Distributed and dynamic management of a fleet of autonomous taxis.

Tatiana Babicheva
OBJECTIVES

To design autonomous vehicle reservation strategies (taxis, shuttles) that

• Allow dynamic sharing of these vehicles by several clients
• Guarantee certain quality of service
• Allow the modelling of charging strategies
• Allow the cost-benefit analysis of such a system
• Converge close to the social optimum
• Provide empty vehicle management
SUBPROBLEM – HOW TO OBTAIN RELEVANT CITY GRAPH?

2 main methods:

**To use GPS data**

| + | - |
| Updates the information in real-life | The GPS coordinates are not exact |

**To use OpenStreetMap data**

| + | - |
| Let to obtain easily the road graph structure | Have no information about congestion |
| Have a lot of information such as kind of the road or the speed restrictions. | Can contain invalid data |
1. Use OsmToRoadGraph project to convert OSM files into a graph of the real map.

BUT!
- Every road turn found in the OSM data yields a vertex of degree 2 in the resulting graph.
- Slow updates on map information.

2. Some modifications were made:
- An updated module of graph contraction to fix a few of bugs
- A module for removing sinks and sources from the graph

3. Actual processing:
- Try to fit each GPS polyline on the graph based on the methods of geometric projection and shortest distances.
- To compute the vehicle speed for each arc.
Trip information on the trajectories for all the 442 taxis running in the city of Porto from 01/07/2013 to 30/06/2014 (over 1.7 million data points).

The data set owners categorize each ride into three categories:
• taxi central based ‘A’ (364770 calls)
• stand-based ‘B’ (817881 calls)
• non-taxi central based ‘C’ (528019 calls)
THE SPEED CLUSTERISATION AT ARCS
THE REDUCED GRAPH OF PORTO AREA
What is the best way to redistribute empty vehicles and will the ridesharing make big difference in terms of passenger waiting times?

- A set of taxi stations and some statistics about expected passenger arrivals are given
- Expected travel times between each pair of stations are considered
- Vehicle fleet size can be given as fixed or variable
- Passengers are modelled to arrive randomly according to a demand prediction
- Destinations of the passengers are known at the moment of their arrival to the station.
• **Basic sending (BS).** If there are a passenger and an empty vehicle at the same station, the vehicle will be sent with this passenger (no redistribution of empty vehicles to other stations)

• **Simple Nearest Neighbours (SNN).** Call the nearest empty vehicles based on longest passenger waiting time in the current moment.

• **Heuristic Nearest Neighbours (HNN).** Call the nearest empty vehicles based on longest passenger waiting time at the vehicle arrival moment. Attempts to improve upon SNN by including the time it takes for a vehicle to move to the waiting passenger.

• **Send The Nearest (STN).** Focusing attention only on stations with passengers currently waiting, reallocate nearest empty vehicles to serve these passengers, prioritising fastest empty vehicles arrivals.
• **Index-based Redistribution (IBR).** The redistribution based on maximum station index.

• **Surplus/Deficit vehicle redistribution (SDR).** The redistribution from the station with the maximum vehicle surplus to the station with the maximum vehicle deficit.
INDEX-BASED REDISTRIBUTION

$PS$ – passenger surplus

Passenger disutility (non-linear impatience) is a function of the waiting time $u(t) = \exp(t) - 1$

- If $PS>0$ (vehicle deficit). The station index is defined as the passenger’s disutility at the time of his departure.
- If $PS\leq 0$. The index equals the probable disutility of the first arriving passenger in the time of his departure.
THE SAMPLE NETWORK

5 minutes ride distance

Station1

5 minutes

Station2

4 minutes
THE FIRST CASE

1. Station 1
2. Station 2
3. 5 minutes
4. 4 minutes
THE SECOND CASE

Diagram:

- Station 1: 5 minutes
- Station 2: 4 minutes
THE THIRD CASE

1. Station1
   - 5 minutes
2. Station2
   - 4 minutes
THE FOURTH CASE

Station1

5 minutes

Station2

4 minutes
### Average and maximal waiting times, in minutes

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th></th>
<th>Case 2</th>
<th></th>
<th>Case 3</th>
<th></th>
<th>Case 4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg</td>
<td>Max</td>
<td>Avg</td>
<td>Max</td>
<td>Avg</td>
<td>Max</td>
<td>Avg</td>
<td>Max</td>
</tr>
<tr>
<td>IBR</td>
<td>8</td>
<td>8</td>
<td>13.5</td>
<td>16</td>
<td>11.5</td>
<td>15</td>
<td>7.5</td>
<td>9</td>
</tr>
<tr>
<td>SNN</td>
<td>9</td>
<td>12</td>
<td>13.5</td>
<td>16</td>
<td>7.5</td>
<td>9</td>
<td>7.5</td>
<td>9</td>
</tr>
<tr>
<td>STN</td>
<td>9</td>
<td>12</td>
<td>8.5</td>
<td>12</td>
<td>7.5</td>
<td>9</td>
<td>8.5</td>
<td>12</td>
</tr>
</tbody>
</table>
VIPSIM PROJECT

Production process
- Fleet size
- Vehicle capacity
- Speed

Network
- Stations
- Roads
- Traffic signals

Operating strategies
- Ridesharing
- Charging
- Vehicle re-assignment

Demand
- Passenger
- Origin-Destination matrix

Optimisation
- Quality of service
- Optimal fleet size
- Fleet utilisation
- Energy
- Ridesharing
- Service reliability

Output KPIs
- Riding times, waiting times, passenger flows, vehicle flows, delays, ridesharing factor, energy use, ...
• Largest public-private investment project in Europe
• Largest French campus
• 15% of the national research activity
• 15 000 students in September 2019
The Saclay network with 21 stations
Massy train station to the right
Combination of Index-Based and Nearest Neighbour strategies seems to be the best:

- Better than each algorithm on its own
- Robust for different demand (rush hour / off peak)
### COMPARISON OF THE ALGORITHMS

<table>
<thead>
<tr>
<th>Strategy</th>
<th>BS</th>
<th>SNN</th>
<th>SNN,SDR</th>
<th>SNN,IBR</th>
<th>HNN</th>
<th>HNN,SDR</th>
<th>HNN,IBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rush hour. Max wait (min)</td>
<td>52</td>
<td>14</td>
<td>13.5</td>
<td><strong>13</strong></td>
<td>30</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Off-peak. Max wait (min)</td>
<td>60</td>
<td>8.4</td>
<td>7.9</td>
<td><strong>5.1</strong></td>
<td>10.7</td>
<td>9.6</td>
<td>6.2</td>
</tr>
<tr>
<td>Rush hour. Avg wait (min)</td>
<td>31</td>
<td>3.3</td>
<td>3.2</td>
<td><strong>2.4</strong></td>
<td>7</td>
<td>6.2</td>
<td>4.7</td>
</tr>
<tr>
<td>Off-peak. Avg wait (min)</td>
<td>20</td>
<td>0.78</td>
<td>0.77</td>
<td><strong>0.25</strong></td>
<td>1.13</td>
<td>1.10</td>
<td>0.36</td>
</tr>
<tr>
<td>Rush hour. Avg queue, pass</td>
<td>872</td>
<td>31</td>
<td>30</td>
<td><strong>21</strong></td>
<td>95</td>
<td>72</td>
<td>57</td>
</tr>
<tr>
<td>Off-peak. Avg queue, pass</td>
<td>398</td>
<td>47</td>
<td>46</td>
<td><strong>15</strong></td>
<td>68</td>
<td>66</td>
<td>22</td>
</tr>
<tr>
<td>Rush hour. Total run, min</td>
<td>262</td>
<td>7376</td>
<td>7649</td>
<td><strong>9451</strong></td>
<td>7331</td>
<td>7385</td>
<td>9922</td>
</tr>
<tr>
<td>Off-peak. Total run, min</td>
<td>609</td>
<td>3416</td>
<td>3327</td>
<td><strong>9305</strong></td>
<td>3317</td>
<td>3342</td>
<td>8975</td>
</tr>
</tbody>
</table>
• The ratio of the total passenger queue at the end of the simulation to the total number of passengers.
Balancing passenger disutility with operator cost:

- Passenger disutility: waiting time $c_{\text{wait}}$
- Operator cost: vehicle fleet cost $c_{\text{vehicle}}$
- Operation loss: empty running of vehicles $c_{\text{empty}}$

$$F = \sum t_{\text{wait}} \cdot c_{\text{wait}} + \sum t_{\text{empty run}} \cdot c_{\text{empty run}} + N_{\text{vehicle}} \cdot c_{\text{vehicle}}$$
EXAMPLE: BENEFITS OF RIDESHARING

No ridesharing

Ridesharing

- More Passengers served
- Shorter passenger queues
- Reduced waiting time
MATCHING STRATEGIES

Station 1

max time = 5 min

Station 2

max time = 4 min

S1

max time 5 min

S2

max time 4 min

V1

V2

1

3 min

2

2 min

3 min

3

8

2

3
### 40 Vehicles in the system

<table>
<thead>
<tr>
<th>No optimisation, no ridesharing</th>
<th>Only ridesharing</th>
<th>Ridesharing and optimisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No matching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Greedy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hungarian</td>
</tr>
<tr>
<td>416</td>
<td>348</td>
<td>285</td>
</tr>
<tr>
<td></td>
<td></td>
<td>269</td>
</tr>
<tr>
<td></td>
<td></td>
<td>266</td>
</tr>
</tbody>
</table>

### 60 Vehicles in the system

<table>
<thead>
<tr>
<th>No optimisation, no ridesharing</th>
<th>Only ridesharing</th>
<th>Ridesharing and optimisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No matching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Greedy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hungarian</td>
</tr>
<tr>
<td>284</td>
<td>229</td>
<td>171</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140</td>
</tr>
<tr>
<td></td>
<td></td>
<td>136</td>
</tr>
</tbody>
</table>
### 40 Vehicles in the system

<table>
<thead>
<tr>
<th>No optimisation, no ridesharing</th>
<th>Only ridesharing</th>
<th>Ridesharing and optimisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No matching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Greedy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hungarian</td>
</tr>
<tr>
<td>251</td>
<td>231</td>
<td>146</td>
</tr>
<tr>
<td></td>
<td></td>
<td>109</td>
</tr>
<tr>
<td></td>
<td></td>
<td>106</td>
</tr>
</tbody>
</table>

### 60 Vehicles in the system

<table>
<thead>
<tr>
<th>No optimisation, no ridesharing</th>
<th>Only ridesharing</th>
<th>Ridesharing and optimisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No matching</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Greedy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hungarian</td>
</tr>
<tr>
<td>142</td>
<td>132</td>
<td>92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>72</td>
</tr>
</tbody>
</table>
• Presented a method of weighted graph obtaining based on OSM and GPS data

• The results are presented on Porto area

• Presented algorithm IBR of empty vehicle redistribution

• Compared against existing methods and evaluated on Paris-Saclay network

• Combination of two algorithms (SNN+IBR) is the most efficient for both rush hour and off-peak

• The optimal fleet-size and passenger utility balancing operator was investigated

• The Greedy+Hungarian multimatching algorithm improves on greedy method to get better results in average passenger waiting time

• The ridesharing strategies improve average waiting time significantly
Thank you for your attention!