A holistic decision making framework for vehicle sharing systems
(...and evaluation of demand forecasting)

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Outline

What is a Vehicle Sharing System (VSS)?

A VSS enables users to use the available vehicles generally for short period of time by an RFID card or smart phone application identification.

- Various system configurations
  - One-way or return trip
  - Station-based or free-floating
  - Dynamic or fixed pricing
  - ...

Car-sharing companies

Bike-sharing companies

PubliBike

mobike

citi bike

PBSC
URBAN SOLUTIONS

Imbalance in the network

- Bicycle-sharing systems (BSSs)
  - Capacitated traveling salesman problem (TSP) (*Pal and Zhang et al., 2017*)
  - Vehicle routing problem (VRP) with commodity flow conservation constraints (*Ghosh et al., 2016*)
  - VRP with previously clustered stations (*Liu et al., 2016*)
- Car-sharing systems (CSSs)
  - Multi-TSP (*Nourinejad et al., 2015*)
  - Mixed Integer Linear Programming (MILP) models (*Boyaci et al., 2017*)
  - Importance of the relation between demand forecasting and rebalancing (*Jorge and Correia, 2013*)
  - Denial of the requests in the case of high demand (*Boyaci et al., 2017*)

Demand estimation

- BSSs
  - Meteorology Similarity Weighed K-Nearest-Neighbor model for station bike pick-up demand prediction (*Liu et al., 2016*)
  - Simulating the demand with a Poisson process (*Ghosh et al., 2016*)
  - Worst-case demand, which maximizes demand loss (*Ghosh et al., 2016*)
- CSSs
  - Forecasting OD pairs between zones with two methods (*Müller and Bogenberger, 2015*):
    - AutoRegressive Integrated Moving Average (ARIMA)
    - Holt-Winter's method

Pricing

- BSSs
  - Prices are assigned dynamically depending on the occupancy at the destination station. (*Chemla et al., 2013, Waserhole, 2013*)
  - Incentives are linearly dependent on the additional travel time. (*Pfrommer et al., 2014*)
  - Dynamic pricing improved the level of service for the weekends. (*Pfrommer et al., 2014*)
- CSSs
  - Incentives on pricing which encourages users to do trips which reduces the imbalance of the network. (*Jorge and Correia, 2013*)
  - Balance of the system is improved, but less demand is served. (*Jorge and Correia, 2013*)

Big picture

- *Shared mobility systems: an updated survey* by Laporte *et al.*, (2018)
    - Two dimensional classification
        - Type of the problem
        - Decision level
    - Lack of research in some specific areas
        - Pricing incentives and rebalancing at strategic level
        - Locating stations in tactical level
- This work aims to provide a holistic solution approach for the VSSs.
    - From decision maker point of view
    - Three dimensional classification
        - Decision levels: Strategic, Tactical, and Operational
        - Actors: Supply and Demand
        - Layers: Data, Models, and Actions
    - Relations between the components

Strategic level

- Corresponds to long-term decisions
  - What kind of system are we dealing with?
  - How is the scope defined?
- Planning horizon
  - More than a year

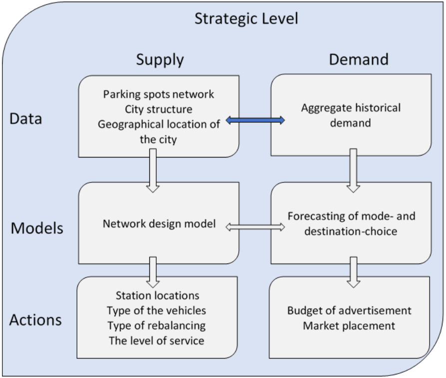


Figure: General framework - strategic level

Tactical level

- Corresponds to mid-term decisions
  - How do we utilize the strategic level decisions?
  - Which decisions should we pass to the operational level?
- Planning horizon
  - 4-6 months

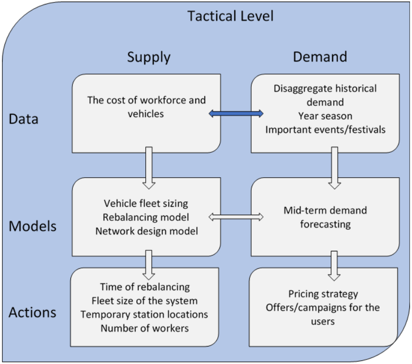


Figure: General framework - tactical level

Operational level

- Corresponds to short-term decisions
  - What is the current situation of the system?
  - What do we do next time step?
- Planning horizon
  - Daily/hourly

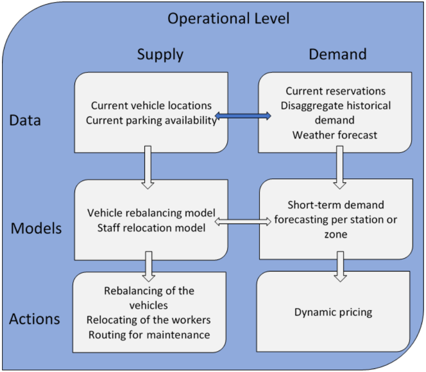


Figure: General framework - operational level

Big picture - revisited

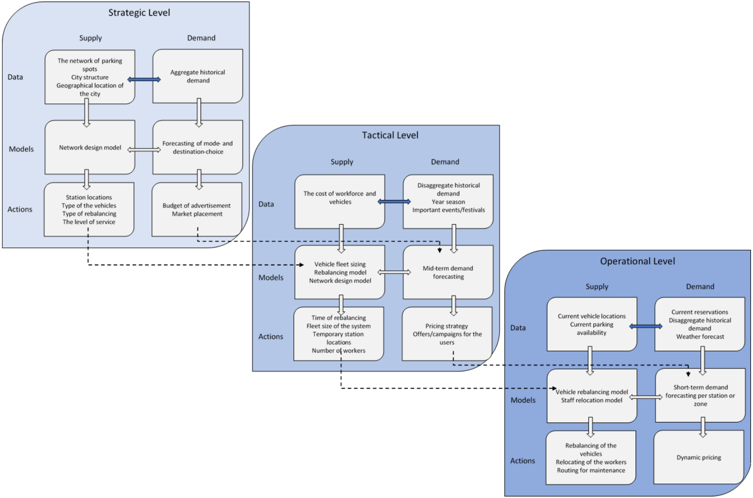


Figure: General framework and inter-relations

Derived questions

- Demand forecasting is given a large attention,...
- ...but what about the added value from constructing a demand model?

- The literature consists of works on BSSs and CSSs.
- New types of vehicles are being introduced in VSSs.
- However, some of the approaches are inapplicable for the new types of vehicles.

The idea

- A discrete event simulation models the system demand throughout the day.
- The vehicle distribution at the end of the day is obtained from the simulation and passed to the optimization model.
- The mathematical model solves the rebalancing problem given a desired initial state for the next day.
- Two cases are investigated:
  - Known demand: the model knows a perfect demand forecast for the next day. The rebalancing is done according to this information.
  - Unknown demand: the system is rebalanced to the same initial state every day.
- The main idea is to compare the trade-off between the lost demand and rebalancing costs, between the two cases.

Setting the scene

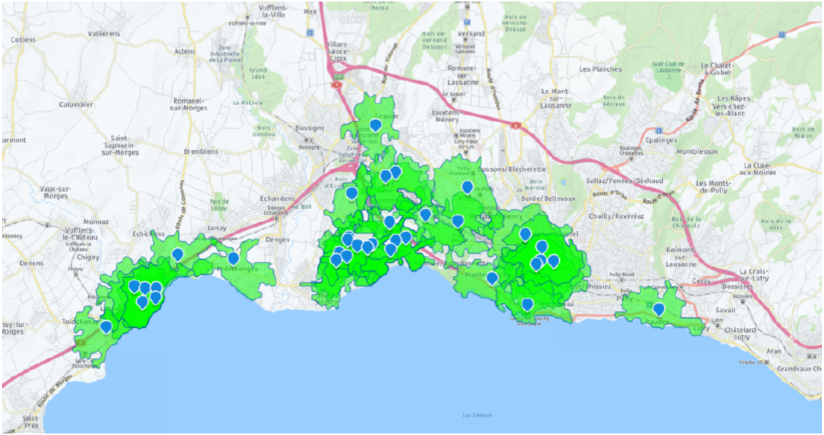
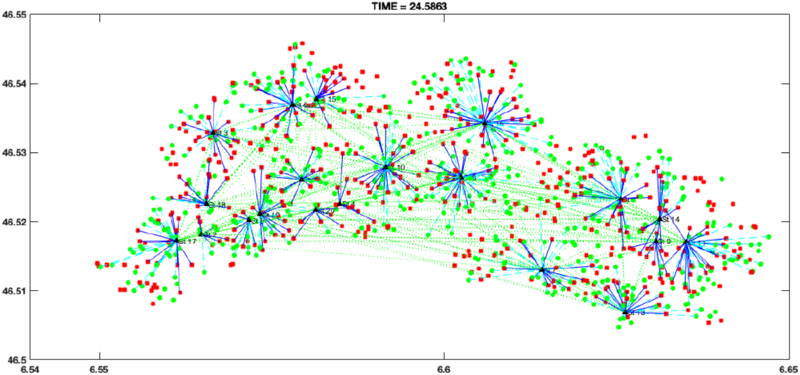


Figure: PubliBike stations and corresponding isoline polygons

Trips simulation



Station ID	1	2	3	4	5	6	7	8	9	10
No. of bikes	8	3	0	0	6	4	15	10	0	5

Station ID	11	12	13	14	15	16	17	18	19	20
No. of bikes	6	9	8	0	2	10	10	0	3	1

Preliminary findings

Day	Unknown demand		Forecasted demand		Total requests
	Lost dem.	Reb. cost	Lost dem.	Reb. cost	
1	172	18681	181	16538	469
2	186	16236	171	16206	477
3	174	16206	165	16264	457
4	172	15938	153	15938	482
5	173	15614	164	15484	482
6	178	15932	169	15932	494
7	172	15484	162	15484	490
8	172	16888	165	16187	499
9	173	15932	162	15932	474
10	163	15614	163	15614	465

Conclusion and future work

- A general framework for VSSs is presented.
- Inter- and intra-relations between framework components are discussed.
- We focused on the evaluation of value of demand modeling and presented preliminary results.

- Different scenarios such as in the case of events will be evaluated.
- Different configurations of VSSs will be analyzed.
- An application will be done on newly introduced LEVs.

An application to Light Electric Vehicles (LEVs)

- A new type of vehicles

- You don't need a car driving license
- You can ride on bicycle lane
- You are protected from bad weather
- There's a room for luggage
- Free-floating parking

- The system is available to a higher portion of the population.
- Conventional rebalancing ideas should be adapted.
- Free-floating structure is not widely studied.

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