FCD data for on-street parking search time estimation

Mannini L, Cipriani E, Gemma A
Department of Engineering

Crisalli U
Department of Enterprise Engineering

livia.mannini@uniroma3.it
Summary

✓ Introduction
✓ State of the art
✓ Methodology
✓ Case study
✓ Conclusions and further developments
Introduction

This research has been carried out within the project:

Development of a Decision Support System for traffic, environmental and accident monitoring

supported by

the Rome Mobility Agency
Roma Servizi per la Mobilità (RSM)

aiming at deploying a new generation of travel planners in Rome

Acknowledgements
Introduction

Research goal

In urban areas: no data about parking (i.e. interviews)

no information about final destination of trips

but a huge amount of Floating Car Data (FCD) are available

this study proposes a modelling framework able to estimate the time spent in on-street parking by using only FCD data

Accurate travel times are useful and necessary for:

• planning (off-line application),
• user’s information and dynamic routing (real-time application),

as they influence modal choice as well as departure time or destination choices
State of the art

Polak and Vytholkas (1993)

The parking problem involves different aspects, such as:

✓ parking policies
✓ parking search behavior
✓ parking search time estimation
State of the art

Parking problem has been investigated by using:

✓ **stated preference surveys**
   
   Axhausen and Polak (1991); Gantelet and Lefauconnier (2006); Belloche (2015)

✓ **field observations**
   
   Bradley and Layzell (1986); Leiser and Stern (1988); Van der Waerden et al. (2009); Horni et al. (2012); Marsden (2016)

✓ **discrete choice models**
   
   Hess and Polak (2004); Yu et al. (2012)

✓ **numerical and simulation models**
   
   Salomon (1986); Young (1986); Fletcher (1995); Gallo et al. (2011);
   Young and Thompson (1987) [PARKSIM]; Benenson et al. (2008) [PARKAGENT];
   Dieussaert et al. (2009) [SUSTAPARK];

✓ **GPS data**
   
   Kaplan and Bekhor (2011); Montini et al. (2012); Van Der Waerden et al. (2014)
State of the art

Focusing on GPS data approach:

✓ Kaplan and Bekhor (2011)
   *investigate the choice of parking type and parking-search route, using GPS data collected in Tel Aviv*

✓ Montini et al. (2012)
   *develop a module of parking search for GPS data and apply this module to analyse the parking search phenomenon using the Swiss GPS data for two cities*

✓ Van Der Waerden et al. (2014)
   *investigate the temporal and spatial components of parking search behaviour, resulting in an average parking search time of case study*

A huge amount of Floating Car Data (FCD) are offered by new technologies at a very low cost, but this potential seems to be little exploited in literature
Methodology

Logical architecture

FCD data → supply model → on-street park time per destination zone

- FCD data
- zoning
- road infrastructures
- study area

Vehicle matching procedure → probe vehicles per destination zone → revealed LoS attributes

- revealed LoS attributes
- gap function estimation

Dynamic shortest path model → predicted LoS attributes → on-street park time estimation model

- on-street park time per destination zone
- park search ceiling distance per destination zone
Methodology

Estimation of **time spent for parking search** by analysing paths that vehicles perform in the final part of their trips before reaching the destination, through FCD.

Identifying the ceiling $c$ of the parking search beginning, from which users’ behaviour can be assumed to be a spiral trajectory around destination

- vehicle parking in $p$
- having destination in $z$
- within a traffic zone $Z$
Methodology

Modeling vehicle behavior in parking search through a spiral trajectory

Linear approaching in polar coordinates, where $\rho_l$ represents the line length, $\theta_l$ is the line angular coordinate, and $\nu$ is the parameter representing the speed of uniform motion in time axis $t$.

Spiral approaching in polar coordinates $(\rho_s, \theta_s)$, with a spiral pitch of $2\pi\beta$ and a spiral development equal to the average of circumferences having radius of $(n-1)2\pi\beta$ and $n2\pi\beta$. $\nu$ is the parameter representing the speed of uniform motion in time axis $t$. 
Gap function estimation

➢ The key point is the identification of the likely begin of parking search

To identify ceiling by using a gap function:

FCD travel time vs. Dynamic Shortest Path

\[ TTFCD_{kpz} = m_z \cdot TTDSP_{kpz} + b_z \]

where

\( TTFCD_{kpz} \) is the travel time detected by FCD point \( k \) for a vehicle parking in \( p \) with destination in \( z \) within traffic zone \( Z \);

\( TTDSP_{kpz} \) is the corresponding shortest path travel time computed by using the dynamic shortest path algorithm.
Methodology

Dynamic Shortest Paths

The used dynamic shortest path algorithm is a version of Dijkstra's algorithm modified to take into account turn prohibitions at intersections, as proposed by Lim and Kim (2005).

It uses a link-based approach for which the Bellman’s principle of optimality in searching dynamic shortest path holds if:

\[
LEC(o, i) + TP[\text{link}(o, i), \text{link}(i, j), \tau] + LC(i, j, \tau) \leq LEC(i, j) \quad \forall o, i, j \in N
\]

where

- \(LC(i, j, \tau)\) is the non-negative link cost required to travel from node \(i\) to node \(j\) at time \(\tau\);
- \(LEC(o, i)\) be the link end cost, or minimum path cost from origin to node \(i\) through \(\text{link}(o, i)\) which refers to the directed link leading from node \(o\) to node \(i\);
- \(TP[\text{link}(o, i), \text{link}(i, j), \tau]\) is the turn penalty which implies the additional cost at node \(i\) from \(\text{link}(o, i)\) to \(\text{link}(i, j)\) at time \(\tau\) defined according to the turning rules at intersection;
- \(o, i, j\) belonging to the set of nodes \(N\) of the road network.
Gap function estimation

\[ S_P(D) = \Phi(D,a,c) \]

The ceiling distance can be identified through the analysis of the derivative of \( S_P(D) \)

\[ \frac{\partial S_P}{\partial D} < \xi \]

\( D \) represents the distance between the detected point \( k \) and the parking point \( p \);

\( a, c \) are parameters to be calibrated for the considered destination zone \( Z \).
On-street parking time estimation

Vehicle Parking Time (PT)

\[ PT = \frac{1}{2} \beta \left[ \theta_s \sqrt{1 + \theta_s^2} + \ln \left( \theta_s + \sqrt{1 + \theta_s^2} \right) \right] - \rho_l \]

\( \theta_s \) is polar coordinate of spiral, \( \beta \) is the spiral parameter, so the spiral step is equal to \( 2\pi\beta \), and \( \rho_l \) is line polar coordinate, so the linear length.
Case Study

**main features**

**Metropolitan area of Rome**

4 million inhabitants

(34% of which live in the hinterland of Rome)

about 5350 kmq
Case Study

FCD

78 000 000 detected points
sample rating: 30 sec and/or 2 km

✓ vehicle ID
✓ timestamp (day, time)
✓ position (latitude, longitude)
✓ state of motion (speed, direction)
✓ quality of signal
✓ distance from previous data

4 000 000 filtered on the basis of:
✓ speed
✓ position
✓ sequence of detected points
✓ permitted link direction

9 000 000 trips
100 000 vehicles

74 000 000 detected points
AVAILABLE

Mannini et al. - FCD data for on-street parking search time estimation
Case Study

Map matching

\[ P_k(i,j) = \text{Prob}(d) \cdot \text{Prob}(\alpha) \]

where:

\[ \text{Prob}(d) = \gamma_1 \cdot e^{-\frac{d}{\gamma_2}} \]

\[ \text{Prob}(\alpha) = \begin{cases} \gamma_3 & \text{if } \alpha \leq \gamma_6 \\ \gamma_4 \cdot e^{-\frac{\alpha}{\gamma_5}} & \text{if } \alpha > \gamma_6 \end{cases} \]

- \( d \) is the distance of \( k \) from link \( (i,j) \);
- \( \alpha \) is the angular deviation between the direction of speed vector and the directionality of the link;

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \gamma_1 )</td>
<td>0.183</td>
</tr>
<tr>
<td>( \gamma_2 )</td>
<td>5.464</td>
</tr>
<tr>
<td>( \gamma_3 )</td>
<td>0.1</td>
</tr>
<tr>
<td>( \gamma_4 )</td>
<td>0.1</td>
</tr>
<tr>
<td>( \gamma_5 )</td>
<td>5.0</td>
</tr>
<tr>
<td>( \gamma_6 )</td>
<td>0.087</td>
</tr>
</tbody>
</table>
Case Study

Analysis of route complexity

Example of data for a given traffic zone

workdays, 8:00 – 10:00 am
Case Study

Gap function

FCD travel time vs. predicted travel time

\( \text{FCD travel time} \quad \text{vs.} \quad \text{predicted travel time} \)

\( (TTFCD) \quad (TTDSP) \)

\[ S_P(D) \]

slope function

\[ \text{slope function} \]

\[ \text{Time [sec]} \]

\[ \text{segments} \]

\[ \text{classes of Euclidean distances every 500 meters} \]
Case Study

3 aggregation levels of **zoning**:

1. 5 macrozones relative to General Urban Traffic Plan (GUTP), adopted in order to obtain 5 macro Key Performance Indicator

2. 58 zones by aggregation urban model RSM, mainly used for the model calibration;

3. 1339 zones, used for detailed result analysis and to test the possibility of using the proposed methodology for real time applications (e.g. advanced travel planners).
Case Study

Ceiling

Destination zone clustering
(k-means method)
✓ 8 classes
✓ 3 types of behaviour in park search

<table>
<thead>
<tr>
<th>cluster</th>
<th>ceiling (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
</tr>
<tr>
<td>5</td>
<td>2.0</td>
</tr>
<tr>
<td>6</td>
<td>0.5</td>
</tr>
<tr>
<td>7</td>
<td>2.0</td>
</tr>
<tr>
<td>8</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Mannini et al. - FCD data for on-street parking search time estimation
Case Study

Results - Parking Search Time [min]

5 GUPT zones – weekdays

Incidence of the average on-street parking search time with respect to the total travel time* to destination.

<table>
<thead>
<tr>
<th>GUPT</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>11</td>
<td>8</td>
<td>7</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

* average total travel time by car is about 45 minutes
Case Study

Results - Parking Search Time [min]

58 zones – weekdays – morning peak hours

1.0 – 3.0 minutes

4.0 – 9.0 minutes

5.5 – 12 minutes
Case Study

Results - Parking Search Time [min]

58 zones – weekdays

7:00 am – 8:00 am

8:00 am – 9:00 am

9:00 am – 10:00 am

10:00 am – 11:00 am
Case Study

Results - Parking Search Time [min] h 8:00-9:00

Legend
Average time [min]
- 0 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
Case Study

Results - Parking Search Time [min] h 9:00-10:00
Case Study

Results - Parking Search Time [min] h 10:00-11:00

Legend
Average time [min]
- 0 - 1
- 1 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
Case Study

Results - Parking Search Time [min] h 8:00-9:00
Case Study

Results - Parking Search Time [min] h 9:00-10:00
Case Study

Results - Parking Search Time [min] h 10:00-11:00

Legend
Upperbound of $T_{avg}$ [min]
- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 15
Case Study

Results - Parking Search Time w.r.t. Total Travel Time

1339 zones – weekdays – 8:00 am

<table>
<thead>
<tr>
<th>Parking Search Time and Total Travel Time Ratio</th>
<th>Average Parking Search Time</th>
<th>Confidence Interval Upper Bound of Parking Search Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>Min</td>
<td>0.2%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Max</td>
<td>10%</td>
<td>18%</td>
</tr>
</tbody>
</table>

Mannini et al. - FCD data for on-street parking search time estimation
Conclusions

This study proposes a model for on-street parking search time estimation by using FCD.

✓ The modelling framework is based on the analysis of FCD to identify the parking search beginning that is modelled by spiral trajectories around the destination.

✓ The case study in the city of Rome demonstrates benefits of the proposed approach to obtain both aggregate indicators about parking time for planning purposes and detailed results for real time applications.
Further developments

Further research activities concern efforts for greater robustness of the methodology by:

✓ the specification and calibration of different gap functions
✓ the application to other cities
✓ further validation based on the comparison with survey data

Moreover, if actual privacy constraints on FCD data will be solved, it will be also interesting to specify and calibrate models for different vehicle types.
FCD data for on-street parking search time estimation

Mannini L, Cipriani E, Gemma A
Department of Engineering

Crisalli U
Department of Enterprise Engineering

livia.mannini@uniroma3.it