A new management framework for a vehicle sharing system

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September 4, 2019

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
  - Rebalancing with operators or trucks
  - Dynamic or fixed pricing
  - ...

Car-sharing companies

Bike-sharing companies

mobike

PubliBike

PBSC
URBAN SOLUTIONS

citi bike

Imbalance in the network

- Bicycle-sharing systems (BSSs)
  - Vehicle routing problem (VRP) (*Ghosh et al., 2016 & Liu et al., 2016*)
  - Capacitated traveling salesman problem (TSP) (*Pal and Zhang et al., 2017*)
- 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
  - Machine learning algorithms (*Liu et al., 2016*)
  - Simulating the demand with a Poisson process (*Ghosh et al., 2016*)
  - Worst-case demand (*Ghosh et al., 2016*)
- CSSs
  - AutoRegressive Integrated Moving Average (ARIMA) (*Müller and Bogenberger, 2015*)
  - Holt-Winter's method (*Müller and Bogenberger, 2015*)

Pricing

- BSSs
  - Prices are assigned dynamically independently of their origin or depending on the itinerary of the customer. (*Chemla et al., 2013, Waserhole, 2013*)
  - 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 routing problems at the strategic level
    - Locating stations in the tactical level
- This work aims to provide a holistic solution approach for the VSSs.
  - From decision maker point of view
  - Three dimensional classification
    - **Actors:** Supply and Demand
    - **Layers:** Data, Models, and Actions
    - **Decision levels:** Strategic, Tactical, and Operational
  - Relations between the components

A decision level

- A first look to the general framework

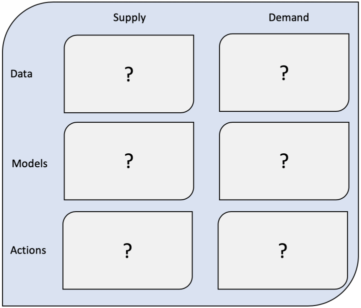

Figure: General framework - the first look

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

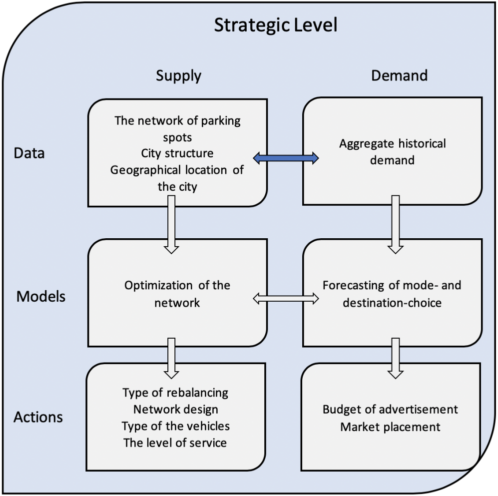

Figure: General framework - strategic level

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

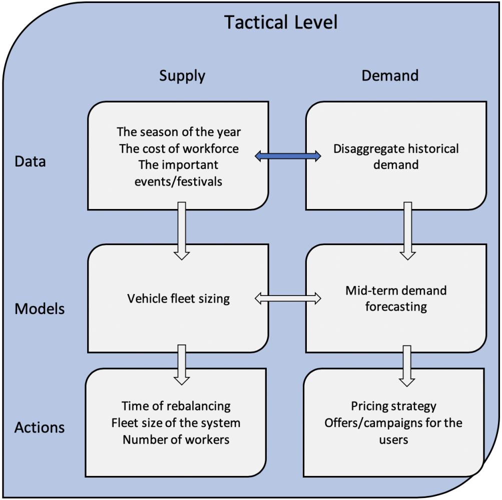

Figure: General framework - tactical level

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

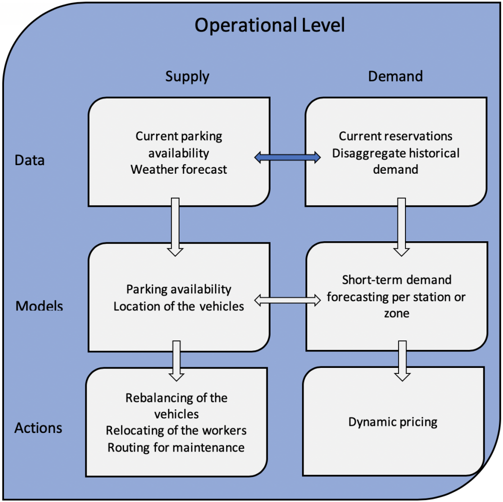

Figure: General framework - operational level

Big picture - revisited

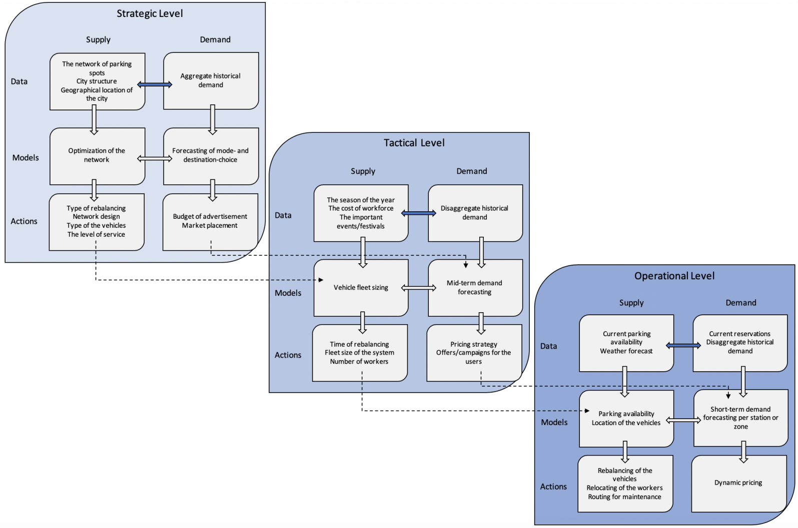

Figure: General framework and inter-relations

Big picture - revisited

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

- Demand forecasting component is quite promising. We will continue to analyze the added value of constructing a disaggregate demand model.

The idea

- A discrete event simulation is developed to imitate the system 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.
- Two cases are investigated
  - Demand known: this case assumes that the model knows everything for the next day perfectly. The rebalancing is done according to this information.
  - Demand unknown: this case rebalances the system to the same initial state every day.
- The main idea is to compare the number of lost demand between the two cases.

Simulation

- Station-based configuration is assumed.
- Reservations are not possible.

Event	Triggered Event	Queue
`Sim Start`	`REQUEST`, `Sim End`	-
`REQUEST`	`REQUEST` (if $t < T$), `PICKUP` (if an available station is in 20 min walk)	$ns = ns + 1$ -
`PICKUP`	`DROPOFF` (if there are available vehicles)	$nu = nu + 1$
`DROPOFF`	`DROPOFF` (if no parking available), `COMPLETED`	- $nu = nu - 1$
`COMPLETED`		$ns = ns - 1$
`Sim End`		-

Mathematical model-Dell'Amico et al. (2014)

$$(F3)\min \quad \sum_{i\in V}\sum_{j\in V} c_{ij}x_{ij} \tag{1}$$

$$\text{s.to} \quad \sum_{i\in V} x_{ij} = 1 \qquad \forall j \in V\setminus\{0\} \tag{2}$$

$$\sum_{i\in V} x_{ji} = 1 \qquad \forall j \in V\setminus\{0\} \tag{3}$$

$$\sum_{j\in V} x_{0j} \le m \tag{4}$$

$$\sum_{j\in V\setminus\{0\}} x_{0j} = \sum_{j\in V\setminus\{0\}} x_{j0} \tag{5}$$

$$\sum_{i\in S}\sum_{j\in S} x_{ij} \le |S| - \max\left\{1, \left[\right| \frac{|\sum_{i\in S} q_i|}{Q} \right\} \qquad \forall S \subseteq V\setminus\{0\}, S \neq \emptyset \tag{6}$$

$$x_{ij} \in \{0,1\} \qquad \forall i,j \in V \tag{7}$$

where

$$x_{ij} = \begin{cases} 1, & \text{if arc } (i,j) \text{ is used by a relocation vehicle} \\ 0, & \text{otherwise} \end{cases} \qquad \forall i,j \in V \tag{8}$$

Preliminary experiments

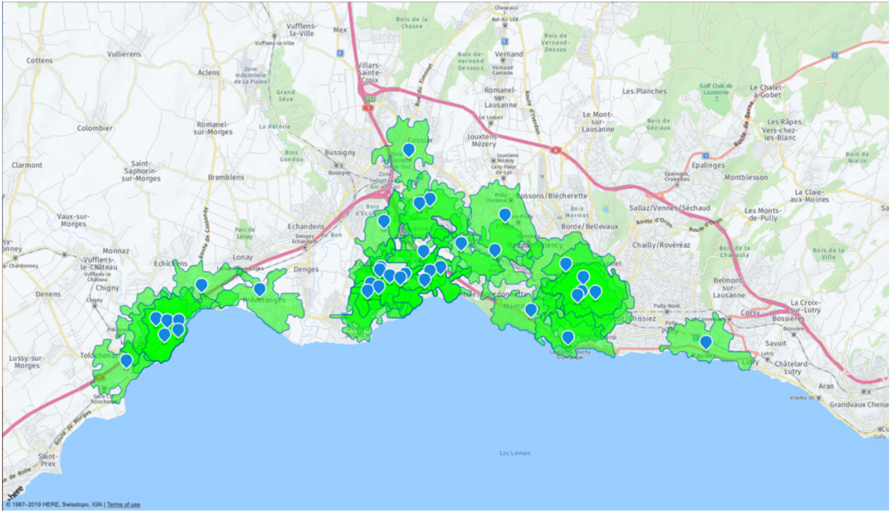

Figure: PubliBike stations and corresponding isoline polygons

Preliminary experiments

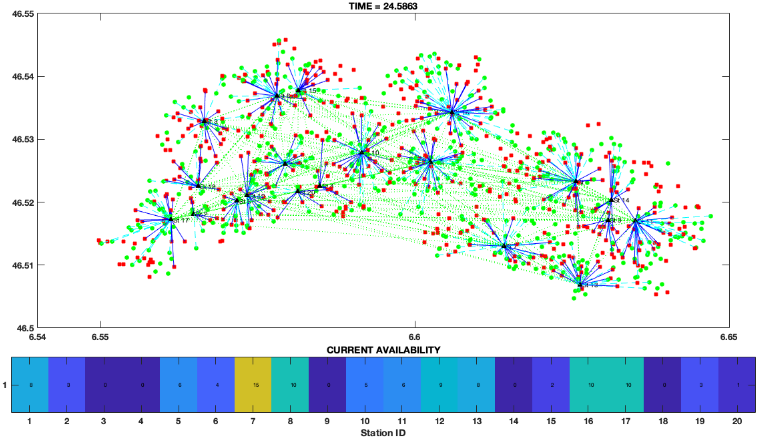

Figure: The trip history and final distribution of bikes in case of spatially random O-D requests (20 stations)

Preliminary experiments

Day	Demand unknown		Demand known		Total number of O-D pair requests
	Lost demand	Rebalancing cost (m)	Lost demand	Rebalancing cost (m)	
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.

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