Location Optimization for a Vehicle Sharing Service

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Why Car-sharing?

- Social and Environmental costs of personal cars
  - Time lost in traffic congestions
  - CO₂ emissions
- Infrastructure costs
  - Build more roads
  - More parking facilities
- Affordability
  - Sharing maintenance, parking and insurance costs
  - Short length of usage daily
  - Flexibility of vehicle choice
How Car-sharing can help

- Costs of car ownership ignored when individuals decide to drive for a trip (focus only on variable costs)
- Hassle of pre-booking likely to cut down on spur-of-the-moment trips
- In the long term, alternative modes – biking, public transportation etc. – will become more accepted
Car-sharing History

- First car sharing attempt in Switzerland (1948)
  - “Sefage” - Selbstfahrergemeinschaft
  - More attempts in Amsterdam and Montpellier (early 1970s)
  - Driven by economics of car ownership
- StattAuto (Germany) and Mobility (Switzerland), commenced services in late 1980s, are more successful
- Service expanded to Asian cities in 2000s
  - Singapore, possibly most successful
Most studies show that a large number of car-sharing customers pick up the vehicle by walking down to the station.

Thus it is imperative for the success of the service to locate stations as close to the consumers as possible.

However, there exists a trade-off:

- Too close $\Rightarrow$ cannibalization (too many choices for the customer)
- Too far $\Rightarrow$ usage reduced (sorry, I take my own car)
Literature

- Ciari et al. (2008): Simulation to evaluate the “true” benefits
- Efthymiou at al. (2012): Drivers of demand
- Fan et al. (2008) / Nair (2011): Optimal fleet sizes at stations
Motivation

- Research so far on drivers of demand and using these drivers to identify “attractive” locations in the target area
- Qualification on attractiveness of a locality, but no pareto studies to show the diminishing returns of placing too many stations
- While optimization of fleet sizes at the stations is studied, optimization of locating the stations has been ignored in the literature
  - Can the problem of locating stations be solved using the algorithms for classical “optimal facility location” problem? Unfortunately, no
Methodology

- **Assumption**
  - Given a super-set of locations
  - Linear relationship between the drivers and station performance

- **Objective**
  - Pick $n$-best locations

- **Constraints**
  - Logical, political or business
  - Example, only $k$ stations from a certain region, at least $k$ stations from a region, etc.

- Modeled as MILP and solved? No
Circle of influence of mobility attractor
Mathematical Model

- Unfortunately, performance of a station depends on the presence of other stations in the vicinity.
- This interaction effect with the same mobility attractor makes problem non-linear.

\[
\begin{align*}
\text{Max} & \quad \sum_{k=1}^{K} z_k \cdot \text{Exp}(Y_k) \\
\text{subject to:} & \\
\sum_{k=1}^{K} z_k &= n \\
\text{Exp}(Y_k) &= \beta_0 + \sum_f \beta_f x_{f,k} \quad \forall \ k \\
x_{f,k} &= \sum_{s \in s_k} \left( \frac{r_{f,s}}{\sum_{k \in k_s} z_k} \right) \quad \forall \ f, k
\end{align*}
\]
Even though the problem formulation is non-linear, the problem can be solved easily to produce “reasonably good” solution using a greedy heuristic

- Fix a set of n variables, \( z_k = 1 \) for which \( \beta_f r_{f,s} \) is maximum
- Recompute X-variables based on the impact of circle of influence
- Fix the new set of n variables, \( z_k = 1 \)
- Continue the above steps till the solution does not improve any further

Is this procedure guaranteed to converge?
Case Study: Autobleue

- Autobleue is the electric-car sharing facility operationalized in the city of Nice and its suburbs in April 2011
- Nice is one of the few cities in world that boasts of a full electric car sharing system
- Plan to locate 70 stations around the city, but the question is where
- Mountainous terrain adds to the complexity
Case Study

- Objectives
  - Understand and analyze the performance of existing Autobleue stations
  - Use this analysis to predict areas for locating additional stations
- Collaborative project between Veolia and EPFL
  - Study from Jan 2012 to Mar 2012
- Available data
  - Autobleue data (until Dec 2011)
  - IRIS data from NCA
  - EMD data
## Proposed Autobleue Growth (Phase 2.3+)

<table>
<thead>
<tr>
<th>LOCALITIES</th>
<th>NB STATIONS AS SPECIFIED INITIALLY</th>
<th>COMPLETED PHASE 1</th>
<th>COMPLETED PHASE 2.1</th>
<th>COMPLETED PHASE 2.2</th>
<th>TO BE DEFINED PHASE 2.3 / 2.4 / 2.5</th>
<th>ESTIMATED TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nice</td>
<td>58</td>
<td>14</td>
<td>10</td>
<td>12</td>
<td>21</td>
<td>57</td>
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<td>0</td>
<td>3</td>
<td>4</td>
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<tr>
<td>Saint Laurent du Var</td>
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<td>0</td>
<td>1</td>
<td>2</td>
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<td>Beaulieu-sur-Mer</td>
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<td>0</td>
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<td>0</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td>70</td>
<td>16</td>
<td>13</td>
<td>13</td>
<td>28</td>
<td>70</td>
</tr>
</tbody>
</table>
Autobleue Performance Map
It is obvious that Autobleue performance is not uniform across geographies and there must be some drivers, which are impacting the station demand and performance.

Thus, the objective of this study is to:

- Understand and analyze the various drivers of demand for Auto Bleue service from the rich data that is made available to us from the different sources,
- Build a mathematical model to represent the performance of Auto Bleue station through these drivers, and
- Use the mathematical model to optimize the location of future stations.
Independent variables

- The following independent variables are considered for modeling as many of these variables show a reasonable correlation with Auto Bleue performance:
  - Velobleue performance indicator
  - Public transport rides
  - Share of residents using their personal cars for transport to office
  - Share of residents using two-wheeler or public transport to reach workplace
  - Share of residents that are entrepreneurs / craftsmen
  - Share of residents that are Managers / Professionals
  - Share of residents that are employees and associate professionals
  - Share of residents that are workers
Independent variables (contd.)

- The list of independent variables (continued):
  - Population density
  - Share of males in the population
  - Share of 25-54 age group persons in the locality
  - Special variable for Gare Thiers
  - Number of other Autobleue stations with 500 m
  - Mobility attractors, such as college lycee, commercial complex, temporary accommodation / hotels, student housing, hospitals, etc.
Sphere of Influence of an Autobleue Station

- From an Autobleue station, we draw a circle of 500 m radius and weight the share of the parameter by the area covered for each IRIS commune.
Key results of the regression model

- The following factors impact the number of avg Autobleue bookings per day at each station (under assumption of linearity):
  - Share of managers and experts (+)
  - Share of car users driving to workplace (-)
  - Public Transport rides (+)
  - Population density (+)
  - Hotels (+)
  - Commercial center (+)
  - College Lycee (+)
  - Distance to another Autobleue station (-)
Optimization Model

- Let the expected performance of Auto Bleue at a locality be represented as \( \text{Exp}(Y_k) \), where

\[
\text{Exp}(Y_k) = \beta_{\text{INTERCEPT}} + \beta_{\text{ME}} X_{\text{ME},k} + \beta_{\text{PT}} X_{\text{PT},k} + \beta_{\text{CR}} X_{\text{CR},k} + \beta_{\text{CC}} X_{\text{CC},k} + \beta_{\text{Hot}} X_{\text{Hot},k} + \beta_{\text{CL}} X_{\text{CL},k} + \beta_{\text{PD}} X_{\text{PD},k} + \beta_{\text{Dist}} X_{\text{Dist},k}
\]

- The basic idea followed by optimization model is to optimize the trade-off between low-potential, but unexplored (untapped) outskirts versus the high-potential, but fast saturating (or already saturated!) center (white versus dark blue areas)

- Model represents the problem mathematically and tries to solve the problem
Model Validation
Model Results (over NCA territory only)
Model Results (City of Nice)
Recommendations for Next Stations within Nice
Concluding Remarks

- One of our major findings is the fact that Auto Bleue service has a strong potential in the heart of the city, but progressively lesser interest as we move outskirts.

- The trade-off for Auto Bleue today is to make a choice between high-performing but saturated heart versus low-interest but untapped outskirts.

- Our study has based the recommendations primarily based on mathematics and science. But locating future stations for Auto Bleue is as much an art and business sense too.

- Impact of the presence of multiple Auto Bleue stations around a target station appears to be underestimated.
Future Research Possibilities

- Linear relationship between variables and car usage
- Time series impact of the station performances
- How to design and operate car sharing systems to complement public transport? Can one-way system help achieve this goal?
  - If yes, how to redesign and operate a new system so that operational costs are minimized, while augmenting the usage of the system?
  - How to forecast demand better?
  - How to define the pricing strategies (differential pricing?)?
  - How to optimally manage inventory of the vehicles
  - How to resize the system and stations?
Thank You!