Multi-State Supernetworks: Recent and Future Development

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Where innovation starts

About me

- **Master study** (Systems Engineering, 2005-2008)
  - University of Shanghai for Sci&Tech

Heuristics

Genetic Algorithm

Ant Colony Optimization

Tabu Search

Traveling Salesman Problem

Knapsack Problem

Constrained Minimum Spanning Tree

Minimum Dominating Set

Connected Minimum Dominating Set

Graph Coloring Problem

About me

- **Ph.D. study** (*cum laude*, 2009-2013)
  - Eindhoven University of Technology

Synchronizing networks ⇒ Improving accessibility

NWO: Dutch Organization for Scientific Research

PVN PTN

Activity-based modeling

- **Background**
  - Travel is derived from the need to conduct activities
  - Better capture activity-travel behavior
  - Sensitive to a larger spectrum of policies
- **Main limitations** *of activity-travel scheduling models*
  - Adopt hierarchical or sequential structure
  - Do not represent activity-travel patterns at high level of detail

(**Ref**: Pinjari and Bhat, 2011; Rasouli and Timmermans 2014)

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Examples

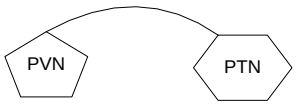
- **Famous activity-based systems**
  - Constraint-based models
    e.g. CARLA, MASTIC, PCATS
  - Utility maximization
    e.g. STARTCHILD, DAS, Tel Aviv
  - Rule-based models
    e.g. ALBATROSS, TASHA, ADAPTS
  - Micro-simulation models
    e.g. CEMDAP, FAMOS, HAPP, MATSim

(**Ref**: e.g., Bowman and Ben-Akiva, 2001; Arentze and Timmermans 2004; Miller, 2009; Balmer & Axhausen et al., 2009; Bhat et al., 2012)

Synchronizing networks

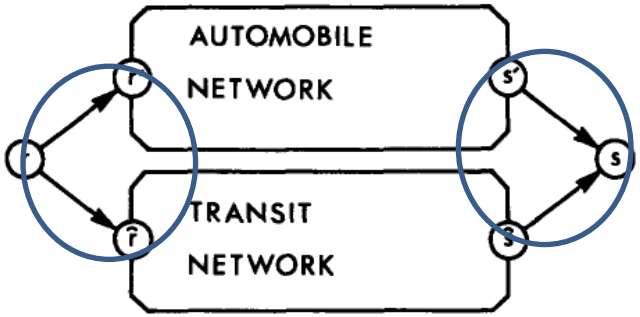
- **Background**
  - Transport networks are largely developed in isolation
  - Location strategies are based on simple accessibility concept
  - New/emerging modalities (e.g. ICT use) are not systematically addressed in planning process
  - Space is limited for large-scale infrastructure improvement
- **Idea**
  - Whether synchronizing networks can improve accessibility and mobility efficiency

(**Ref**: van Wee et al., 2014; Liao et al., 2015)

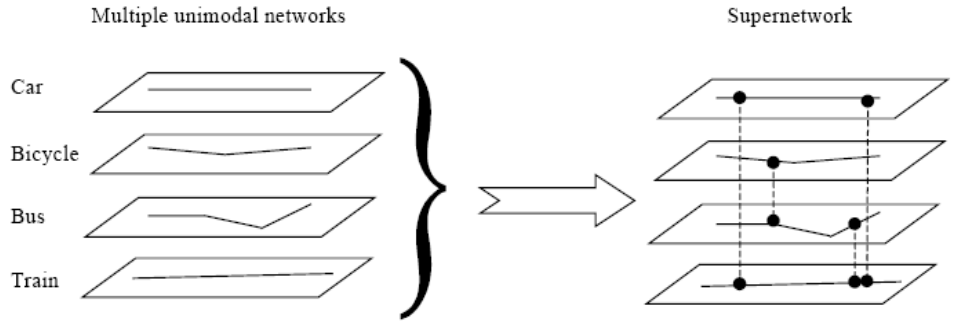


Supernetwork models

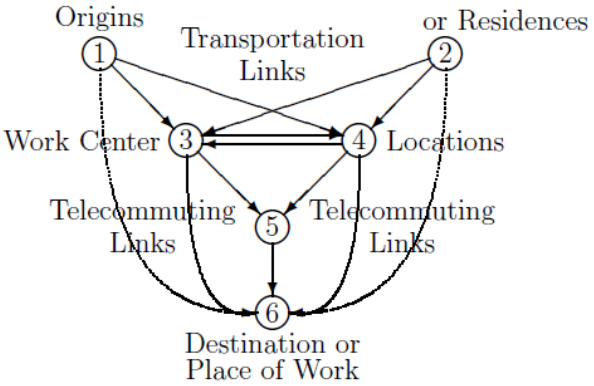
- **Suitable for modeling multiple choice facets simultaneously**



Sheffi (1985)



Carlier et al. (2003)



Nagurney et al. (2002, 2003)

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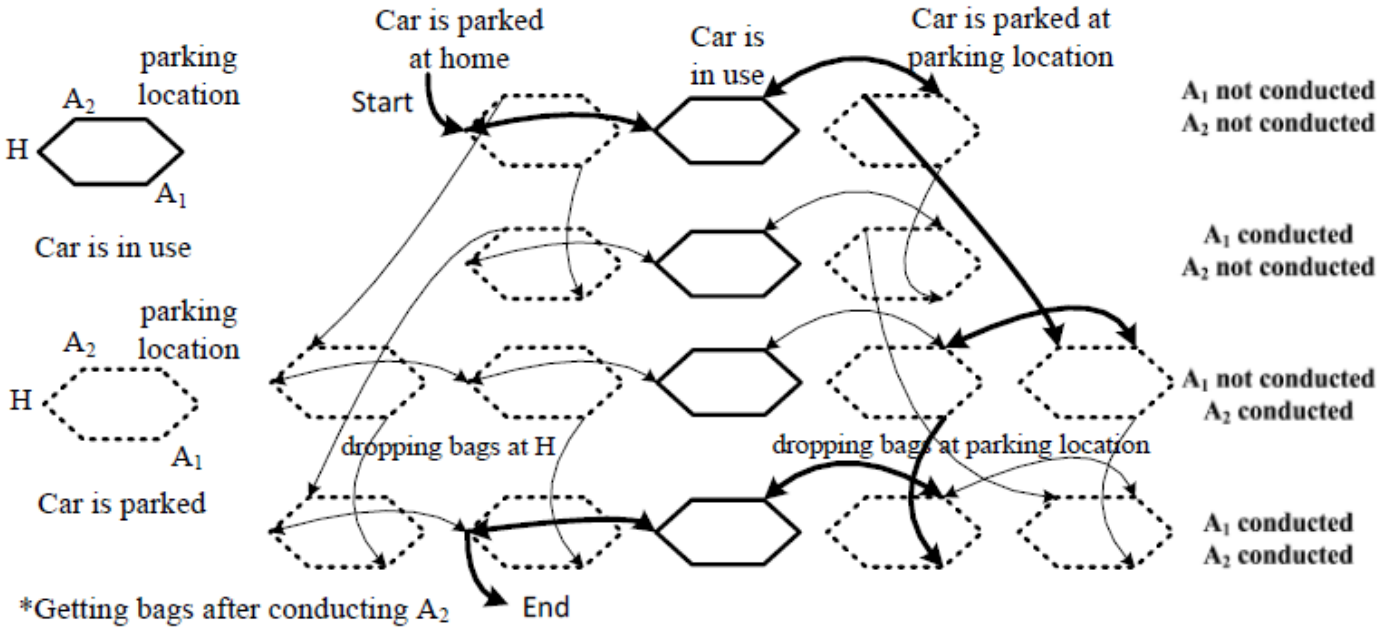
Activity-based supernetworks

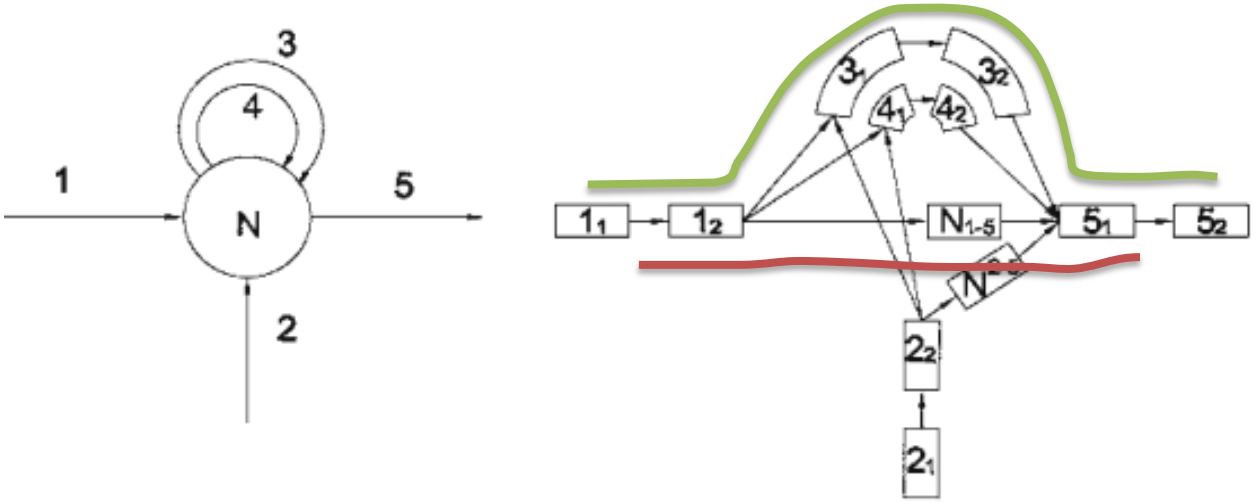
- **Multi-state supernetwork**



Arentze and Timmermans (2004)

Activity-based supernetworks

- **supernetwork**



Arcs 1 and 2 are incoming (into Node N) travel arcs.
Arcs 3 and 4 are activity arcs. Arc 5 is an outgoing travel arc.

The equivalent cell-based representation of arcs is shown on the right.
1_1 and 1_2 are two cells representing arc 1.

Ramadurai and Ukkusuri (2010)

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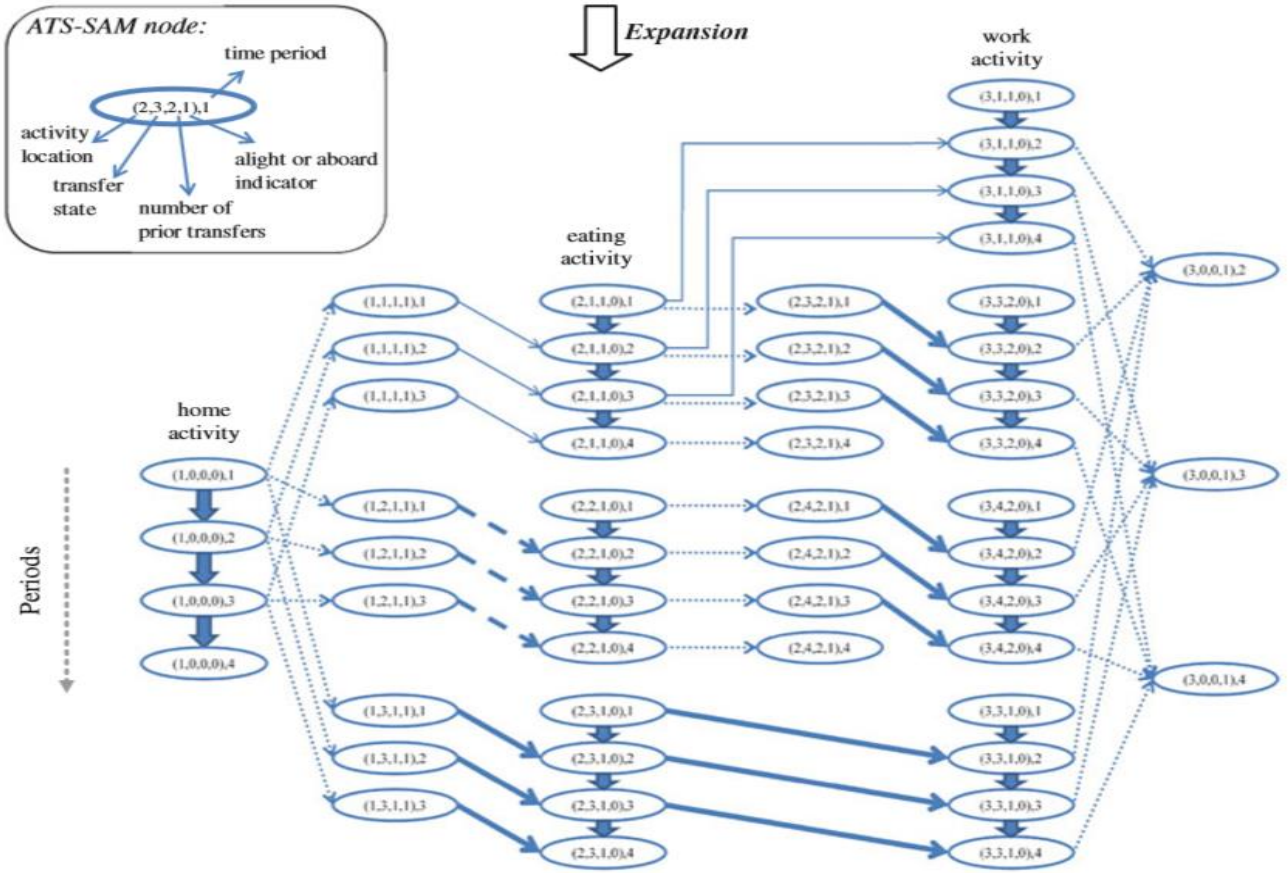
Activity-based supernetworks

- **Multi-modal transit supernetwork**

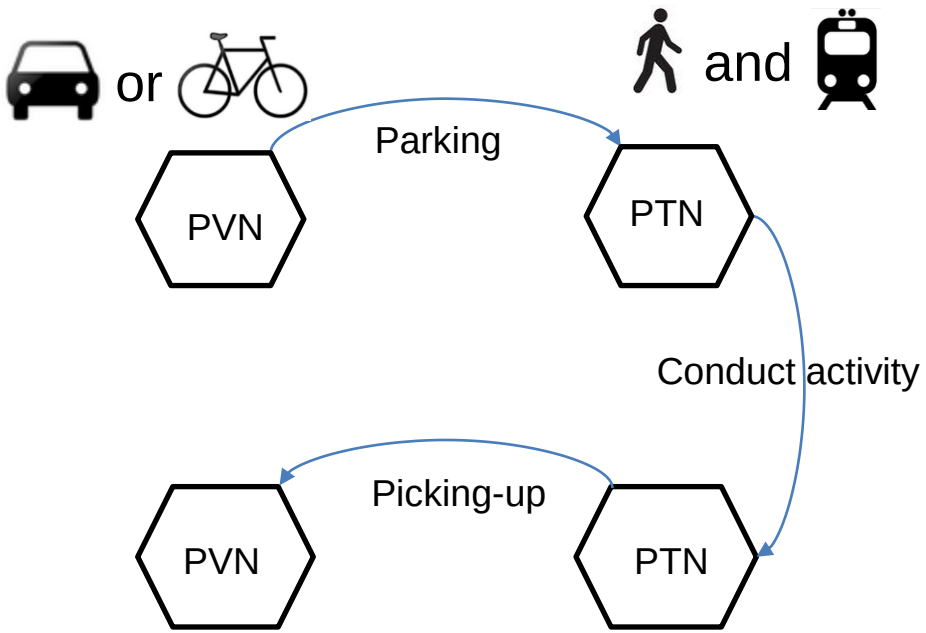


Fu and Lam (2014)

Improvement on multi-state supernetwork

➢ **Ph.D. study** (Supernetwork, 2009-2013)

1. An efficient multi-state supernetwork



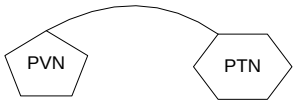
*PVN: private vehicle network
*PTN: public transport network

Split into PVN and PTN

PVN → PTN: park a PV

PTN → PTN: conduct an activity

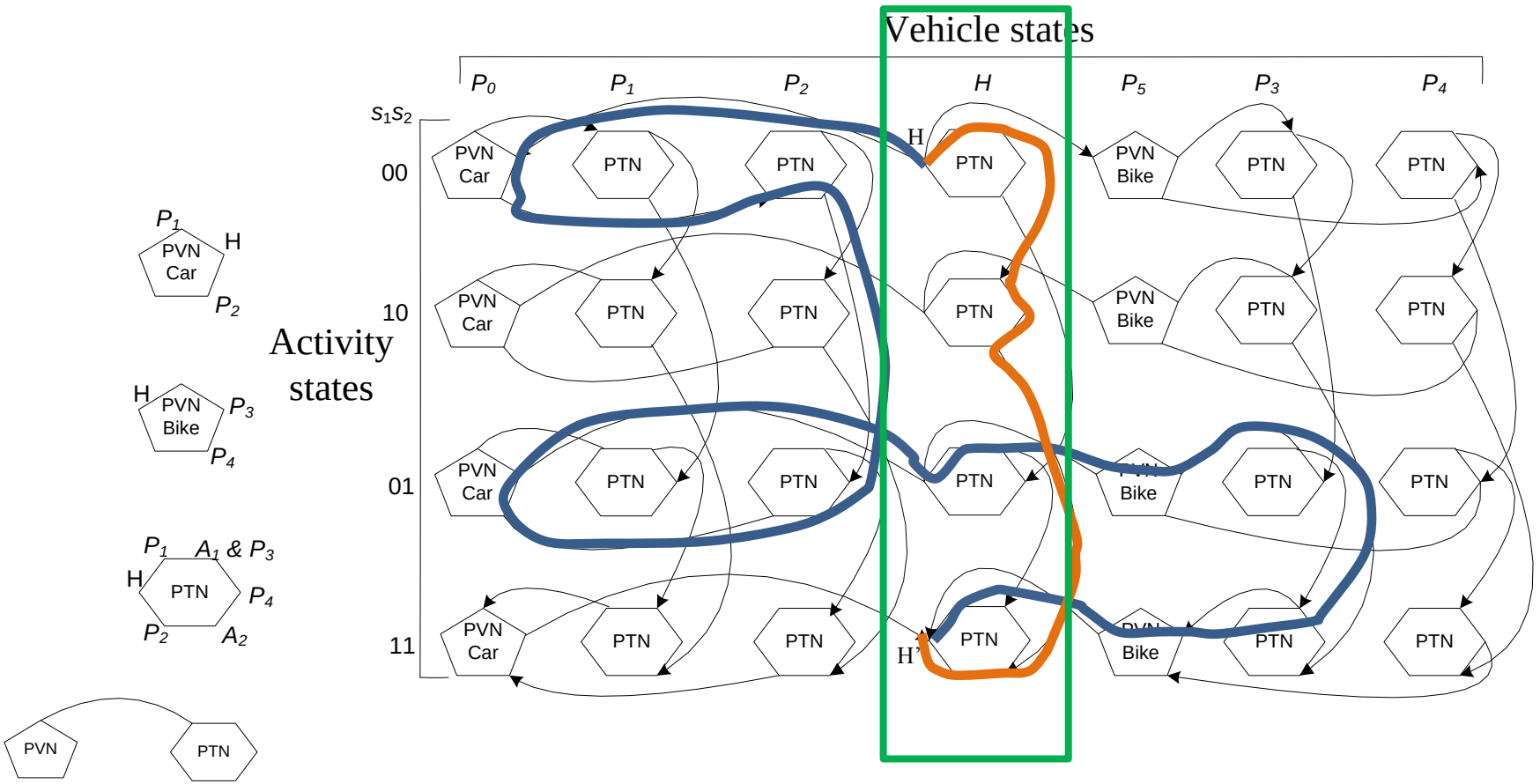
PTN → PVN: pick up a PV



Improvement on multi-state supernetwork

1. An efficient multi-state supernetwork (cont'd)

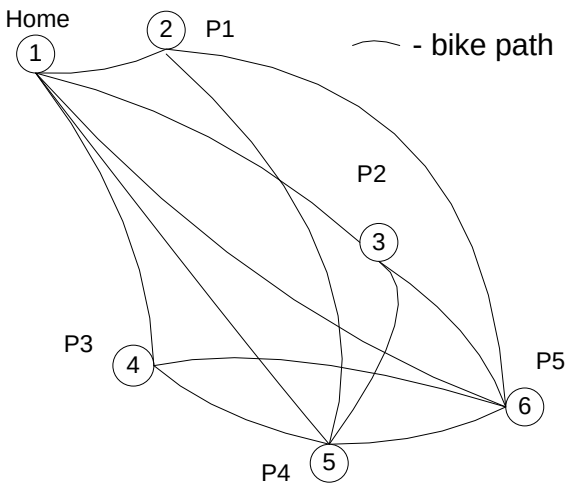
→ multi-modal and multi-activity trip chaining



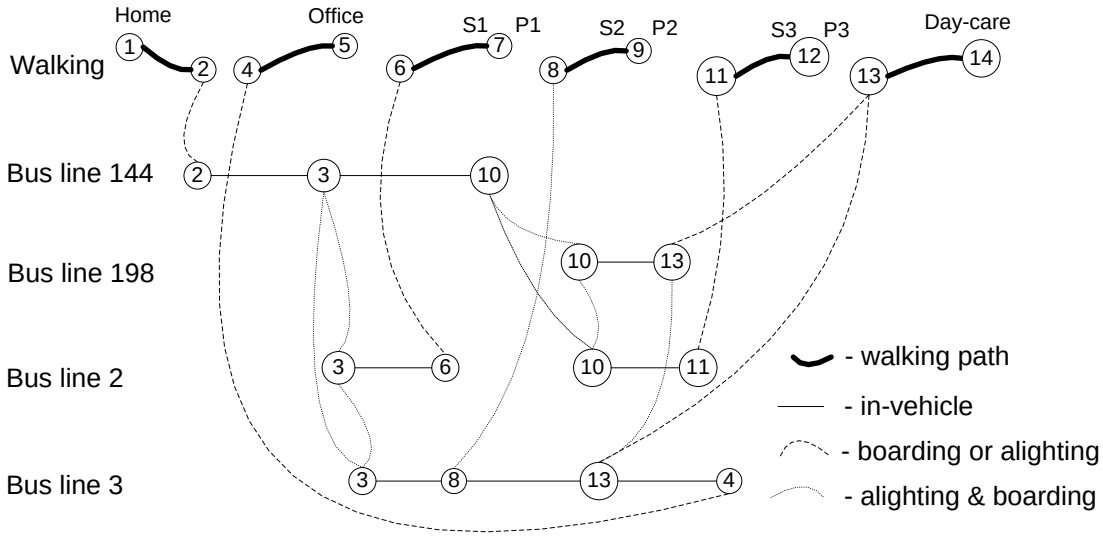
Improvement on multi-state supernetwork

➢ **Ph.D. study** (Supernetwork, 2009-2013)

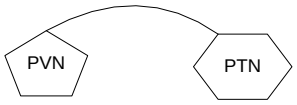
2. Personalized networks from abstract to concrete



(a) PVN for bike

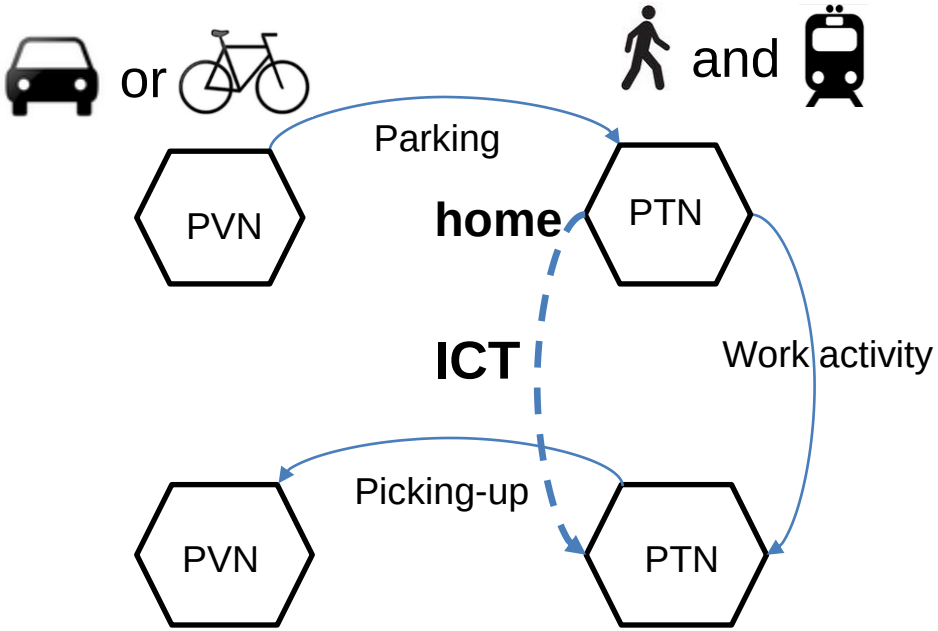


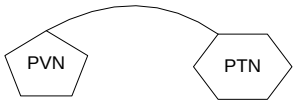
(b) PTN for walking and PT



- **Ph.D. study** (Supernetwork, 2009-2013)

3. From physical to virtual mobility

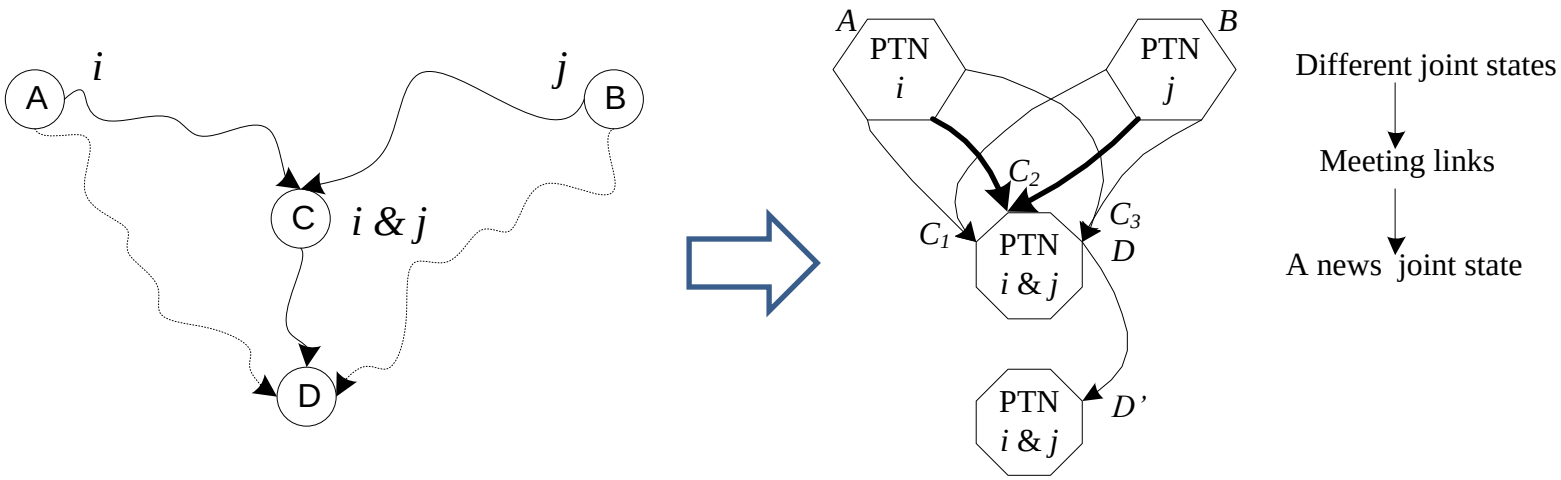


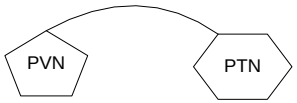


Improvement on multi-state supernetwork

- **Ph.D. study** (Supernetwork, 2009-2013)

4. From one-person to two-person





Improvement on multi-state supernetwork

- **Ph.D. study** (Supernetwork, 2009-2013)

5. From static to dynamic

$$disU_{isml} = \boldsymbol{\beta_{ism}} \times \boldsymbol{X_{isml}} + \epsilon_{isml}$$

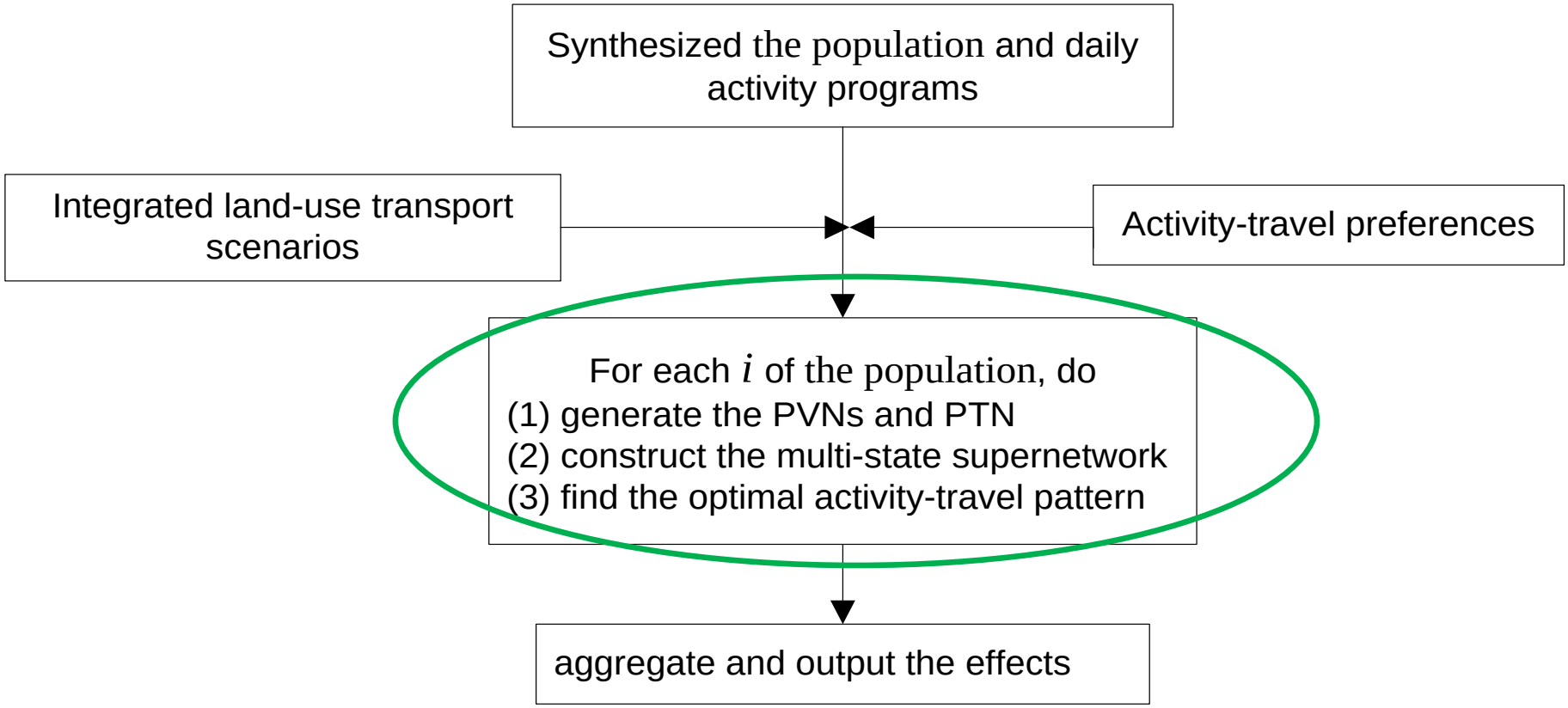
$$\Downarrow$$

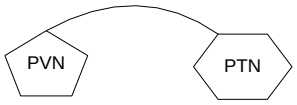
$$disU_{isml}(t) = \boldsymbol{\beta_{ism}} \times \boldsymbol{X_{isml}}(t) + \epsilon_{isml}$$

Computation complexity increases from $O(V \cdot \log V)$ to $O({N_T}^2 \cdot PASS)$, where N_T is the number of time instances.

Application - accessibility

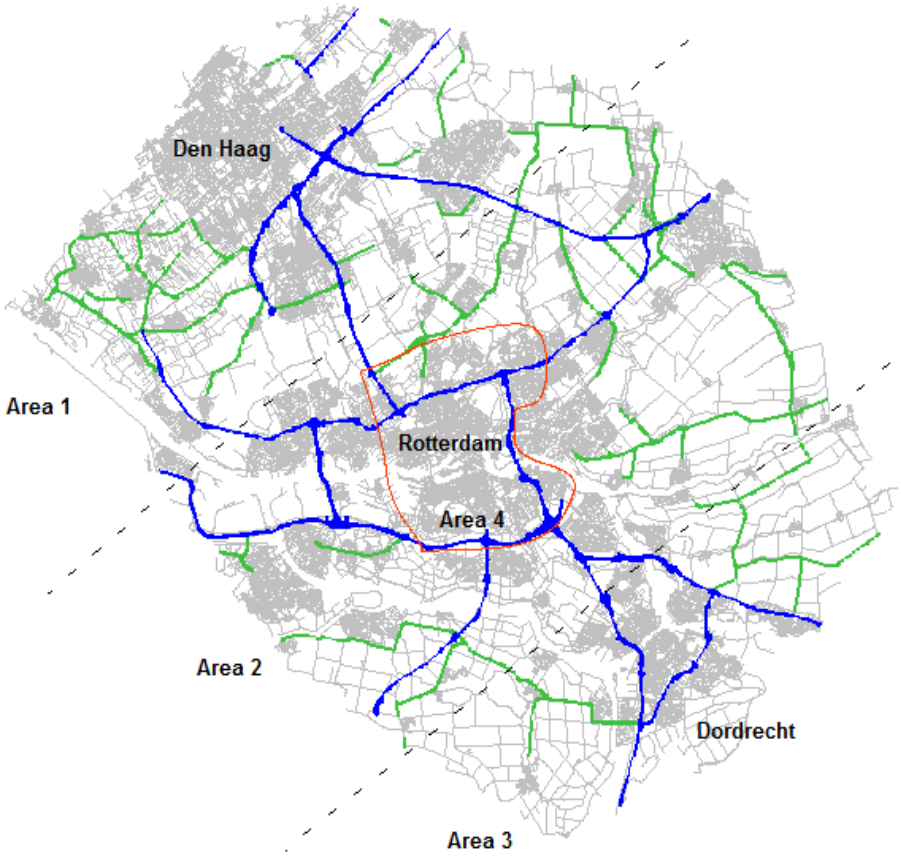
➢ **Ph.D. study** (Supernetwork, 2009-2013)





Application - accessibility

- **Simple population synthesis**
  - Dutch travel diary (2004 to 2008)
  - >=12 years old
  - Around 20, 000 individuals
- **Scenario**
  - Transit improvement
  - Land-use redevelopment
  - 8 scenarios
- **Results**
  - Accessibility change
  - Mode distribution shift
  - Usage of facilities



PVN PTN

About me

- **Post-doc research** (Supernetwork, 2013-2016)
  - Eindhoven University of Technology

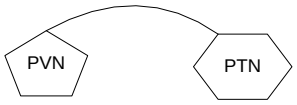
Activity-based modeling + Dynamic traffic assignment

Improvement on multi-state supernetwork

➢ **Post-doc research** (2013-2016)

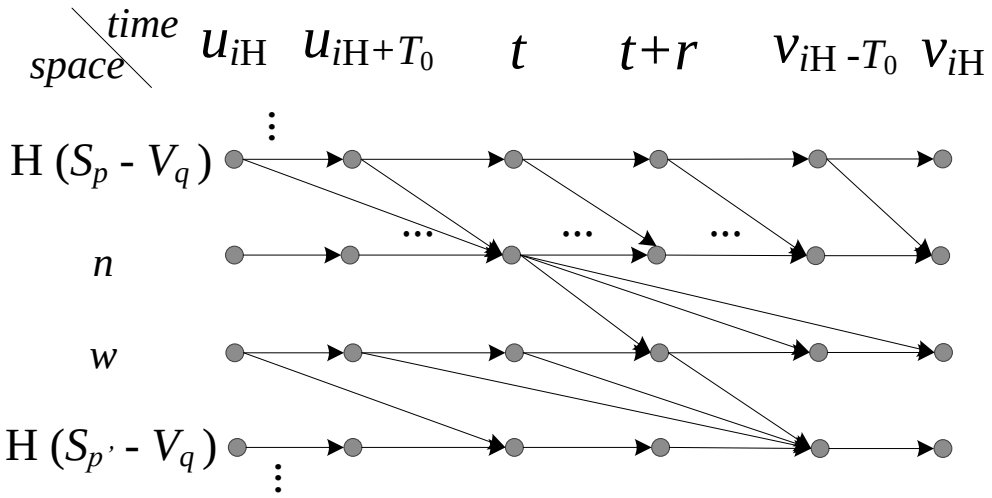
6. From certainty to uncertainty

- The concept of *alpha*-shortest path is adopted for activity-travel scheduling.
- Finding the travel patterns given the confidence level.
- Limitation: no correlation & no time dependency



➢ **Post-doc research** (2013-2016)

7. From time-dependent to space-time representation



Time complexity decreases from $O(N_T{}^2 \cdot PASS)$ to $O(N_T \cdot PASS)$

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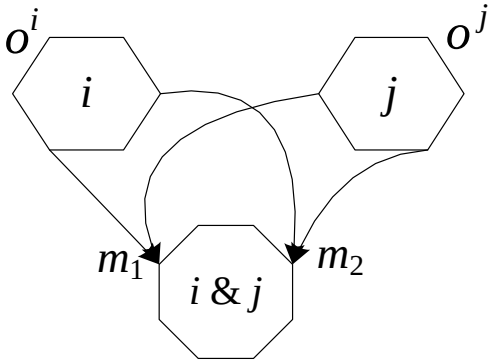
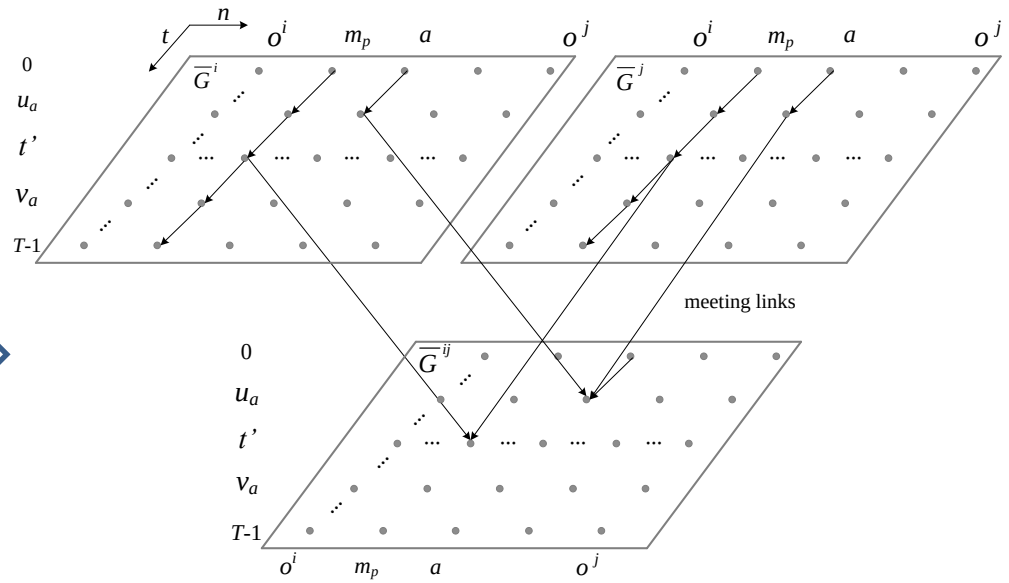
Improvement on multi-state supernetwork

➢ **Post-doc research** (2013-2016)

8. Joint travel in space-time supernetwork





→Time complexity from $O(N_T \cdot |E|)$

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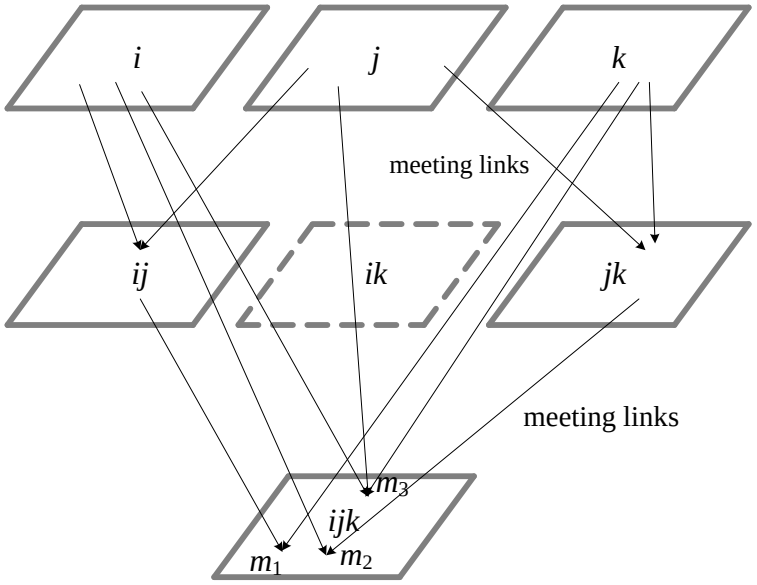
➢ **Post-doc research** (2013-2016)

8. Joint travel (cont'd) of $|I|$ person



→ Steiner Tree Problem of time complexity $O(2^{|I|} * N_T * |E|)$

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➢ **Post-doc research** (2013-2016)

9. From disaggregate to aggregate

- User equilibrium in a deterministic transport system
- User equilibrium incorporating location capacity

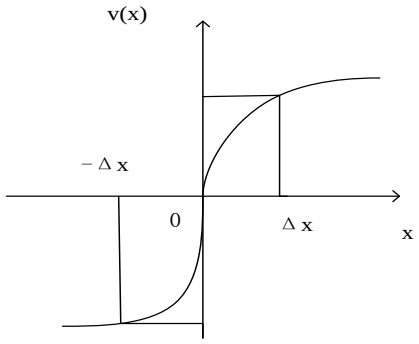
$$disU_p^{hi*}(k)\begin{cases} = disU_{\min}^{hi}(k) & \text{if } f_p^{hi*}(k) > 0 \\ \geq disU_{\min}^{hi}(k) & \text{if } f_p^{hi*}(k) = 0 \end{cases}, \quad \forall h \in H, i \in I, p \in P_h, k \in K,$$

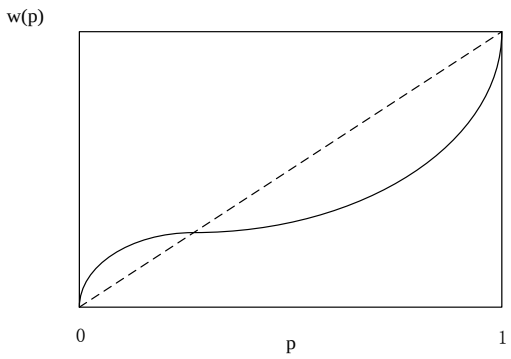
About me

- **Post-doc research** (2013-2016)

10. From utility maximization to reference-dependent utility

  - User equilibrium of loss-averse under certainty
  - User equilibrium under prospect theory under uncertainty





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Improvement on multi-state supernetwork

➢ **Post-doc research** (2013-2016)

11. Starting empirical studies

- Choice experiment with efficient design
- Large-scale data collection (2600 respondents, Beijing)
- Complex model estimations
- 1st round analysis: scaled mixed logit model
- 2nd round analysis: scaled mixed latent class model

$$U_{ani\tau} = \mu_a \left(\beta_{ani0} + \sum_{k=1}^{K} \beta_{aik} \cdot X_{anik\tau} \right) + \sum_{j} \eta_{anij} + \varepsilon_{ani}$$

PVN PTN

Improvement on multi-state supernetwork

- **Post-doc research** (2013-2016)

12. Ongoing topics

  - Incorporating *need* to day-to-day dynamics and equilibria
  - Incorporating carsharing in an activity-based model of UE and SO
  - Household activity scheduling in space-time supernetwork
  - Data collection on uncertainty travel time and ICT effects

About me

- **Assistant professorship** (tenure track, Feb. 2016-)
  - Eindhoven University of Technology

→ to develop Large Scale Model Systems of Urban Transportation Planning

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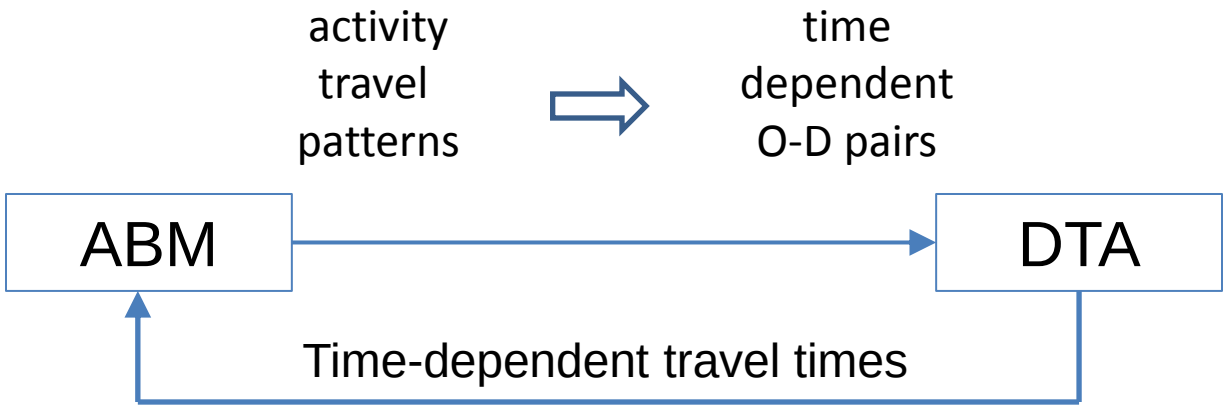
Integration of ABM and DTA

- In travel behavior community



- In network modeling community
  - specific network extensions (*supernetworks*) to model specific (limited) combined choices

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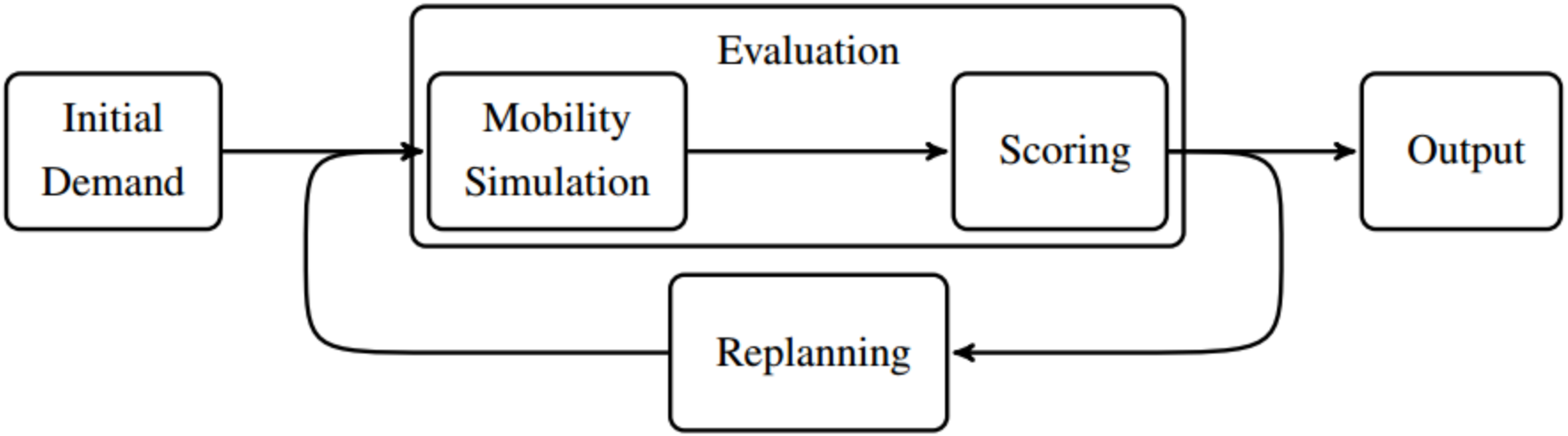
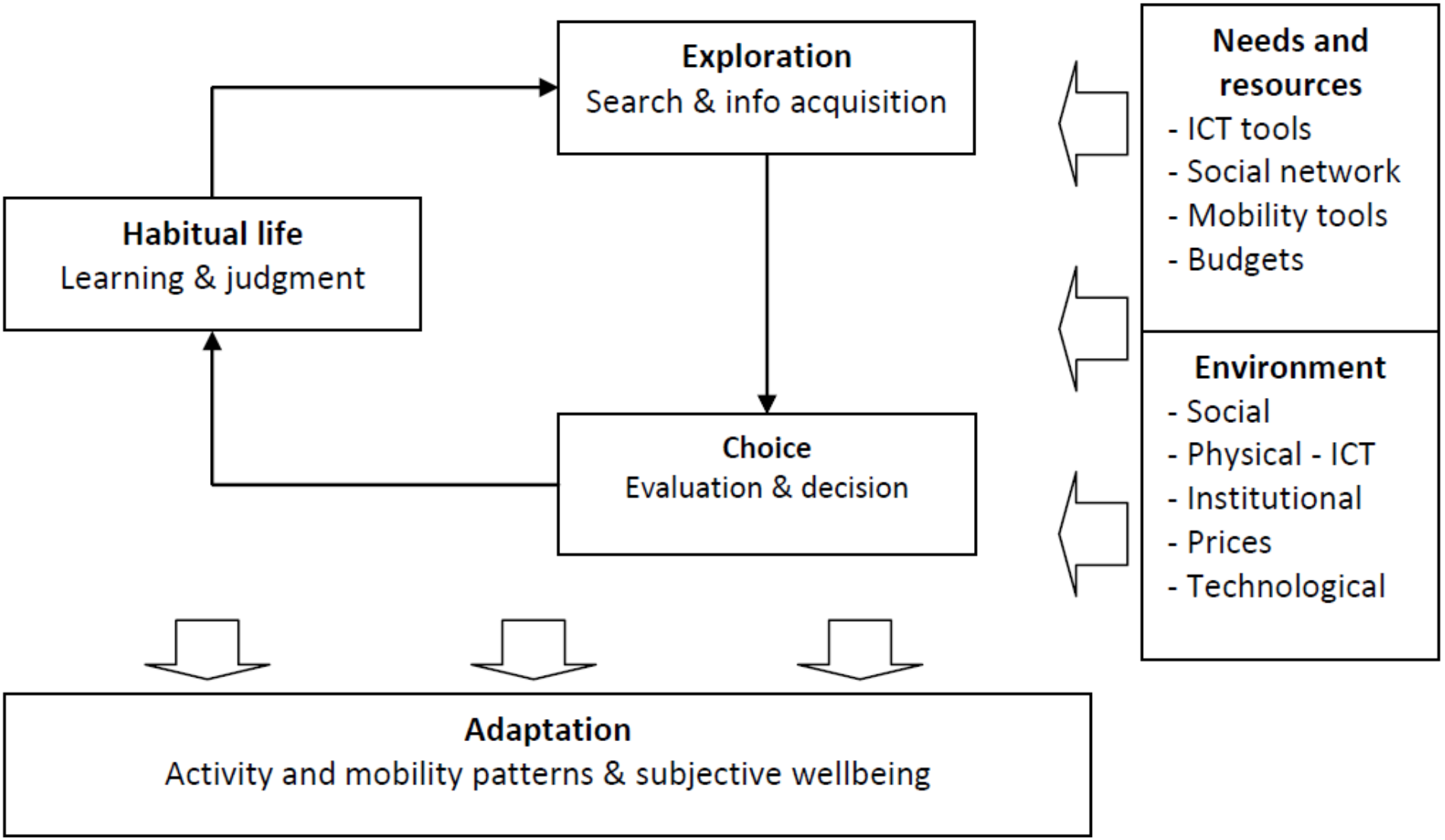
Micro-simulation

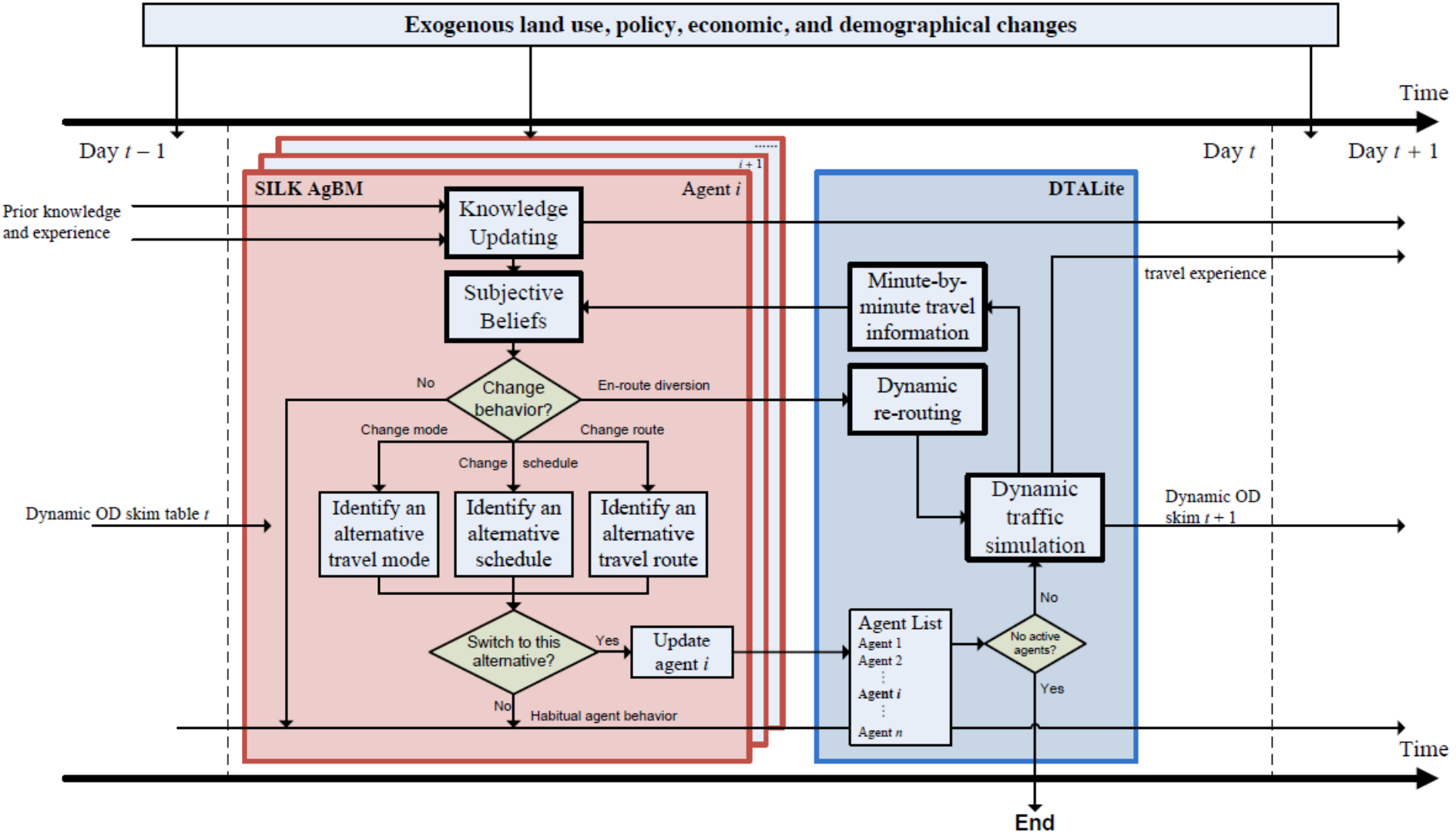
- MATSim framework



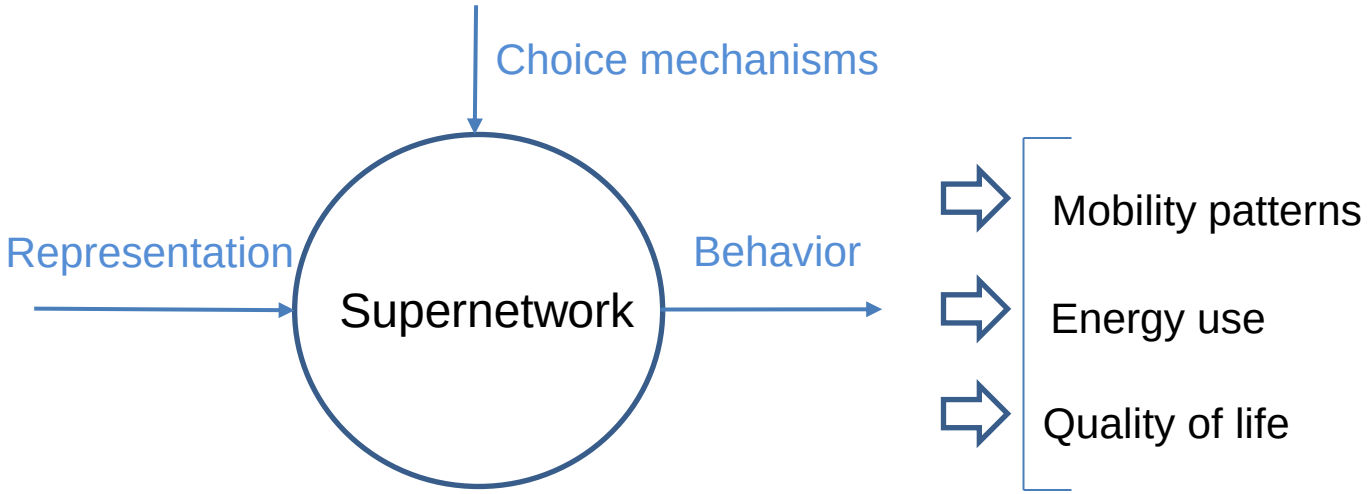
Micro-simulation (Arentze, 2015)

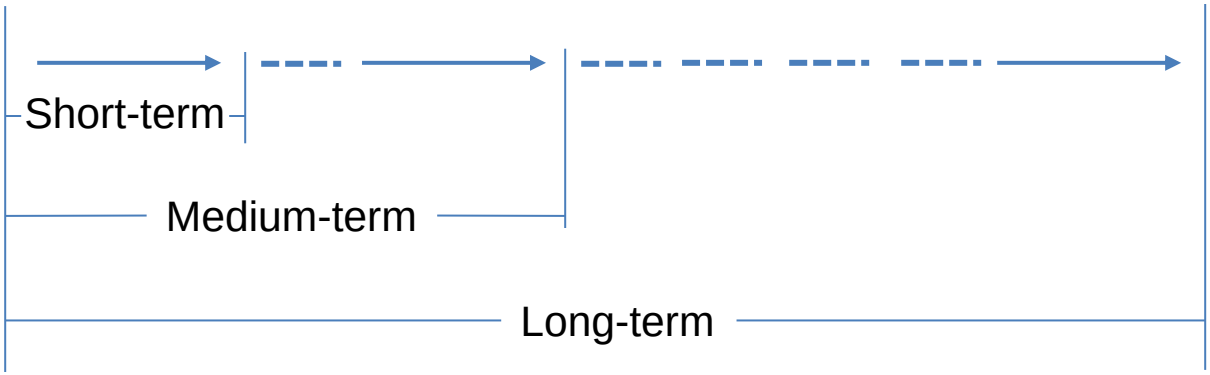


Micro-simulation (Xiong et al., 2016)



Begin with end in mind





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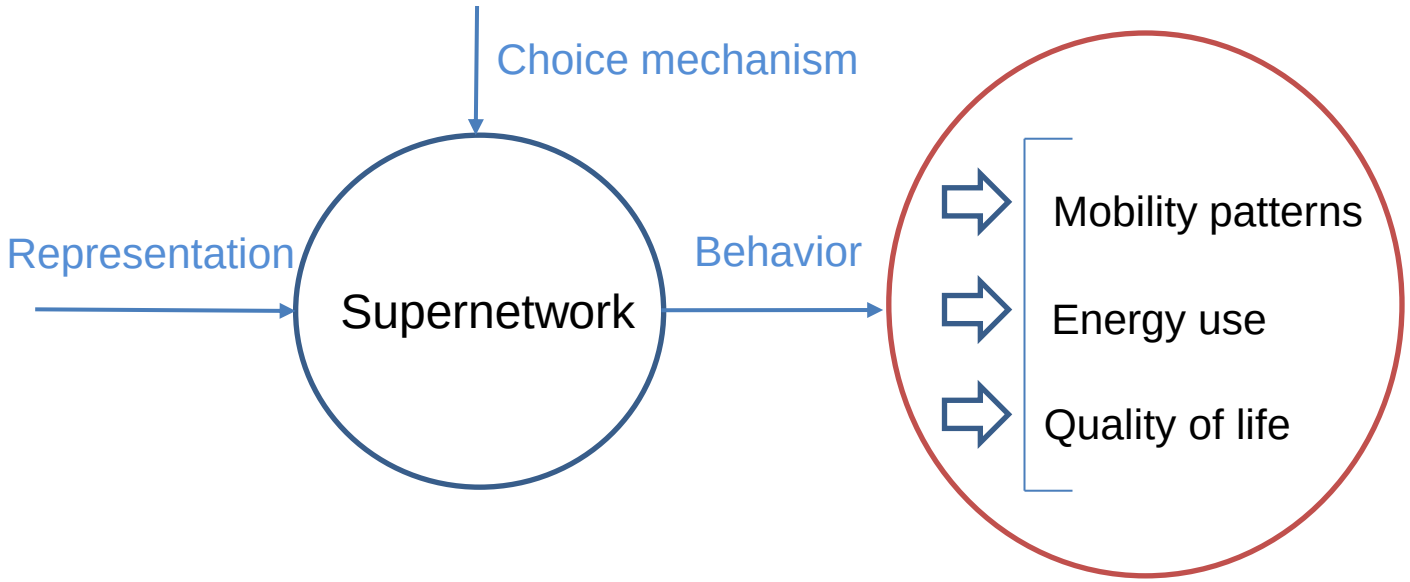
Knowledge utilization



Talk with the user groups and they will come back to you!

PVN PTN

Prospective collaboration

➢ Subjects

- Dynamic population synthesis (life trajectory)
- Joint activity-travel behavior modeling
- Activity-travel scheduling under uncertainty
- Habitual activity generation, scheduling & implementation
- Micro-simulation system

- End -

Thanks for your attention.

Dr. Feixiong Liao