THE CHOICE OF SHIPMENT SIZE IN FREIGHT TRANSPORT
INTRODUCTION

- Context
- Problem Statement
- General Objectives
- Thesis Outline
- Presentation Outline
Classic freight transport models are based on the four stages representation. It details:

1. The location decision
2. The supplier-customer decision
3. The mode choice
4. The route choice

This representation has shortcomings:

- The definition of origins and destinations is ambiguous
- The discrete nature of freight transport operations is absent
The purpose of this work is to investigate the difficulties and potential benefits of representing explicitly the choice of shipment size in spatialised freight transport models.
General Objectives

Selected requirements
- A representation of the freight transport system
- A widely valid model of choice of shipment size
- A reasonable complexity

Selected perspectives
- Logistic-based modelling of shippers’ preferences
- Simultaneous use of two modes for a given commodity flow
Thesis Outline

Part I: Framework and bibliography
- Chapter 1: Advances in freight transport modelling
- Chapter 2: Logistic issues and their modelling

Part II: Systems analysis and metrology
- Chapter 3: Freight transport systemic representation
- Chapter 4: Road-side survey protocol improvement
- Chapter 5: Econometric validity of the EOQ model

Part III: Microeconomic analysis
- Chapter 6: Shipment size and freight rates
- Chapter 7: Logistic imperatives and mode choice
Presentation Outline

- Introduction
- Part I: Systems analysis
- Part II: A simple modelling framework
- Part III: Improving the representation of costs
- Part IV: Logistic imperatives and mode choice
- Conclusion
Part I: Systems analysis

- Objectives
- Freight transport supply
- Freight transport demand
- Full representation

Based on Chapters 1, 2 and 3
Objectives
What should be represented

- A representation of the freight transport system should distinguish:
  - What is exchanged on the freight transport market
  - The formation of freight transport demand
  - The formation of freight transport supply

- This representation should be consistent with existing models
The decision unit

- **Shipment** definition (adapted from Guilbault *et al.* 2006):

  « a given amount of freight of a given type, handed over at given place and time, by a unique shipper in order to be carried as a whole towards a given, unique receiver »

- What is exchanged on the freight transport market: *door-to-door shipment transport operations*
Freight transport supply (1/2)

Principles

- Carriers produce door-to-door shipment transport operations with given characteristics
  - Date, place, travel duration, cost, reliability, etc.

- These operations most often combine transshipments

- General characteristics of the freight transport technology:
  - Economies of scale
  - Economies of scope
Freight transport supply (2/2)

Representation

- Shipment transport.
- Elementary transport operations.
- Fixed assets location

Logistics of carriers.

Decision

Observable

- Shipments door-to-door transport.
- Traffic.
- Industrial land use
Freight transport demand (1/2)
Principles

- Shippers consume freight transport operations of given characteristics
  - Date, place, travel duration, cost, reliability, etc. (and not mode or route)
- The preferences of shippers derive from those of their customers: goods provide utility to customers if they are available.
- Logistic of shippers:
  
  «The art and manner to provide a given commodity at the right time, right place, at the lowest cost and with the best quality»

Definition from ASLOG, French Association for Logistic
Freight transport demand (2/2)

Representation

Location of production facilities

Supply decisions

Logistic network design

Shipment sending

Observation

Industrial land use.

Consumption-production flows

Commodity flows

Shipments door-to-door transport.
Full representation

Introduction
I Systems Analysis
II Modelling Framework
III Costs Representation
IV Logistic Imperatives
Conclusion

Objectives
Decision Unit
Supply
Demand

Full Representation
Part II : A simple modelling framework

- Framework description
- Costs and trade-offs
- Extensions

Based on Chapters 3, 6 and 7
A simple supply chain
Characteristics

- Many modelling options:
  - Demand: continuous/periodic, deterministic/stochastic, etc
  - Commodity: perishable or not
  - Customers: backlogging or not
  - Transport costs: linear or not

- Many features disregarded by construction:
  - More complicated spatial interactions (one-to-many, many-to-many)
  - Production/Marketing/Transport interactions
  - Intermediate inventories
  - Advanced logistic strategies (MTO-MTS, postponement, highly variable demand)
  - Market structure and contracts, information availability
Framework description (3/3)
Costs taken into account

- Transport costs
- Inventory costs
  - Pipeline
  - Cycle
  - Safety
- Customer costs
Costs and trade-offs (1/3)
Place in the freight transport system
Costs and trade-offs (2/3)
The classic freight transport modelling approach
Costs and trade-offs (3/3)
Some logistics-based microeconomic models

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Framework
Costs and trade-offs
Extensions

Transport technology

- Pipeline inventory costs
- Transport costs
- Customer dissatisfaction costs

EOQ
Baumol Vinod

Cycle inventory costs
Safety inventory costs

Production
Marketing
Etc.

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Extensions (1/2)

Improving the representation of costs

- Transport technology
- Cycle inventory costs
- Pipeline inventory costs
- Transport costs
- Safety inventory costs
- Customer dissatisfaction costs

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Framework
Costs and trade-offs
Extensions

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Extensions (2/2)

Logistic drivers of freight transport demand
Part III : Improving the representation of costs

- Objectives
- Qualitative observations
- Carriers
- Shippers
- Market equilibrium
- Some results
- Conclusion

Based on Chapter 5 and 6
Objectives

- Model the freight transport market equilibrium with:
  - Explicit shipment sizes
  - Detailed description of the transport technology
  - Endogeneous demand with explicit logistic decisions
- Explain some observed qualitative properties of freight transport prices
- Make a first step towards a comprehensive model of prices simple and realistic enough to be included in a spatialised freight transport model
Qualitative observations

- **Market studied**: industrial freight transport by trucks
- **On a given OD pair, price schedule** \( p(s) \) **properties**:
  - \( p(0) > 0 \)
  - Unit rates decrease,
  - Flat for large shipment sizes
- **Objective**: finding the minimal set of hypotheses accounting for these properties
Spatial configuration

Technology:
- Each transport operation implies a shipment specific access cost $b$ and a joint hauling cost $c$
- Vehicles of capacity $S$
- Fleets are fully flexible, no routing, no backhaul.

Simplifying assumption: shipments can be of size 1, 2 or 3. Vehicle capacity is 3. (Objective: to avoid the bin-packing problem)
Carriers are price-taker, profit maximising.

Carriers can freely enter and leave the market.

Denote $Q_i$ the amount of shipments of size $i$ a carrier will have to transport.

For each carrier, the demands for transport of each shipment size are stochastics. They can decide its expected value $q_i$

$$Q_i \approx U \left( \left(1 - \frac{K_s}{2}\right)q_i, \left(1 + \frac{K_s}{2}\right)q_i \right)$$
Cost function

- **Separability of the cost function:**
  \[ C(Q_1, Q_2, Q_3) = C(Q_1, Q_2) + C(Q_3) \]

- **Full truck load:**
  \[ C(Q_3) = (b + c)Q_3 \]

- **Less than truck load: two cases**
  - \( Q_1 \geq Q_2 \): \( Q_2 \) full trucks + \( Q_1/3 \) full trucks
  - \( Q_1 < Q_2 \): \( Q_1 \) full trucks, \( Q_2 - Q_1 \) partially empty trucks
  \[ C(Q_1, Q_2) = b(Q_1 + Q_2) + \frac{c}{3} \Delta + cQ_2 \]
  \[ \Delta = (Q_1 - Q_2)^+ \]
Profit maximisation conditions:

\[ \forall i, \quad \frac{\partial}{\partial q_i} \mathbb{E}[C] = p(i) \]

For a given transport demand \( (n_i^s) \):

\[
\begin{align*}
    p(1) &= b + c \frac{\partial \delta}{\partial q_1} (n_1^s, n_2^s) \\
    p(2) &= b + c + c \frac{\partial \delta}{\partial q_2} (n_1^s, n_2^s) \\
    p(3) &= b + c
\end{align*}
\]
Price schedules for given demands

- Carriers
- Shippers
- Market Equilibrium

Some Results

Conclusion

Price schedules for given demands

<table>
<thead>
<tr>
<th>Shipment size (s)</th>
<th>Transport price (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Access cost</td>
</tr>
<tr>
<td>2</td>
<td></td>
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<tr>
<td>3</td>
<td></td>
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</tbody>
</table>

- $n_1^s / n_2^s = 0.4$
- $n_1^s / n_2^s = 0.85$
- $n_1^s / n_2^s = 1.15$
- $n_1^s / n_2^s = 1.6$

Full transport cost

Access cost

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Shippers
Description

- Shippers are described by:
  - The exogenous commodity flow rate $Q$
  - The exogenous commodity value of waiting time savings $a$ (distributed in the population)

- Shipment sizes are endogeneous. Their choice is EOQ-like

- As a result, transport operations of shipments of distinct sizes are substitutes
Market Equilibrium

- The sequence of decisions:
  1. Carriers display their prices
  2. Each shipper chooses a carrier
  3. Given this carrier’s price schedule, each shipper chooses the size of its shipments

- The market equilibrium exists and is unique
Some results
Cost structure and market structure

- The costs of carriers are characterised by:
  - Constant returns to scale
  - Increasing returns to scope

- The costs of shippers are endowed with increasing returns to scale. This is due to the presence of user inputs.

- Price variability is not necessarily evidence of market distortion

- No simple relationship between model parameters and the average loading factor

- Information availability: a rationale for contracts heterogeneity
Part IV: Logistic imperatives and mode choice

Based on Chapter 7
Consider a simple supply chain
- Periodic review
- Linear transport costs
- Stochastic demand
- Customers wait (backlogging hypothesis)

There is an optimal logistic policy
- Aim: keeping the destination inventory level around a target: the safety stock
- Outcome of a trade off between inventory costs and customer dissatisfaction costs
One mode (2/2)
Microeconomic properties

- It is possible to calculate the derivative of the full cost function with respect to the duration of the transport operation. This gives the **value of time** of the shipper.

\[
\alpha = a_c + \frac{\zeta}{2\sqrt{1 + d}} \sigma
\]

- Pipeline inventory cost
- Value of **supply chain reactivity** (proportional to the relative variance of the demand)

- This framework can be extended to:
  - Stochastic travel time (and yields a value of reliability)
  - Two modes
Two modes
Basic presentation

- Combining two modes optimally is possible but not easy: a naive heuristic is used

- Microeconomic mechanism: increasing the heavy mode share implies:
  - A lower transport cost
  - A lower supply chain reactivity
    - Higher inventory costs
    - Higher customer dissatisfaction

- Used together, distinct modes have asymmetric roles
Conclusion
Assessment

Making the shipment size explicit in freight transport models needs:

- An improved systems analysis
- Some empiric validation of the existing microeconomic theory
- A detailed representation of technology and costs

Outcomes:

- A better knowledge of the cost structure of carriers
- The strong difference between the costs of carriers and of shippers
- A first step towards the microeconomic modelling of supply chains (with a logistics-based value of time)
The big issue: introducing shipment size into fully-fledged spatialised simulation models

Issues

- The supply side
  - Many constraints have been left aside
    - Spatial constraints: empty return, more complex routing
    - Temporal constraints: wait or leave?
  - Consolidation cannot be represented

- The demand side
  - More complex logistics
    - Intermediate inventories
  - MTS/MTO...
  - Distinct products

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The big issue: introducing shipment size into fully-fledged spatialised simulation models

Perspectives

- Mode choice should be easy (it is strongly compatible with EOQ-like models)
- A statistic approach may prove efficient for prices (but what about the linkage between shipment movements and vehicle movements?)
- A statistic approach (EUNET2.0-like) can be used for logistic networks (once shippers logistics is distinguished from carriers logistics)
- Data collection protocols should be adapted