EMPTY VEHICLE REDISTRIBUTION AND FLEET-SIZE IN AUTONOMOUS TAXI SYSTEMS

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• Research Institute
• Dedicated to automated vehicles and their mobility
• Public-private partnership
• Gathering all stakeholders involved in the road to automation
• Created in 2014

Main partners:
• PSA Group
• Groupe Renault
• Valeo
• Transdev
• PTV Group
VEHICLE REDISTRIBUTION PROBLEM FORMULATION

- Given a set of taxi stations and statistics about expected passenger arrivals
- Fixed travel times between each pair of stations
- Vehicle fleet size fixed or variable
- Passengers arrive randomly according to a demand prediction
- Stations have waiting passengers with known destinations
- Stations are associated with vehicles in the station or approaching
REACTIVE ALGORITHMS

• Basic sending (BS). If there are passengers and empty vehicles in the same station, the vehicle will be sent with this passenger (no redistribution of empty vehicles to other stations).

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

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

• 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 depart.
- If \( PS \leq 0 \) The index equals the probable disutility of the first arriving passenger in the time of his depart.
• Largest public-private investment project in Europe
• Largest French campus
• 15% of the national research activity
• 15 000 students in September 2019…
EVALUATION OF THE ALGORITHMS

The Saclay network with 21 stations
Massy train station to the right
EVALUATION OF THE ALGORITHMS

• BS. Basic Sending. No redistribution of empty vehicles between the stations
• SNN. Simple Nearest Neighbours
• SNN+SDR. Simple Nearest Neighbours combined with Surplus-Deficit Redistribution
• SNN+IBR. Simple Nearest Neighbours combined with Index-Based Redistribution
• HNN. Heuristic Nearest Neighbours
• HNN+SDR. Heuristic Nearest Neighbours combined with Surplus-Deficit Redistribution
• HNN+IBR. Heuristic Nearest Neighbours combined with Index-Based Redistribution
## 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>
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</thead>
<tbody>
<tr>
<td>Rush hour. Max wait (min)</td>
<td>52</td>
<td>14</td>
<td>13.5</td>
<td>13</td>
<td>30</td>
<td>25</td>
<td>23</td>
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<tr>
<td>Off-peak. Max wait (min)</td>
<td>60</td>
<td>8.4</td>
<td>7.9</td>
<td>5.1</td>
<td>10.7</td>
<td>9.6</td>
<td>6.2</td>
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<tr>
<td>Rush hour. Avg wait (min)</td>
<td>31</td>
<td>3.3</td>
<td>3.2</td>
<td>2.4</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>0.25</td>
<td>1.13</td>
<td>1.10</td>
<td>0.36</td>
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<tr>
<td>Rush hour. Avg queue, pass</td>
<td>872</td>
<td>31</td>
<td>30</td>
<td>21</td>
<td>95</td>
<td>72</td>
<td>57</td>
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<tr>
<td>Off-peak. Avg queue, pass</td>
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<td>47</td>
<td>46</td>
<td>15</td>
<td>68</td>
<td>66</td>
<td>22</td>
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<tr>
<td>Rush hour. Total run, min</td>
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<td>2871</td>
<td>2854</td>
<td>9935</td>
<td>2928</td>
<td>2894</td>
<td>10248</td>
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<tr>
<td>Rush hour. Total run, min</td>
<td>871</td>
<td>7921</td>
<td>8122</td>
<td>8821</td>
<td>7720</td>
<td>7833</td>
<td>8649</td>
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</tbody>
</table>
COMBINING TWO STRATEGIES. RUSH HOUR

Average waiting time

IBR, Times per second  SNN, Times per second
COMBINING TWO STRATEGIES. OFF-PEAK

Average waiting time

IBR, Times per second  SNN, Times per second
The ratio of the total passenger queue at the end of the simulation to the total number of the passengers.
Balance passenger disutility with operator cost
- Passenger disutility: waiting time $c_{wait}$
- Operator cost: vehicle fleet cost $c_{vehicle}$
- Operation loss: empty running of vehicles $c_{empty}$

Optimum fleet size

$$F = \sum t_{wait} \cdot c_{wait} + \sum t_{empty run} \cdot c_{empty run} + N_{vehicle} \cdot c_{vehicle}$$
CONCLUSIONS

• New index based empty vehicle redistribution algorithm IBR
• Compared with existing methods on Saclay test case:
  • Combination of two algorithms (SNN + IBR) is the most efficient
  • SNN is most efficient during the rush hour IBR is most efficient outside the rush hour
  • Can result in many empty trips – can be remedied by incorporating operator costs in objective function
• Generalized cost function to determine optimal vehicle fleet size from both passenger and operator perspectives

• Next steps:
  • Optimal Ride-sharing strategies
  • Charging and energy use strategies
  • Incorporate station, road and vehicle capacity constraints