A Parking-State-Based Transition Matrix of Traffic on Urban Networks

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“We started out to view the town … Round and round the blocks we drove trying to find a place to park… Every curb was black with backed-in cars… “There’s a place!” Alas! It was the wrong side of the street. So on we would go to the next corner hoping to be able to turn but invariably the traffic officer would firmly signal us, till time after time, we would find ourselves… in the very center of things, entangled in the traffic. ”

“Touring New England on the Trail of the Yankee”

Clara Whiteside, in Connecticut, 1926

## Data on parking

<table>
<thead>
<tr>
<th>Year</th>
<th>City</th>
<th>Share of cruising traffic</th>
<th>Average cruising time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1927</td>
<td>Detroit (1)</td>
<td>19%</td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>Detroit (2)</td>
<td>34%</td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>Washington</td>
<td></td>
<td>8.0</td>
</tr>
<tr>
<td>1960</td>
<td>New Haven</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>1965</td>
<td>London (1)</td>
<td></td>
<td>6.1</td>
</tr>
<tr>
<td>1965</td>
<td>London (2)</td>
<td></td>
<td>3.5</td>
</tr>
<tr>
<td>1965</td>
<td>London (3)</td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td>1977</td>
<td>Freiburg</td>
<td>74%</td>
<td>6.0</td>
</tr>
<tr>
<td>1984</td>
<td>Jerusalem</td>
<td></td>
<td>9.0</td>
</tr>
<tr>
<td>1985</td>
<td>Cambridge</td>
<td>30%</td>
<td>11.5</td>
</tr>
<tr>
<td>1993</td>
<td>Cape Town</td>
<td></td>
<td>12.2</td>
</tr>
<tr>
<td>1993</td>
<td>New York (1)</td>
<td>8%</td>
<td>7.9</td>
</tr>
<tr>
<td>1993</td>
<td>New York (2)</td>
<td></td>
<td>10.2</td>
</tr>
<tr>
<td>1993</td>
<td>New York (3)</td>
<td></td>
<td>13.9</td>
</tr>
<tr>
<td>1997</td>
<td>San Francisco</td>
<td></td>
<td>6.5</td>
</tr>
<tr>
<td>2001</td>
<td>Sydney</td>
<td></td>
<td>6.5</td>
</tr>
</tbody>
</table>

**Average**

<table>
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<th>Share of cruising traffic</th>
<th>Average cruising time (min)</th>
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<tr>
<td>30%</td>
<td>8.1 min</td>
</tr>
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</table>

Source: Shoup (2005)
Globally, drivers have spent an average of nearly \textbf{20 minutes} searching.

African drivers averaged both the shortest and longest times searching for parking in the last year when compared to the other 18 cities -- Johannesburg averaged 12.7 minutes and Nairobi averaged 31.7 minutes.

IBM Global Parking Survey (2011)
Data on parking

2003: Beijing had 0.65 million parking spaces for 1.57 million vehicles

Dec 2010: 1.3 million vs. 5 million

This gap is the price urban planners have to pay for their lack of vision - most of the buildings built in the 1990s have no provisions for underground parking lots and even today very few housing units have well-designed and efficient parking facilities.

Source: http://europe.chinadaily.com.cn/opinion/2011-04/02/content_12270087.htm
Data on parking

Introduction

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Dec 2010:
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Data on parking

In some other cities?

**BIN THE PARKING MINs!**

**HOW ONE SILLY LITTLE RULE IS RUINING AUCKLAND.**

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**WHY IS IT A "BAD" RULE?**

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1. **RIDICULOUS COST**
   (Underground parking adds avg $50,000 per park)

2. **POOR USE OF URBAN SPACE**
   (1/3 of new developments devoted to car parks)

3. **REDUCES TRANSPORT CHOICE**
   (creates expectation you should always own a car)

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**THE BAD RULE**

“for every residential unit there shall be at least two off-street parking spaces provided”

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**OR INSTEAD**

Let People Decide.

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**COUNCIL IS DECIDING ON INCLUDING THIS RULE IN THE UNITARY PLAN.**

They probably don’t think anyone cares about it. We sure do.

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**#BIN THE PARKING MINs**

Let them know....

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Parking

Individual impact

- How many of the cars on congested streets are simply searching for curb parking rather than going somewhere?
- How much fuel does this cruising waste, and how much air pollution does it create?
- How much congestion it causes on the urban transportation system?
- How much time is wasted on such a part of the trips?

Collective consequences
Urban Parking & Traffic Performance

Extra traffic delay caused by parking maneuvers

Searching/cruising for parking traffic

It is harder for traffic to enter the city if the road space is continuously kept by cruising traffic or parking vehicles.
Model the impact of parking on urban traffic

Extra traffic delay caused by parking maneuvers

Searching/cruising for parking traffic

**Accessing parking**: how many vehicles are conducting parking maneuvers?

**Searching for parking**: how many vehicles are cruising?

Collective consequences

Macroscopic approaches?
The parking-state-based transition matrix of vehicles on network

<table>
<thead>
<tr>
<th></th>
<th>t1</th>
<th>t2</th>
</tr>
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<tbody>
<tr>
<td>Driving</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Searching</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Parking</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Driving</td>
<td>...</td>
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In the matrix, the number of cars in each parking-state is shown.

See similar ideas used in Arnott (2008): Modelling parking; and Geroliminis (2007, Dissertation 4.2)
Parking-state-based Transition Matrix

Cumulative number of vehicles

"Queuing diagram" of vehicles on urban networks
Construct the Matrix

Introduction

Model

Conclusions

Incrementally construct the curves/matrix

Cumulative number of vehicles

New cars access parking

Time slices

decide to search

access parking

Time
Construct the Matrix

Basic assumption.

Number of cars access parking in a given time slices

Variables for each time slice:

• *Number of searchers*, \( N \).
• *Number of available parking spots*, \( A \).
• *A maximum distance a car can drive in each time slice*, \( d \).
• *The length of the road network*, \( L \).

See similar use of the ring road network in parking at Arnott (2008), Geroliminis (2014).
Construct the Matrix (results)

\[
\text{when } d \in [0, s], n = N \cdot \left[1 - \left(1 - \frac{d}{L}\right)^A\right].
\]

\[
\text{when } d \in (s, L), n =
\]

\[
\begin{align*}
&\left\{ A \cdot \left\{ 1 - \frac{N}{L} \cdot \int_{d-(m-1)s}^{s} \left[ \sum_{i_{m-2} = m-2}^{A-1} C_{A-1}^{i_{m-2}} \left(\frac{(N-m+2)s-x}{L}\right)^{A-1-i_{m-1}} \cdot \sum_{i_2 = 1}^{i_2} \sum_{i_1 = 1}^{i_1} C_{i_1}^{i_2} \left(\frac{x}{L}\right)^{i_1} \cdot s^{i_2}\right] \right\} dx \right\} \\
&\quad \text{if } A < m
\end{align*}
\]

\[
\begin{align*}
&\left\{ A \cdot \left\{ 1 - \frac{N}{L} \cdot \int_{d-(m-1)s}^{s} \left[ \sum_{i_{m-2} = m-2}^{A-1} C_{A-1}^{i_{m-2}} \left(\frac{(N-m+1)s-x}{L}\right)^{A-1-i_{m-1}} \cdot \sum_{i_2 = 1}^{i_2} \sum_{i_1 = 1}^{i_1} C_{i_1}^{i_2} \left(\frac{x}{L}\right)^{i_1} \cdot s^{i_2}\right] \right\} dx \right\} \\
&\quad \text{if } A = m
\end{align*}
\]

\[
\text{when } d \in [L, \infty), n = \min\{A, N\}.
\]

Advantages

- **Minimum data requirements.**
- **The sequence of the car arrivals to each parking stall is considered, it is close to real situation.**
- **The instantaneous change of the parking supply are consider (within each time slice).**

Although, the model can only provide a average number of cars that can access parking, the real situation could be with more randomness.
Construct the Matrix

Introduction

Model

Conclusions

Incrementally construct the curves/matrix
Construct the Matrix

### Number of cars depart parking in a given time slices

Assume the parking duration obeys a known distribution, then the number of departure can be found based on the arrival and parking duration.
Results from the Matrix

“Queuing diagram” of vehicles on urban networks
Results from the Matrix

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```

```
Total searching time (Delay caused by searching) 

Cumulative number of vehicles

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- **Cumulative number of vehicles**
- **Total searching time (Delay caused by searching)**
- **Total parking load (space-hours used)**

```
“Queuing diagram” of vehicles on urban networks
```
Results from the Matrix

“Queuing diagram” of vehicles on urban networks

Curve of “depart parking”, elevated by the capacity of the parking facilities

Cumulative number of vehicles

Available parking

Occupied parking

Access parking

Depart parking

Time
Unavailable results from the Matrix

Info shortage for any individual trip, as the system is not a FIFO.

“Queuing diagram” of vehicles on urban networks
Summary

- The model for $n_{access}$ allow us to imitate a practical situation with the imbalance between parking availability and demand, as well as the parking search phenomenon.

- But the model neglects the influence of the network shape (by assuming all streets have the same likelihood of being visited), and personal requirements for parking.

- Next step, to find the value of $n_{depart}$, number of cars departs from the parking facilities. Then build the matrix under the current framework and assumptions.

- Explore information from the transition matrix (or queuing diagram), relax the assumptions and improve the model to more generalized conditions.
THANK YOU
Examples

(a) if $x \in \left[0, \frac{1}{6}\right]$, a number of $m=3$ cars can reach $x$.

if $x \in \left[\frac{1}{6}, \frac{1}{3}\right]$, a number of $m-1=2$ cars can reach $x$.

For validation: the results (equation) is compared to the average value given by programmed experiments.