{T_{max}} {}^{T_i}p_i^k(t) = 1$$

Constraint 6: a vehicle only performs one task at a time

$$\sum_{i} [u_i^k(t+1) + \sum_{j} (v_{ij}^k(t) + w_{ij}^k(t))] \leq 1$$

Research Methodology (Model)

SAEV model

Constraint 7: vehicles can not transport more passengers than are waiting at stations

$$\sum_{k} v_{ij}^{k}(t) \leq d_{ij}(t) + c_{ij}(t)$$

Constraint 8,9 and 10:the bound for the energy and the energy must be enough for the picking up/relocating trip

$$q_{min} \leq q^{k}(t) \leq q_{max}$$

$$q^{k}(t) \geq \alpha_d T_{ij} v_{ij}^{k}(t) + q_{min}$$

$$q^{k}(t) \geq \alpha_d T_{ij} w_{ij}^{k}(t) + q_{min}$$

Research Methodology (Model)

SAEV model

Constraint 11&12: upper bounds for the energy charged/ discharged for vehicle k, note that a vehicle can't discharge at a node where power outage occurs

$$e^k(t) \leq \alpha_c \sum_i (1 - outage[i,t])\, u_i^k$$

$$g^k(t) \leq \alpha_{v2g} \sum_i u_i^k$$

Constraint 13： relation between Q_{v2b} and $v2b^k$

$$Q_{v2b}(t) = \eta \sum_k v2b^k(t)$$

Research Methodology (Model)

SAEV model

Relation 14： discharging in emergency needs the vehicle to be parked at node n

$$g2b^k(t) = g^k(t) * u_n^k(t)$$

Constraint 15,16 and 17： linearization of relation 14

$$g2b^k(t) \geq outage[n,t] * \left(g^k(t) - \alpha_{v2g} * \left(1 - u_n^k(t)\right)\right)$$

$$g2b^k(t) \leq outage[n,t] * \alpha_{v2g} * u_n^k(t)$$

$$0 \leq g2b^k(t) \leq g^k(t)$$

Research Methodology (Model)

SAEV model

Constraint 18 & 19： bound for energy discharged to critical building during emergency

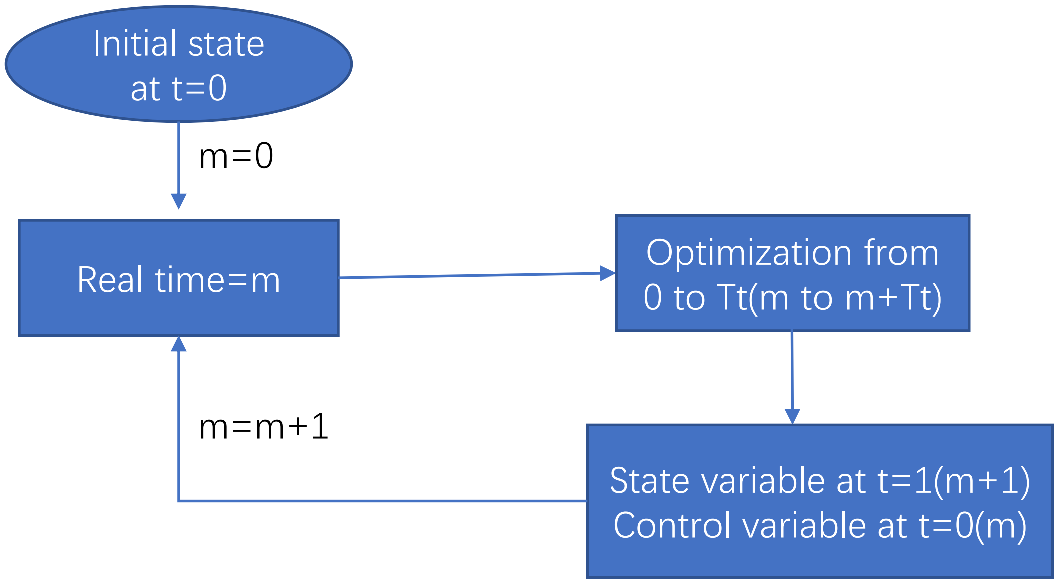
$$\mathrm{outage}[n,t](Q_d - Q_m) \geq Q_{v2g}(t) \geq \mathrm{outage}[n,t]R_d(Q_d - Q_m)$$

Research Methodology (Model)

MPC control

The principal for MPC control:

From the real time 0 to Me, at each time step m, we run an optimization in time horizon Tt and we take the result of state in t=1 as the value of m+1 and the initial state of the optimization start at m+1



Research Methodology (Model)

MPC control

Conclusion: global optimal solution in [0,Me] → series of optimal solution in prediction horizon [m,m+Tt]

Why MPC?

· basic SAEV model : MILP, solved by Branch and Bound Algorithm, Exponential Time Solvable

· increasing time horizon by hours ⇔ increasing thousands of variables → increasing exponential of time

· for MPC control Tt for optimization is fixed, increasing time horizon ⇔ increasing Me

linear increase in time

Case Study

the electricity price m m(t)~γ(2,10)   (Iacobucci 2019)

Travel distance (in time interval)T[i,j]
taken from the taxi travel data in New York Blooklyn,2020-05, 11 nodes that possesses most trips between them

T	1	2	3	4	5	6	7	8	9	10	11
1	0	2	2	3	2	1	2	2	2	3	2
2	2	0	2	7	2	2	2	2	1	6	2
3	2	2	0	2	2	2	2	2	3	2	1
4	3	7	2	0	3	3	5	3	4	1	3
5	2	2	2	3	0	1	3	1	2	2	1
6	1	2	2	3	1	0	2	2	2	3	1
7	2	2	2	5	3	2	0	3	3	4	3
8	2	2	2	3	1	2	3	0	1	2	1
9	2	1	3	4	2	2	3	1	0	4	2
10	3	6	2	1	2	3	4	2	4	0	2
11	2	2	1	3	1	1	3	1	2	2	0

Case Study

Arrival of passengers $c_{ij}[t]$

$c_{ij}[t] \sim Poisson(\lambda_{ijt})$

λ_{ijt} is the average trip number between node i and j.

Notion: the real trip number is grouped in 30 minutes → t=5n+1:5n+5 λ_{ijt} is the same

Me=120, we run the simulation between 7:00 and 19:00

Initial condition of vehicles:

All vehicle has a SOC initial of 0.8

Vehicle i parked at node i(vehicle 1 parked at node 1,etc)

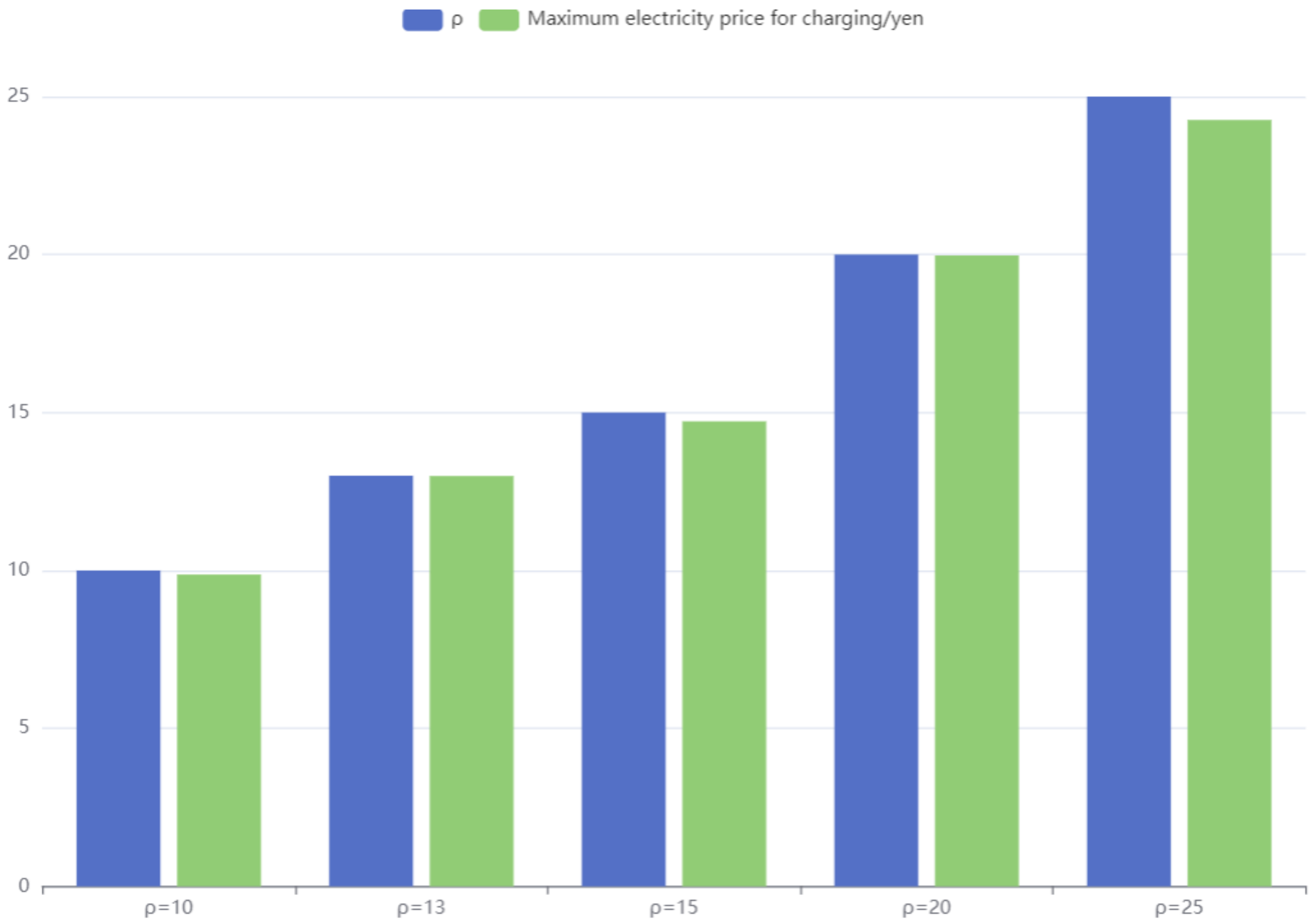
Power outage duration is always 1 hour

Results

Part 1:without emergency

Results

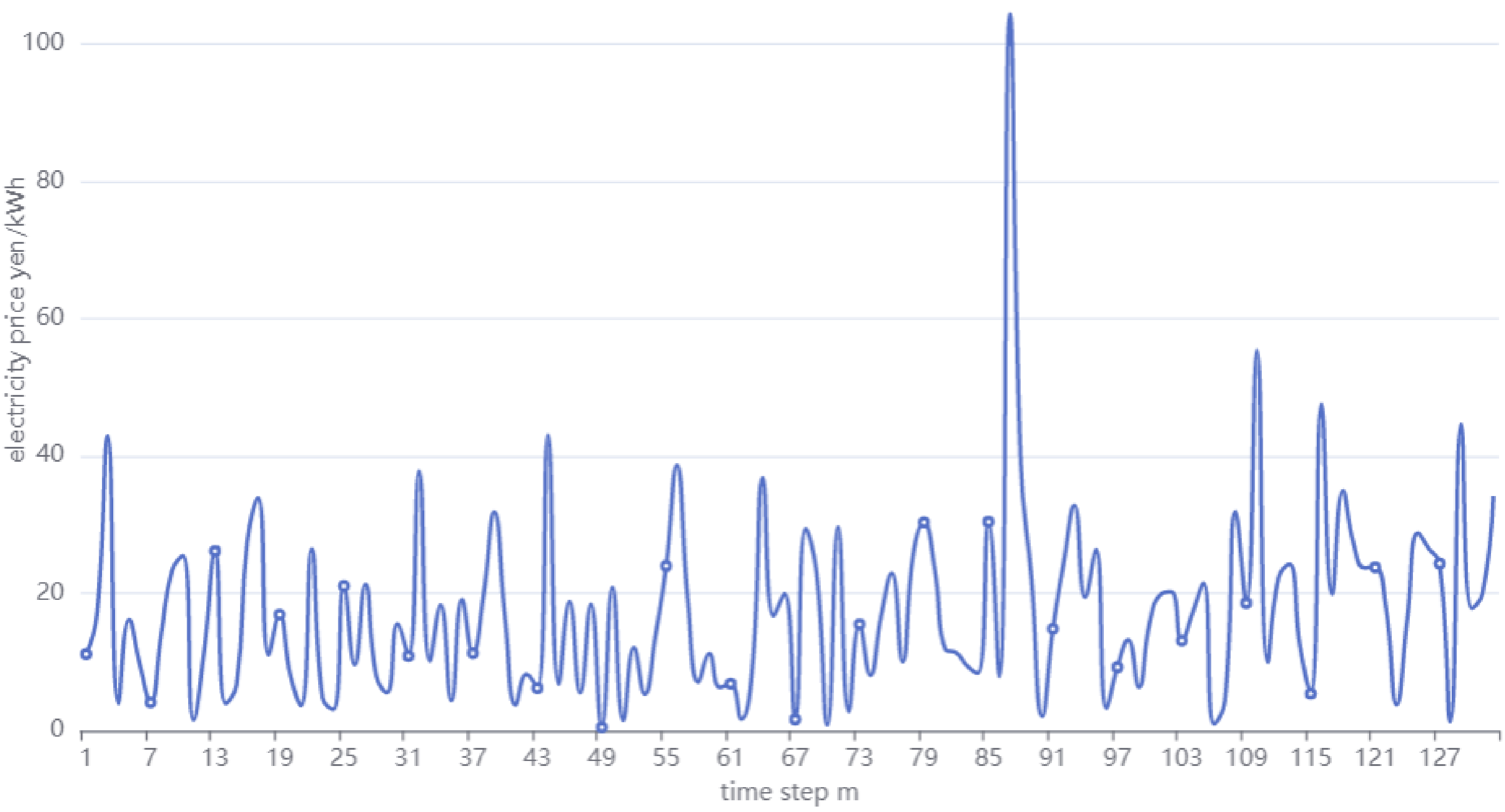
How ρ_3 controls the final SOC



An upper bound for charging price: any higher price is rejected

Results

Evolution of the electricity price



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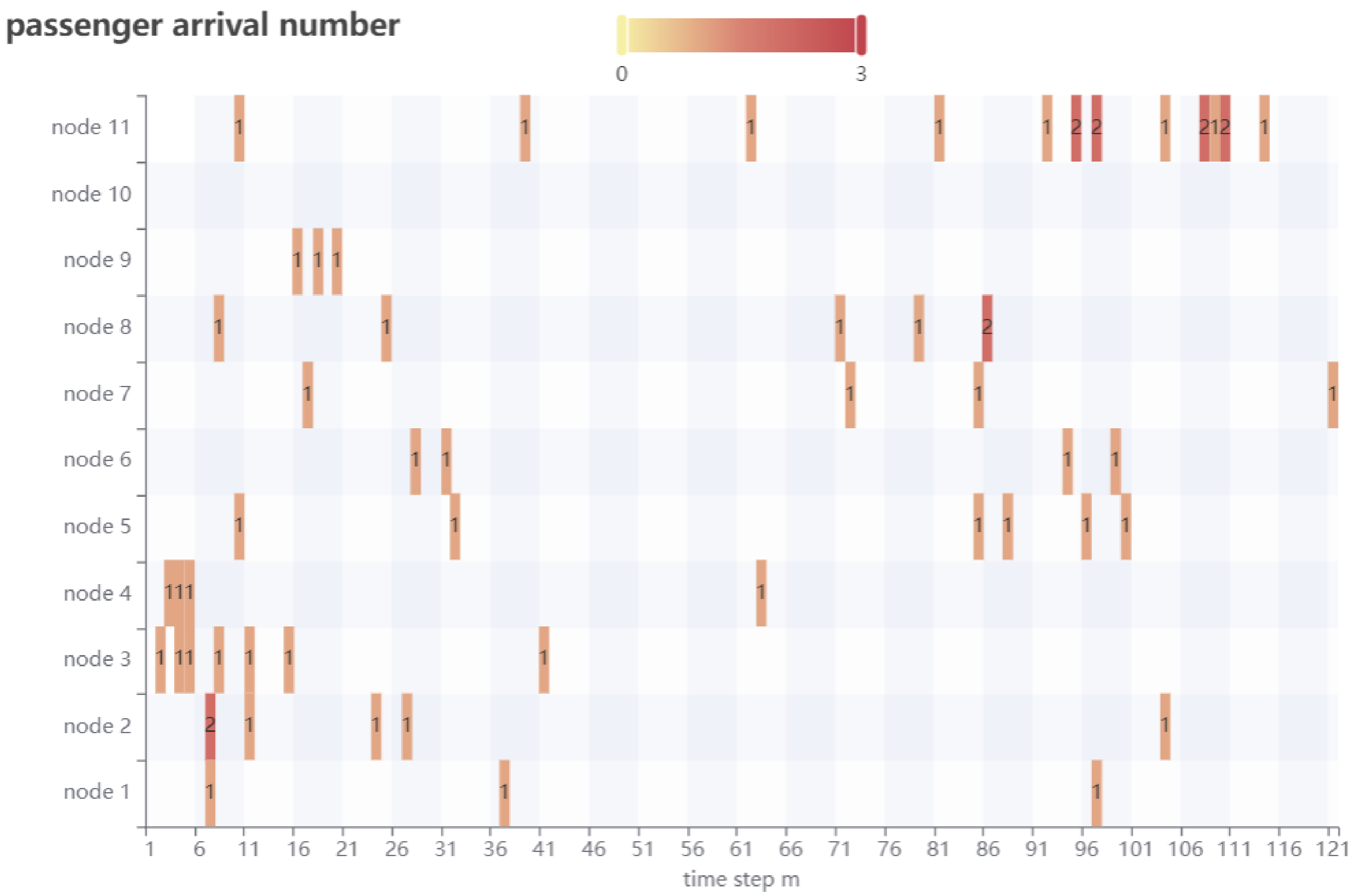
Results



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Results

Passenger waiting time= 6 min

Relocating time = 366 min

Charging cost=-2929.66 yen

related

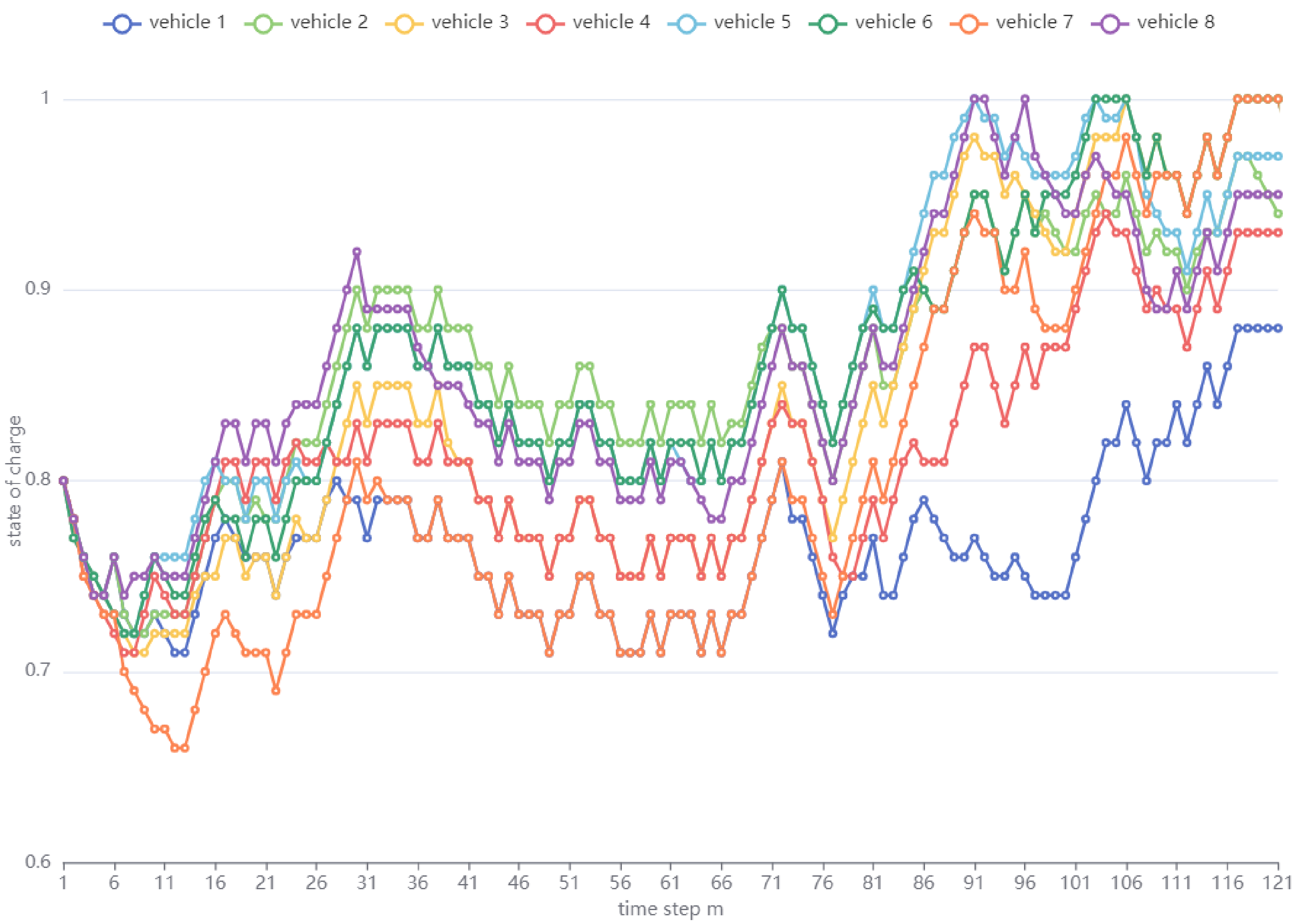
$$J_x(m) = \sum_i \sum_j d_{ij}(m)$$

$$J_u(m) = \sum_k \sum_i \sum_j T_{ij} w^k_{ij}(m)$$

$$J_q(m) = \sum_k \left(e^k(l) - \eta * g^k(l)\right) * m(l) + g^k(l)\gamma_{cycle}$$

Results

Evolution of the energy status



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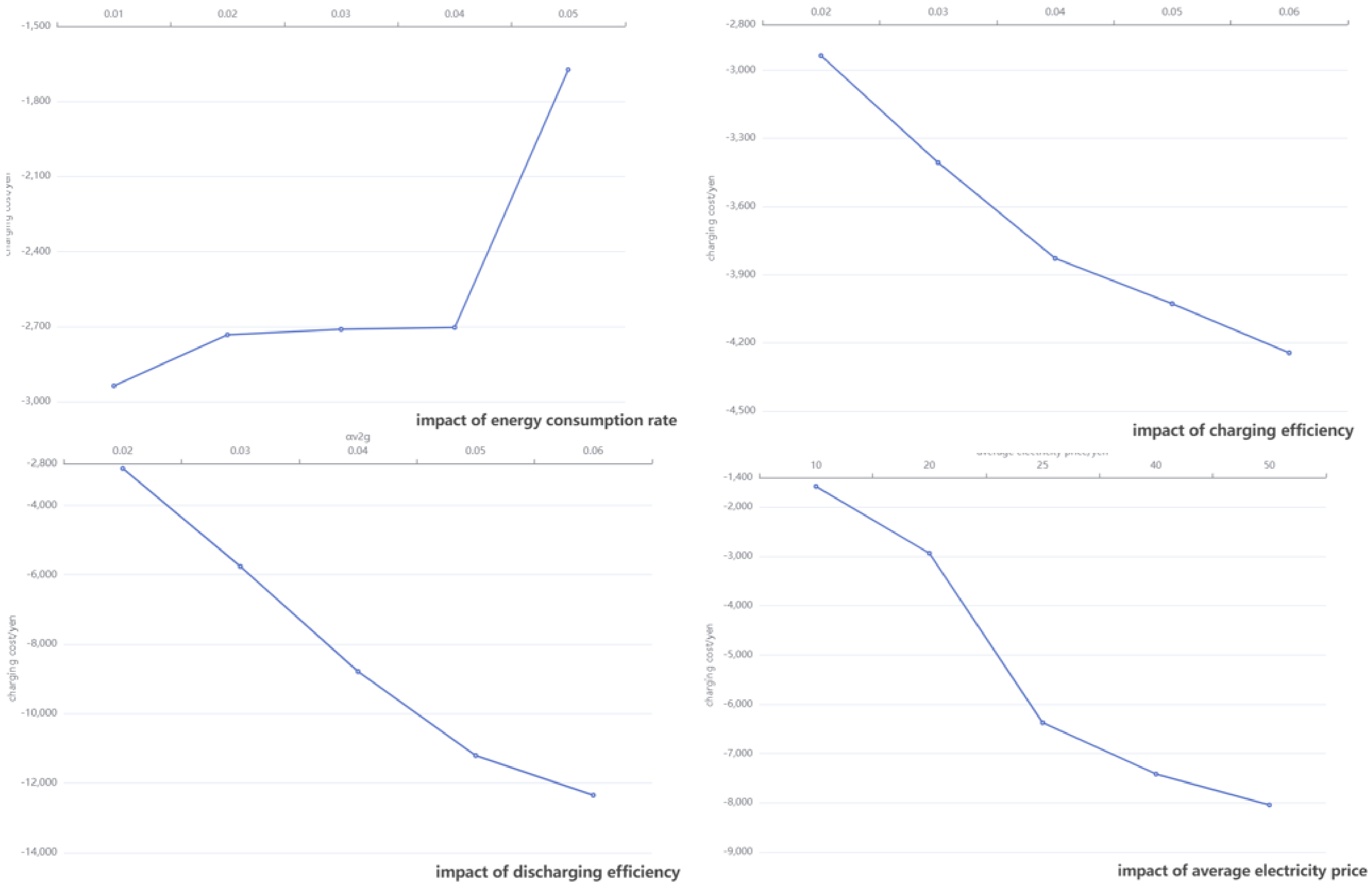
Results



Only charging cost is influenced

SAEV system manage to deal it with a cost of final SOC

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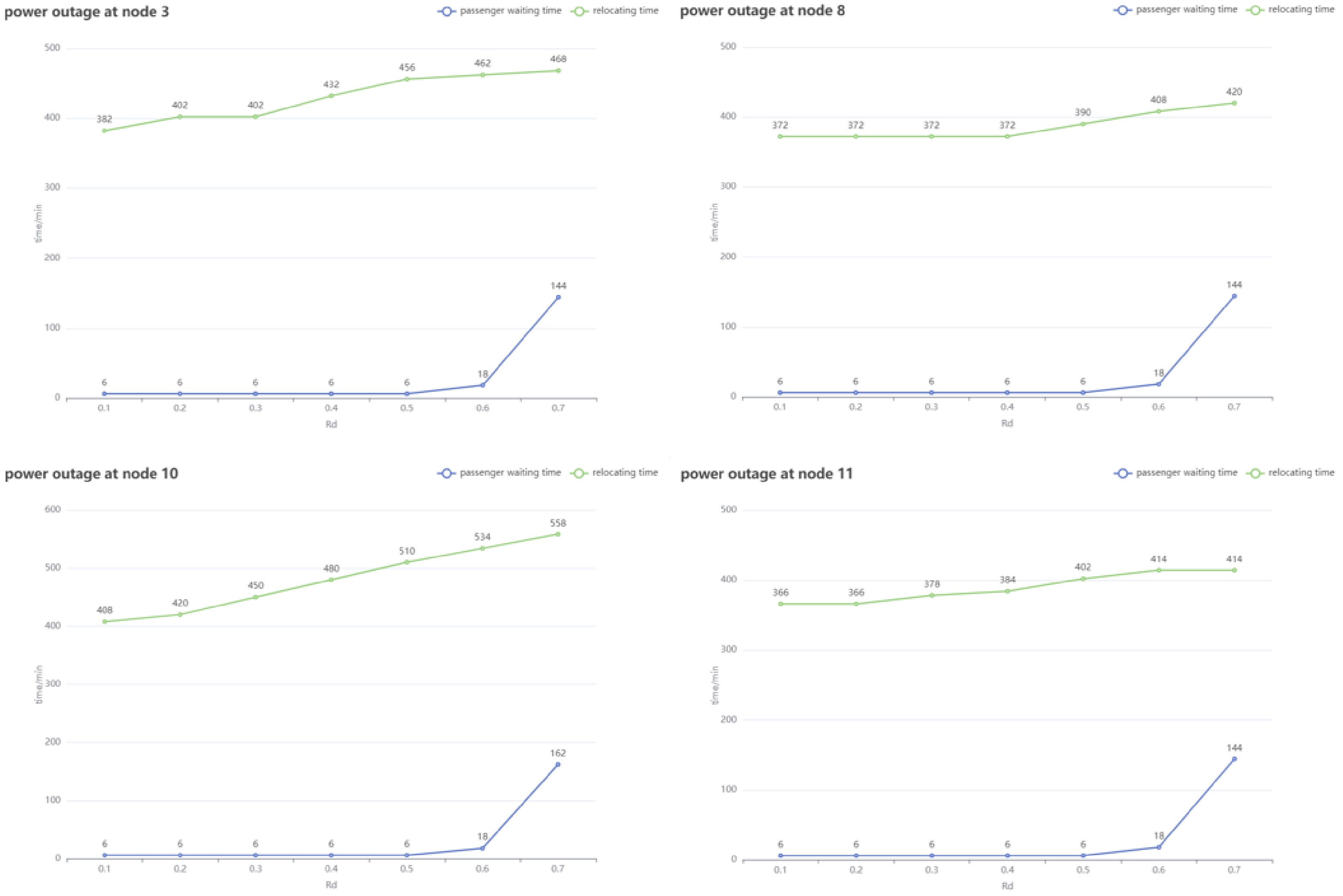
Results

Part 2:with emergency

Results

Impact of Rd when power outage occurs at 11:00-12:00



$$R_{d\,max} = \frac{K\eta\alpha_{\mathrm{v2}g}}{Q_{\mathrm{d}} - Q_m} = 0.72$$

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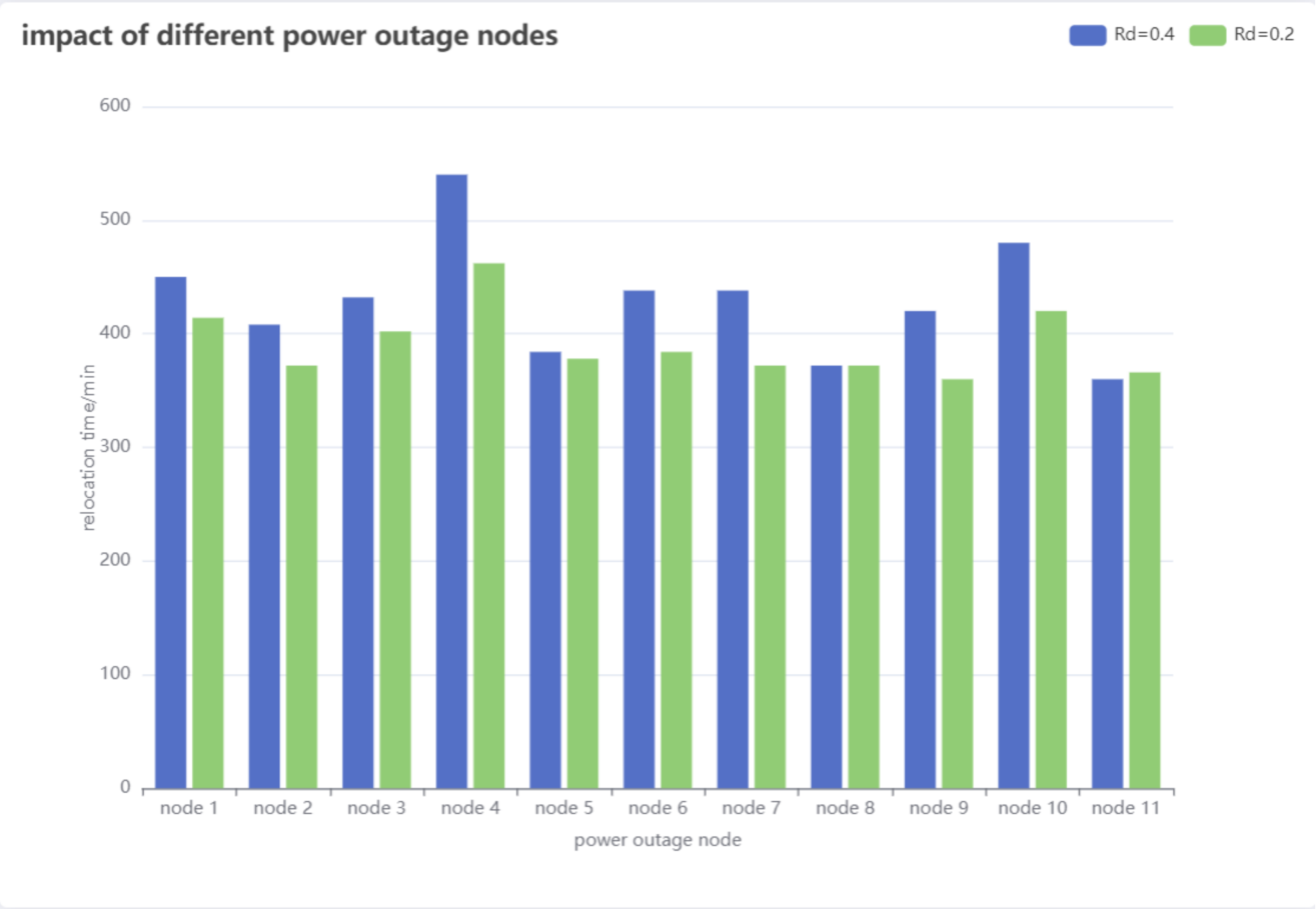
Results



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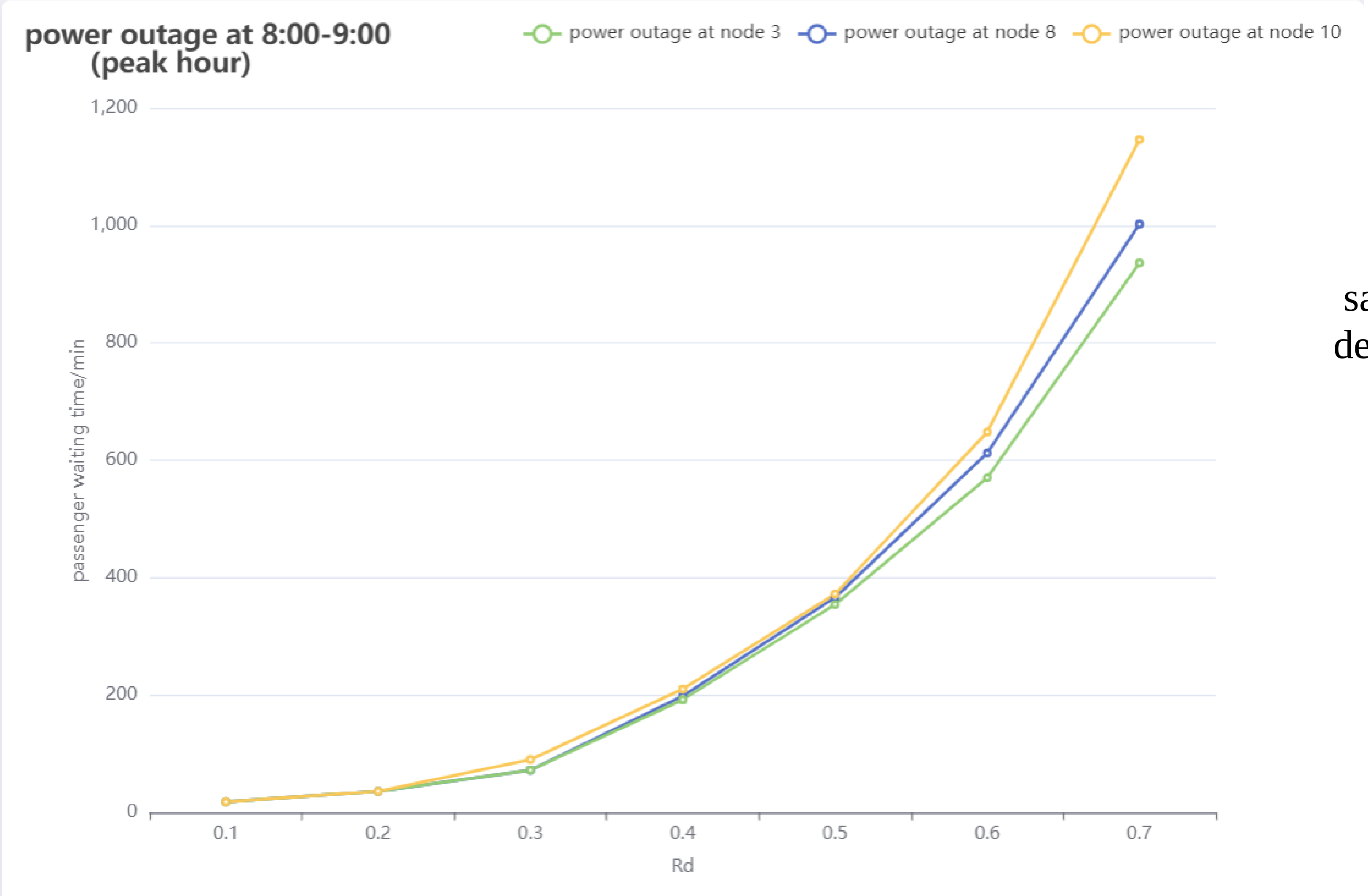
Results



satisfy the emergency demand at a high cost

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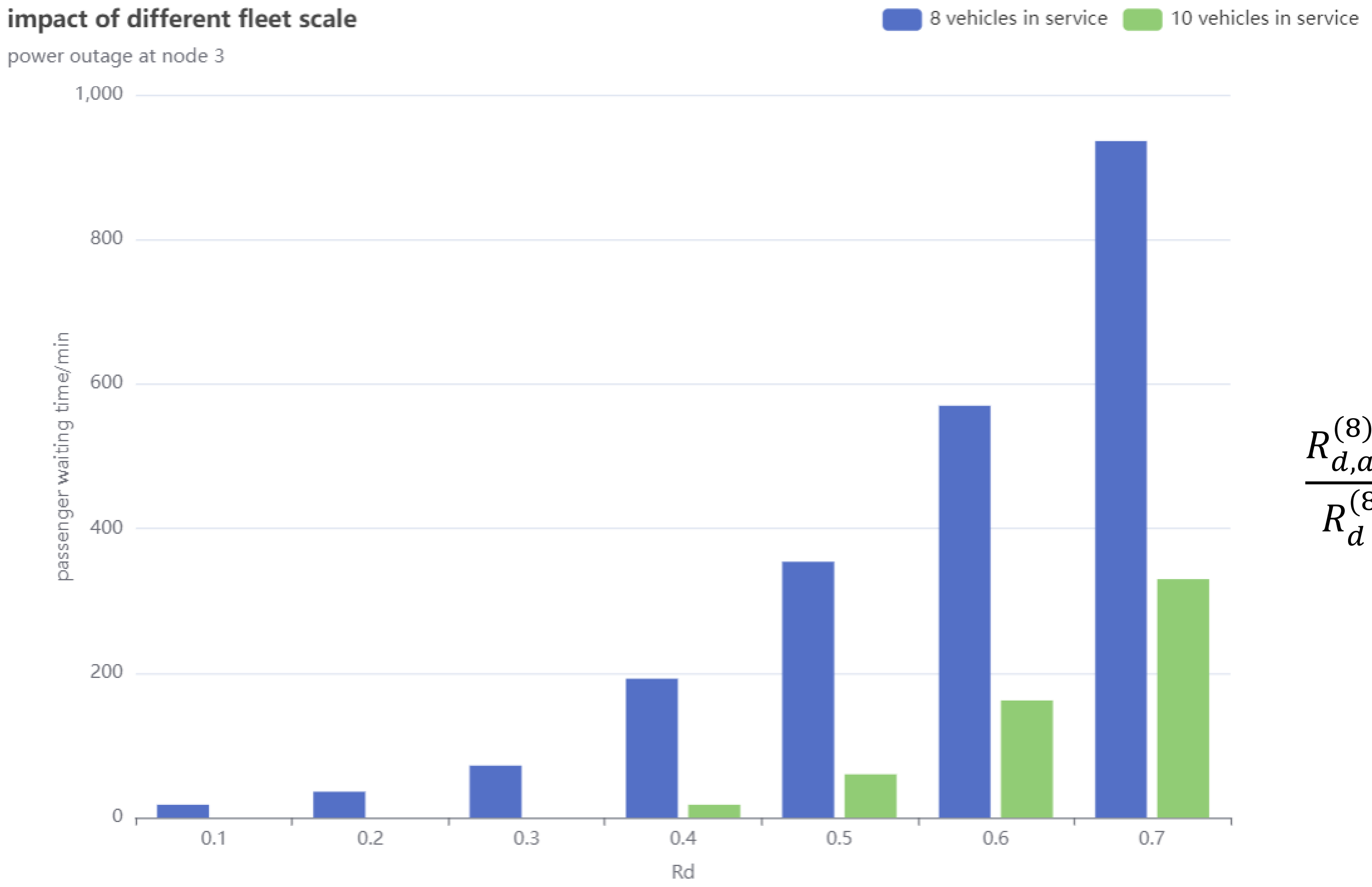
Results



a solution

$$\frac{R^{(8)}_{d,accept}}{R^{(8)}_{d\ max}} = 0.14, \frac{R^{(10)}_{d,accept}}{R^{(10)}_{d\ max}} = 0.44$$

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Conclusion

- An implantation of emergency situation
- Detection of the sensitivity in different situation
- Power outage time is an important factor
- R_d = 0.5 acceptable for a normal hour while R_d = 0.1 almost unacceptable for a busy hour
- Increasing the fleet scale is a strategy but the cost needs to be balanced
- Limitation: resilience is often estimated with statistics methods while R_d model is difficult in switching in different situn.

Future plan

Estimation resilience with probabilistic method

- Model of power outage
- Monte-Carlo simulation for model presented with different outage case
- Amplification of model: fixed R_d not suitable
- Remove R_d and set a new cost function (balancing the weight)

Collecting data in Beijing and do a case study in Beijing

Internship report

A robust optimization approach for coordination between the recharge management of autonomous electric vehicles and power network

Hadrien HERUBEL

November 2021

Summary

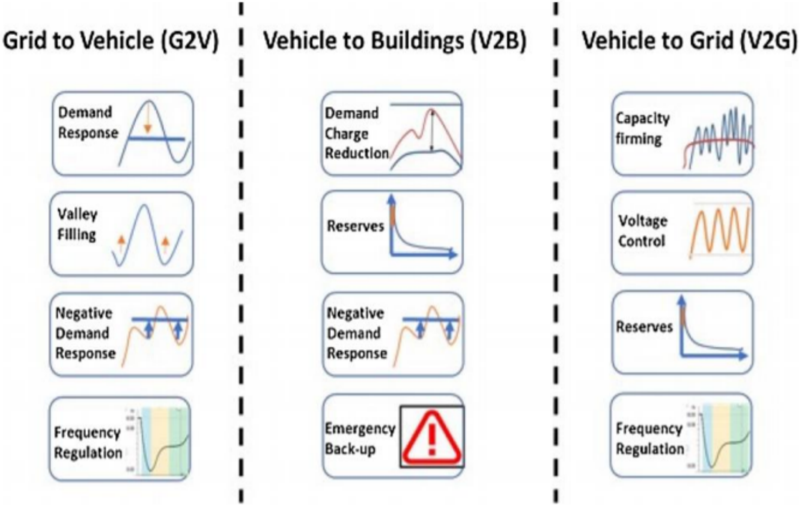
Introduction

- Optimization model for SAEV management
- Utilizing Distributionnaly Robust Optimization
- Incorporating interactions between vehicles and the grid
- In a model subject to uncertainty

SAEV

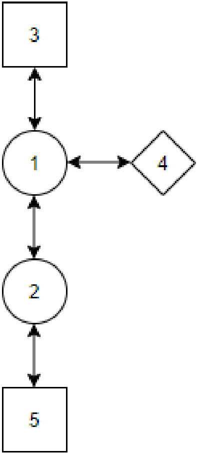
- Economic and environmental incentives
- Comparable costs for users
- Entirely electric vehicles
- 1 SAEV per 3 to 9 private cars

Interaction opportunities



Link Transmission Model

Link Transmission Model



- Vertices
  - Traffic
  - Centroids
    - Capacity
    - Loading
- Arcs
  - Connectors / Traffic
  - Capacity
  - Length
  - Speed

Optimization model

Kinematic Wave Theory

- Describes the propagation of vehicles through the model

$$C_{ij}^{\downarrow sv}(t+1) = C_{ij}^{\downarrow sv}(t) + \sum_{(j,k)\in\Gamma_j^+} y_{ijk}^{sv}(t)$$

Demand

- Describes the evolution of waiting clients on centroids
- Sets the kinematic wave theory in motion

$$w_r^s(t+1) = w_r^s(t) + d_r^s(t) - \sum_{v \in V} e_r^{sv}(t)$$

Energy

- Evolution of all SoC

$$in^v(t) = \sum_{i \in Z_{charge}} (p_i^v(t) * cIn_i)$$

$$out^v(t) = \sum_{(i,j) \in A} \sum_{s \in Z} ((C_{ij}^{\downarrow sv}(t) - C_{ij}^{\downarrow sv}(t-1)) * L_{ij}) * cOut^v$$

$$pw^v(t+1) = pw^v(t) + in^v(t) - out^v(t)$$

Objective

- Minimize Total System Travel Time
- Vehicle travel time

$$\sum_{(i,j)\in A}\sum_{s\in Z}\sum_{v\in V}\sum_{t=0}^{T}(C_{ij}^{\uparrow sv}(t) - C_{ij}^{\downarrow sv}(t))$$

- Client waiting time

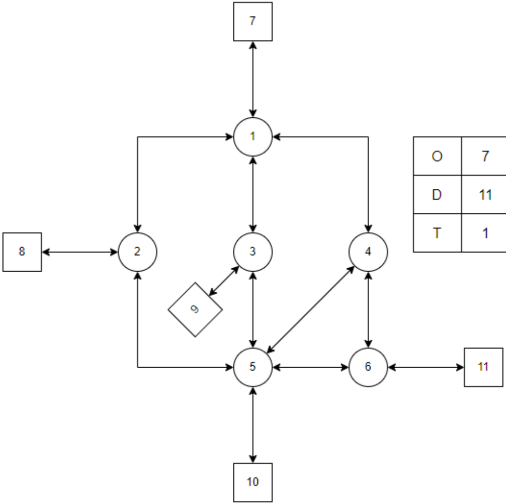
$$\sum_{(r,s)\in Z^2}\sum_{t=0}^{T} w_r^s(t)$$

Current state & Results

Observations

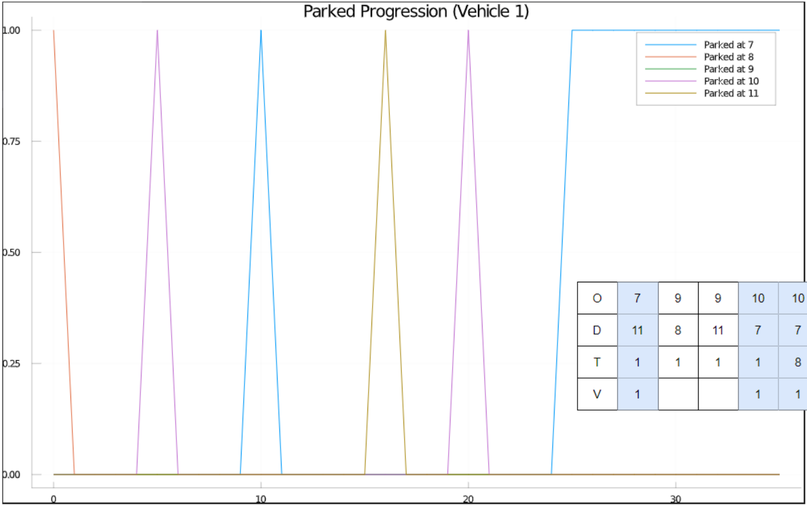
- Original model unfit for large problems
- Battery constraints and related changes burdened the model further
- Current program does not solve non trivial cases
- Unable to extract meaningful results at present

Topology & Demand



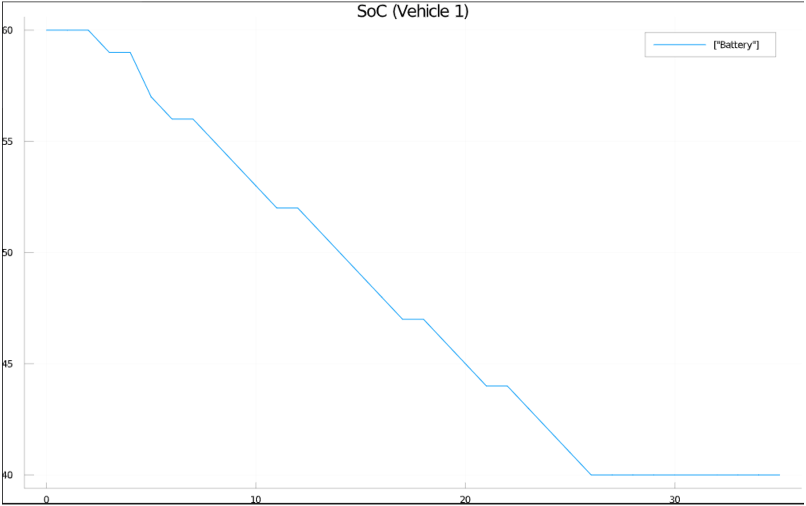
O	7	9	9	10	10	11
D	11	8	11	7	7	7
T	1	1	1	1	8	1

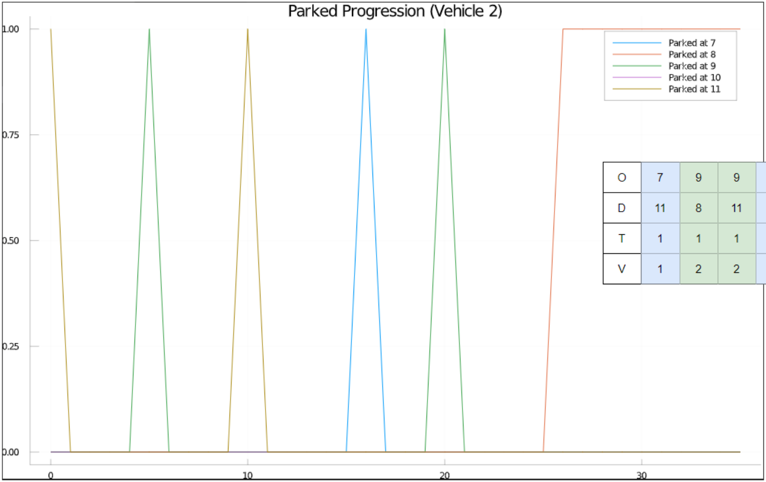
Activity of Vehicle 1



O	7	9	9	10	10	11
D	11	8	11	7	7	7
T	1	1	1	1	8	1
V	1			1	1	

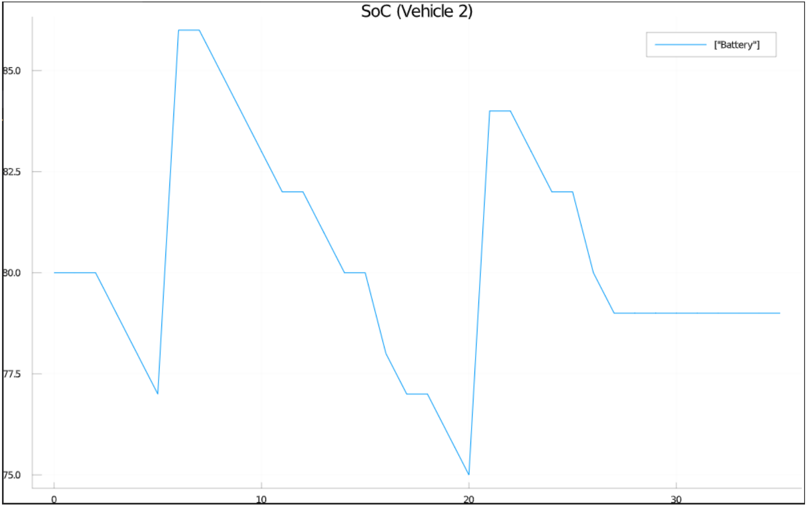
Battery of Vehicle 1





O	7	9	9	10	10	11
D	11	8	11	7	7	7
T	1	1	1	1	8	1
V	1	2	2	1	1	2

Battery of Vehicle 2



Conclusion

Conclusion

Next Seminar

RELIABILITY OF THE PUBLIC SERVICE MARKET AGAINST CASCADING IMBALANCE

Jinxiao DUAN, Beijing

WEDNESDAY, December 8th, 2021 | 10-11 AM CEST

Register here