Traffic Flow Theory and its Applications in Urban Environments

An Innovative Approach

Presented by Dr. Jin Cao

Traffic issues in urban environments

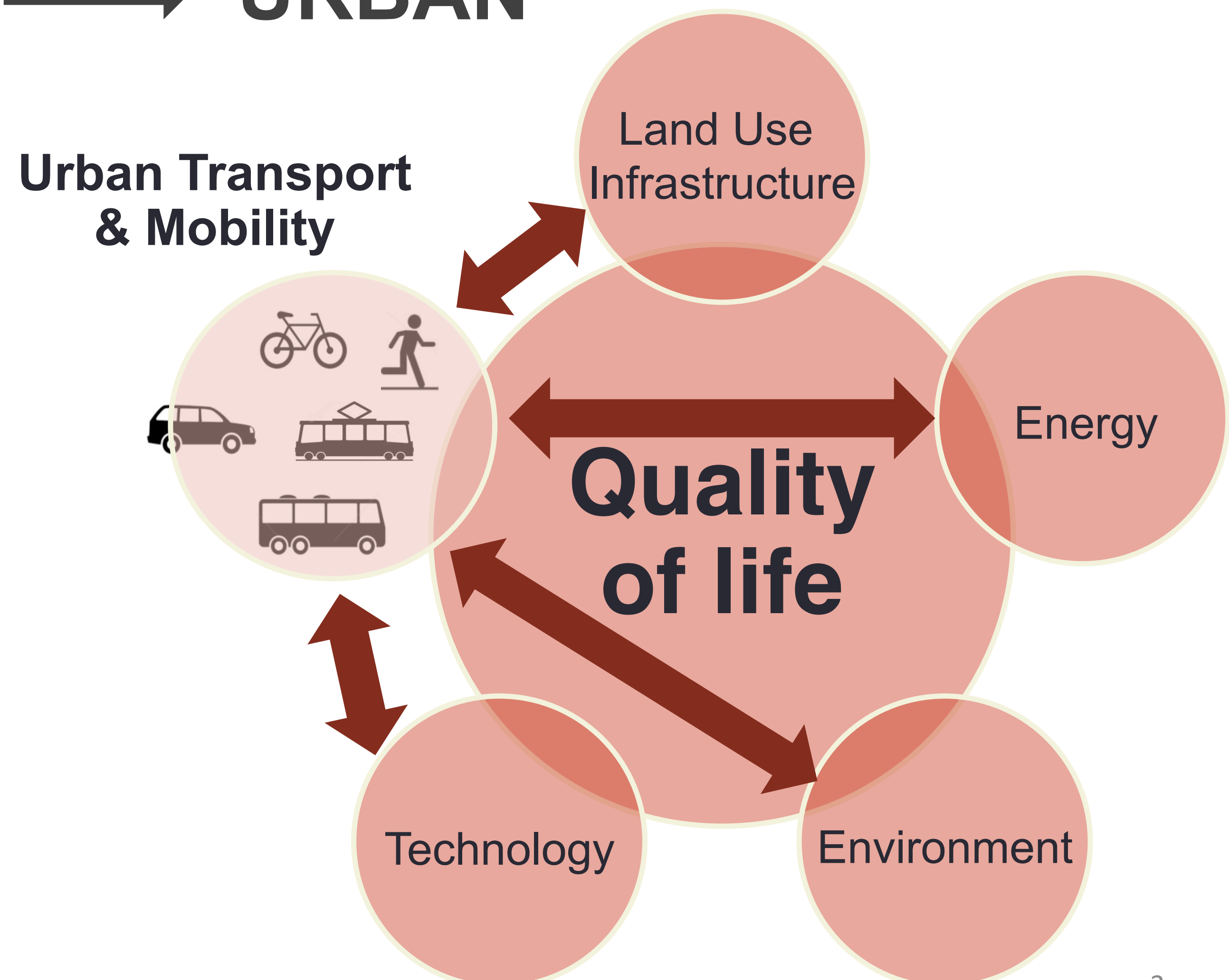
Pedestrian

Safety

Environment

Traffic interacts with other systems

HIGHWAY → URBAN



An innovative approach?

Use ***Traffic Flow Theory*** in the

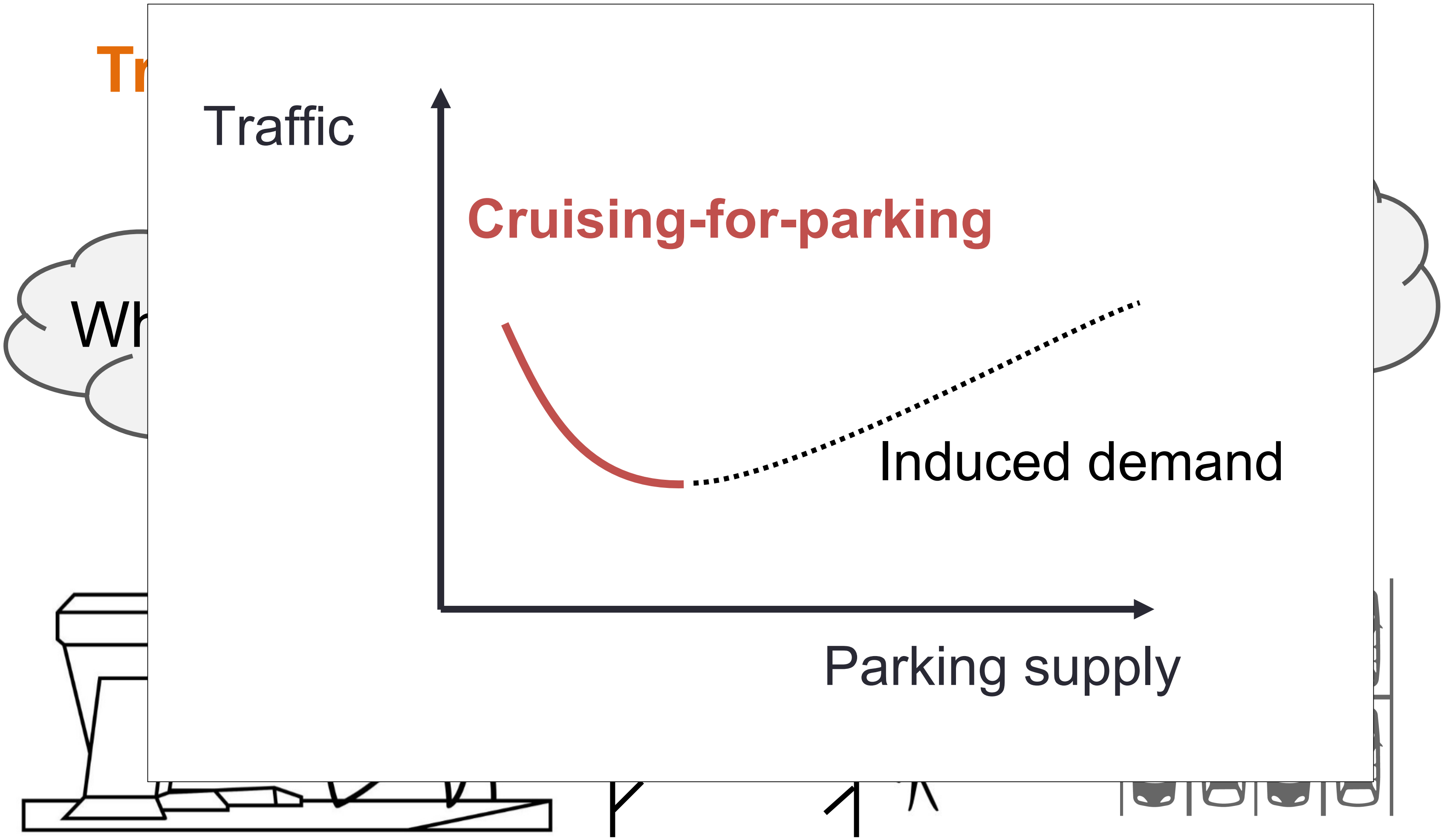
Macroscopic Modelling of

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

Ci

197

198

1993 New York 8 min 8%

200 ... ay

The

201

IBM Global Parking Survey

Traditional data collection

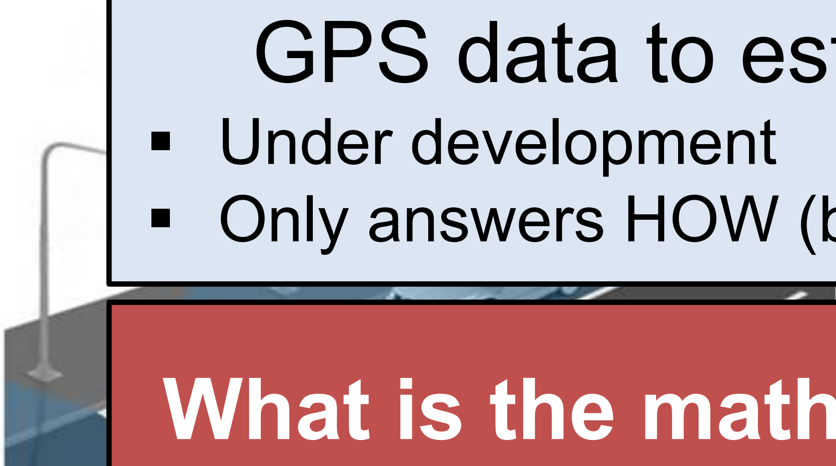
- Non-transferrable conclusions (to other cities)
- Trip data is hard to acquire

Is there a generic approach to estimate cruising conditions?

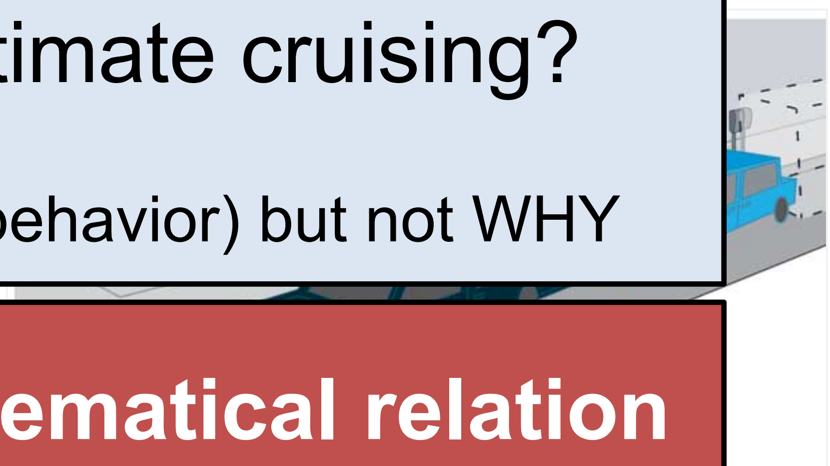
Global issue: cruising-for-parking

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?

Rea

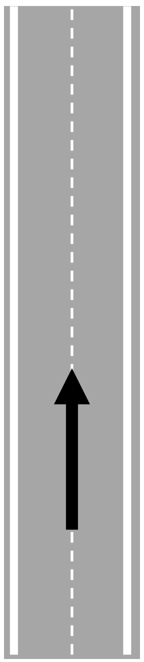
- cannot remove **bottleneck**
- cannot estimate **cruising traffic**
- cannot solve **competition**

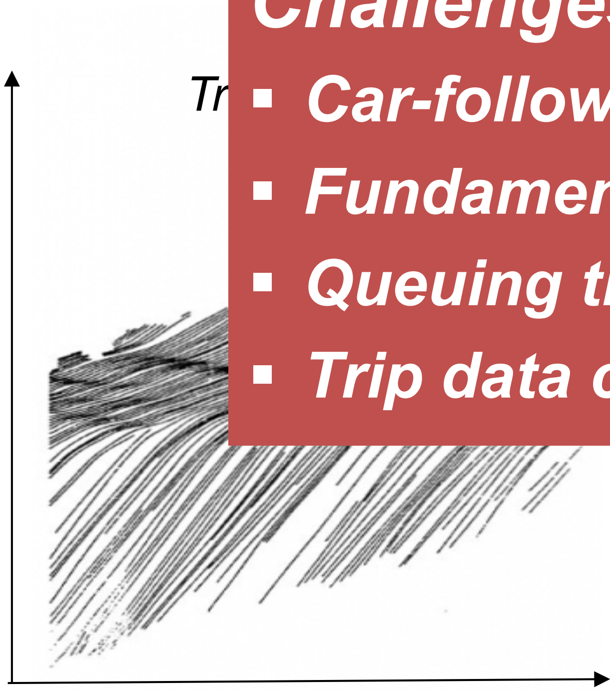
- cannot fully remove **cruising**
- slow **reaction**
- cannot reflect system **dynamics**

Urban traffic – difficult to model

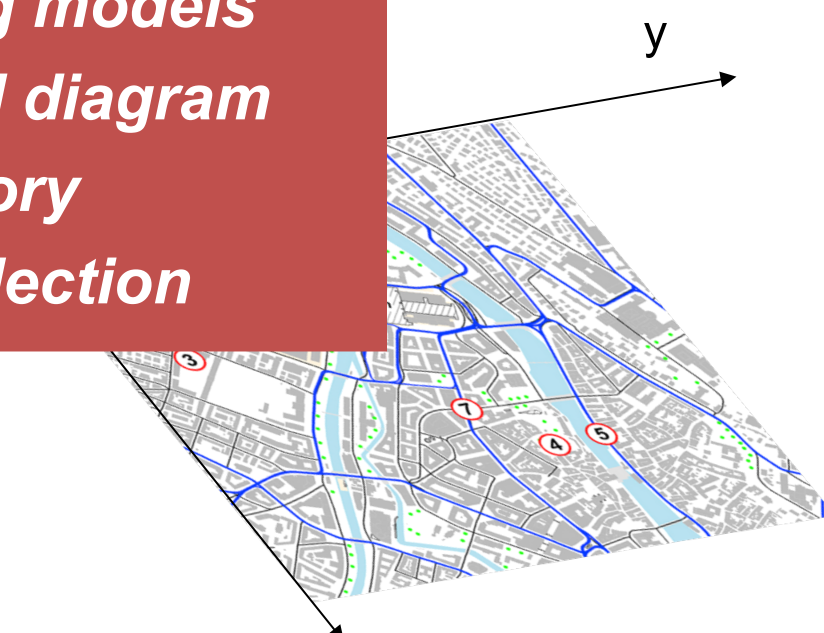
Traditional *traffic flow theory* not always applicable

Single roads





Network



Challenges

- ***Car-following models***
- ***Fundamental diagram***
- ***Queuing theory***
- ***Trip data collection***

Traffic + Parking – more complex

Parking causes cruising

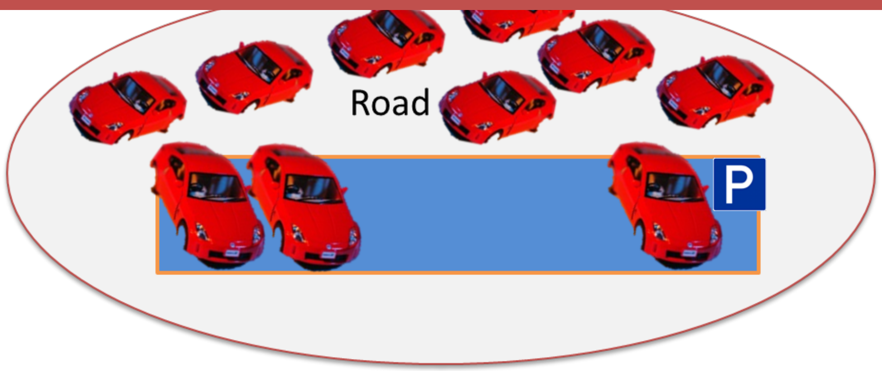
Parking could lead to congestion

Congestion affects parking

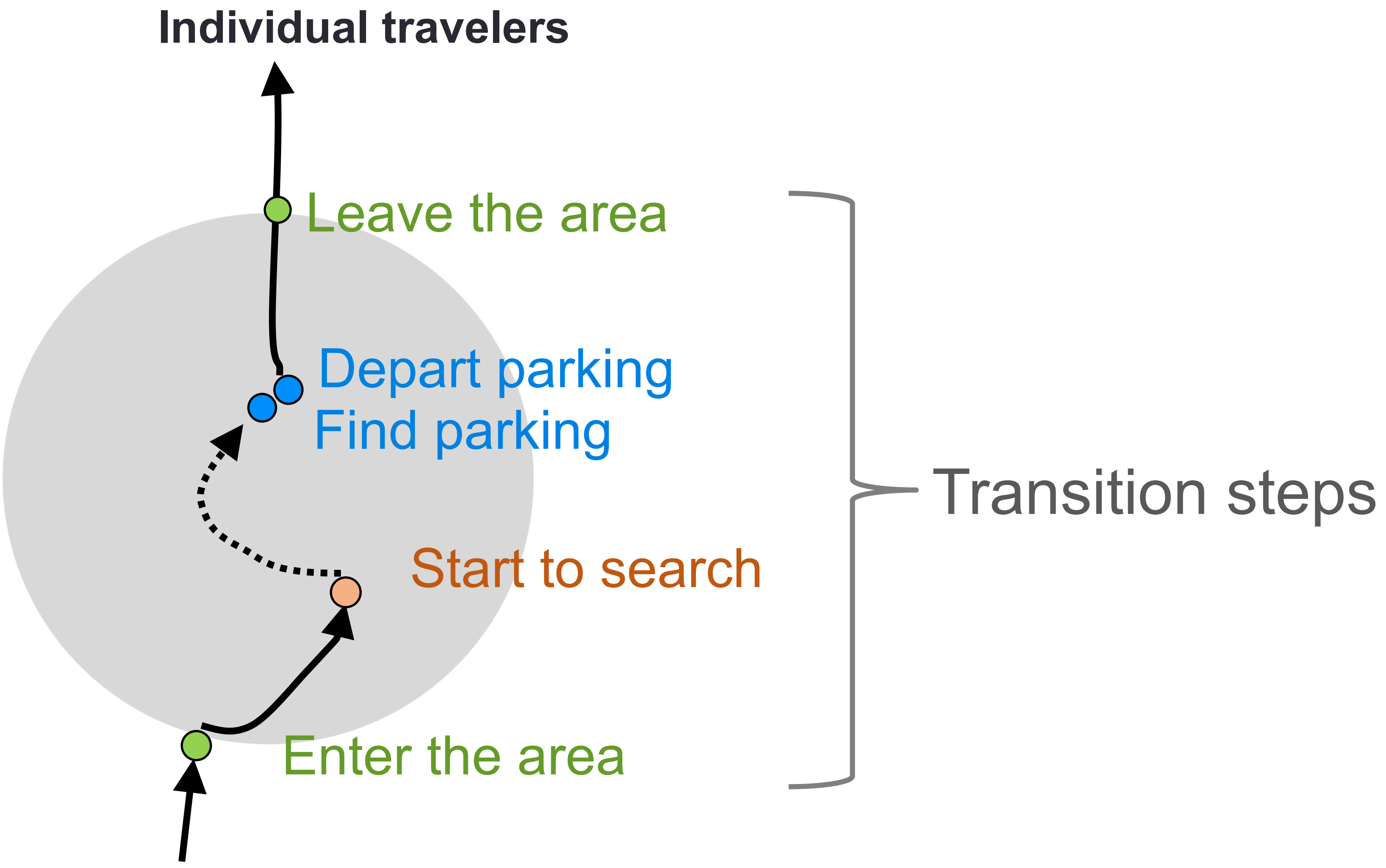
Congestion hinders drivers to park

Challenges

- ***Model the dynamics of both systems***
- ***Incorporate the dynamics to calculate the probability of finding parking***



Vehicular flow on urban networks

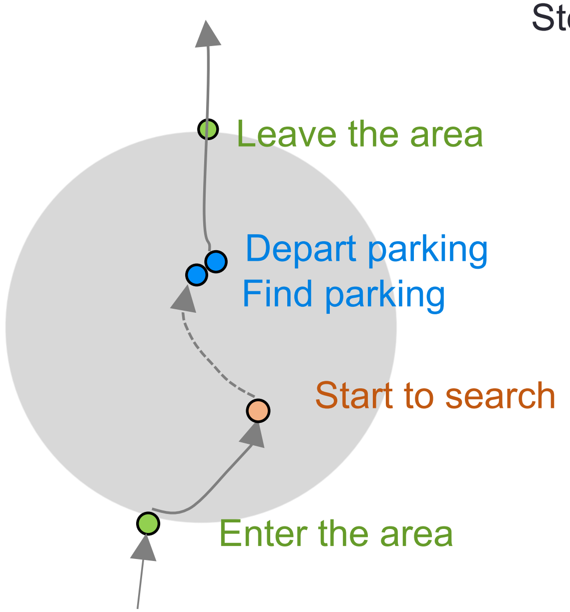


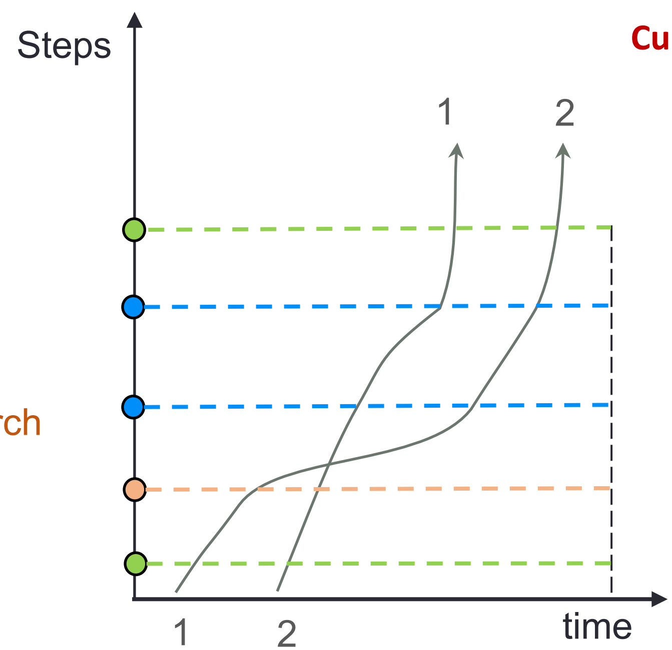
Traditional method

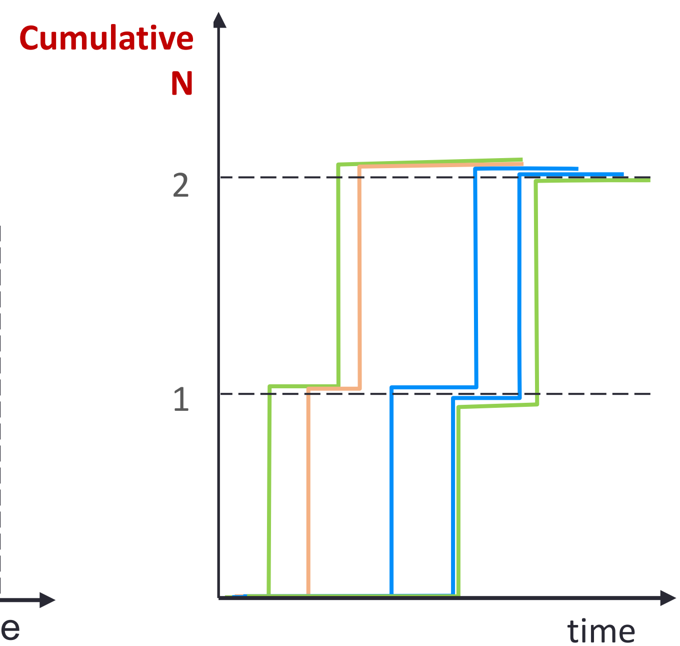
Collect travel time of each individual traveler

Trips made → **Plot trajectories** → **Aggregate info**

Individual steps | **Time – step diagram** | **Cumulative plot**







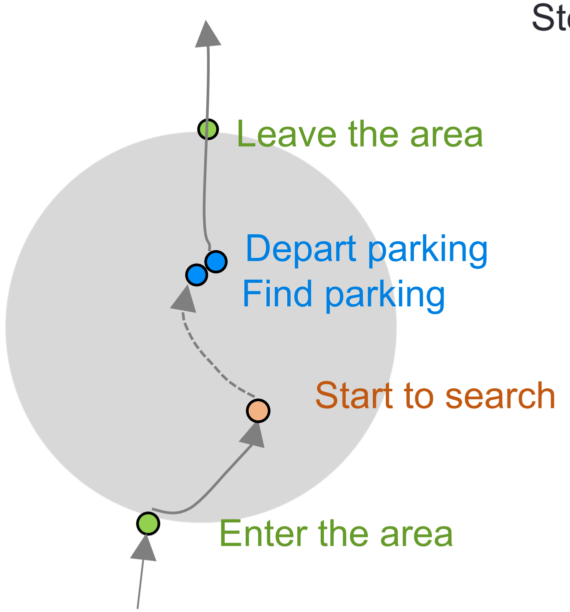
Macroscopic method

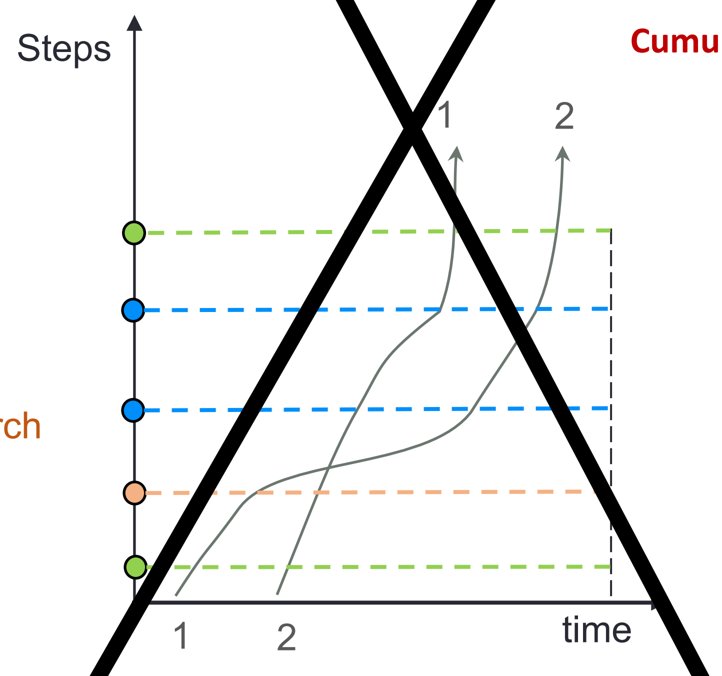
Trips made

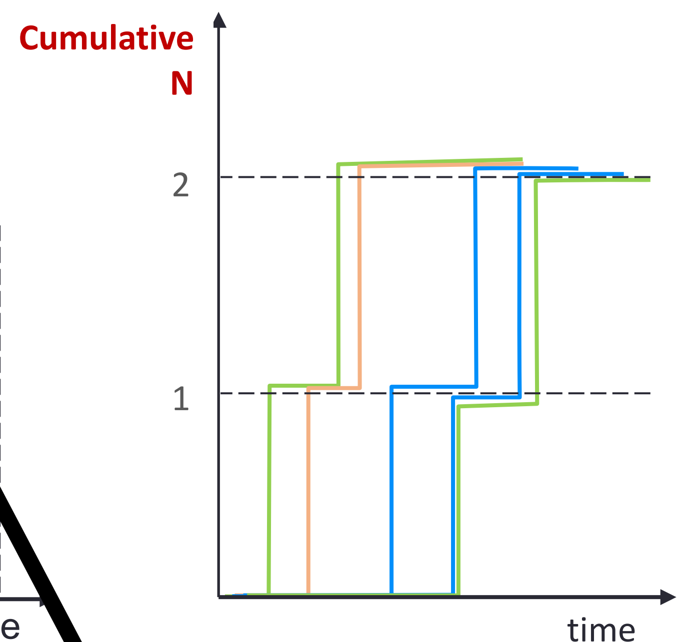
Individual steps

Aggregate info

Cumulative plot







Macroscopic method

Estimates car exchange between different states

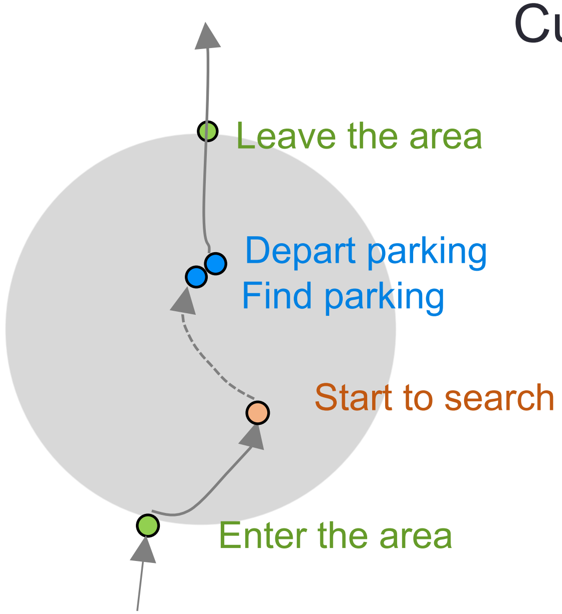
Trips made

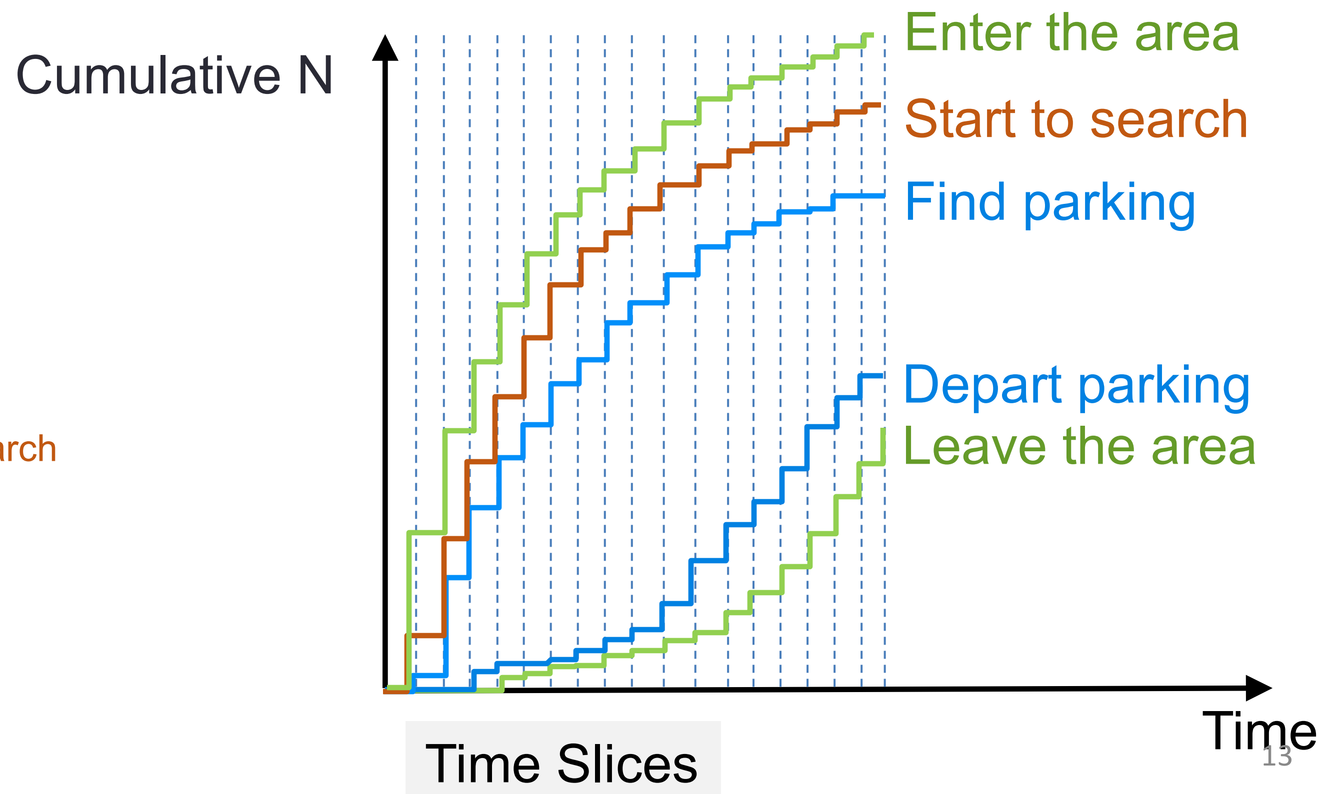
Individual steps

→

Aggregate info

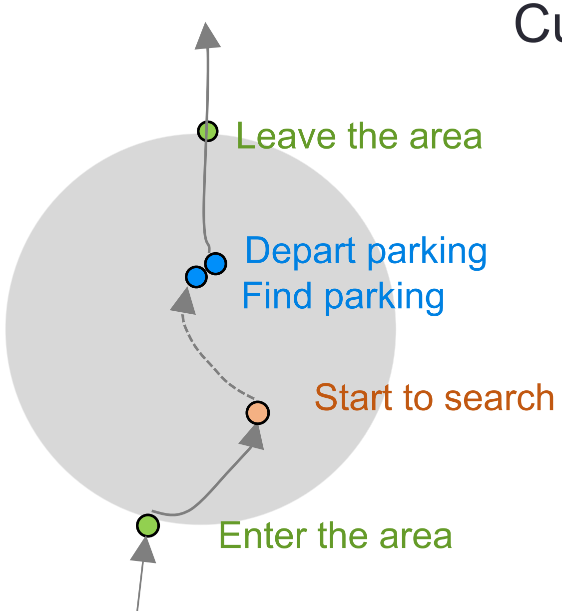
Cumulative plot

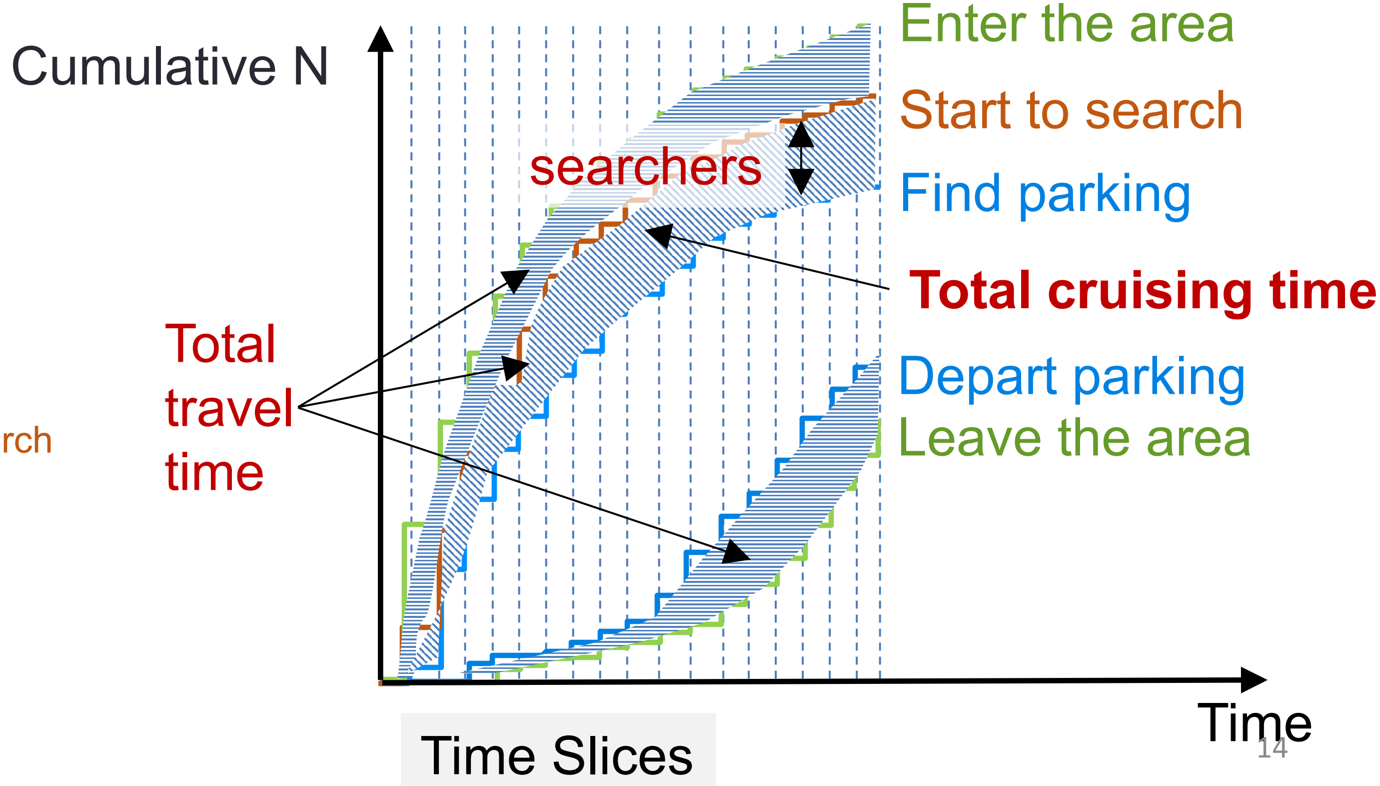




Macroscopic method

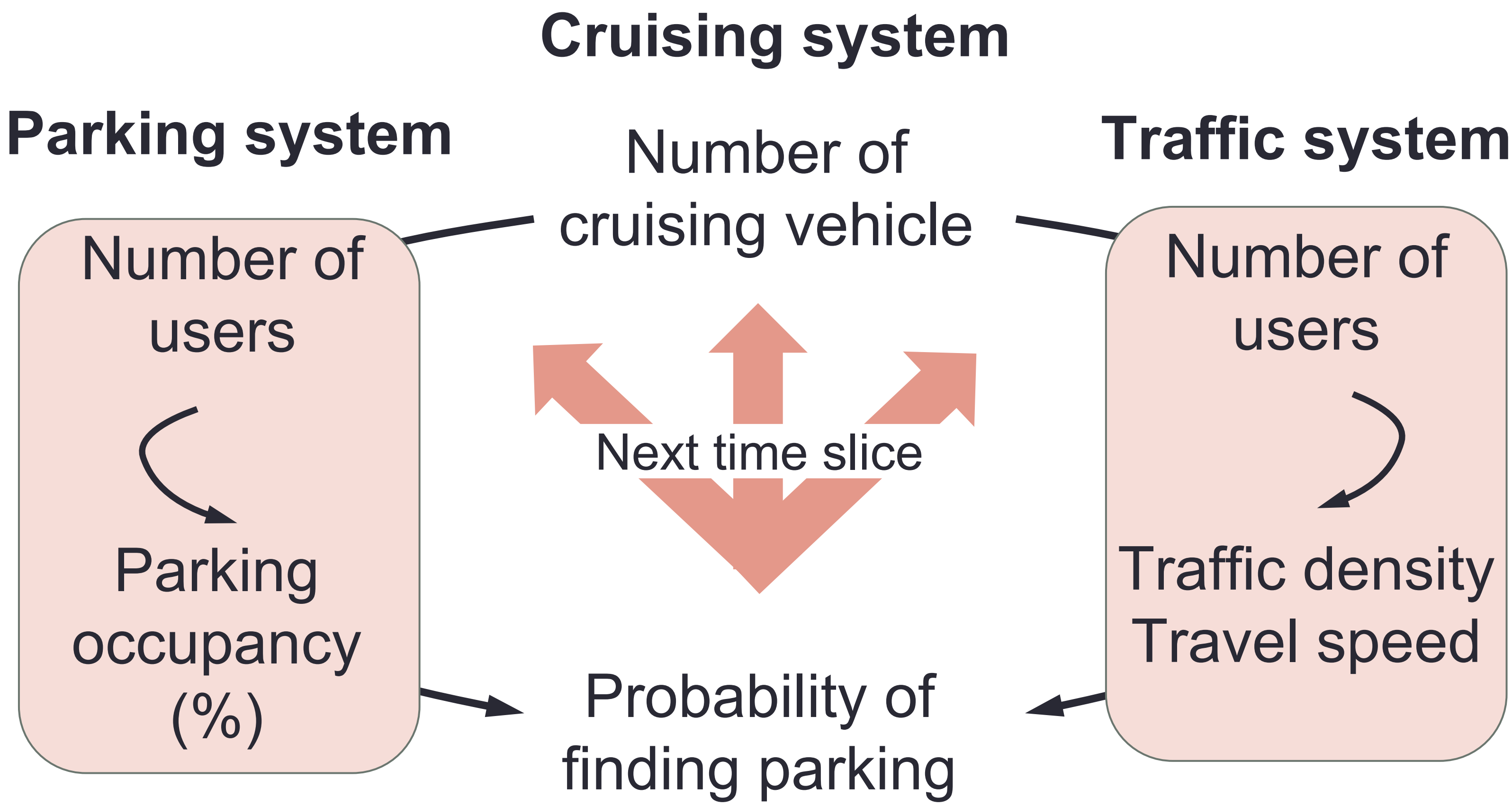
Provides macroscopic outputs regarding cruising



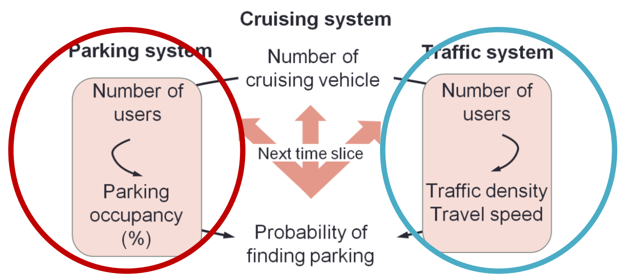


Macroscopic method

Evaluates system dynamics of cruising conditions



Macroscopic method - formulation



Parking condition

This image cannot currently be displayed.

$$d^i = v^i \cdot t$$

$$s^i = \frac{L}{N_s^i}$$

$$m^i = \left\lceil \frac{d^i}{s^i} \right\rceil$$

$$d_r^i = d^i - \left\lfloor \frac{d^i}{s^i} \right\rfloor \cdot s^i \text{ for } d^i > s^i$$

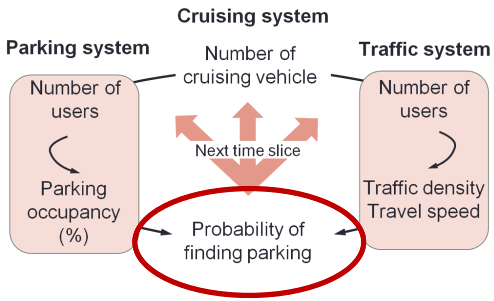
Traffic condition

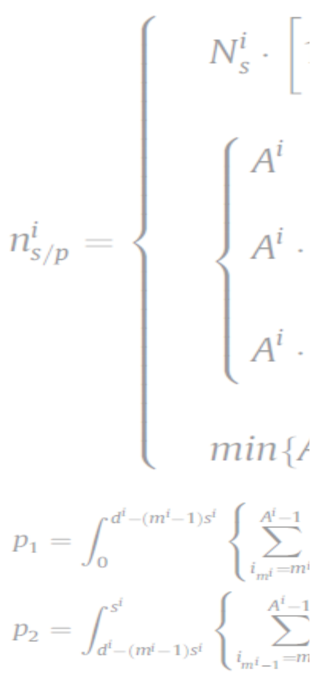
$$k^i = \frac{N_s^i + N_{ns}^i}{L}$$

$$v^i = \begin{cases} v, & \text{if } 0 \leqslant k^i \leqslant k_c \\ \frac{Q_{max}}{k_c - k_j} \cdot \left(1 - \frac{k_j}{k^i}\right), & \text{if } k_c < k^i \leqslant k_j \end{cases}$$

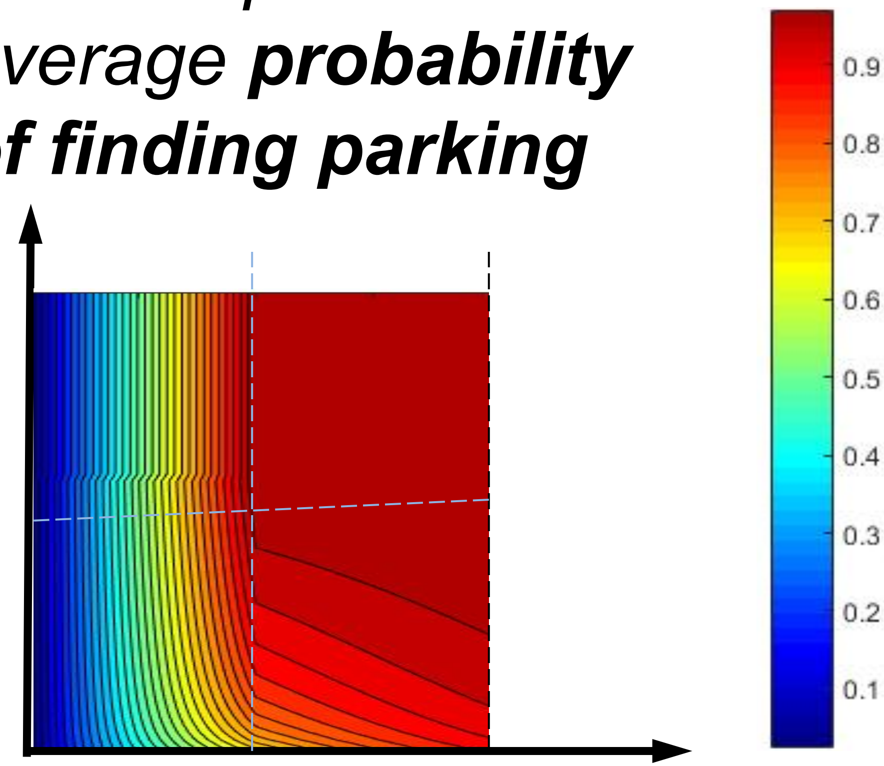
based on
Macroscopic Fundamental Diagram

Macroscopic method - formulation

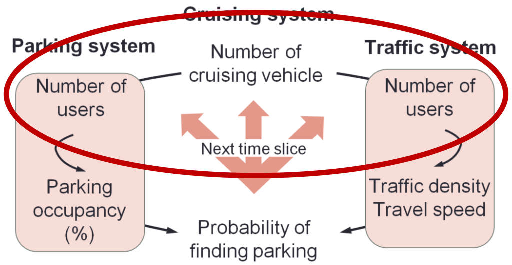




Contour plot of the average ***probability of finding parking***



Macroscopic method - formulation



Vehicles go through each transition

$$n^{i}_{ns/s} = \sum_{i'=1}^{i-1} \underbrace{(1-\beta^{i'}) \cdot n^{i'}_{/ns}}_{\text{term 1}} \cdot \underbrace{\gamma^{i'}_{ns/s}}_{\text{term 2}}$$

$$\gamma^{i'}_{ns/s} = \begin{cases} 1, & \text{if } l_{ns/s} \leqslant \sum_{j=i'}^{j=i-1} d^{j} \text{ and } \sum_{j=i'}^{j=i-1} d^{j} \leqslant l_{ns/s} + d^{i-1}. \\ 0, & \text{if otherwise.} \end{cases}$$

$$n^{i}_{p/ns} = \sum_{i'=1}^{i-1} n^{i'}_{s/p} \cdot \int_{(i-i')\cdot t}^{(i+1-i')\cdot t} f(t_d)\, dt_d$$

$$n^{i}_{ns/} = \sum_{i'=1}^{i-1} \left(\beta^{i'} \cdot n^{i'}_{/ns} \cdot \gamma^{i'}_{/} + n^{i'}_{p/ns} \cdot \gamma^{i'}_{p/}\right)$$

$$\gamma^{i'}_{/} = \begin{cases} 1, & \text{if } l_{/} \leqslant \sum_{j=i'}^{j=i-1} d^{j} \text{ and } \sum_{j=i'}^{j=i-1} d^{j} \leqslant l_{/} + d^{i-1} \\ 0, & \text{if otherwise.} \end{cases}$$

$$\gamma^{i'}_{p/} = \begin{cases} 1, & \text{if } l_{p/} \leqslant \sum_{j=i'}^{j=i-1} d^{j} \text{ and } \sum_{j=i'}^{j=i-1} d^{j} \leqslant l_{p/} + d^{i-1} \\ 0, & \text{if otherwise.} \end{cases}$$

Vehicles in each relevant state

$$N^{i+1}_{ns} = N^{i}_{ns} + n^{i}_{/ns} + n^{i}_{p/ns} - n^{i}_{ns/s} - n^{i}_{ns/}$$

$$N^{i+1}_{s} = N^{i}_{s} + n^{i}_{ns/s} - n^{i}_{s/p}$$

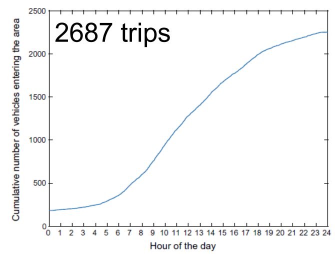
$$N^{i+1}_{p} = N^{i}_{p} + n^{i}_{s/p} - n^{i}_{p/ns}$$

Validation of the model (Zürich)

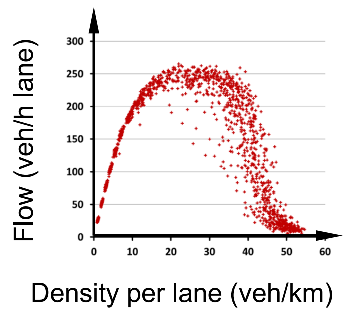
Case study

Parking supply
Road network

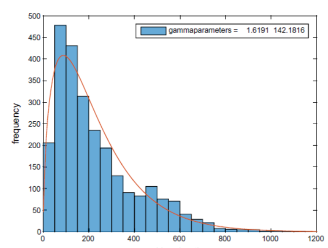
Model Inputs



Traffic arrival to the network (MATSim)



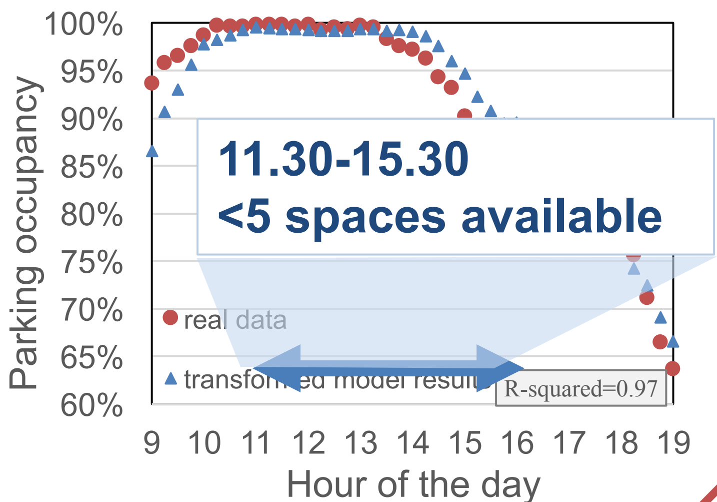
Macroscopic fundamental diagram of Zürich (SVT)



Parking durations (MATSim)

Validation of the model (Zürich)

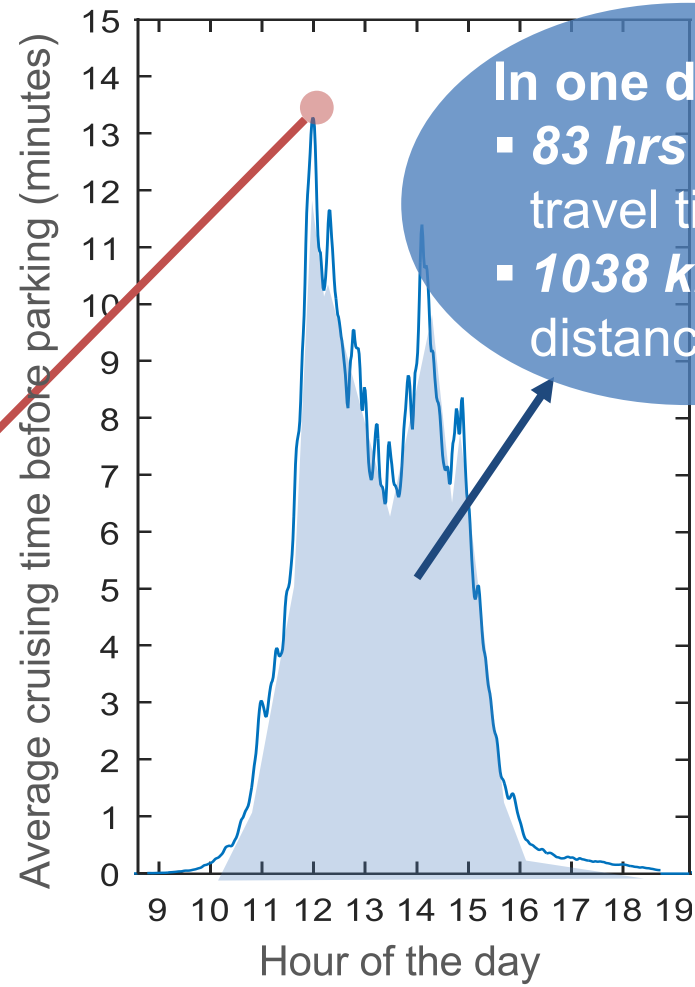
Parking occupancy



Cruising at 12.00:

- ***30 cars*** searching
- ***2 spaces*** available
- **13 *min*** cruising time
- **60%** of share
- No speed drops

Average cruising time



In one day:

- ***83 hrs*** additional travel time
- ***1038 km*** cruising distance

Contributions and applications

Academic

Mathematical relation between parking availability & traffic condition

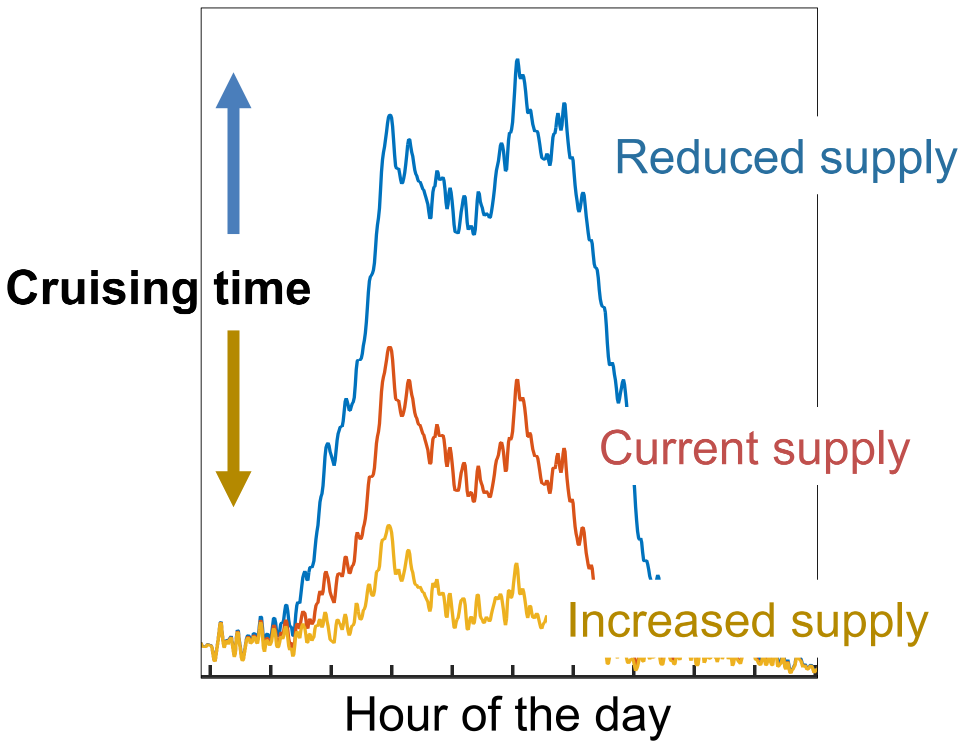
- Multiple systems
- Generic
- Dynamic
- Macroscopic

Low data requirements and computational effort

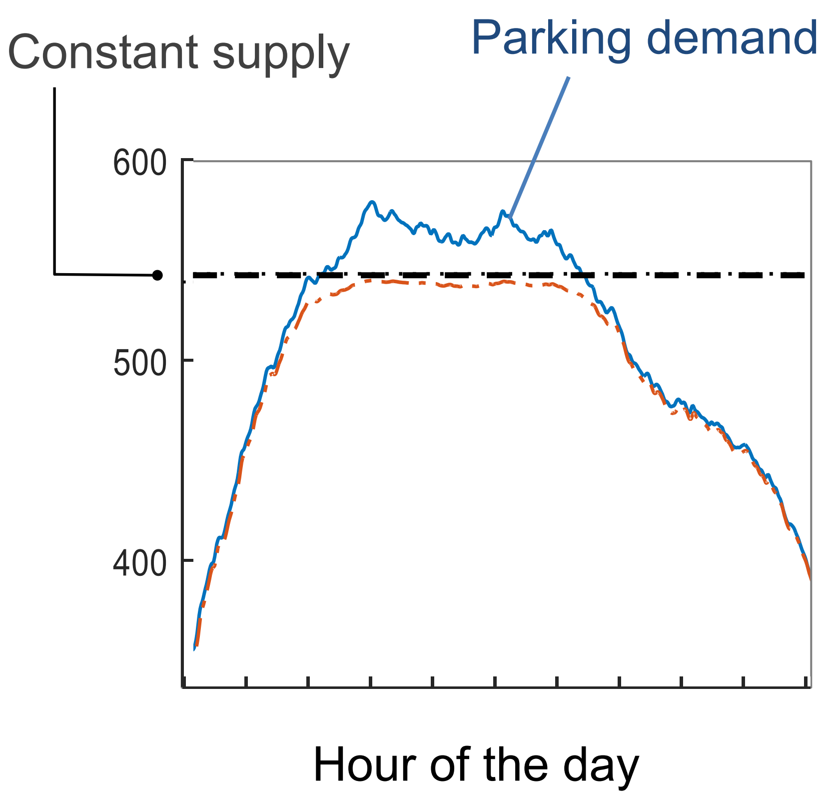
Practical

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

Application – parking policy

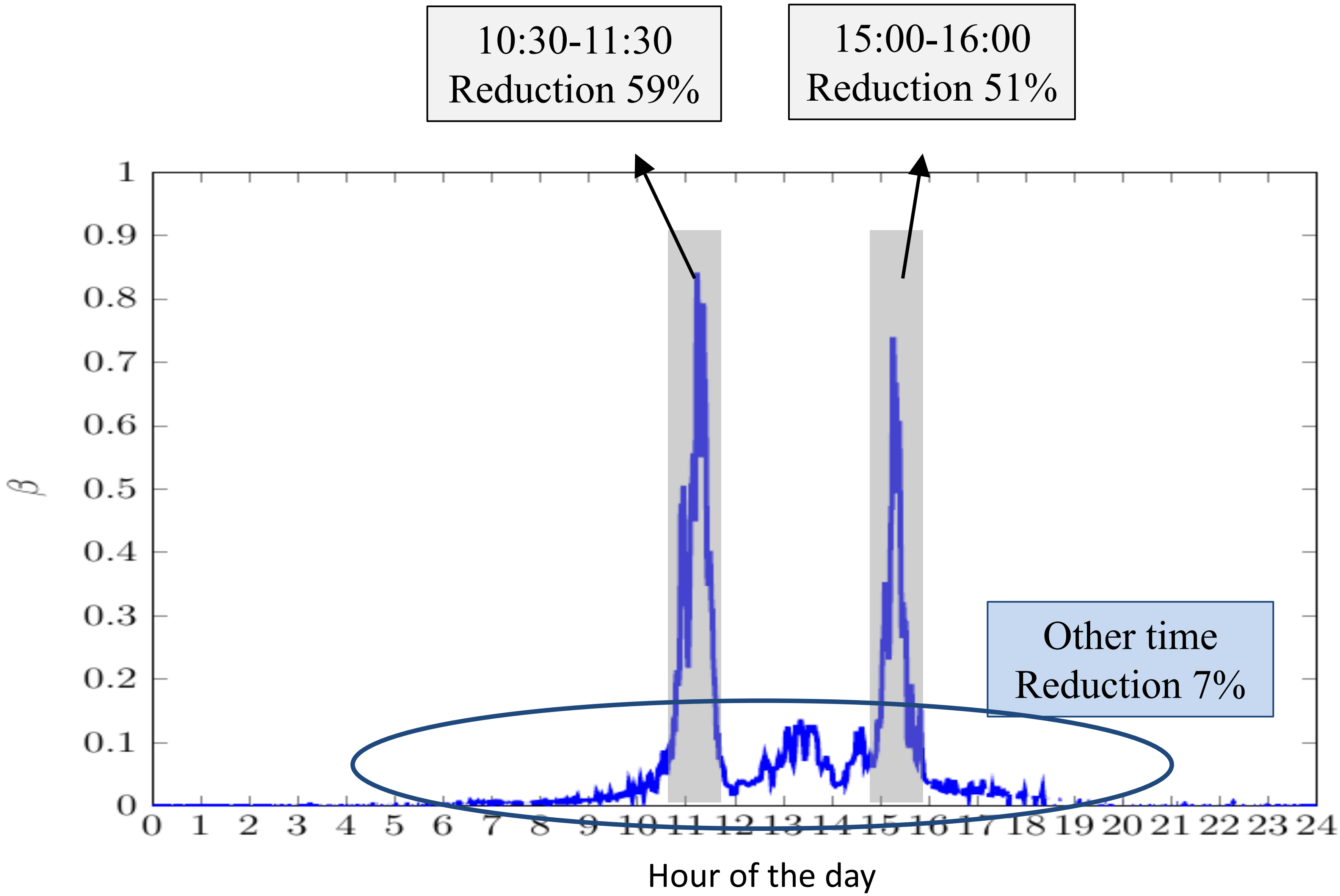


Scientific foundation for **Dynamic pricing**



Policy tests - quantify effects on traffic

Application – IPS evaluation
(Intelligent Parking System)



Further development of the model

Investigate the distribution of parking and traffic in urban networks

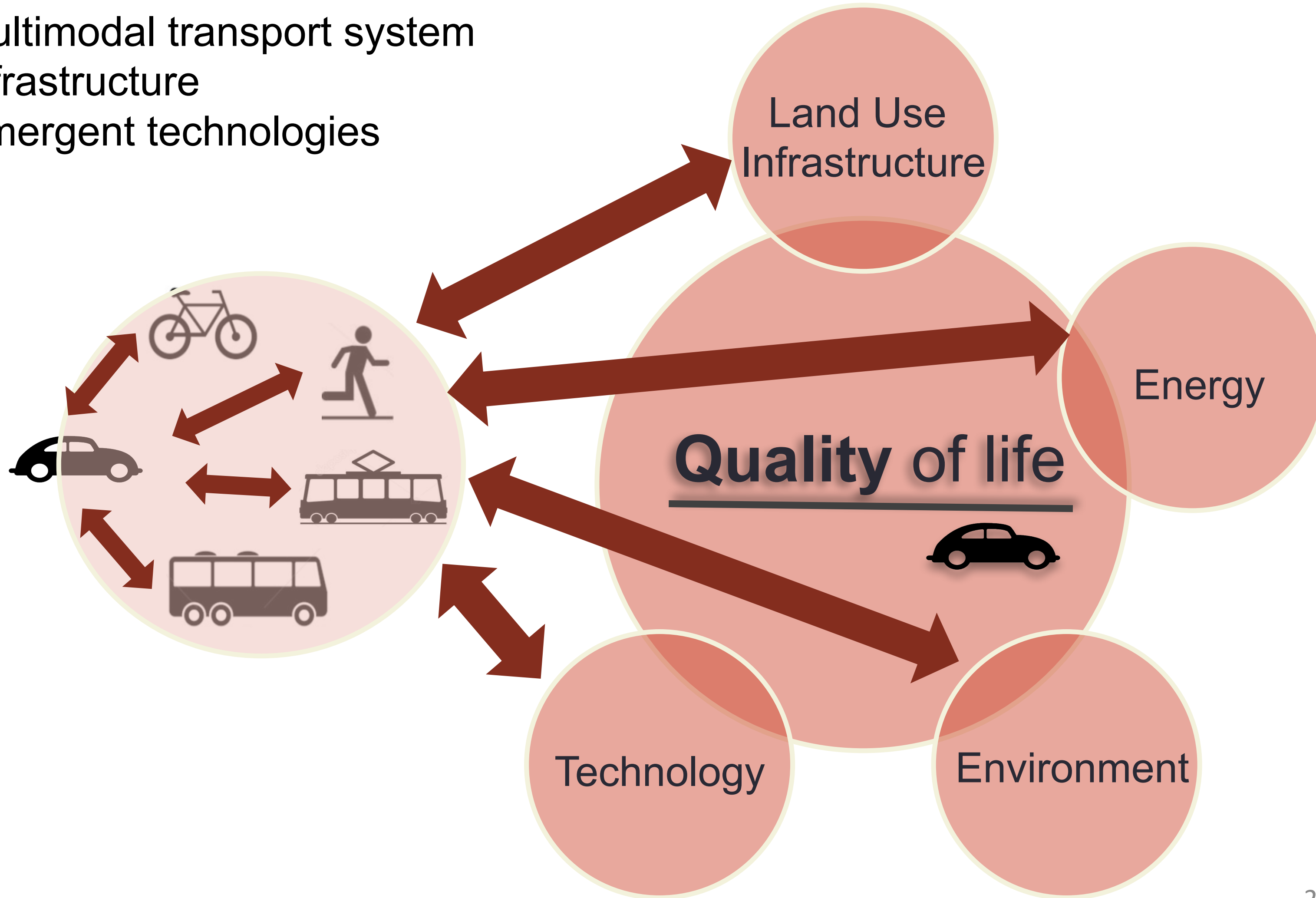
Incorporate big data and machine learning into the model to improve the accuracy

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

Future research

Urban Traffic Management

- Multimodal transport system
- Infrastructure
- Emergent technologies



Thank you for your attention !

Presented by Dr. Jin Cao

Reference

- Cao, J. and Menendez, M., 2015. System dynamics of urban traffic based on its parking-related-states. *Transportation Research Part B: Methodological*, *81*, pp.718-736.

- Cao, J., Menendez, M. and Waraich, R., 2017. Impacts of the urban parking system on cruising traffic and policy development: the case of Zurich downtown area, Switzerland. *Transportation*, pp.1-26.