Lecture-1: Introduction to Freight Transportation Demand Modeling
In Today’s Class

- Focus is on methods and techniques for freight modelling
- Short rehearsal of general introduction on modelling
- We follow the 4 step model architecture – modified for freight

1. Introduction to freight demand issues
2. Demand modelling principles
   - Production / attraction
   - Trade
   - Mode choice
   - Route choice
   & integrative forms
What is Globalization?

What does it take to have a cup of coffee in a café?

The combined efforts of 29 companies in 18 countries

Road Transport has become a production tool!

Source: IRU
Q1: what’s behind growth?
Q2: What’s behind structural change?

Growth in freight travel by land modes 2000-2050

- OECD North America
- OECD Europe
- OECD Pacific
- FSU
- Eastern Europe
- China
- Other Asia
- India
- Middle East
- Latin America
- Africa
Q2: What’s behind structural change?
Autos/freight: fundamental differences

- One decision maker or many?
- Unit of transport = decision maker?
- Many interactions between decision makers, or few?
- Correspondence between demand and trips: simple or complex?
- Heterogeneity in trip purposes: low or high?

_NCFRP 25. Holguin Veras et al, 2010_
Modelling freight transport demand in the context of public policy

macro: "the region"

normative "best situation"

e.g. transport network design

descriptive "as it happens"

disaggregate transport demand models

OUR FOCUS

e.g. supply chain design

micro: "the firm"
Freight reorganization responses & their determinants

Producer 1
Producer 2
Producer 3
Distribution Center
Consumer 1
Consumer 2
Transshipment Hub

Production reorganisation
Supply chain reorganisation
Transport reorganisation
There is more than transport costs...

Gemiddeld aandeel kosten in verkoopprijs
48% 27% 15% 6% 4%

Fabricage kosten
Marketing kosten
Logistieke kosten
Transportkosten
Winst marge

Production costs
Marketing costs
Other logistics costs
Transport costs
Profit margin

Groothedde, 2004
Total logistics costs: determinants

LOGISTICS FAMILIES

TOTAL FLOW
INTEREST RATES
TRANSPORT DISTANCE
TRANSPORT SERVICES
HANDLING RATES
STOCK RATES

VALUE DENSITY
INVENTORY POLICY
CONSIGNM. SIZE
VALUE OF SERVICE
PACKAGING DENSITY
VOLUME TO WEIGHT

INVENTORY COSTS
TRANSPORT COSTS
WAREHOUSE COSTS

PHYSICAL DISTRIBUTION COSTS

LOGISTICS FAMILIES

Total logistics costs: determinants
Goods types & critical cost fields

- Transport costs
- Inventory costs
- Handling costs
- Packaging density

Value density

Ploos van Amstel, 2003
A layered model of logistics decisions

**Decision maker**

- Producent / plant mgr.
- Consumers
- Sales managers
- Sourcing managers
- Logistics service provider
  - Logistics manager
- Logistics manager
- Transport manager
  - Forwarder
- Transport planner
- Driver

**Decision**

- Production Location choice
- Type of product
- Production volume
- Consumer choices
- Trading contracts
- Shipment sizes, frequencies
- Location en volume of inventory
- Distribution channels
- Mode(s) of transport
- DIY or Hire & Reward?
  - Long term or spot contract?
  - Means of transport
- Routing and scheduling
  - Time of departure
  - Capacity planning
The conventional 4-stage model

1. trip generation models
   e.g. as function of GDP or floor area

2. trip distribution models
   e.g. gravity type model
   as function of transport costs

3. mode choice models
   e.g. as function of transport costs

4. route choice models
   e.g. as function of transport costs
Model taxonomy: 4 stage and beyond

- Production/consumption
- Distribution
- Inventory location
- Mode choice
- Route choice

SCGE

Supernetwork

Hypernetwork
Intermediate conclusion

- **Freight changes caused by:**
  - Changes in the economy
  - Changes in number of tons lifted
  - Changes in the transport performance
  - Changes in traffic performance

- **Supply chain considerations: logistics service & total logistics costs**
  - Transport
  - Inventory
  - Handling

- **4 step transport demand model needs to be extended to accommodate freight specific issues**
Freight generation

Production/consumption
Distribution
Inventory location
Mode choice
Route choice

SCGE

Supernetwork

Hypernetwork
Simple freight trip generation models

- Freight generation vs. freight trip generation
  - Increases with economic activity (business size, # of consumers)
  - Depends on sector/goods type
  - Mostly simplified into linear model

**Zonnnenberg, 1989**

**Problem:** Just Regression

(why a problem?)

**Klaver, 2001**
**Problem** Ordering goods from manufacturer: what order size?

EOQ - economic order quantity

Total costs = product costs + ordering costs + inventory costs
- Price (P) * demand (D)
- Ordering costs /unit (O) * # units (D/Q)
- Inventory cost / unit (I) * average inventory (Q/2)

$$TC = P \times D + \frac{O \times D}{Q} + \frac{I \times Q}{2};$$ minimize for shipment size Q

Solution at OD/Q = IQ/2; $$Q^* = \sqrt{2OD/I}$$
Effect of logistics on freight trip generation – or...?

NCFRP 25. Holguin Veras et al, 2010
Production and consumption networks

- Input/Output analysis allows us to trace demand effects through sectors as pulled by consumer demand (“final demand”)
  => I/O model with fixed relations

- More realistic approach through flexible production functions
  => computable general equilibrium models
Input-Output analysis: basic framework

\[ I/O \text{ origin } = \text{estimation of GDP for national accounts} \]

(1) Total production \( \mathbf{t} = \) Final demand \( \mathbf{y} + \) Intermediate demand \( f(\mathbf{t}) \)

(2) Intermediate demand = technical coefficient \( \mathbf{A} \) \(*\) total production \( \mathbf{t} \)

\[ \mathbf{t} = \mathbf{y} + \mathbf{A} \mathbf{t} \Rightarrow \mathbf{t} = \mathbf{y}(\mathbf{I}-\mathbf{A})^{-1} \]

\( \mathbf{t} = \) vector of total production
\( \mathbf{y} = \) vector of final demand
\( \mathbf{A} = \) matrix of technical coefficients

All in Euro per year per sector

Assumed fixed!
Distribution models

- Production/consumption
- Distribution
- Inventory location
- Mode choice
- Route choice
- Spatial equilibrium
- Supernetwork
- Hypernetwork
Trade depends also on costs of interaction

**Logistics costs in EU and US**

- **% of GDP**
- **Sources:** ELA/AT Kearney and CSCMP

**Costs of transport**

- **Cost index, 1980 = 100**
- **European Commission, 2004**

**Trade tariffs**

- **Percent of import value**
- **Source:** WTO

**World GDP, trade and container transport 1990-2006**

- **World container port turnover, TEU**
- **World trade, USD**
- **World GDP, USD**
Understanding the gravity model (1)

\[ \text{Margin} = \text{Price}_i - \text{Price}_j - \text{Costs}_{ij} \]
Understanding the gravity model (2)

\[ M_{ij} = p_j - p_i - c_{ij} \]

Interregional trade
\[ T_{ij} = T \cdot \text{Pr}\{ij\} \]

Choice probability based on logit discrete choice model
\[ \text{Pr}\{ij\} = \frac{\exp(M_{ij})}{\sum_i \exp(M_{ij})} \]

Then:
\[ T_{ij} = \exp(p_j - p_i - c_{ij}) \cdot \frac{T}{\sum_i \exp(M_{ij})} \]
Replace \( T/\sum_i \exp(M_{ij}) \) bij \( \zeta \) (constant) for convenience ➔

\[ T_{ij} = \zeta \cdot \exp(-p_i) \cdot \exp(p_j) \cdot \exp(-c_{ij}) = \zeta \cdot A_i \cdot B_j \cdot \exp(-c_{ij}) \]

\( M = \) margin, \( p = \) price, \( c = \) costs of interaction, \( i \& j: \) regions
\( T = \) total trade
\( A, B, \zeta: \) constants
Economy/transport linkages

- **LUTI model**
  - Trip generation as simple regression function of accessibility
  - $T_{i^g} = f(A_{rs})$; e.g. 10% change in accessibility means 10% more trips

- **Regional (quasi-) production function model**
  - Trip generation changes via changes in regional GDP
  - $T_{i^g} = f(GDP_{is})$ and $GDP_{is} = f(L_i K_i R_i A_{is})$

- **SCGE models**
  - Trip generation as result of general spatial price equilibrium
  - $T_{ijg} = f(L_{i,j,s} K_{i,j,s} R_{i,j,s} t_{ijs})$

*where*
- $T_{i^g}$ = Trips from i to all other regions, for good $g$
- $A$ = Accessibility of sector $s$ in region $i$
- $L$, $K$, $R$: Labor, Capital, Land
- $i$, $j$ = short for all $ij$ and sector pairs
# Evolution of spatial interaction models

<table>
<thead>
<tr>
<th>Location of activities</th>
<th>Interaction between activities</th>
<th>Intensity of economic activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spatial interactions</td>
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<tr>
<td></td>
<td>Sectoral interactions</td>
<td></td>
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<tr>
<td>Land Use models</td>
<td>Gravity type models</td>
<td>Input/Output models</td>
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<td></td>
<td><em>LUTI models: elasticities for regional trip generation</em></td>
<td>Equilibrium models</td>
</tr>
<tr>
<td></td>
<td><em>Multi-regional I/O models (MRIO): stepwise IO &amp; gravity</em></td>
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<td></td>
<td><em>Spatial Computable General Equilibrium models</em></td>
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</tbody>
</table>
Spatial equilibrium models

Production/consumption

Distribution

Inventory location

Mode choice

Route choice

Spatial equilibrium

Supernetwork

Hypernetwork
Production, consumption and trade combined: spatial general equilibrium

Barriers to trade

Costs of trade

Factor costs region A

Factor costs region B

NEW INTERREGIONAL EQUILIBRIUM
Towards an integrated system model for passengers and freight

- Generalized transport costs
  - migration
  - commuting
  - labour market
  - production
  - income
  - consumption
  - trade
  - Product varieties
Intermediate conclusion

- Production and consumption: from I/O to production functions
- Spatial interaction well described by the gravity model
- Gravity model can be replaced by disaggregate logit
- I/O & gravity: MRIO (multiregional IO) models
- Land Use Transport Interaction models
- Linkage with production functions: spatial general equilibrium
- Also link to integration with passenger transport modelling
Modelling inventory chains

- Production/consumption
- Distribution
- Inventory location
- Mode choice
- Route choice

SCGE

Supernetwork

Hypernetwork
Positioning logistics within the 4 step model

I. Trade/Economy linkages

II. Supply chains

III. Multimodal networks

Production and Consumption

Trade (Sales and Sourcing)

Logistics Services

Transportation Services

Network Services
Inventories affect spatial flow patterns
P/C vs. O/D:

Inventories

Producer

Inventory

Consumer

Low frequency, Large shipments

High frequency, Small shipments

Scale

Shipment size

Cycle stock

Frequency

service orientation
cost orientation

transport costs

depot costs

total costs

level of centralisation

transport costs

Shipment scale

High frequency, Small shipments

Low frequency, Large shipments

Inventory

Consumer
Mechanism 1: economies of scale

Transport Costs / ton

1 Euro/tripkm

Vehicle size

FTL

Shipment size
Mechanism 2: inventory policy

Demand

Cycle stock

Delivery

Ordering frequency

Shipment size

time
Supply chain changes in Europe

- depot costs
- total costs
- transport costs

level of centralisation

CENTRALITY
Mode choice models

- Production/consumption
- Distribution
- Inventory location
- Mode choice
- Route choice

SCGE

Hypernetwork

Supernetwork
Mode choice: some stats

- **Road (18 bn tonnes)**
  - Agricultural products and live animals
  - Foodstuffs & animal fodder
  - Solid mineral fuels
  - Petroleum products
  - Ores & metal waste
  - Metal products
  - Crude & manuf. minerals, building materials
  - Fertilisers
  - Chemicals
  - Machinery, transp. equipment, manuf. & misc. articles

- **Rail (1,5 bn tonnes)**

- **Waterways (0,5 bn tonnes)**
Mode choice: some stats

- Agricultural prod. & live animals
- Foodstuffs & animal fodder
- Solid mineral fuels
- Petroleum products
- Ores & metal waste
- Metal products
- Crude & man. minerals, build. mat.
- Fertilisers
- Chemicals
- Mach., transp. eq, manuf. & misc. art.

[Graph showing mode choice for different categories with bars for tonnes and tonkm.]
Mode choice: some stats

- Road (18 billion tonnes)
- Rail (1.5 billion tonnes)
- Waterways (0.5 billion tonnes)

- Agricultural products and live animals
- Foodstuffs & animal fodder
- Solid mineral fuels
- Petroleum products
- Ores & metal waste
- Metal products
- Crude & manuf. minerals, building materials
- Fertilisers
- Chemicals
- Machinery, transport equipment, manuf. & misc. articles
Mode choice models

- Mode attributes (=> *which ones?*)
- Commodity attributes (=> *which ones?*)

- Behavioural models
- Discrete choice models
- Total logistics costs based
  - Include inventory costs
  - In transport
  - At shipper
Table 2.1: Qualitative overview of modal characteristics, taken from (T.E. Platz, 2009)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Road</th>
<th>Rail</th>
<th>Inland Waterway</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Users</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Transport costs per unit</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>2 Ability to achieve the transport of large volumes</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>3 Transport speed</td>
<td>+</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>4 Network connectivity</td>
<td>+</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>5 Predictability of transport process</td>
<td>0</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>6 Transport frequency</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7 Transport safety</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>8 Transport security</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>9 Convenience and flexibility</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10 Resistance to extreme weather conditions</td>
<td>-</td>
<td>0</td>
<td>-</td>
</tr>
<tr>
<td>11 Limitation of infrastructure capacity, congestion</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td><strong>Governments</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Energy-use per ton-km</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>B Emission of harmful substances</td>
<td>-</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>C Emission of greenhouse gas</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>D Noise, negative effects on ground and water</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Legend: + relatively good performance, 0 medium performance, - weak performance.

Q: with all these “-“scores, how come road is so popular?
Mode choice modelling approaches

- **Inventory (cost based, all-or-nothing) models**

- **Behavioural models:**
  
  Minimize out-of-pocket costs (K) \( \Rightarrow \) utility maximization \( U = -K \)
  
  \[ V = K_m + \alpha T_m \]

  Probabilistic approach discrete choice
  
  \[ U_m = K_m + \alpha T_m + \epsilon \]

  Deterministic choice & random preferences
  
  \[ U_m = K_m + \alpha T_m + \epsilon \]
Operational approaches depend on data used

**Aggregate Data**
- Land use data
- Trade statistics
- Transport statistics
- Time and costs

**Disaggregate data**
- Company surveys
- Shipment records
- Goods attributes
- Time and cost data

**Combine**
- Split aggregate flow data using firm size onto firm level
  - Or
  - Make aggregate distributions of goods’ attributes

**Choice model**
- Mode
- Shipment size
- Inventories
- Routing
**Transport costs**

- **D1**: break-even point Road/Rail
- **D2**: break-even point Rail/Inland navigation
- **Tx**: terminal costs (load/unload costs)
- **Cx**: cost function mode x

**Diagram:**
- Graph showing transport costs per unit against distance.
- Different lines represent different modes of transport:
  - **C_{Road}**
  - **C_{Rail}**
  - **C_{InlandNav}**

**Legend:**
- **T_{InlandNav}**
- **T_{Rail}**
- **T_{Road}**
Trade-offs through value of service

\[ U_{mg} = \alpha_g \cdot T_m + P_m + \varepsilon_m \]
Typical VOT switching values between modes

- **AIR**: 15 \$/ton/hr
- **ROAD**: 1 \$/ton/hr
- **RAIL**: 0.6 \$/ton/hr
- **WATERWAYS**: 0.3 \$/ton/hr
- **SEA**: 0.6 \$/ton/hr
Determination of market shares

\[ U_{\text{prijs}} = K_m + a_g T_m \]
Ways to measure the value of time

- Accounts based
  - Factor costs or market prices

- Behavioural analysis (experimental)
  - Aggregate vs. Disaggregate
  - Revealed and Stated Preferences
  - Between mode or Within mode choice experiments
  - Discrete choice modelling in trade-off situations
  - Various alternative choice models
  - Other choice situations than mode choice possible

- Disaggregate measurements: *sampling* and *aggregation*

- Aggregate approach: based on *statistics*
Route choice models

- Production/consumption
- Distribution
- Inventory location
- Mode choice
- Route choice

SCGE → Supernetwork → Hyernetwork
Route choice for freight

- Most freight models apply similar route choice techniques as in passenger transport (e.g. Dijkstra algorithm)

- Specific concerns for freight:
  - Road: round trips (TSP); restrictions: weight & size regulations
  - Rail: train paths; restrictions: gauge width; voltage; priorities
  - Waterways: waterways sizes & ship classes
  - Sea: shipping line & feeder services; restrictions: port depth
  - Air: hub & spoke networks; flight level 0 (trucking)
Dynamics in efficiency

Utilization of the available capacity (%)

1997 1999 2001 2003 2005 2007

Empty Running (%)


Countries:
- Czech Republic
- Denmark
- Germany
- Hungary
- Netherlands
- Portugal
- Slovenia
- Spain
- Sweden
- United Kingdom
- Austria
- Latvia
- Portugal
- Slovenia
- Spain
- Sweden
- United Kingdom
A note on the degree of loading

Survey A10-20/RN10 (F): volume and weight of equal importance
(Combes, Univ Paris-Est, 2010)

26%
38%
26%
10%
74%

LTL / empty  FTL (m³)  FTL (m³ + ton)  FTL (ton)
Simple route vs. round trips

Notation:
- Loaded vehicle-trip
- Empty vehicle-trip
- Commodity flow
- Consumer of cargo (receiver)

NCFRP 25. Holguin Veras et al, 2010
Transport reorganization: routing

CASE A

CASE B
Models for empty trips

Classic model Noortman & Van Es (1978)
Empty trips (i,j) ~ laden trips (j,i)
- laden trips (i,j) = $m_{ij}/a$
- empty trips (i,j) = $p*m_{ji}/a$

But this leads to differences in # of trucks moving (i,j) and (j,i)
(why? why is this a problem?)

Alternative formulation (Hautzinger, 1984)

Extensions for trip chain models
Supernetworks

- Production/consumption
- Distribution
- Inventory location
- Mode choice
- Route choice

SCGE

Supernetwork

Hypernetwork
Combined mode & route choice
Synchromodal network services with dryports & extended gates

- Truck
- Rail
- Zeppelin
- Waterways

T1-T6: Routes along Terminals 1-6
- Truck only
- Rail only
- Waterways only

PD

VOT
Hypernetwork models (briefly)
Combining choices in hypernetworks

Manufacturer

Large shipment size networks

Route I

Route II

Stock Points: Network Switch

Small shipment size networks

Consumer
On hypernetwork models

- **Advantages**
  - Elegant & simple method (all in one)
  - Close to physical representation, increases first sight acceptance
  - Behavioural principles aligned between subproblems

- **But...**
  - Complexity is high; longer calculation times
  - Difficult to find one good parameter setting for 3 choice problems
  - Difficult to calibrate due to many degrees of freedom
Concluding remarks

- A brief introduction into freight demand modelling
- Focus was on descriptive, static, deterministic, aggregate models
- Further studying:
  - Static vs. dynamic models
  - Equilibrium vs. disequilibrium approaches
  - Supply models: capacity, scale economies, prices and service levels
  - Aggregate (region) vs. disaggregate (firm level) models
  - Accounting for heterogeneity and uncertainty
- Reading material for exam on the blackboard
  - Introduction in Willumsen & Ortuzar
  - Review papers
Summary, questions

**Decision maker**
- Producent / plant mgr.
  - Consumers
- Sales managers
- Sourcing managers
- Logistics service provider
  - Logistics manager
- Logistics manager
  - Transport manager
  - Forwarder
- Transport planner
  - Driver

**Decision**
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- Type of product
- Production volume
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- Means of transport
- Routing and scheduling
  - Time of departure
  - Capacity planning

"shipper"

"carrier"
Acknowledgement

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