Introduction into challenges and approaches in behavioral freight demand modelling

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Agenda

• 4-step process in passenger transport modelling
• Particularities of freight transport
• 9-step process in freight transport modelling
• Decision-based freight modeling framework

• Freight carrier model integrated with traffic flow simulation
• Case study on food retailers
Standard method for passenger transport planning:

- Trip generation (sources and sinks of traffic)
- Destination choice (connection of sources and sinks)
- Mode choice
- Traffic assignment (route choice considering congestion)
Trip generation
Destination choice
Mode choice
Network assignment
Trip generation
Destination choice
Mode choice
Route choice
Dynamic network loading
## Passenger vs. freight transport

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Passenger transport</th>
<th>Freight transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cause of transport</td>
<td>Time-space shifting between activities, which satisfy human needs</td>
<td>Provisioning &amp; distributing for assuring the companies’ functioning</td>
</tr>
<tr>
<td>Microscopic flow of the moved objects</td>
<td>cycles</td>
<td>not cycles</td>
</tr>
<tr>
<td>Microscopic flow of vehicles</td>
<td>cycles</td>
<td>cycles</td>
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## Passenger vs. freight transport

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<tr>
<td><strong>Actors</strong></td>
<td>Households and persons transport companies</td>
<td>buyers, shippers, carriers and forwarders</td>
</tr>
<tr>
<td><strong>Optimization criteria</strong></td>
<td>Utility of whole-day activity structure</td>
<td>Cost, customer satisfaction</td>
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<td><strong>Communication and co-ordination</strong></td>
<td>Within households</td>
<td>Trade within business networks between different actors</td>
</tr>
<tr>
<td><strong>Archetypes</strong></td>
<td>Typical people (“workers”, “non-workers”, ...)</td>
<td>Large diversity (economic activity, logistics activity, size)</td>
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## Passenger vs. Freight Transport

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<tr>
<td><strong>Time-space structure</strong></td>
<td>Activity scheduling with limited time budget</td>
<td>Time-window structure, vehicle dispatching</td>
</tr>
<tr>
<td><strong>Activity</strong></td>
<td>Time consuming process at a specific location</td>
<td>Actions of forwarding freight, decisions concerning transport and logistics operations</td>
</tr>
</tbody>
</table>
| **Nature of constraints**       | a) Physical limits of human beings  
b) Limited budget   
c) Limited resources (car availability) | a) Properties of the goods,  
b) Legislation (such as limited behind-wheel time)  
c) Coordination institutions (such as time-windows or time-tables)  
d) Limited resources |
| **Routines**                    | Occurrence of patterns (e.g. of a regular working day)        | Relevance of contracts, optimized regular working processes, e.g. a regular tour |
$P_i^g = \beta^g \cdot B_i^g$

- $P$: commodity production [t]
- $B^g$: employees in the sector generating commodity $g$
- $\beta$: generation rate [t/employee]
\[ P_i^g = \frac{\tilde{P}_i^g}{\rho^g} \]

\( \rho \): value density [EUR/t]
\[
\Phi_{ij}^g = P_i^g \frac{C_j \cdot f(c_{ij})}{\sum_k C_k \cdot f(c_{ik})}
\]

C: commodity attraction (consumption)
f: deterrence function
c: generalised Transport cost
$$\Phi_{ij}^{gm} = \Phi_{ij}^{g} \frac{\exp(-\mu^g \cdot c_{ij}^{gm})}{\sum_{n} \exp(-\mu^g \cdot c_{ij}^{gn})}$$

m/n: modes
μ: homogeneity parameter
c: generalised transport cost
Value-weight-transformation

\[
\Phi_{ij}^{gl} = a_l \Phi_{ij}^g \quad a_i: \text{share of lot size } l \quad a_1 + a_2 + \ldots = 1
\]

\[
\Phi_{ij}^{glm} = \Phi_{ij}^{gl} \frac{\exp\left(-\mu^{gl} \cdot c_{ij}^{gm}\right)}{\sum_{n} \exp\left(-\mu^{gl} \cdot c_{ij}^{gn}\right)}
\]

Generation

Value-weight-transformation

Distribution

Lot size

Mode split

Assignment

<table>
<thead>
<tr>
<th>Lot size</th>
<th>0-2 t</th>
<th>2-5 t</th>
<th>5-15 t</th>
<th>.....</th>
</tr>
</thead>
</table>

Least-cost path search

- Generation
- Value-weight-transformation
- Distribution
- Lot size
- Mode split
- Assignment
Trip construction

Value-weight-transformation

Distribution

Lot size distribution

Mode split

Trip construction

Assignment

Empty runs, loading rate
Recapitulation: 4-Step process in freight transport

- Similar to passenger transport
- Robust methods
- Additional computation steps:
  - values → weight
  - weight → shipments
  - shipments → trips
Distribution on logistics and transport chains represent additional steps
Additional transformation steps

- values to weight
- weight to shipments
- shipments to vehicles

Distribution of flows on logistics and/or transport chains

Difficulties

- Several types of decision makers
- Mismatch between decisions and process-steps
- Logistics network shortest path search = logistics decision?
Sources for the following part

Schröder, S. & Liedtke, G.
Modeling and analyzing the effects of differentiated urban freight measures -- a case study of the food retailing industry
*Transportation Research Board, 2014*

Schröder, S.; Zilske, M.; Liedtke, G. & Nagel, K.
A computational framework for a multi-agent simulation of freight transport activities
*Transportation Research Board, 2011*
From aggregate multi-step modelling to behavior-modelling

- Generation
- Weight-value transf.
- Regional distribution
- Distr. Log. chains
- Distr. Lot size
- Distrib. Transp. chains
- Mode split
- Trip construction

- Economic Activity
  - Internal coordination
- Purchase and Sale
  - Internal coordination
- Logistics Planning
  - Market-based coordination
- Transport Network Planning
  - Market-based coordination
- Vehicle Tour Construction
  - Internal coordination
- Route Choice
From aggregate multi-step modelling to behavior-modelling

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Economic Activity
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Vehicle Tour Construction
  - Internal coordination
Route Choice

Dynamic network loading
Freight activity simulation
Decision problems and complexity

Logistics network planning / Shortest path search in logistics network graph
Lot-size choice
Mode choice
Transport network planning / Shortest path search in transport network graph
Vehicle routing
Route search

- hard problems, heuristic approximation necessary in all practical cases
- for each shipment: shortest path search in a network of up to about $10^6$ edges
- low constant computation time per O/D-pair or shipment
Effects of policy decisions on urban freight traffic

Introduce timed congestion toll for heavy vehicles from 7am to 7 pm.

What would happen?

• carriers avoid toll time
• carriers avoid toll area
• carriers avoid heavy vehicles
• shippers change shipping policy
• long-term effects on urban development
Carrier agents decide on:
- Vehicle fleet (by type)
- Allocation of customers to depots
- Tour planning
- Departure times
- Routes through the road network

To minimize total cost:

$$\min\left[C_{\text{Fixed}} + C_{\text{Variable}}\right]$$
Implementation

Vehicle Routing

- Ruin-and-Recreate principle (Schrimpf et al., 2000)
  - Take a feasible solution
  - Remove some activities
  - Sequentially reinsert them «at cheapest point». Assignment of fixed-cost evolves over insertions. (Dell’Amico et al, 2007)
- Implemented in Java, reusable! (https://github.com/jsprit/jsprit)

Schrimpf et al. (2000)
Initial plan → Execution → Scoring → Analysis

- Replanning
  - Vehicle tour construction
  - Route choice
Initial plan → Execution → Scoring → Replanning

Vehicle tour construction
Route choice

Mode choice
Activity time choice
Route choice

freight

passengers
Policy scenarios

For heavy vehicles within the policy area:

1. **Cordon toll** (20€ per day per vehicle)
2. **Distance toll** (1€ per km)
3. **Prohibition**
4. **Night-time prohibition** (22h-7h).
Policy scenarios

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4. **Night-time prohibition** (22h-7h).
Results

Cordon toll
Reduced access to toll zone
Slight increase in total mileage

Distance toll
Further reduced mileage in toll zone
Results

Prohibition
Increase in total mileage

Night-time prohibition
Serve outer locations first
Shift to light vehicles
Results

Behavioral simulation is policy-sensitive in a plausible way: The taxed behavior is suppressed.

Policy in environmental zone has plausible side-effects outside the environmental zone.

Behavioral reaction which prompts extension of the model: Carriers want to move their hubs.
Limitations of results

Tours are on average too short and too fast compared to experience. How to calibrate?
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Tours are on average too short and too fast compared to experience. How to calibrate?
Summary & Conclusion

Behavioral freight model + traffic microsimulation: Plausible reactions in several choice dimensions to fine-grained urban policy measures

Freight operations model hard to calibrate: Need realistic tour planning

Next steps: (Realistic) transport market
Next after that: (Realistic) logistics network planning

This is open-source, you can download it, and it is runnable (bring your own data (shipments, depot positions))

www.matsim.org