Application and Validation of a Dynamic Freight Simulation-Assignment Model to a Large-scale Intermodal Rail Network: the Pan-European Case

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87th TRB Annual Meeting, Washington, D.C., January 13-17, 2008
Outline

• Introduction
• Methodological features
  – Overall network modeling structure
  – Shipper decisions and shipment assignment to multimodal network
  – Utility function specification and estimation
  – Implementation considerations for large-scale networks
• Validation and application: the REORIENT corridor case
  – Supply and demand
  – Model validation: algorithm convergence and model split
  – Model application: some illustrative results
• Conclusions
Introduction

• Analysis of the complex interactions over space and time associated with the movement of freight over intermodal networks entails use of sophisticated network modeling methodologies.

• The modeling of multiple-product intermodal freight flow over multimodal networks has attracted much interest (though limited application in practice) in the last four decades, using both analytical and simulation approaches:
  – Analytical approach examples: Harker and Friesz (1986), Crainic et al. (1990), Fernandez et al. (2004), etc.
  – Simulation approach: Mahmassani et al. (TRB 2007)

• THIS PAPER: Implementation, validation, and application to a practical large-scale network (the European REORIENT corridor), of the simulation-based model by Mahmassani et al. (2007)
Overall network modeling structure

Role of the model

- Demand
- Network Services
- Mode and Path Choice
- Assignment
- Simulation
- Intermodal Path Computation
- Scheduling Algorithm
- Route Design Model
- CDM Operational Rules
- Modal/Market Shares, by Service
- Travel Times, Terminal Delays
Shipper decisions and shipment assignment to multimodal network

- Shippers (or their agents) are the decision-makers
  - Shippers determine the transport choice for their respective shipments based on available service supply
  - Aggregate demand are compiled into to shipment units that are unitized (containers, swap-bodies or semi-trailers) or railcars (i.e. bulk commodities)
  - A logit-based discrete choice model for joint mode and route choices made by shippers with regard to each shipment (i.e. shippers’ choices are reflected in shipments’ choices)
  - A set of alternatives (mode-path combinations) consists of a multidimensional choice set that includes mode, path, service, and carrier for each shipment product type (with associated specific attributes)
Utility function and estimation

• Data source:
  – a survey of shippers conducted by the Norwegian Institute of Transport Economics

• Systematic utility function
  – Truck Only mode
    \[ V_{TO}^p = -0.3038 \times 10^{-5} \times \text{TravelTime} \times D_{TT \_S} \times \text{Value}^p \]
    \[ -0.2151 \times 10^{-6} \times \text{TravelTime} \times D_{TT \_L} \times \text{Value}^p \]
    \[ -1.8411 \times \frac{\text{Price}^p}{\text{Value}^p} \times \text{TravelDist} \]
  – Intermodal “mode”
    \[ V_{IM}^p = -0.5215 - 0.4616 \times 10^{-5} \times \beta_{TT \_S} \times \text{TravelTime} \times D_{TT \_S} \times \text{Value}^p \]
    \[ -0.2151 \times 10^{-6} \times \text{TravelTime} \times D_{TT \_L} \times \text{Value}^p \]
    \[ -1.8411 \times \frac{\text{Price}^p}{\text{Value}^p} \times \text{TravelDist} \]
    \[ +1.6001 \times D_{\text{Hazard}}^{IM} \]
Solution framework: implementation considerations for large-scale networks

1. Pre-defined path set generation
2. Initial shipment assignment
3. Multi-resolution multimodal freight network simulation
4. Time-dependent intermodal least-cost paths
5. Mode-path choice set generation
6. Shipment dynamic micro-assignment
7. Update of mode and path assignment
8. Convergence checking

1. Pre-defined path for new services and historical paths
2. An efficient grand path set (3.2 millions shipments v.s. 20 thousands spatial paths)
3. Multi-resolution simulation interval 0.1 min (road) v.s. 1 min (rail)
The REORIENT corridor

The corridor spans 23 countries

<table>
<thead>
<tr>
<th>Network</th>
<th># of Nodes</th>
<th># of Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail part</td>
<td>5577</td>
<td>5753</td>
</tr>
<tr>
<td>Road part</td>
<td>4713</td>
<td>5460</td>
</tr>
<tr>
<td>Sea part</td>
<td>54</td>
<td>21</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10344</strong></td>
<td><strong>11234</strong></td>
</tr>
</tbody>
</table>
3.2 million shipments per week (2006)
5.8 million for forecast year 2020
Source: ETIS
117 x 117 O-D zone pairs
11 commodity types
2 manifestations (‘bulk’ and ‘unitized’)

<table>
<thead>
<tr>
<th>Description</th>
<th>Ton/TEU</th>
<th>Import Flows</th>
<th></th>
<th>Export Flows</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>€/ton</td>
<td>s.d.</td>
<td>€/ton</td>
<td>s.d.</td>
</tr>
<tr>
<td>Agricultural products and live animals</td>
<td>12.74631</td>
<td>192.11</td>
<td>440.11</td>
<td>184.99</td>
<td>317.2</td>
</tr>
<tr>
<td>Foodstuffs and animal fodder</td>
<td>13.31296</td>
<td>276.13</td>
<td>661.47</td>
<td>230.32</td>
<td>358.3</td>
</tr>
<tr>
<td>Solid mineral fuels</td>
<td>18.40739</td>
<td>116.72</td>
<td>1678.30</td>
<td>121.49</td>
<td>1841.1</td>
</tr>
<tr>
<td>Petroleum products</td>
<td>14.92787</td>
<td>109.93</td>
<td>228.82</td>
<td>44.94</td>
<td>63.1</td>
</tr>
<tr>
<td>Ores and metal waste</td>
<td>16.14077</td>
<td>89.04</td>
<td>269.82</td>
<td>70.54</td>
<td>160.9</td>
</tr>
<tr>
<td>Metal products</td>
<td>15.25173</td>
<td>212.82</td>
<td>487.00</td>
<td>223.05</td>
<td>1078.5</td>
</tr>
<tr>
<td>Crude and manufactured minerals, building materials</td>
<td>15.07911</td>
<td>321.49</td>
<td>2461.83</td>
<td>236.05</td>
<td>1476.5</td>
</tr>
<tr>
<td>Fertilizers</td>
<td>18.45192</td>
<td>58.91</td>
<td>147.86</td>
<td>93.32</td>
<td>481.8</td>
</tr>
<tr>
<td>Chemicals</td>
<td>14.04991</td>
<td>957.13</td>
<td>5955.17</td>
<td>1149.15</td>
<td>10085.2</td>
</tr>
<tr>
<td>Machinery, transport equipment, manufactured articles and miscellaneous articles</td>
<td>9.290191</td>
<td>805.45</td>
<td>4090.65</td>
<td>9493.87</td>
<td>159626.8</td>
</tr>
<tr>
<td>Crude oil</td>
<td>16.23117</td>
<td>159.30</td>
<td>1526.82</td>
<td>83.02</td>
<td>200.8</td>
</tr>
</tbody>
</table>
Illustration of convergence pattern

- Avg_Diff

Iteration

- 0
- 10
- 20
- 30
- 40
- 50
- 60

1 2 3 4 5 6 7 8 9 10
Validation of model split

Europe Commission

Weekly Flow in Tons (57,616,633)

<table>
<thead>
<tr>
<th>Road only</th>
<th>IM</th>
</tr>
</thead>
<tbody>
<tr>
<td>47,327,745</td>
<td>10,288,888</td>
</tr>
<tr>
<td>(82.14%)</td>
<td>(17.85%)</td>
</tr>
</tbody>
</table>

This model

European Commission

2005: 17.4%
Four proposed service routes

T1 = Green (Bulk)
Swinoujscie - Vienna/Bratislava - Budapest

T2 = Yellow (Unitized)
Trelleborg-Swinoujscie-Bratislava/Vienna

T3 = Red (Unitized)
Gdansk/Gdynia-Bratislava/Vienna-Budapest-Beograd-Thessalonica

T4 = Blue (Bulk and Unitized)
Bratislava-Budapest-Bucharest- Constantia
Illustrative results (1): barrier reduction at borders

Increase serviced flows by 20.5%

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Border crossing times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservative</td>
<td>3-4 hours</td>
</tr>
<tr>
<td>Sophisticated</td>
<td>15-45 min</td>
</tr>
</tbody>
</table>
Illustrative results (2): Infrastructure improvements

- A bundle of infrastructure improvements:
  - 20% increase in rail maximum speeds in Poland
  - that would result from improvements in the track, electrification of track along all newly proposed services,
  - terminal processing time improvements

![Chart showing current and improved serviced flows with increases by 33%](chart.png)
Conclusions

- Illustrated steps and challenges in application to a large-scale network of a dynamic intermodal freight network modeling framework for policy evaluation and market assessment of proposed new Pan-European rail services.
- Addressed methodological challenges due to the multidimensional nature of the demand (e.g. multiple product types, very large number of shipments) and the supply (e.g. multiple interacting modes, transfer processes, multiple carriers).
- Issues of system representation, problem size, computational and memory considerations, as well as limited data availability and its aggregate static nature called for methodological refinements.
- Tool provides a capability to evaluate performance measures, costs and benefits derived from implementation of
  - interoperability directives,
  - barrier-removing or barrier-reducing improvements in physical,
  - operational or managerial aspects/business practices of the rail system,
  - as well as other policy measures and potential inducements aimed towards achieving EC policy objectives.
Thank you & comments!