Comparing different rebalancing operations strategies in car sharing systems: A generic optimization framework

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Outline

1. Introduction
2. Evaluating different rebalancing operation strategies
   - Motivation
   - Literature
3. Methodology
   - Considered system and the framework
   - Preliminary experiments
   - Rebalancing operations optimization
4. Conclusion

Introduction

- 37.5% of the U.S. greenhouse gas emissions is due to transportation (EPA, 2021[1]).
  - Passenger cars contribute the most with 40.5%.

[1] EPA (2021) Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019.

[2] Amatuni, L., Ottelin J., Steubing B. and Mogollón J. M. (2020) Does car sharing reduce greenhouse gas emissions? Assessing the modal shift and lifetime shift rebound effects from a life cycle perspective, Journal of Cleaner Production.

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  - Short rentals
  - Higher car and less parking utilization
  - Examples: Mobility, car2go, SHARENOW

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    - Examples: Mobility, car2go, SHARENOW
- Introducing a car sharing system results in between 3% and 18% reduction in CO2 emissions (Amatuni et al., 2020[2]).

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Motivation

- Is shared mobility as sustainable as we think?
  - Reck et al. (2022)[3] claim that personalized micro-mobility is more sustainable than the shared one.
  - One reason is costly rebalancing operations.

[3] Daniel J. Reck, Henry Martin, and Kay W. Axhausen. Mode choice, substitution patterns and environmental impacts of shared and personal micro-mobility. Transportation Research Part D: Transport and Environment, 102:103134, 2022.

[4] Jia Shu, Mabel Chou, Qizhang Liu, Chung Teo, and I-Lin Wang. Models for effective deployment and redistribution of bicycles within public bicycle-sharing systems. Operations Research, 61:1346–1359, 11 2013.

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- The added-value of bike rebalancing in bike sharing systems?
  - Shu et al. (2013)[4] find that the number of substituted trips change as a function of number of bicycles and number of redistributions per day.
  - Periodic and frequent rebalancing operations are not necessary for some configurations of the system.

[3] Daniel J. Reck, Henry Martin, and Kay W. Axhausen. Mode choice, substitution patterns and environmental impacts of shared and personal micro-mobility. Transportation Research Part D: Transport and Environment, 102:103134, 2022.

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- The added-value of rebalancing operations in car sharing systems
  - The effect of city characteristics
  - The effect of trip demand behavior
  - The effect of different rebalancing operations strategies
  - ...

Previously in the literature..

- Martinez et al. (2017)[5]
    - Agent-based model and supply side, i.e., operations by the staff such as maintenance, rebalancing, and refueling

[5] Martínez, L. M., G. H. de Almeida Correia, F. Moura and M. M. Lopes (2017) Insights into carsharing demand dynamics: Outputs of an agent-based model application to Lisbon, Portugal, International Journal of Sustainable Transportation, 11 (2) 148-159.

[6] Vasconcelos, A. S., L. M. Martinez, G. H. Correia, D. C. Guimarães and T. L. Farias (2017) Environmental and financial impacts of adopting alternative vehicle technologies and relocation strategies in station-based one-way carsharing: An application in the city of Lisbon, Portugal, Transportation Research Part D: Transport and Environment, 57, 350-362.

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- Vasconcelos et al. (2017)[6]
  - The same agent-based model as in Martinez et al. (2017)
  - Comparison between with and without rebalancing
  - Evaluating three different policies that investigates the effect of electric vehicle adoption

[5] Martínez, L. M., G. H. de Almeida Correia, F. Moura and M. M. Lopes (2017) Insights into carsharing demand dynamics: Outputs of an agent-based model application to Lisbon, Portugal, International Journal of Sustainable Transportation, 11 (2) 148-159.

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- Uses a transport simulation toolkit, i.e., MATSim, and its car sharing API.
- Incorporates rebalancing operations optimization.

The framework

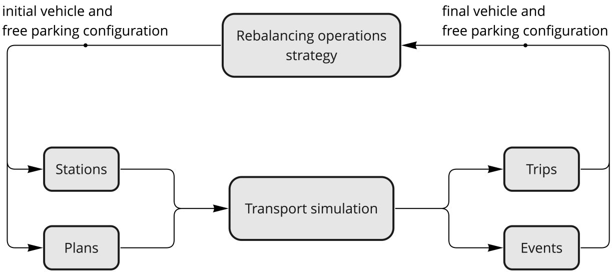

Figure: The framework

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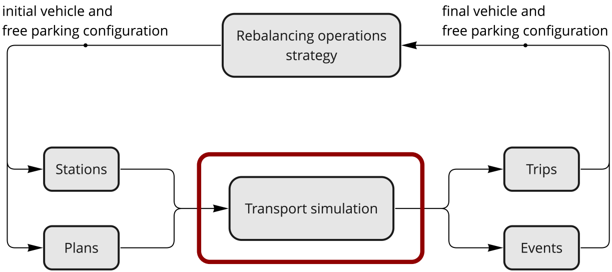

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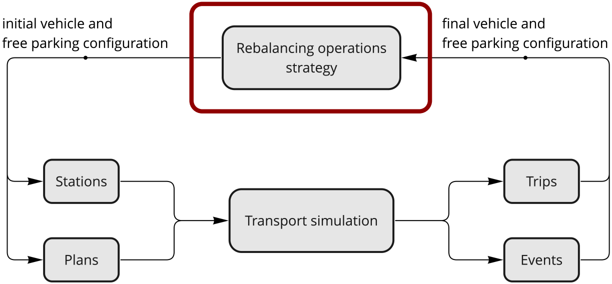

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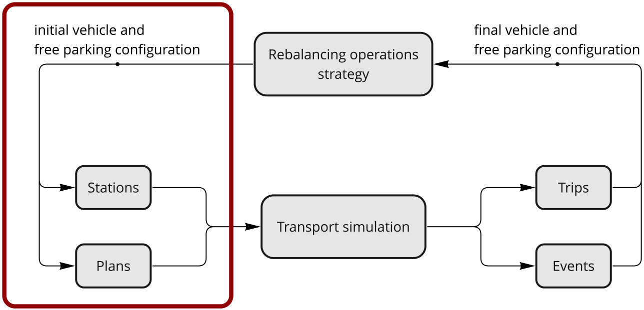

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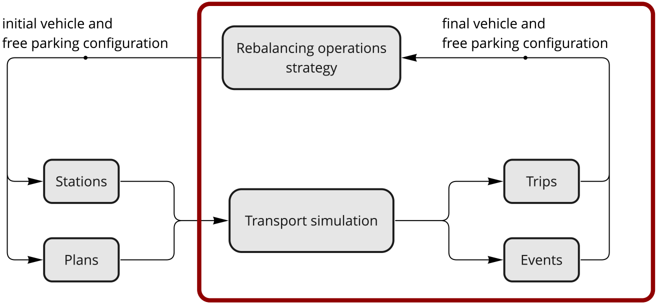

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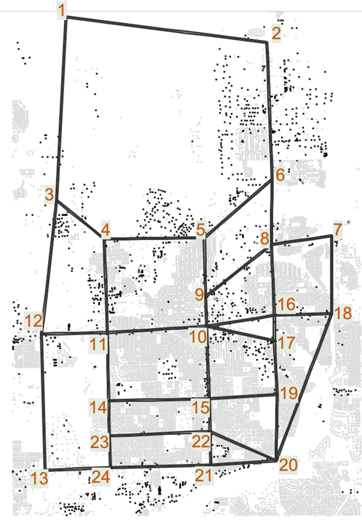
Illustrative case study

- Sioux Falls, US scenario
  - 84110 agents
  - 24 stations (5 vehicles and 5 free parking spots per station)



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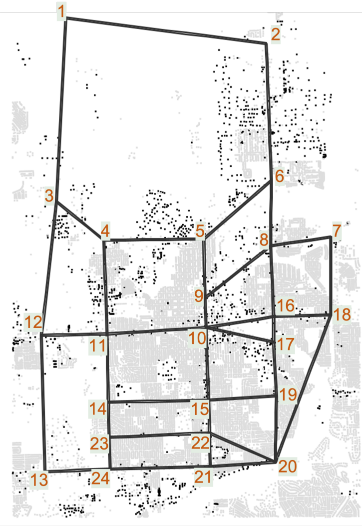

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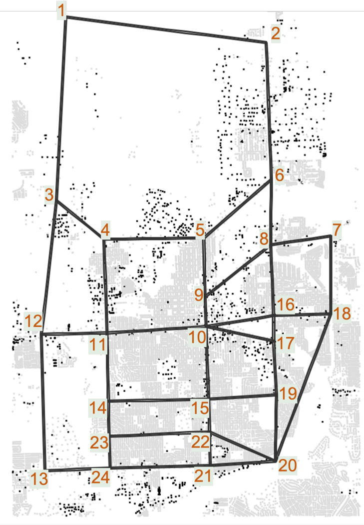

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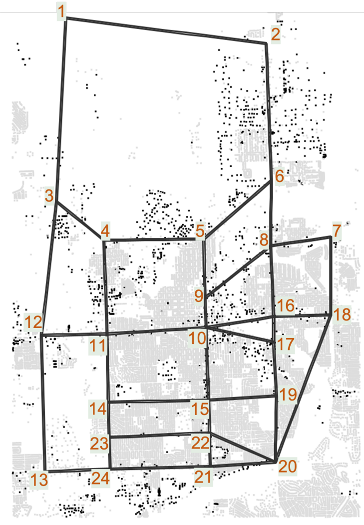

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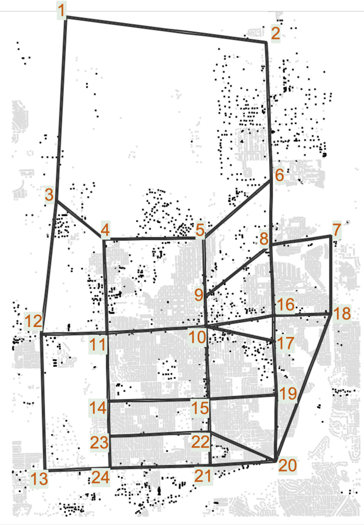
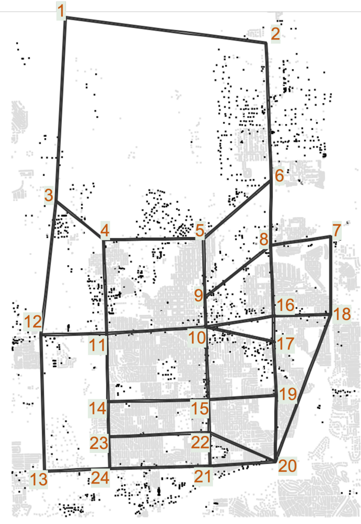
- Every agent has a membership.
- Parameters are set to default.



Scenarios

- "do nothing" scenario
  - The final configuration of the vehicles for one iteration is fed back to MATSim as an initial configuration for the next iteration.



Scenarios

- "do nothing" scenario
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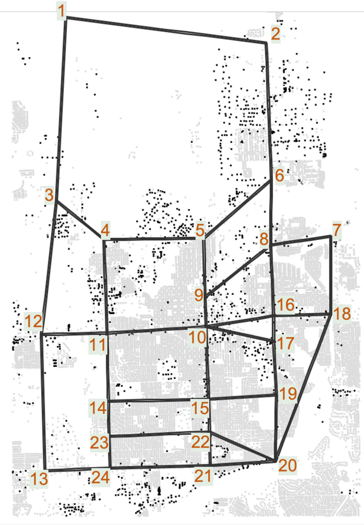
- "rebalance" scenario
  - The minimum required number of vehicles per station is computed and the free parking is determined where each station has 10 total parking spots.



Results

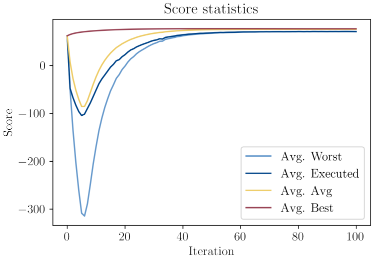


Figure: Score statistics (rebalance)

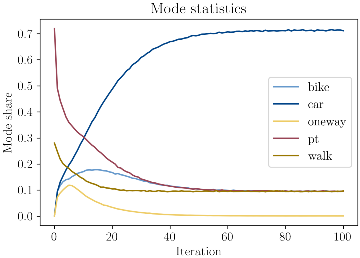


Figure: Mode statistics (rebalance)

Comparison of two strategies

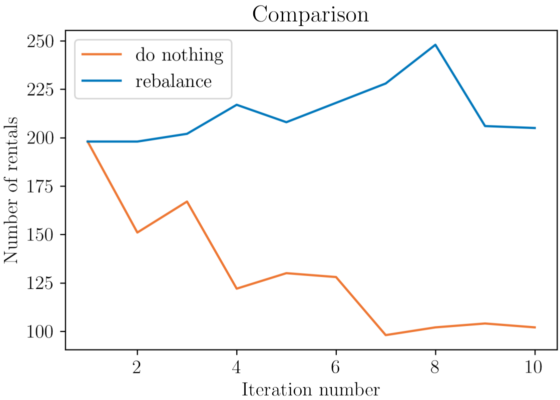


Figure: Number of rentals for both strategies

What happens if we plug in an optimization model?

- Models proposed in Gambella et al. (2018)[7] and Zhao et al. (2018)[8].
  - Gambella et al. (2018): maximize system profit with fixed numbers of vehicles and staff and limited station capacity.
  - Zhao et al. (2018): determine the optimal numbers of vehicles and staff to serve all demand while minimizing costs, with unlimited capacity at all stations.
- A third strategy based on these two models.
  - Derived from the first strategy by considering a priority trip list and forcing the model to serve them.

[7] Claudio Gambella, Enrico Malaguti, Filippo Masini, and Daniele Vigo. Optimizing relocation operations in electric car-sharing. Omega, 81:234-245, 2018.

[8] Meng Zhao, Xiaopeng Li, Jiateng Yin, Jianxun Cui, Lixing Yang, and Shi An. An integrated framework for electric vehicle rebalancing and staff relocation in one-way carsharing systems: Model formulatio and lagrangian relaxation-based solution approach. Transportation Research Part B: Methodological, 117:542-572, 2018.

What happens if we plug in an optimization model?

- A case study from Turin, Italy.
  - 10 stations
  - 10-70 number of vehicles
  - 0-3 staff
  - 418 trips/day
  - 96 timesteps (15 mins intervals)
  - Each instance is solved by CPLEX 22.10 on a server with Xeon(R) Gold 6140 CPU clocked at 2.30GHz and 36 processors with a time limit of 72 hours.
- ... but
  - The scale of the problem is not realistic and we can only solve it in three days!

Conclusions and future work

- A generic framework to evaluate different rebalancing operations strategies is presented.
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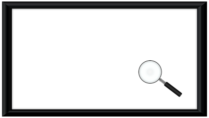
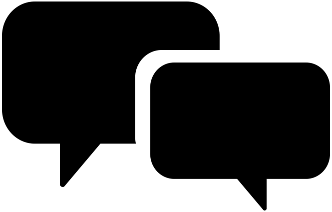
- The next steps include
  - selecting a choice model and rebalancing operations strategies from the literature,
  - analyzing the effect of rebalancing operations that consider different strategies, and
  - applying to a bigger case study, such as Zurich, Switzerland.



Questions and discussion



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