Traffic Flow Theory and its Applications in Urban Environments

An Innovative Approach

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Traffic issues in urban environments

Pedestrian Safety Environment
Traffic interacts with other systems

HIGHWAY  ➔  URBAN

Urban Transport & Mobility

Quality of life

- Land Use Infrastructure
- Energy
- Technology
- Environment

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An innovative approach?

Use *Traffic Flow Theory* in the

**Macroscopic Modelling** of

the Dynamics and Interactions of Urban Systems

Urban *traffic* and *parking* systems
Dynamics and interactions between two urban systems – traffic and parking
Global issue: cruising-for-parking

Status quo - studies

- 2005 - Average (16 cities)
- 2011 - Average (20 cities)

IBM Global Parking Survey

1977 - Freiburg
1985 - Cambridge
1993 - New York
2005 - L.A.
2011 - Dallas

Traditional data collection:
- Non-transferrable conclusions (to other cities)
- Trip data is hard to acquire

Is there a generic approach to estimate cruising conditions?
Global issue: cruising-for-parking

Status quo - solutions

Smart parking (data)  Parking policy

GPS data to estimate cruising?
- Under development
- Only answers HOW (behavior) but not WHY

What is the mathematical relation between parking and traffic?
- cannot remove bottleneck
- cannot estimate cruising traffic
- cannot solve competition
- cannot fully remove cruising
- slow reaction
- cannot reflect system dynamics
Urban traffic – difficult to model

Traditional traffic flow theory not always applicable

Challenges
- Car-following models
- Fundamental diagram
- Queuing theory
- Trip data collection
Traffic + Parking – more complex

Parking causes cruising
Parking could lead to congestion

Congestion affects parking
Congestion hinders drivers to park

Challenges

- Model the dynamics of both systems
- Incorporate the dynamics to calculate the probability of finding parking
Vehicular flow on urban networks

Individual travelers

Enter the area

Start to search

Find parking

Depart parking

Leave the area

Transition steps
Traditional method
Collect travel time of each individual traveler

Trips made → Plot trajectories → Aggregate info

Individual steps → Time – step diagram → Cumulative plot

- Leave the area
- Depart parking
- Find parking
- Start to search
- Enter the area

Steps

Cumulative

1

2

N

1 2

time

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Macroscopic method

Trips made
Individual steps

Time – step diagram

Aggregate info
Cumulative plot

Steps

1
2

Cumulative
N

1
2

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Macroscopic method
Estimates car exchange between different states

Trips made
Individual steps

Aggregate info
Cumulative plot

Cumulative N

Enter the area
Start to search
Find parking
Depart parking
Leave the area

Time Slices

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Macroscopic method
Provides macroscopic outputs regarding cruising

Trips made
Individual steps

Aggregate info
Cumulative plot

Cumulative N

Enter the area
Start to search
Find parking
Depart parking
Leave the area

Total cruising time

Total travel time

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Macroscopic method
Evaluates system dynamics of cruising conditions

Parking system
Number of users
Parking occupancy (%)

Cruising system
Number of cruising vehicle
Next time slice
Probability of finding parking

Traffic system
Number of users
Traffic density
Travel speed
Macroscopic method - formulation

Parking condition

\[ d^i = v^i \cdot t \]
\[ s^i = \frac{L}{N^i_s} \]
\[ m^i = \left\lfloor \frac{d^i}{s^i} \right\rfloor \]
\[ d_r^i = d^i - \left\lfloor \frac{d^i}{s^i} \right\rfloor \cdot s^i \text{ for } d^i > s^i \]

Traffic condition

\[ k^i = \frac{N^i_s + N^i_{ns}}{L} \]
\[ v^i = \begin{cases} 
  v, & \text{if } 0 \leq k^i \leq k_c \\
  \frac{Q_{max}}{k_c-k_j} \cdot \left(1 - \frac{k_j}{k_i}\right), & \text{if } k_c < k^i \leq k_j 
\end{cases} \]

based on Macroscopic Fundamental Diagram
Macroscopic method - formulation

Contour plot of the average probability of finding parking

\[
n_{s/p} = \begin{cases} 
N_s^i \\
A^i \\
A^i \\
\min \{i\} 
\end{cases}
\]

\[
p_1 = \int_0^{d - (m^i - 1)s^i} \left\{ \sum_{i' = m^i}^{A^{i-1}} \right\} \\
p_2 = \int_{d - (m^i - 1)s^i}^{d} \left\{ \sum_{i' = m^i}^{A^{i-1}} \right\}
\]

Number of free spaces in relation to the number of searchers

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Macroscopic method - formulation

Vehicles go through each transition

\[ n_{ns/s}^i = \sum_{t=1}^{i-1} (1 - p_{ns}^t) \cdot n_{p/ns}^t \cdot \frac{1}{i_{ns/s}} \]  

\[ i_{ns/s}^i = \begin{cases} 1, & \text{if } l_{ns/s} \leq \sum_{j=t}^{i-1} d^j \text{ and } \sum_{j=t}^{i-1} d^j \leq l_{ns/s} + d^{-1} \\ 0, & \text{if otherwise.} \end{cases} \]

\[ n_{p/ns}^i = \sum_{t=1}^{i-1} n_{s/p}^t \cdot \int_{(i-t)}^{(i-1-t)} f(t_d) \, dt_d \]

\[ n_{ns/s}^i = \sum_{t=1}^{i-1} (\beta^t \cdot n_{ns}^t \cdot \gamma_{p}^t + n_{p/ns}^t \cdot \gamma_{p}^t) \]

\[ \gamma_{p}^t = \begin{cases} 1, & \text{if } l_{p} \leq \sum_{j=t}^{i-1} d^j \text{ and } \sum_{j=t}^{i-1} d^j \leq l_{p} + d^{-1} \\ 0, & \text{if otherwise.} \end{cases} \]

\[ \gamma_{p}^t = \begin{cases} 1, & \text{if } l_{p} \leq \sum_{j=t}^{i-1} d^j \text{ and } \sum_{j=t}^{i-1} d^j \leq l_{p} + d^{-1} \\ 0, & \text{if otherwise.} \end{cases} \]

Vehicles in each relevant state

\[ N_{ns/s}^{i+1} = N_{ns}^i + n_{ns/s}^i + n_{p/ns}^i - n_{ns/s}^i - n_{ns/s}^i \]

\[ N_{s}^{i+1} = N_{s}^i + n_{ns/s}^i - n_{s/p}^i \]

\[ N_{p}^{i+1} = N_{p}^i + n_{s/p}^i - n_{p/ns}^i \]
Validation of the model (Zürich)

Case study

Model Inputs

Traffic arrival to the network (MATSim)

Macroscopic fundamental diagram of Zürich (SVT)

Parking durations (MATSim)
Validation of the model (Zürich)

Parking occupancy

Average cruising time

Hour of the day

R-squared=0.97

In one day:
- 83 hrs additional travel time
- 1038 km cruising distance

Cruising at 12.00:
- 30 cars searching
- 2 spaces available
- 13 min cruising time
- 60% of share
- No speed drops

11.30-15.30
<5 spaces available

Parking occupancy

Average cruising time before parking (minutes)

Hour of the day
Contributions and applications

Academic
- Mathematical relation between parking availability & traffic condition
- Multiple systems
- Generic
- Dynamic
- Macroscopic
- Low data requirements and computational effort

Practical
- Governing Policy-wise
  - Parking supply
  - Time control
  - Pricing
  - Enforcement
  - On-/off-street
  - Evaluate the effectiveness of new technology
- Technology-wise
- Information-wise
- Forecast
- Large event management
- Modal choice based on full travel time
Application – parking policy

Scientific foundation for Dynamic pricing

Policy tests - quantify effects on traffic
Application – IPS evaluation
(Intelligent Parking System)

10:30-11:30
Reduction 59%

15:00-16:00
Reduction 51%

Other time
Reduction 7%
Further development of the model

Investigate the distribution of parking and traffic in urban networks

Incorporate big data and machine learning into the model to improve the accuracy

Evaluate the impact of connected / autonomous vehicles on traffic and parking
Future research

Urban Traffic Management
- Multimodal transport system
- Infrastructure
- Emergent technologies

Quality of life

Land Use
Infrastructure

Energy

Technology

Environment
Thank you for your attention!

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Reference
