An empirical agent-based model for urban road freight transport

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Urban freight modeling

Urban freight transport has many externalities:
- Environmental impacts (CO2, Nox, PM10)
- Social impacts (Noise, Safety)
- Economic impacts (Travel time losses)

Many relevant developments for freight transport demand:
- Last-mile distribution
- Environmental zoning
- Road user charges for heavy vehicles
- Growth of e-commerce

However, there are hardly any analytical tools available for the impact assessment of policies on freight transport demand!
Evolution of strategic freight models

- Strategic freight models are (slowly) evolving in the direction of microscopic (agent based) models

<table>
<thead>
<tr>
<th>Aggregate</th>
<th>Disaggregate</th>
<th>Microsimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basgoed TransTools and many more...</td>
<td>ADA SVRM4 Trimode SMILE+ ...</td>
<td>FAME (US) FREMIS (US) INTERLOG (D) TAPAS (S) ...</td>
</tr>
</tbody>
</table>

- Practical
- Regional
- Much applied
- State-of-practice
- Operational
- Zonal
- Logistic choice
- State-of-art
- Academic (no policy application)
- At firm level
- Logistic behavior
Logistic Choices and Agents

**Commodity Market**
- Producers
- Receiving / consumers

**Logistic services market**
- Network design
- Location selection DC's
- Warehousing and storage
- Packaging/shipment size

**Transport market**
- Carrier selection
- Mode selection
- Vehicle type choice
- Routing and scheduling

**Infrastructure (Market): Network and performance**
- Pricing measures
- Infrastructure investment
- Subsidies
- Environmental zones
- Zoning schemes

**Issues:**
- DATA and modeling
- COMPLEXITY

Choices in a supply chain are interrelated.
Objective of MASS-GT

The MASS-GT research project aims at developing a more comprehensive behavioral agent-based microsimulation framework for strategic freight transport demand.

Two main challenges:
1. **Data:** to analyse logistic decision making, and develop the simulation framework. For this purpose we use high density freight transport data.
2. **Manage complexity** during model development. For this purpose we follow an incremental development process.
XML data CBS

- opgaveId (Truck)
  - License plate
  - Year & week
  - In BasGoed sample [yes/no]
  - Transporting company
    - Ownership type
      - Owned, hired, leased, or not owned anymore
  - Fuel consumption [L per 100 km]
  - Home base
    - Country
    - ZIP
    - Town
    - Lat/Lon
  - Carrying capacity [kg]
  - Vehicle type

- ritId (Tour)
  - Serial tour number
    - Describes order of tours for a truck
  - Distance [km]
    - From origin to destination of tour
  - Date & time
    - Start
    - End
  - Origin & destination
    - Country
    - ZIP
    - Town
    - Lat/Lon
  - Operator type
    - Hired carrier or own-account
  - Capacity utilization
    - % m²
    - % m³
  - Border crossing
    - Country
    - Lat/Lon

- zendingId (Shipment)
  - Serial shipment number
    - Describes order of shipments for a tour
  - Distance [km]
    - From loading to unloading point
  - Gross weight [kg]
  - Shape
    - Fluid, solid bulk, sea containers, other containers, pallets, hanging goods, goods in ropes, mobile units with own power, or other mobile units.
  - Loading and unloading location
    - Country
    - ZIP
    - Town
    - Lat/Lon
  - Loading and unloading location type
    - Production, consumption/processing, retail, seaport, inner port, rail terminal, airport, distribution/wholesale, or home base.
  - Goods type
    - Description
    - NSTR
    - NST2007
    - Hazardous [yes/no]
  - Invoice value [€]
  - Volume [L or m³]

- Automated collection from TMS
- +2M individual trips in raw data
- Load/unload locations: Lat/long
- Privacy regulations
Data: illustration
Strict separation between data analysis and model application:

CBS Remote Access

(Discrete) choice analyses
Descriptive statistics

XML data
Business register
Travel times / distance

MASS-GT

Firm synthesis
Shipment synthesis
Tour-formation
Distribution centres
Incremental development process (minimum viable product principle)

[Diagram showing progress from car to skateboard]

- This contribution presents our first Skateboard
Objective:
- Simulate urban freight transport patterns.

Main spec’s:
- **Data-driven** approach
- **Monte Carlo simulation** (MCS) is used to determine shipment or tour characteristics

Prototype consists of two modules:
- **Shipment** synthesizer
- **Tour formation** model.

MASS-GT: structure of first prototype
Shipment Synthesizer
• Determine shipment size:

Probability density function for shipment size by commodity type:

<table>
<thead>
<tr>
<th>NST/R</th>
<th>Shipment size</th>
<th>Average</th>
<th>StdDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Agricultural products and live animals</td>
<td>15.3</td>
<td>9.5</td>
</tr>
<tr>
<td>1</td>
<td>Foodstuffs and animal fodder</td>
<td>13.7</td>
<td>9.9</td>
</tr>
<tr>
<td>2</td>
<td>Solid mineral fuels</td>
<td>25.6</td>
<td>4.2</td>
</tr>
<tr>
<td>3</td>
<td>Petroleum products</td>
<td>25.4</td>
<td>11.5</td>
</tr>
<tr>
<td>4</td>
<td>Ores and metal waste</td>
<td>16.8</td>
<td>7.9</td>
</tr>
<tr>
<td>5</td>
<td>Metal products</td>
<td>14.8</td>
<td>10.1</td>
</tr>
<tr>
<td>6</td>
<td>Crude and manufactured minerals, building materials</td>
<td>22.2</td>
<td>9.9</td>
</tr>
<tr>
<td>7</td>
<td>Fertilizers</td>
<td>16.7</td>
<td>11.4</td>
</tr>
<tr>
<td>8</td>
<td>Chemicals</td>
<td>15.8</td>
<td>10.3</td>
</tr>
<tr>
<td>9</td>
<td>Machinery, transport equipment, manufactured articles and miscellaneous articles</td>
<td>7.7</td>
<td>8.0</td>
</tr>
</tbody>
</table>
Allocation of shipments to firms
Allocation of shipments to firms:
- By commodity and make/use tables
  [Source: EM-Basgoed]

Producers: ‘make’ probability by sector:

<table>
<thead>
<tr>
<th>Make sector</th>
<th>NST/R</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Agriculture</td>
<td>0.91  0.10 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>2 Manufacturing</td>
<td>0.06  0.00 1.00 1.00 0.18 0.95 1.00 1.00 0.94 1.00</td>
</tr>
<tr>
<td>3 Construction</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>4 Trade and Retail</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>5 Restaurants and Food services</td>
<td>0.02 0.90 0.00 0.00 0.00 0.00 0.00 0.00 0.05 0.00</td>
</tr>
<tr>
<td>6 Transport, Warehousing and Communication</td>
<td>0.00 0.00 0.00 0.00 0.82 0.05 0.00 0.00 0.01 0.00</td>
</tr>
<tr>
<td>7 Finance</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>8 Business services</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>9 Government</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>10 Education</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>11 Health Services</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>12 General Services</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
</tbody>
</table>

Consumers: ‘use’ probability by sector:

<table>
<thead>
<tr>
<th>Use sector:</th>
<th>NST/R</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Agriculture</td>
<td>0.13  0.11 0.01 0.04 0.00 0.00 0.01 0.62 0.04 0.01</td>
</tr>
<tr>
<td>2 Manufacturing</td>
<td>0.15  0.02 0.97 0.73 1.00 0.85 0.23 0.34 0.79 0.53</td>
</tr>
<tr>
<td>3 Construction</td>
<td>0.03  0.00 0.02 0.03 0.00 0.12 0.67 0.00 0.05 0.12</td>
</tr>
<tr>
<td>4 Trade and Retail</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>5 Restaurants and Food services</td>
<td>0.64 0.70 0.00 0.02 0.00 0.01 0.01 0.00 0.03 0.05</td>
</tr>
<tr>
<td>6 Transport, Warehousing and Communication</td>
<td>0.01 0.01 0.00 0.11 0.00 0.01 0.02 0.02 0.01 0.15</td>
</tr>
<tr>
<td>7 Finance</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.01</td>
</tr>
<tr>
<td>8 Business services</td>
<td>0.03  0.14 0.00 0.04 0.00 0.00 0.04 0.01 0.03 0.07</td>
</tr>
<tr>
<td>9 Government</td>
<td>0.00  0.00 0.00 0.02 0.00 0.01 0.01 0.01 0.01 0.04</td>
</tr>
<tr>
<td>10 Education</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
<tr>
<td>11 Health Services</td>
<td>0.01  0.02 0.00 0.01 0.00 0.00 0.00 0.00 0.05 0.02</td>
</tr>
<tr>
<td>12 General Services</td>
<td>0.00  0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00</td>
</tr>
</tbody>
</table>
Tour formation model
Tour formation: input statistics

- Determination of vehicle type: Probability density function

<table>
<thead>
<tr>
<th>NST/R</th>
<th>2: Lorry</th>
<th>3: Trailer truck</th>
<th>4: Special Vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.200</td>
<td>0.800</td>
<td>0.000</td>
</tr>
<tr>
<td>1</td>
<td>0.096</td>
<td>0.902</td>
<td>0.002</td>
</tr>
<tr>
<td>2</td>
<td>0.100</td>
<td>0.896</td>
<td>0.003</td>
</tr>
<tr>
<td>3</td>
<td>0.394</td>
<td>0.603</td>
<td>0.003</td>
</tr>
<tr>
<td>4</td>
<td>0.609</td>
<td>0.383</td>
<td>0.007</td>
</tr>
<tr>
<td>5</td>
<td>0.190</td>
<td>0.809</td>
<td>0.000</td>
</tr>
<tr>
<td>6</td>
<td>0.459</td>
<td>0.538</td>
<td>0.003</td>
</tr>
<tr>
<td>7</td>
<td>0.195</td>
<td>0.770</td>
<td>0.035</td>
</tr>
<tr>
<td>8</td>
<td>0.362</td>
<td>0.574</td>
<td>0.064</td>
</tr>
<tr>
<td>9</td>
<td>0.185</td>
<td>0.781</td>
<td>0.034</td>
</tr>
</tbody>
</table>
Tour formation: input statistics

- ‘Stop’ probability:
  Conditional probability function additional shipment: \( P(n+1|n) \)

<table>
<thead>
<tr>
<th>NST/R 0: Agricultural products</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Round</th>
</tr>
</thead>
<tbody>
<tr>
<td>NST/R 1: Foodstuffs</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>2: Lorry</td>
<td>0.435</td>
<td>0.821</td>
<td>0.854</td>
<td>0.854</td>
<td>0.030</td>
</tr>
<tr>
<td>3: Trailer truck</td>
<td>0.448</td>
<td>0.810</td>
<td>0.820</td>
<td>0.826</td>
<td>0.009</td>
</tr>
<tr>
<td>4: Special Vehicles</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>NST/R 2: Solid mineral fuels</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>2: Lorry</td>
<td>0.832</td>
<td>0.941</td>
<td>0.923</td>
<td>0.916</td>
<td>0.003</td>
</tr>
<tr>
<td>3: Trailer truck</td>
<td>0.640</td>
<td>0.800</td>
<td>0.800</td>
<td>0.817</td>
<td>0.017</td>
</tr>
<tr>
<td>4: Special Vehicles</td>
<td>0.941</td>
<td>0.969</td>
<td>0.845</td>
<td>0.942</td>
<td>0.019</td>
</tr>
<tr>
<td>NST/R 3: Other goods</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>2: Lorry</td>
<td>0.251</td>
<td>1.000</td>
<td>1.000</td>
<td>0.450</td>
<td>0.000</td>
</tr>
<tr>
<td>3: Trailer truck</td>
<td>0.033</td>
<td>1.000</td>
<td>1.000</td>
<td>0.756</td>
<td>0.000</td>
</tr>
<tr>
<td>4: Special Vehicles</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Tour formation process:

1. Start
2. Select additional shipment
3. Stop time
4. Update tourschedule
5. Nship = MAX? Y or N
   - Y: Add shipment to tour?
   - N: More shipments in data?
   - N: End
   - Y: Export tour
      - More shipments in data?
      - N: End
      - Y: More shipments in data?
4. Start tour/select shipment
5. Vehicle type choice
6. Start time tour
7. Add shipment to tour?
   - Y: Conditional prob function extra shipment
   - N: Export tour
8. Tours
   - More shipments in data?
   - N: End
   - Y: More shipments in data?
9. …
First results
Highlighted example tour: delivering 3 shipments of NST/R 8 with a Lorry (veh.type 2)
First results

• Synthetic truck patterns for all freight transport to and from Rotterdam
• Results: 8343 tours, delivering 13892 shipments
By vehicle type:
By tour types:
Possible applications

• **Synthetic truck patterns** can be used as a quantitative ‘screenshot’ to explore emerging trends. For instance to quantify:
  - vehicle type specific indicators (safety, emissions)
  - which truck tours will be affected by environmental zoning
  - the potential for last-mile solutions, e.g. pick-up points
  - possible impact of logistic hub’s for urban construction works

• **Agent based model** can be used to analyse *behavioural response* to new technologies and logistic trends. For instance to simulate impact of:
  - strategies for road user charges: vehicle types
  - environmental zoning: vehicle type
  - changes in logistic infrastructure: distribution patterns
  - new technologies (IoT): possibilities for horizontal collaboration
  - new vehicle technologies
Truck patterns for building materials (NST/R 6)
Conclusions & further research
Conclusions and discussion

- Hardly any analytical tools exists that can support evidence based decision making for freight transport demand.
- Emerging sources of ‘big data’ allow the development of such analytical tools.
- This first prototype simulating synthetic truck trip patterns can be seen as a proof-of-concept. It demonstrates:
  1. simple simulation frameworks can be built
  2. the microscopic results allow intuitive analyses (face-validity)
- For better impact assessment, agent based choice models are a promising methodology; it addresses agents and logistic decision making explicitly.
Further research

Analytical phase:
• Data analysis on XML data **CBS:** Enrich data by linking XML coordinates to other GIS layers, e.g. Land use, Logistic nodes and the Business register (ABR).
• Develop **Vehicle & shipment size choice** model
• Develop **Tourformation** model

MASS-GT version 2.0:
• Extend dimensions:
  • Study area, include logistic nodes, own account/hired account
• Implement **logistic choice models**
  • vehicle type and shipment size choice
  • tourformation
• Develop interface with **Network Model**
Questions

Further info see workshop paper:


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