An agent-based methodological approach for modeling travelers’ behavior on modal shift: The case of inland transport in Denmark

ABMoS-DK

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The Danish government has engaged in the ambitious goal of becoming independent of fossil fuels by 2050.

**Motivation for Agent-Based?**

- **Behavioral Changes (Modal shift)**
  - Capable of simulating behavioral aspect
  - Can not capture total system cost

- **Technological Changes**
  - Technology rich optimization model
  - Calculate cumulative emissions

- **Decarbonization of inland transport**

**Agent Based**
Dimensions of modes for modal shift
Overview of the model

- Travelers are regarded as group of agents.

- The Danish National Travel Survey (TU), is an interview survey that documented the travel behavior of the Danish population, is used to capture the characteristics of travelers.

- Agents don’t have interaction with each other. In TU Survey, there is no data about how people make decision. However, there are the historical data that how people accomplished the trip.

- Make decision according to mode choice algorithm.

- AnyLogic tool based on JAVA programming.
Data gathering and model structure

The annual demand is taken from Danish national transport model (LTM) which is a newly developed four-stage simulation transport model of Denmark.

Data from LTM

- Value of Time (VoT)
- Average Speed
- Congestion time
- Penalty parameters
- Aggregated demand

Data from TU Survey

- Income Category
- Car ownership
- Residential area DKE/DKW
- Urbanization type (U/R/S)
- Travel Time
- Travel Distance
- Trip purpose (business/not-business)

Assign the attributes of agents

Calculate total cost of modes

Assign the attributes of agents

Mode choice algorithm

Agent Based Model

The annual demand is taken from Danish national transport model (LTM) which is a newly developed four-stage simulation transport model of Denmark.
Assign the attributes of TU responders to Agents

Session weight is determined in TU so that the surveyed population reproduces the real Danish population.

This weighting factor represents the number of people in each group of our agents.
Geographical zones

- Denmark
  - DK-East
    - Urban
    - Suburban
    - Rural
  - DK-West
    - Urban
    - Suburban
    - Rural
Methodological framework

- The aggregation of demand in each urbanization area matches the LTM demand

\[ L_{UT}^{Trip} \times W_{Factor} \times N_{Days} \geq D_{UT}^i \] (1)

- Population synthesis matches demographic data

\[ \sum_{year} W_{Factor} \approx P^i \] (2)

TU Survey Database

Start

Year < 2016

Yes

Mode choice algorithm

Export the results

No

Generate random agents (Monte Carlo)

Year i++

Yes

No

End

No

Compute total cost for each mode & select the cheapest

Car owner?

Yes

Has Driver's License

Yes

Accompanying the trip?

Yes

Member of car sharing scheme

Yes

Check availability of infrastructure for NMT and public

Agent j++

No

Change the year to i

Eqs (1 & 2) are satisfied?

Generate a random number N [0, the last index of database)

Take the attributes of Nth agent in database

Generate agent j

Follow mode choice algorithm
Decision Rules:

1. The driver should have driving license and access to car.
2. The passenger of private car does not required to have a driving license.
3. The agent might not own a car but rent a car.
4. The speed of private cars in urban areas during rush hours decrease by 30% and the congestion time of private cars increase by 30%.
5. The alternative mode should be available in the area
6. If the agent does not have a bicycle, he/she cannot choose bike.
7. If the bike is electric, the electricity price and maintenance cost, will make the tangible cost.
8. If the agent is educated, the trip is longer than 25 km and the purpose of trip is business/education, there is no in-vehicle time associated with the intangible cost in public modes. (study or work while commuting)
9. The model compares the total cost associated with each mode and chooses the cheapest mode of transport.
Layers of this study

Timetable
Minutes between departures.

<table>
<thead>
<tr>
<th>M1, M2 Between</th>
<th>M1 Between</th>
<th>M2 Between</th>
</tr>
</thead>
<tbody>
<tr>
<td>Varloose and Christianshavn</td>
<td>Vestmager and the airport and Christianshavn</td>
<td></td>
</tr>
</tbody>
</table>

Rush hour
07-09 2 4 4
14-18

Day/Evening outside rush hour and weekends
3 6 6

Night
Sun-Thurs. 20 20 20
24-05

Night Fri-Sat. 7-8 15 15 01-07

Notice: If you change trains between the M1 and M2 lines, you should add waiting time to your travelling time.
Non-Motorized

\[ C_w^{Intangible} = VOT_{IC} \times \left( L_w^{Trip} / S_{w,UT,age}^{Average} \right) \]

\[ C_b^{Tangible} = L_b^{Trip} \times C_b^{Maintenance} \]

\[ C_b^{Intangible} = VOT_{IC} \times \left( L_b^{Trip} / S_{b,UT,age}^{Average} \right) \]

VoT (DKK/Min) from LTM varies across
- trip purpose (e.g., business vs. other purposes) and
- household income.
Private car

\[
C_p^{Tangible} = L_p^{Trip} \times (C_a^{Fuel} + C_a^{Tire} + C_a^{Maintenance} + C_a^{Insurance} + C_a^{Tax} + C_a^{other} + C_a^{Dep})/M_a
\]

\[
C_a^{Fuel} = M_{a,p} \times FP/FE_p
\]

\[
C_p^{Intangible} = VOT_{IC} \times (T_{p,Vehicle}^{InVehicle} + T_{p,UT}^{Congestion} \times Penalty_{p,TP}^{Congestion})
\]

\[
T_{p}^{InVehicle} = L_p^{Trip}/S_{p,UT}^{Average}
\]

• CongestionTime: Changes across zones (from LTM)

• Penalty parameter represents inconvenience time in traffic

• Penalty parameters: Changes across trip purpose –business/other purposes- (from LTM)

Public

\[ C_{pu}^{\text{Intangible}} = VOT_{IC} \times \left( T_{pu}^{\text{InVehicle}} + (T_{pu,UT}^{\text{Wait}} \times \text{Penalty}_{pu}^{\text{Wait}}) + (T_{pu,UT}^{\text{ACC/EGR}} \times \text{Penalty}_{pu}^{\text{ACC/EGR}}) \right) \]

\[ T_{pu}^{\text{InVehicle}} = \frac{L_{pu}^{\text{Trip}}}{S_{pu,UT}^{\text{Average}}} \]

\[ C_{pu}^{\text{Tangible}} = \text{TicketCost} \]

Total Cost

\[ C_{m}^{\text{Total}} = C_{m}^{\text{Tangible}} + C_{m}^{\text{Intangible}} \]

- Individual n will choose alternative \( i^* \) if and only if: \( C_{ni^*} < C_{ni}, \forall i \in D_n \) and \( i \neq i^* \)
The calibrated model is validated by reproducing the historical data of modal share in 2015 (LTM).

The model is calibrated by adjusting the decision rules in mode choice algorithm with the aim of reproducing the historical data of modal share in 2010 (LTM).
Number of Replications: 50

The probability that the true value of modal demand be outside the Mean±2*SE is less than 2%.

Number of generated agents: 11 million

Simulation time: 434 seconds

All results represent the mean value for 50 replications.

\[ RSE_{Total} = \sqrt{\sum_{All Modes} \left( \frac{SE}{meanValue} \right)^2} \]
Results

• **Business as Usual (BAU)**
  - Expansion of Copenhagen metro in the beginning of 2020.
• **Expansion of Infrastructure (EIN)**
  - What if metro is available in DKW urban area,
  - What if S-Train is available in DKW urban and suburban area
  - Increasing the level of service 20%

**Maximum Shift Potential**

*DTU Management Engineering, Technical University of Denmark*
• **Incentives for Sustainable Modes (ISM)**
  - Decreasing public transport price by 20%
  - Park and ride facilities for private cars in train and s-train stations
  - Everybody has electric bike and recharging is free.
• **Disincentives for Private Cars (DPC)**
  
  - Increase tax of fuel by 50%
  
  - Increase registration and ownership tax of fossil fuel vehicle by 50%
  
  - Doubling the parking cost
  
  - Collecting toll (30DKK/trip), vehicles coming to CPH, weekdays 6-18

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**Maximum Shift Potential**
• Combination of all scenarios (COM)

Maximum Shift Potential
How people choose the mode in this model?

Male, 54 years old
Does not have bike
Has License / Not handicap
1 Diesel car at home, 12 years old
Income: 500 KDKK

Weight factor: 304
Weekday, 6:00 am from DKW/U to DKW/U
Length: 1.5 km
Mode in real life: Private car / Driver
Trip purpose: Business -> VoT = 1.539 DKK/min

<table>
<thead>
<tr>
<th>Mode</th>
<th>BAU Intangible</th>
<th>EIN Tangible</th>
<th>ISM Intangible</th>
<th>DPC Intangible</th>
<th>COM Tangible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walk</td>
<td>0</td>
<td>77</td>
<td>0</td>
<td>77</td>
<td>0</td>
</tr>
<tr>
<td>Bike</td>
<td>N/A</td>
<td>N/A</td>
<td>0</td>
<td>13</td>
<td>N/A</td>
</tr>
<tr>
<td>Private</td>
<td>72</td>
<td>4</td>
<td>72</td>
<td>4</td>
<td>78</td>
</tr>
<tr>
<td>Strain</td>
<td>N/A</td>
<td>N/A</td>
<td>24</td>
<td>27</td>
<td>N/A</td>
</tr>
<tr>
<td>Bus</td>
<td>24</td>
<td>54</td>
<td>24</td>
<td>49</td>
<td>19</td>
</tr>
<tr>
<td>Train</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Metro</td>
<td>N/A</td>
<td>N/A</td>
<td>24</td>
<td>11</td>
<td>N/A</td>
</tr>
<tr>
<td>Must</td>
<td>PrivateCar</td>
<td>Metro</td>
<td>Bike</td>
<td>Walk</td>
<td>Bike</td>
</tr>
</tbody>
</table>
Comparing the scenarios

Expansion of Infrastructure, reduce car use by 7%
Incentives for Sustainable Modes, 19%
Disincentives for Private Cars, 30%
and Combination of all scenarios, 49% in 2050 compared to BAU.
Soft link of TIMES-DK and ABMoS

Inputs to ABM:
- Socioeconomic description: gender, income class, car ownership, age, nr. of children, marital status,
- Infrastructure: existing and planned
- Average mode travel cost
- ...

Outputs from ABM (2010-2050):
- Maximum shift potential (pkm) From agents’ point of view

Outputs from TIMES-DK:
- Fuel Prices
- Technology choice
- Infrastructure Investment

TU Survey → LTM

JAVA Interface

Iterations

TIMES-DK
Concluding Remarks

- Agent-based model could capture the travelers’ behavior on mode of transport.

- Scenario measures which affect tangible or intangible costs could be analyzed.

- ABM could be linked to energy optimization model to represent modal shift with a bottom-up approach.

- Next stage is to exchange data with TIMES model.
THANK YOU FOR YOUR ATTENTION

Questions?
Comments!

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