Freight Demand

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Transportation Systems Analysis: Demand & Economics

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Outline

● **Background**
  – Volumes
  – Types
  – Econometric Indicators

● Freight demand modeling
  – Framework
  – Logistics choices
  – Model system

● Trends and Summary

● Appendices: Extensions, Activity Systems, Model System
Major Types of Freight

● Bulk
  – Coal
  – Oil, Gas
  – Ores, Minerals, Sand and Gravel
  – Agricultural

● General Merchandise
  – Supermarket grocery

● Specialized Freight
  – Automobile
  – Chemicals

● Small Package
Bulk

● Commodity Characteristics
  – Cheap
  – Vast quantities
  – Transport cost is a major concern

● Relevant Modes
  – Rail unit train and multi-car shipments
  – Heavy truck
  – Barge and specialized ships
  – Pipeline
General Merchandise

● Commodity characteristics
  – Higher value
  – Greater diversity of commodities
  – Many more shippers and receivers
  – Logistics costs are as important as transport costs

● Relevant Modes
  – Rail general service freight car
  – Intermodal
  – Truckload
  – LTL (Less-than-Truckload)
Specialized Freight

● Commodity Characteristics
  – Large volumes, relatively few customers
  – Specialized requirements to reduce risk of loss and damage
  – High value (can afford special treatment)

● Relevant Modes
  – Specialized rail (multi-levels, tank cars, heavy duty flats)
  – Specialized trucks (auto carriers, tank trucks, moving vans)
  – Air freight
Small Package

● Commodity Characteristics
  – Very high value
  – Logistics costs are more important than transport costs
  – Deliveries to small businesses or consumers

● Relevant Modes
  – LTL
  – Small packages services
  – Express services
  – Air freight
Growth in US Domestic Freight Ton-Miles by Mode: 1996 - 2005

SOURCE: U.S. Department of Transportation, Research and Innovative Technology Administration, Bureau of Transportation Statistics. BTS Special Report: A Decade of Growth in Domestic Freight, Table 1 (July 2007).
Freight Demand

- Freight transport demand is a derived demand
  - Related to the volumes of goods produced and consumed
  - Location of suppliers and consumers is critical
  - Freight flows shift with
    - New sources of and uses for materials
    - New locations for manufacturers and retailers
    - New products and specialized transport
# Freight Elasticities

<table>
<thead>
<tr>
<th>Model, elasticity type</th>
<th>Elasticity estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rail</td>
</tr>
<tr>
<td></td>
<td>Truck</td>
</tr>
<tr>
<td>Aggregate mode split model (^a)</td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td>-0.25 to −0.35</td>
</tr>
<tr>
<td></td>
<td>-0.25 to −0.35</td>
</tr>
<tr>
<td>Transit time</td>
<td>-0.3 to −0.7</td>
</tr>
<tr>
<td></td>
<td>-0.3 to −0.7</td>
</tr>
<tr>
<td>Aggregate model from translog cost function (^b,^c)</td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td>-0.37 to −1.16(^d)</td>
</tr>
<tr>
<td></td>
<td>-0.58 to −1.81(^e)</td>
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<tr>
<td>Disaggregate mode choice model (^b,^f)</td>
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<tr>
<td>Price</td>
<td>-0.08 to −2.68</td>
</tr>
<tr>
<td></td>
<td>-0.04 to −2.97</td>
</tr>
<tr>
<td>Transit time</td>
<td>-0.07 to −2.33</td>
</tr>
<tr>
<td></td>
<td>-0.15 to −0.69</td>
</tr>
</tbody>
</table>


\(^b\) These estimates vary by commodity group; we report the largest and smallest.


\(^d\) The first value applies to mineral products; the second value to petroleum products.

\(^e\) The first value applies to petroleum products; the second value to mineral products.

Freight Value of Time (VOT)

VOT estimates

<table>
<thead>
<tr>
<th>Total transit time (in days)</th>
<th>Rail</th>
<th>Truck</th>
</tr>
</thead>
<tbody>
<tr>
<td>(As percentage of shipment value)</td>
<td>6-21</td>
<td>8-18</td>
</tr>
</tbody>
</table>

The lower value applies to primary and fabricated metals; the higher value applies to perishable agriculture products.

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Freight Modeling Framework

Economic Activity
- Growth Factor
- Gravity
- Input-Output

Production-Consumption Flows

Logistics Choices

Origin-Destination Flows

Network Assignment
Forecasting Freight OD Flows

● Growth Factors:
  – Factor an existing OD trip table of commodity flows to estimate future flows

● Gravity Models:
  – The distribution step in a 4-step model

● Economic Activity Models:
  – Trace the flows of commodities between economic sectors and between regions
Growth Factors

- Supply and Demand from a region are predicted using “Growth Factors”
- Iterative Proportional Fitting (IPF) technique is used
- Given the $S_i$, $D_j$ and $T_{ij}^0$, calculate $T_{ij}$, $\alpha_i$ and $\beta_j$

\[T_{ij} = \alpha_i \beta_j T_{ij}^0\]
\[\sum_i T_{ij} = S_i, \quad i = 1, \ldots, I\]
\[\sum_j T_{ij} = D_j, \quad j = 1, \ldots, J\]

Where,
- $T_{ij}$ = predicted OD flow between region $i$ and region $j$
- $T_{ij}^0$ = initial OD flow between region $i$ and region $j$
- $\alpha_i$ and $\beta_j$ = balancing factors for regions $i$ and $j$ respectively
- $S_i$ = supply at region $i$ and $D_j$ = demand at region $j$
Gravity Model

- IPF with

\[ T_{ij}^0 = S_i D_j f(C_{ij}) \]

\[ T_{ij} = \alpha_i S_j \beta_j D_j f(C_{ij}), \ i = 1, \ldots, I \ and \ j = 1, \ldots, J \]

\[ \sum_j T_{ij} = S_i, \ i = 1, \ldots, I \]

\[ \sum_i T_{ij} = D_j, \ j = 1, \ldots, J \]

Where,

- \( C_{ij} \) = generalized cost of shipping between regions \( i \) and \( j \)
- \( f(C_{ij}) = e^{-\theta C_{ij}} \) = generalized cost function

If \( \theta \rightarrow \infty \), the model is equivalent to a linear programming problem:

\[ \text{Min} \ \sum_i \sum_j T_{ij} C_{ij}, \ s.t. \ \sum_j T_{ij} = S_i, \ \sum_i T_{ij} = D_j \]
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Logistics Chain

Image removed due to copyright restrictions.
Multi-Leg Logistics Chain

$N$ : number of legs in a logistics chain
$m$ : sender
$n$ : receiver
$h$ : mode
$t$ : transhipment location
Decision Maker

- No single decision maker
  - Producers
  - Wholesalers, Distributors
  - Consumers
  - Carriers
  - Logistics service providers
Logistics Choices

- Shipment size/frequency
- Choice of loading unit
  - e.g. container, pallet, refrigerated
- Formation of tours
  - consolidation and distribution, multi-stop deliveries, batching
- Location of consolidation and distribution centers
Logistics Choices (cont.)

- Mode used for each tour leg
  - Road transport: vehicle types
  - Rail transport: train types
  - Maritime transport: vessel types
  - Air

- Shipment schedule
Logistics Costs

- Order management
- Transport
- Transshipment
- Loss and damage
- Capital tied up
- Inventory management
- Unreliability
Factors Affecting Logistics Costs

Inventory Management

Inventory vs. Time Graph
Factors Affecting Logistics Costs

Order Management

The optimal quantity $Q^*$ is also known as the Economic Order Quantity (EOQ).
Modeling Complexities

- Widely varying commodities with different requirements and characteristics
- Level-of-service attributes
  - e.g. shipment time, cost, reliability
- Characteristics of the shipment
  - e.g. size, frequency, goods typology
    (perishability, value)
- Characteristics of the firm
  - annual revenue, availability of own trucks, availability of railway sidings
Data Requirements

- Size of firms by commodity and by region at production and consumption ends
- Shipments
- Consolidation center and distribution center locations, ports, airports, rail terminals
- Cost data
  - time and distance from network models combined with cost models
Freight Mode Choice Model

- Shippers Characteristics
- Shipment, Commodity, Mode Attributes

Logistics Costs

Choice
Model Specification

\[ U_{in} = \mu(\text{logistics cost}_{in}) + \epsilon_{in} \]

\[ \text{logistics cost}_{in} = C_{in} + W_{in} \theta + r(T_{in} + Z_{in} \gamma) \]

\( \mu \): negative scale parameter;

\( \epsilon_{in} \): error term that are i.i.d. standard normal;

\( C_{in} \): transportation cost;

\( W_{in} \): row vector that contains the mode-specific constant, mode-specific variables that capture the effects of ordering costs, on-time delivery and equipment availability;

\( T_{in} \): daily value of in-transit stocks;

\( Z_{in} \): discount rate related variables such as loss and damage costs and stock-out costs;

\( \theta, \gamma \): vectors of unknown coefficients;

\( r \): discount rate.
Example of Estimation

• Data:
  - Survey of 166 large US shippers (1988)
  - Alternatives: Truck, Rail, Intermodal

Example of Estimation (cont)

• Estimated logistics cost functions:

\[
\text{Truck Cost} = -0.138 + (\text{Transportation cost}) + 0.372(\text{Distance}) - 0.811(\text{Delivery time reliability}) - 4.35(\text{Equipment usability}) - 0.0980(\text{Value/ton}) + 0.456(\text{In transit stock holding cost}) + 0.169(\text{Safety stock costs}) + 1.65(\text{Loss and damage})
\]

\[
\text{Rail Cost} = (\text{Transportation cost}) - 0.811(\text{Delivery time reliability}) - 4.35(\text{Equipment usability}) + 0.456(\text{In transit stock holding cost}) + 0.169(\text{Safety stock costs}) + 1.65(\text{Loss and damage})
\]

\[
\text{Intermodal Cost} = 1.64 + (\text{Transportation cost}) - 0.811(\text{Delivery time reliability}) - 4.35(\text{Equipment usability}) + 0.456(\text{In transit stock holding cost}) + 0.169(\text{Safety stock costs}) + 1.65(\text{Loss and damage})
\]
Sources of Heterogeneity

- Inter-shipper
  - Attitudes
  - Perceptions of service quality
  - Awareness of modal alternatives

- Intra-shipper
  - Shipment type (regular vs. emergency)
  - Customer (large vs. small)
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Model System

- Multi-regional Input-Output Model
- Conversion of Trade Flows to Freight Quantity
- Mode Choice
- Path Choice and Assignment
- Generalized Transport Cost
- Level of Service Attributes
- Final Demand by Sector and Region
- Matrices of Region-to-Region Trade Flows (in Value)
- O/D Matrices
- O/D Matrices by Mode

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Trends in Freight Modeling

● **Emerging Issues:**
  Smaller Inventories, Shorter lead time, Consolidation

● **Data:**
  Commodity Flow Surveys → Automated Data Collection (e.g. AVI, Remote Sensing)

● **Modeling Methods:**
  Aggregate Models → Disaggregate Models

● **Application/Forecasting:**
  Aggregate Forecasting → Disaggregate Forecasting

● **Behavioral Representation:**
  Homogeneous → Heterogeneous (commodity types, supply-chains)
Summary

- Freight demand is expected to continue to grow at a steady rate
- Discrete choice models are useful to predict intermodalism in freight demand with explicit treatment of heterogeneity and perceptions
- Estimation requires detailed shipment data, not all of which are available
- Aggregate data can be used to calibrate the overall freight model system in absence of detailed shipment data
Appendix A

Extensions of logistics choice modeling
Extension 1: Distributed Discount Rate

● Shippers use *Discount Rate* \((r)\) to calculate costs of inventory

● *Discount rate* varies significantly among shippers and shipments

● Model Specification:

\[
  r \sim \text{log normal}(\mu, \sigma^2)
\]

\[
  \mu = -0.715, \sigma = 0.481
\]

\[
  \bar{r} = 0.549, \sigma_r = 0.280
\]

Distribution of Discount Rate
Extension 2: Shipper-Specific Discount Rate

- Multiple observations of the same shipper
- Shipper-specific discount rate captures correlation between observations from the same shipper
- Model Specification:

\[ U_{int} = X_{int} \beta + Z_{int} r_{nt} + \varepsilon_{in} \]

shipper specific discount rate

\[ r_{nt} = r_n \quad \forall t \]

\[ r_n \sim \text{log normal}(\overline{r}, \sigma_r^2) \]
Extension 3: Latent Variable Models

Shippers Characteristics

Shipment, Commodity, Mode Attributes

Logistics Costs

Choice

Latent Variables
Latent Variable Models (cont.)

● “Qualitative Indicators” Provide Information on Latent Variables
  – Awareness
    • I could use rail as a substitute to truck service.
  – Sensitivity to Quality
    • I am willing to pay more for a mode with greater flexibility to accommodate emergency shipments.
  – Image
    • I like to use the most reliable technology
Latent Variable Model (cont.)

- Shippers Characteristics
- Shipment, Commodity, Mode Attributes

Logistics Costs

Choice

Latent Variables

Psychometric Indicators

Latent Variable Model
Latent Variable Model (cont)

- Transit Time of Mode $i$
- Availability of EDI* for Mode $i$
- Equipment Condition of Mode $i$
- Satisfaction with response of Mode $i$
- Level of effort to deal with Mode $i$
- Satisfaction with payment & billing of Mode $i$

*EDI: Electronic Data Interchange, which is a set of standards for structuring information that is to be electronically exchanged between and within businesses, organizations, government entities and other groups.
Latent Variable Model (cont)

- Significant improvement in log-likelihood
- Significant changes in some of the parameter estimates

\[\text{Truck Cost} = -0.266 + (\text{Transportation cost}) + 0.627(\text{Distance}) - 0.905(\text{Delivery time reliability}) \]
\[-0.466(\text{Value / ton}) - 4.67(\text{Equipment usability}) \]
\[+ 0.356[(\text{In transit stock holding cost}) + 0.0970(\text{Safety stock costs}) \]
\[+ 2.28(\text{Loss and damage})] - 0.769(\text{Perceived Quality})\]

\[\text{Rail Cost} = (\text{Transportation cost}) - 0.905(\text{Delivery time reliability}) - 4.67(\text{Equipment usability}) \]
\[+ 0.356[(\text{In transit stock holding cost}) + 0.0970(\text{Safety stock costs}) \]
\[+ 2.28(\text{Loss and damage})] - 0.769(\text{Perceived Quality})\]

\[\text{Intermodal Cost} = 1.65 + (\text{Transportation cost}) - 0.905(\text{Delivery time reliability}) - 4.67(\text{Equipment usability}) \]
\[+ 0.356[(\text{In transit stock holding cost}) + 0.0970(\text{Safety stock costs}) \]
\[+ 2.28(\text{Loss and damage})] - 0.769(\text{Perceived Quality})\]
Extension 4: Combining Revealed and Stated Preference Data

● Features
  – Bias correction through explicit specification of stated preference model
  – Joint estimation with all available data
Combining Revealed & Stated Preferences Data (cont)

- Significant changes in parameter estimates and t-stats

|                                | Estimates (t-statistics) |  |
|--------------------------------|--------------------------|--|---|
|                                | RP&SP                    | RP |   |
| Delivery time reliability      | 3.6 (-7.8)               | -0.91 (-1.0) |   |
| Equipment usability            | -1.4 (-7.8)              | -4.7 (-3.3)  |   |
| Discount rate                  | 0.20 (6.6)               | 0.36 (1.9)   |   |
| Stock out costs                | 0.029 (0.1)              | 0.097 (2.9)  |   |
| Loss and damage costs          | 5.0 (6.4)                | 2.3 (0.8)    |   |
References

Appendix B

Freight Economic Activity System Models
Economic Activity Models

- Spatial Price Equilibrium (SPE)
- Multiregional Input Output (MRIO)
Spatial Price Equilibrium (SPE) Models

- Demand and supply curves of each region/economic sector
- Deterministic demand behavior: there is commercial exchange of goods between two regions only if the price in the origin region plus the transport cost is equal to the price in the destination region
- Freight flows may be concentrated to a small number of OD pairs due to the deterministic nature of the model
SPE Models (cont.)

Equilibrium quantities and prices in Region A and Region B:

Region A

- Price: $P^*_A$
- Quantity: $Q^*_A$
- Demand and Supply curves

Region B

- Price: $P^*_B$
- Quantity: $Q^*_B$
- Demand and Supply curves
SPE Models (cont.)

Transport Cost A→B

\[ P_t = P_B - P_A \]

S-D: excess supply of Region A

D-S: excess demand of Region B

\[ Q_{AB} \]

\[ Q \text{ shipped A→B} \]
Multiregional Input-Output (MRIO) Models

- Application of economic production functions to freight demand
- Economic activities of production and consumption are classified into sectors:
  - Production
    - Goods manufacturing
    - Services
  - Consumption
    - Household
    - Public
    - Investments
    - Stock variations
    - Export
MRIO Models (cont.)

- Study area is divided into regions
- MRIO models also account for external (or ‘international’) trade
MRIO Models: Example of Sectors

- The input-output tables available for Italy are disaggregated in 17 sectors (11 of physical goods and 6 of services)
  - Agriculture and fishing
  - Energy
  - Ferrous/non-ferrous minerals and materials
  - Non-metal minerals and products
  - Chemical and pharmaceutical products
  - Machinery and metal products
  - Means of transport
  - Food and drink industry, tobacco
  - Textiles, clothing, leather and shoes
  - Paper, book trade, other industrial products
  - Wood, rubber
  - Civil constructions
  - Retail trade, hotels, public concerns
  - Transport and communications
  - Insurance and credit
  - Other sale-related services
  - Non sale-related services
MRIO Models: Inputs

● Input-output table (matrix of technical coefficients)
  – Characterizes intermediate demand (i.e. how much of sector $m$ production is required for sector $n$ production)

● Matrix of trade coefficients
  – Characterizes interregional trade.

● Final demand
  – The final demand of each sector in each region.

● Value of quantity coefficients
  – Used to transform flows in monetary units to physical quantities
MRIO Models: Steps

1. The following relationship is used to relate production and intermediate demand:

\[ K_{mn}^j = a_{mn}^j X_n^j \]

Where,

- \( K_{mn}^j \) = the value of the intermediate demand of the production in sector \( m \) (input) necessary for the production of sector \( n \) (output) in region \( j \)
- \( a_{mn}^j \) = technical coefficient that depends on the production “technologies” available in region \( j \)
- \( X_n^j \) = the value of the production of sector \( n \) in region \( j \)
2. By definition, the total supply (production and import) of sector $m$ in region $i$ must be equal to the total demand (intermediate and final) of section $m$ in region $i$. This leads to a system of simultaneous linear equations in which we solve for the value of production of each sector in each region.

3. Given the trade coefficients, OD matrices of region-to-region trade flows are produced. The values in these matrices are all in monetary units.

4. Given the value-of-quantity coefficients, the values in the region-to-region trade flow matrices are converted to physical freight units (e.g. tons or vehicles).
Appendix C

Aggregate/Disaggregate Modeling
References

Combining Aggregate and Disaggregate Models

Aggregate flows

P/C flows

OD flows

Assignment

Disaggregation

A

C

Aggregation

Disaggregate firms and shipments

Firms (agents)

Shipments

Logistics decisions
Modeling Steps

- **Step A**
  allocation of flows to individual firms at production (P) and consumption (C) ends

- **Step B**
  logistics decisions: chain type, mode, shipment size

- **Step C**
  aggregation of the individual shipments to OD flows for assignment
Step A: Allocation of Flows

- Aggregate P/C flows disaggregated to the level of decision-making unit
- General approaches:
  - Re-weighting
    - Use an existing sample or population and re-weight using marginal distributions
  - Synthetic
    - Draw from a sequence of conditional distributions
  - Hybrid
    - Begin with re-weighting and enrich the set of characteristics using synthetic draws
Step B: Logistics Chain Choice

Minimize: Total cost to transport a shipment of size $q$ between firm $m$ and firm $n$ using logistics chain $k$
Step C: OD Flows for Assignment

- Shipments for the same commodity type aggregated to OD flows in vehicles
- Summation over shipments
Calibration and Validation

● Aggregate calibration
  – Concerns different equilibrium situations
  – Coefficients of sub models are adjusted to better match aggregate data

● Validation
  – Inputs from a different year is used and the predicted OD flows are compared against the actual flows
  – Major discrepancies may lead to readjustment of model coefficients
Application

● National model systems for freight transport in Norway and Sweden

● Previous models
  – Norway: NEMO, Sweden: SAMGODS
  – Multi-modal assignment with deterministic logistics model

● Proposed model
  – Aggregate-Disaggregate-Aggregate (ADA) freight model system
Freight Model System: Norway and Sweden

- Two-step logistics cost minimization:
  - Step 1:
    Determine the optimal transshipment locations for each type of transport chain and OD region.
  - Step 2:
    Determine the shipment size and transport chain.
Freight Model System: Norway and Sweden (cont.)

Estimation, Calibration and Validation of the Model System

[Diagram showing the flow of data and models: P/C Model, P/C Matrix, Logistics Model, OD Matrices Model, Assignment, Link Flows, with inputs like National accounts, Foreign trade data, Prod/cons data, CFS, and outputs like CFS terminal data, Transport and logistics costs, Transport costs, OD information (flow data: road, sea), Traffic count data (especially road).]
Freight Model System: Norway and Sweden (cont)

- Shipment size (and frequency) and transport chain determined on the basis of deterministic costs minimization
  - 10 road vehicle types, 28 vessel types, 8 train types, 2 aircraft types
  - Container and non-container vehicle and vessel types
- P/C flows
  - Senders (P): more than 100,000 firms
  - Receivers (C): more than 400,000 firms
  - Result: 6 million firm-firm flows per year