FREIGHT MODE CHOICE

Outline

- Overview
- Overview of Freight Mode Choices
- Intermodalization
- Containerization
- Modal Choice and Intermodal Transport Costs
- Transport chain choices
- Empirical studies
- Utah Statewide Model

Overview

- Urban freight movements: mode choice is trivial; the coverage provided by non-road modes is extremely limited. Our focus is on non-urban movements
- Who makes the decision?? The shipper!
- Aggregate level mode choice modeling: it is often treated using a Multinomial Logit (MNL) formulation based on generalized costs, as described for passenger transportation
- MNL limitation: the information can only capture those elements of mode choice incorporated in the generalized costs

Overview

- Cost is certainly an important component of the generalized cost function
- Cost is a function of the volumes a carrier moves between each O–D pair
- There are interactions inside mode choice which go beyond that encountered between passengers and public-transport operators. This problem is often ignored at high levels of aggregation

Overview

- Transport chain choices
  - The number of legs in the transport chain (direct transport, two legs, etc.).
  - Use (and location) of consolidation and distribution centers for road and rail transport, but also including ports and airports
  - Mode (road, rail, sea, and air) used for each leg, including choice of vehicle/vessel type and loading unit (unitized or not)

Freight Mode Choices- Road

- Road continues to be among the leading modes due to its:
  - reliability
  - speed –few stops
  - flexibility –large road network infra
  - service level -door to door
  - easiness of administration -easy trackability
  - part of intermodalizm –combination to other modes
  - but with an image of ”not very green mode”-
- Services are produced by specialized transportation or logistics service companies and producers’ own units, which either own or lease the equipment

Freight Mode Choices- Rail

- Rail transportation is economical and reliable
- High investments needed-need for update in most countries
- Fixed routes –poor flexibility also for services
- National isolated networks (lack of cooperation)
- Generally fails to provide the flexibility needed by modern logistics customers
- Several cargo handling phases
- Not very fast
- Very efficient and green! CSX: 470 ton.miles per gallon
- Rail is normally part of intermodal transport

Freight Mode Choices- Air

- Suitable for damage sensitive goods, high spoilage or high value goods
  - Previously only express goods, not part of regular transports
  - spare parts and components - Vaisala
  - electrical equipment - computers
  - seasonal goods - xmasmarket, clothing
  - Flowers and perishables
- High variable costs (fuel)
- Extremely high growth of air traffic-infra left behind
- Sensitive to interruptions (e.g., weather)
- Terminal centered operations – use of hubs

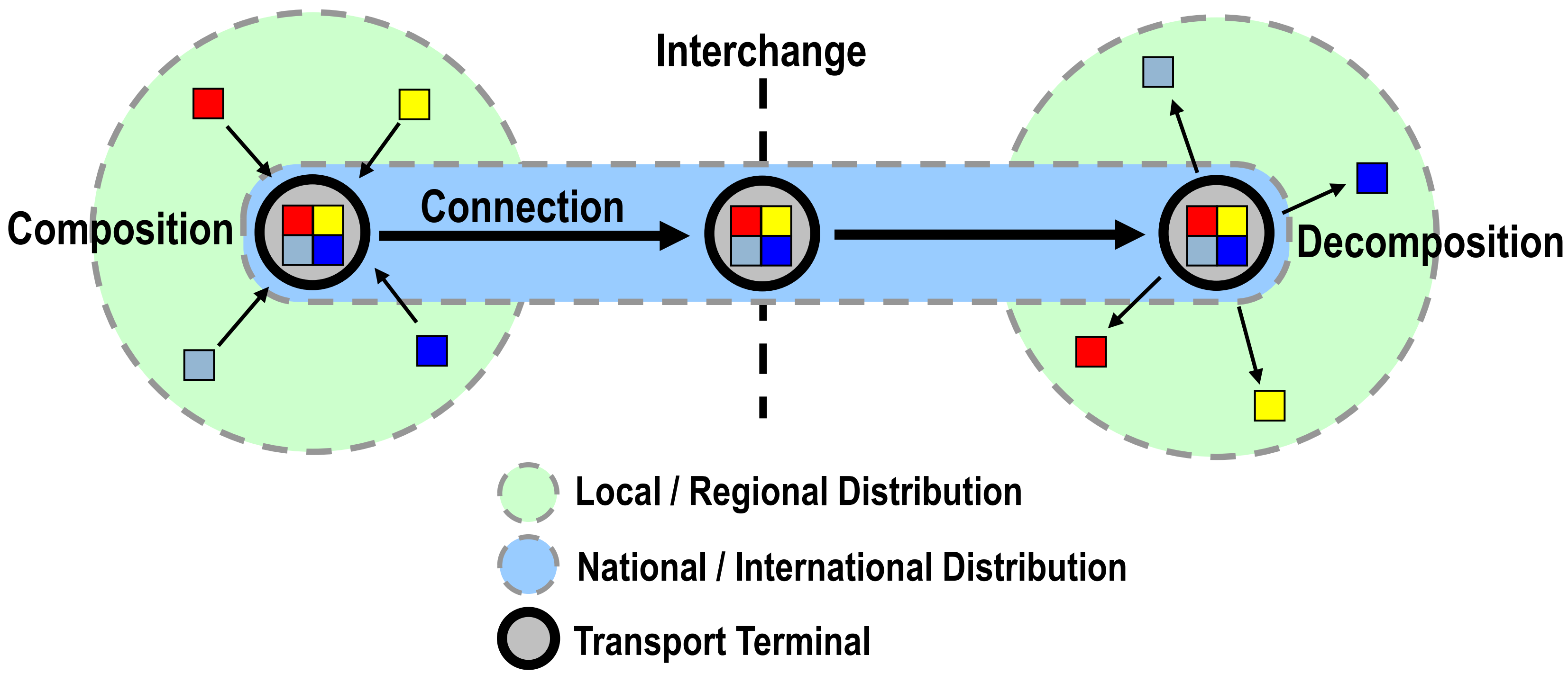
Freight Mode Choices- Maritime

- Waterway types include high sea, short sea, rivers and canals
- Sea transport is the most important component of intermodalizm
- Cargo types: dangerous materials, volume shipments, bulky and heavy shipments, high breakage goods, etc.
- Speed -The actual voyage time is comparatively slow
- Risk of delays due to: pre-shipment delays, delay at discharge port, and unexpected delays due to bad weather, missed tides
- Cost economies

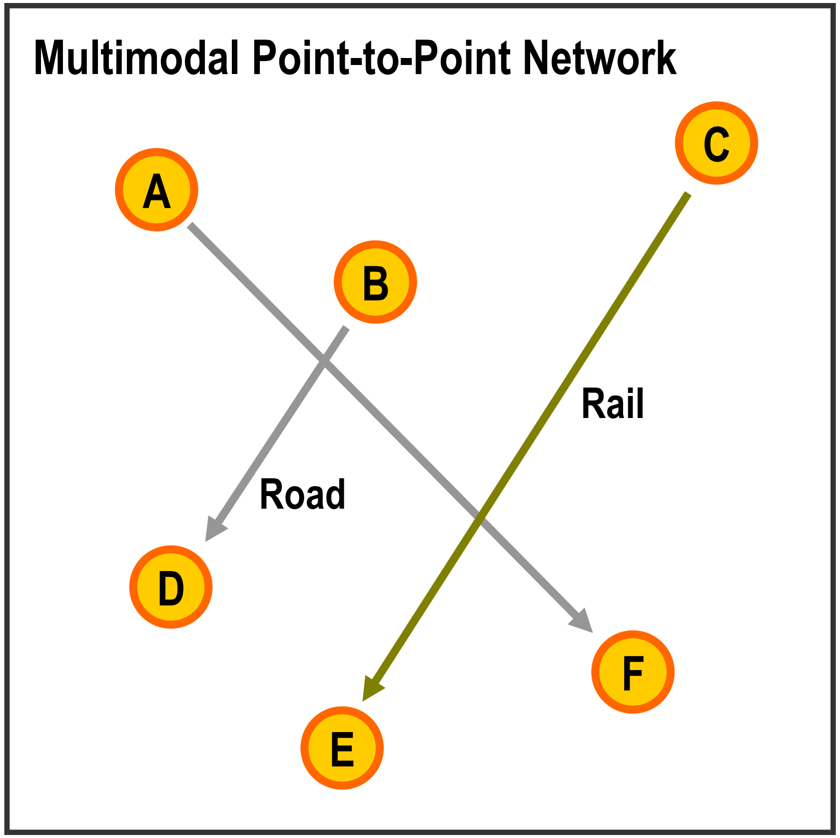
Intermodalizm

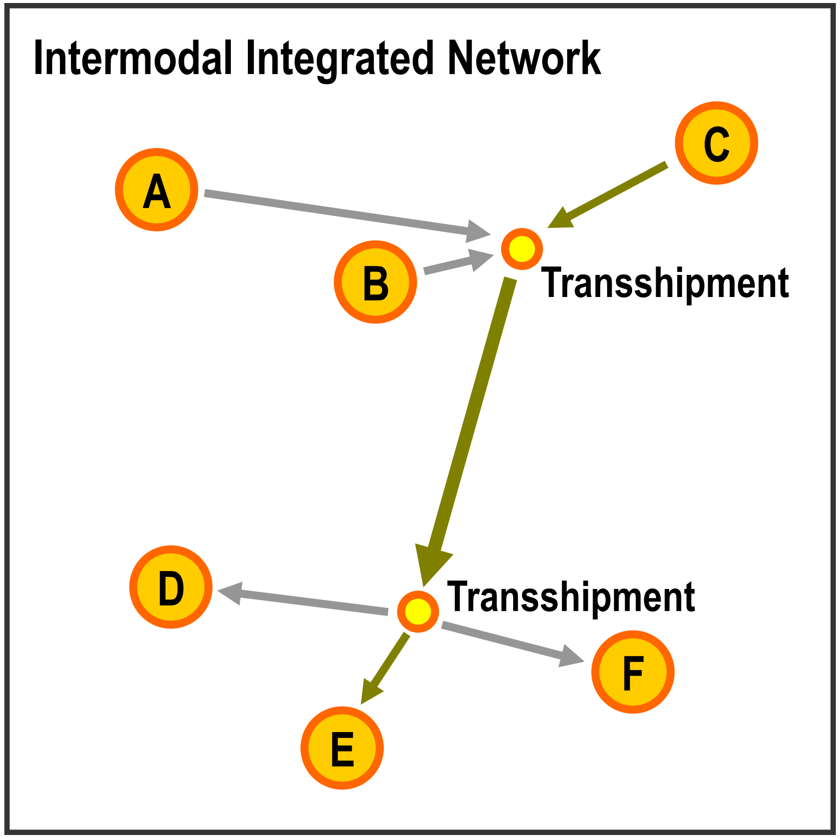
- Integrated transport systems
  - Use of at least two different modes in a trip from origin to destination through an intermodal transport chain.
  - Brought about in part by technology.
  - Techniques for transferring freight from one mode to another have facilitated intermodal transfers.
  - The container has been the major development:
    - Becoming a privileged mode of shipping for rail and maritime transportation.

Intermodal Transport Chain



Multimodal and Intermodal Transportation





Containerization

- Container
  - Load unit that can be used by several transport modes.
  - Usable by maritime, railway and road modes.
  - Foremost expression on intermodal transportation.
  - Rectangular shape that can easily be handled.
  - Reference size is the Twenty-foot Equivalent Unit (TEU).
  - The most common container is the 40 footer (12 meters)

Containerization

- Advantages of containers
  - Standard transport product:
    - Can be manipulated anywhere in the world (ISO standard).
    - All segments of the industry have access to the standard.
    - Specialized ships, trucks and wagons.
  - Flexibility of usage:
    - Transport a wide variety of goods ranging.
    - Raw materials, manufactured goods, cars to frozen products.
    - Liquids (oil and chemical products).
    - Perishable food products ("reefers"; 50% of all refrigerated cargo).
  - Management:
    - Unique identification number and a size type code.
    - Transport management no not in terms of loads, but in terms of unit.

Containerization

- Costs:
  - Low transport costs,
- Speed:
  - Transshipment operations are minimal and rapid.
  - Containerships are on average 35% (19 knots versus 14 knots) faster than regular freighter ships.
- Warehousing:
  - Its own warehouse.
  - Simpler and less expensive packaging.
  - Stacking capacity on ships, trains (doublestacking) and on the ground.
- Security:
  - Contents of the container is unknown to shippers.
  - Can only be opened at the origin, at customs and at the destination.
  - Spoilage and losses (theft), especially those of valued commodities, are therefore reduced.

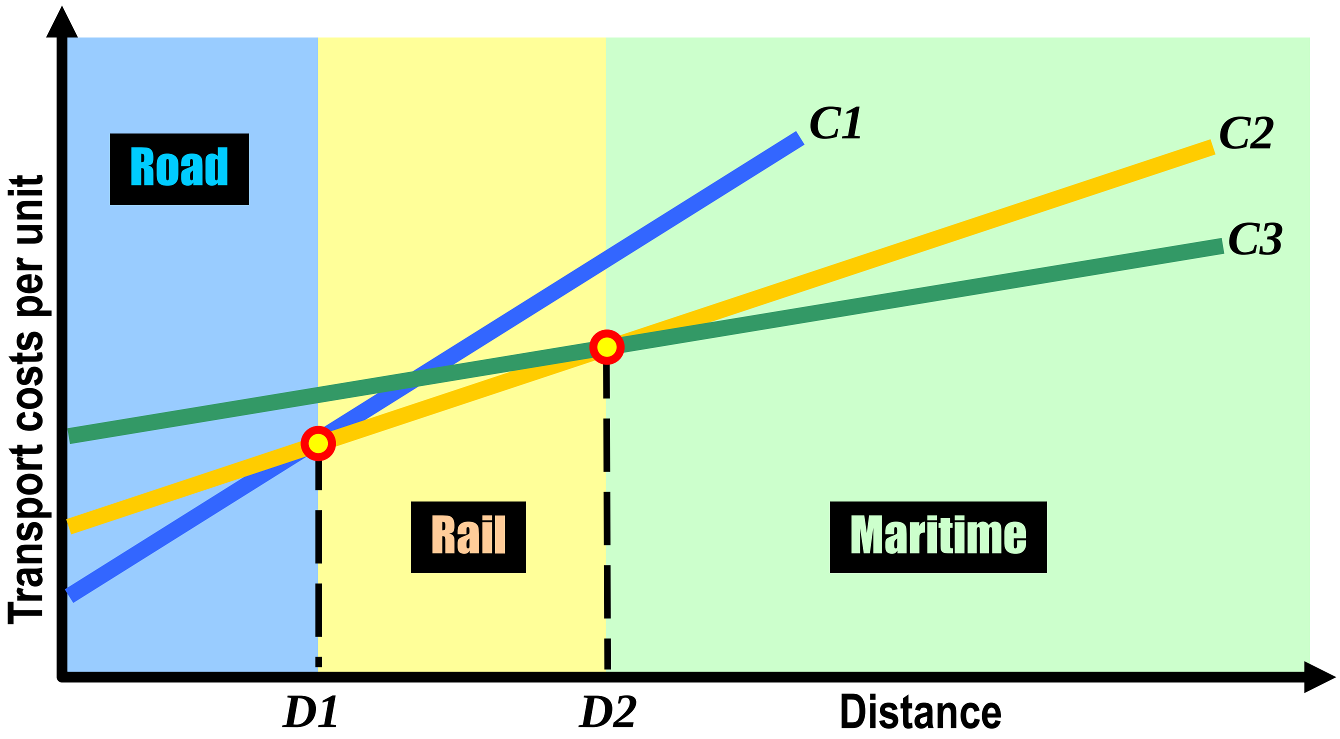
Containerization

- Disadvantages
  - Consumption of space.
  - Infrastructure costs:
    - Container handling infrastructures, such as giant cranes, warehousing facilities and inland road and rail access, represent important investments for port authorities and load centers.
  - Stacking.
  - Management logistics:
    - Requires management and tracking of every container.
  - Empty travel.
  - Illicit trade:
    - Common instrument used in the illicit trade of drug and weapons, as well as for illegal immigration.
    - Worries about the usage of containers for terrorism.

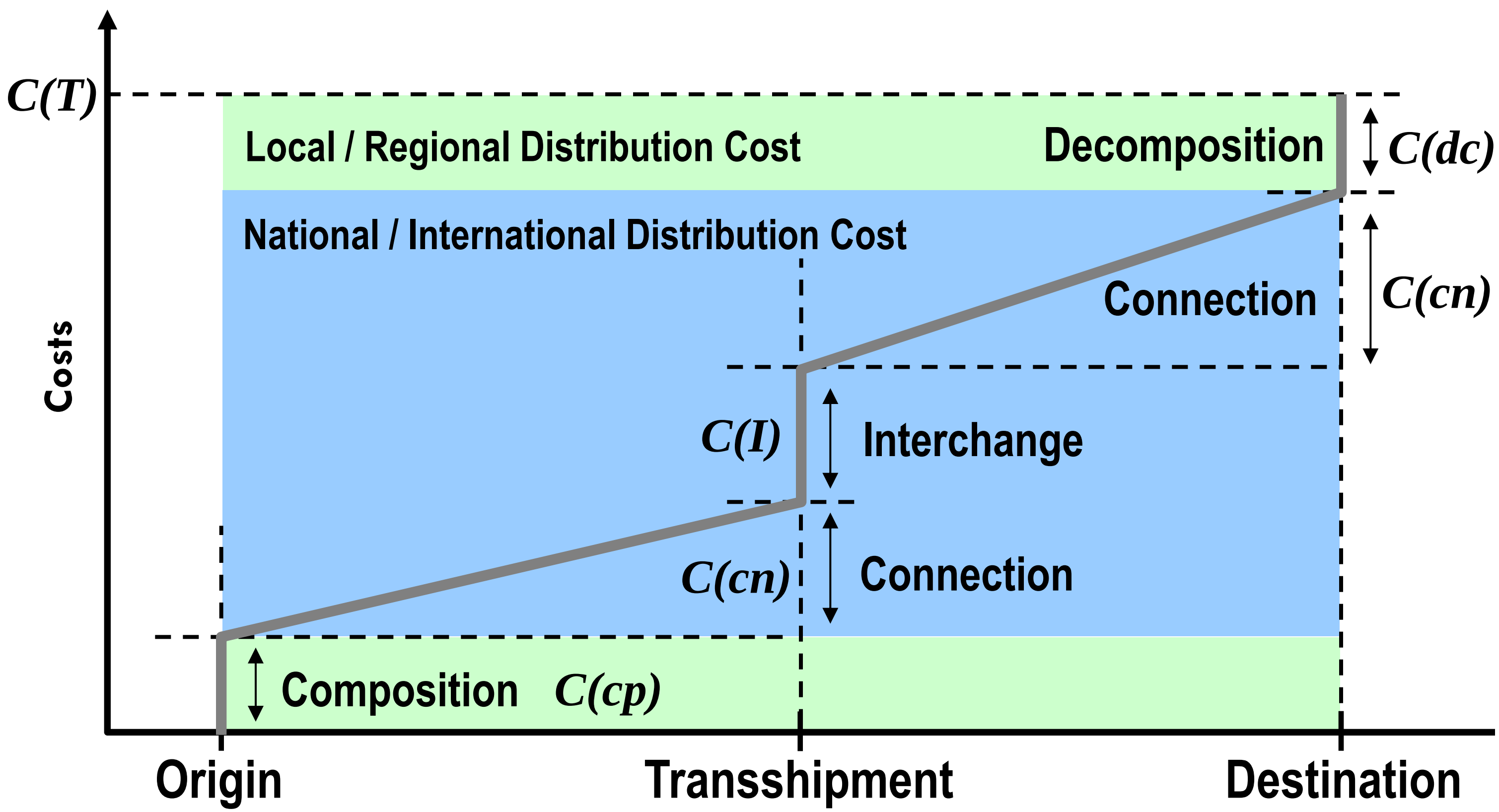
Modal Choice and Intermodal Transport Costs

- Modal choice
  - Relationship between transport costs, distance and modal choice:
    - Road transport is usually used for short distances (from 500 to 750 km).
    - Railway transport for average distances.
    - Maritime transport for long distances (about 750 km).
  - Intermodalizm:
    - The opportunity to combine modes.
    - Find a less costly alternative than an unimodal solution.
  - Efficiency of contemporary transport systems:
    - Capacity to route freight.
    - Capacity to tranship it.

Distance, Modal Choice and Transport Costs



Intermodal Transportation Cost Function



Transport Chain Choices (TCC) – 1

- Inventory logistics
  - Large inventories reduce the risk of not being able to serve demand
  - Small and frequent deliveries lead to higher transport and stockout costs but lower inventory costs
  - A trade-off between transport and keeping inventories
  - Wholesalers can be included both at the production and the consumption end. Production-Wholesale-Consumption (PWC) matrices are inputs of modeling TCC
  - Assuming that the total annual demand for a good (Q) is known, we only need to determine shipment size (q) or the frequency of ordering (f) because $Q = f * q$

Transport Chain Choices (TCC) – 2

- The shipment size to be determined: the size of the shipment as it arrives at the destination end C
- The total annual logistics costs G of commodity *k* transported between firm *m* in production zone *r* and firm *n* in consumption zone *s* of shipment size *q* using logistic chain *l*:

$$G_{rskmnql} = O_{kq} + T_{rskql} + D_k + Y_{rskl} + I_{kq} + K_{kq} + Z_{rskq}$$

- G is total annual logistics costs; O, order costs; T, transport, consolidation and distribution costs; D, cost of deterioration and damage during transit; Y, capital costs of goods during transit; I, inventory costs (storage costs); K, capital costs of inventory; and Z, stockout costs

Transport Chain Choices (TCC) – 3

- Optimal shipment size is the one that minimizes logistics cost. De Jong and Ben Akiva (2007) solve an optimization model and show that the optimal shipment size for commodity k is:

$$q_k = \sqrt{\frac{(o_k \cdot Q_k \cdot 2)}{(w_k + d \cdot v_k)}}$$

where o is the constant unit cost per order; Q the annual demand (tons per year); *d* the discount rate (per year); *w* the storage costs per unit per year; and *v* the value of the goods that are transported (per ton)

Transport Chain Choices (TCC) – 4

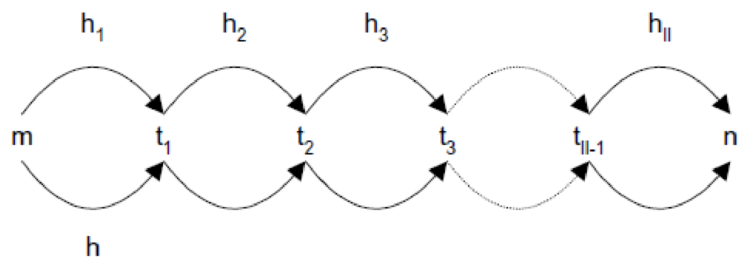
- Transport logistics
  - As is discussed, consolidation reduce transport costs

Symbols used for logistic chains	
Sender	m
Receiver	n
Logistic chain	l
Commodity type (omitted)	k
Value	v
Mode/vehicle type/loading unit	h
Transshipment location	t
Leg	i
Number of legs	I_l

  - No index for commodity types as they are independent

Transport Chain Choices (TCC) – 5

- The logistic chain *l* consists of a chain of modes and transshipment locations



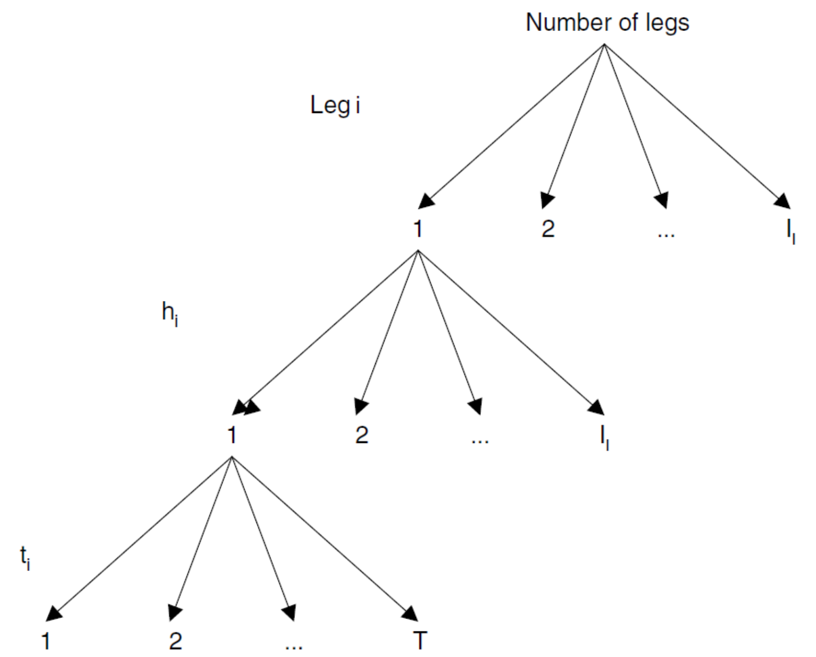
- Let *i* denote a leg of logistics chain *l*; and the number of legs of logistic chain *l* is I_1
- At consolidation centers t_1 till t_{I1-1}, goods change modes
- The logistic chain can now be written as a series of mode-transshipment location points:

$$l = \{(h_1, t_1), (h_2, t_2), \ldots, (h_{\mathrm{Il}}, n)\}$$

- Each pair indicates a leg i, i = 1,. . ., I_1

Transport Chain Choices (TCC) – 6

- So, the problem is a three sub choices within *l*



- The choice of transport chain is determined on the basis of the same logistics costs function as used for shipment size
- A random utility discrete choice model can be employed to model the choice problem

Aggregate mode choice models

$$log\left(\frac{S_i}{S_j}\right) = \beta_0 + \beta_1(P_i - P_j) + \sum_w \beta_w(x_{iw} - x_{jw})$$

$\left(\frac{S_i}{S_j}\right)$: ratio of market share of mode i to the market share of mode j

$(P_i - P_j)$: transportation cost of mode i and j

$(x_{iw} - x_{jw})$: are the difference in attributes (w= 1,2,…n) of mode i and j

Empirical studies – 1

- Samimi et al. (2011)
  - Competition between rail and truck in the US
  - Probit and logit binary choice models
  - Shipping cost is a central factor for rail, while road shipments are more sensitive to haul time
  - Mode choice is not sensitive to fuel price – even a 50% increase in fuel cost does not cause a significant modal shift between truck and rail
  - A 150% increase in fuel price shifts around 7% of total shipments from truck to rail

Empirical studies – 2

- Wang et al. (2013)
  - Modal behavior in the three zones in Maryland, US
  - Binary probit and logit models
  - There is no major difference between the probit and logit models
  - Shipments from Washington D.C show a negative propensity to use truck, and shipments from remainder of Maryland show a positive propensity to use truck
  - Statistically significant variables: nondurable manufacturing, high value of time, import, export, transportation mileage ratio in origin zone and destination zone, and fuel cost

Empirical studies – 3

- Arunotayanun and Polak (2011)
  - Stated preference data collected in Java, Indonesia
  - Mixed logit model, mixed multinomial logit, and latent class model
  - Taste heterogeneity: situations in which different decision making agents take into account different factors or take the same factors into in different ways than others
  - The study finds presence of significant levels of taste heterogeneity, only some of which can be accounted for by conventional commodity-type based segmentations

Empirical studies – 4

- Rich et al. (2009)
  - Freight choice behavior in Oresund
  - Weighted discrete choice model

Commodity group	Tonnage (mill)	VOT (€/ton/h)
Agriculture products	30	€ 3.07
Food and feed	64	€ 2.25
Wood, cork, textile fibres, etc.	50	€ 2.60
Non-liquid fossils	27	€ 0.18
Oil products (dangerous freight)	247	€ 0.08
Chemical products (dangerous freight)	36	€ 1.36
Ore products	23	€ 1.53
Metallurgic products	24	€ 4.01
Paper mass	10	€ 2.55
Stone, sand, concrete, and fertilisers	144	€ 1.77
Machines	24	€ 5.13
Manufactured goods	62	€ 2.29
General cargo	6	€ 4.76
Total	747	€ 1.529 (weighted average)

Utah Statewide Model – 1

Long-Haul
Commodity Flow Freight Model

Generation	Trip end production & attraction in tons by 12 commodity groups
Distribution	Use gravity models to link together trip ends
Mode Share	Determine tonnage moved by truck & other modes
Assignment	Assign medium & heavy trucks to roadway

Short-Haul
Commercial Vehicle & Truck Model

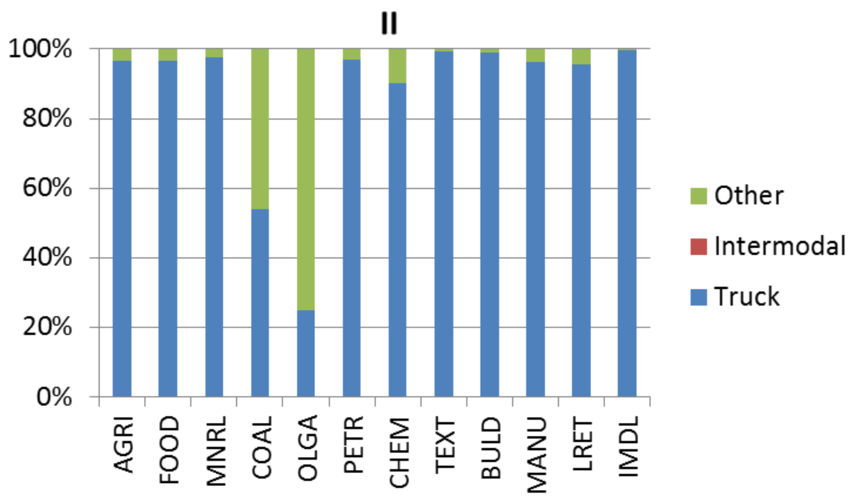
Generation	Trip end production & attraction in vehicles
Distribution	Use gravity models to link together trip ends
Assignment	Assign light, medium & heavy commercial vehicles & trucks to roadway

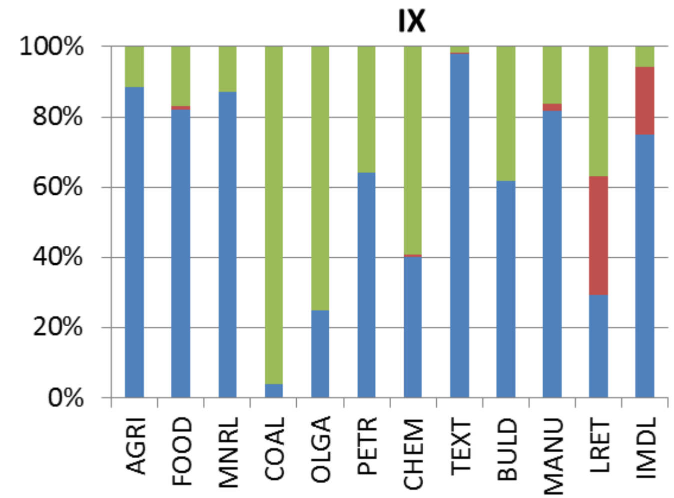
Utah Statewide Model – 2

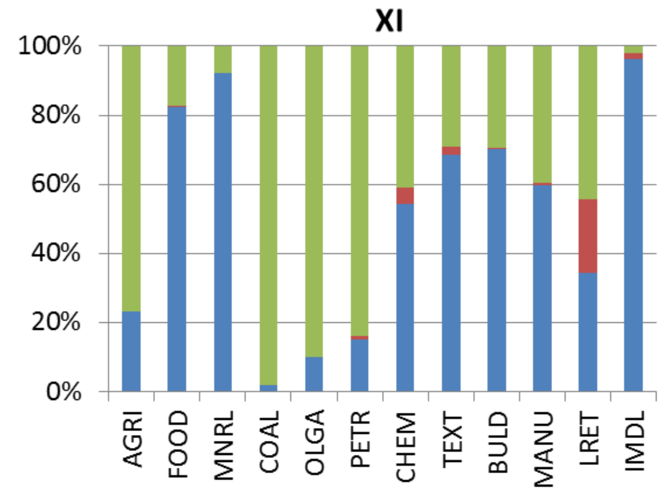
- **Long haul only**
- **Modes**
  - **Truck – primary mode & purpose of model**
  - **Intermodal (IMX) – to identify truck element**
    - Goods moved by combination of TRUCK and RAIL
    - Connections happen at railroad terminals
    - No ports and airports terminals
  - **Other – modes not assigned**
    - Pipeline and air
    - These modes are not assigned
- **Mode Share**
  - **Mode shares determined by Transearch**
  - **Exceptions:**
    - Coal
    - Oil and gas

Utah Statewide Model – 3

Mode shares







- *Most II goods moved by truck*
- *IX & XI goods have larger share moved by modes other than truck*
- *Mineral, which had very high tonnage, is dominated by truck mode*

Note: internal-internal (II), internal-external (IX), external-internal (XI), and external-external (XX)

Utah Statewide Model – 4

Payload factors

Average tons/truck

	Commodity	Average Payload (Tons)
1	Agricultural/meat/fish	23.5
2	Prepared foodstuff	23.1
3	Metal & Nonmetal Ores	26.3
4	Coal	48.4
5	Crude Petroleum & Gas	30.9
6	Petroleum or Coal Products	32.3
7	Chemicals	18.7
8	Textile & Paper	13.5
9	Building material & machinery	22.6
10	Manufactured equipment	16.5
11	Lumber & Retail	19.5
12	Intermodal & Mail	25.9

Florida Statewide Model – 1

*Model structure based on the Aggregate-Disaggregate-Aggregate (ADA) framework***

- Disaggregation of commodity flows at their production and consumption ends to firm-to-firm flows, shipping and receiving firms paired then treated as a single behavioral unit
- Modeling of logistics decisions that are made by the shipper-receiver pair based on evaluation of the total transport and logistics costs on available paths; and
- Aggregation of individual shipments to origin and destination zones for network assignment purposes

*** implemented in Norway and Sweden by de Jong and Ben-Akiva*

Florida Statewide Model – 2

Total Costs = Transport costs + Non-Transport costs

Non-Transport Costs

=

ordering

+

carrying

+

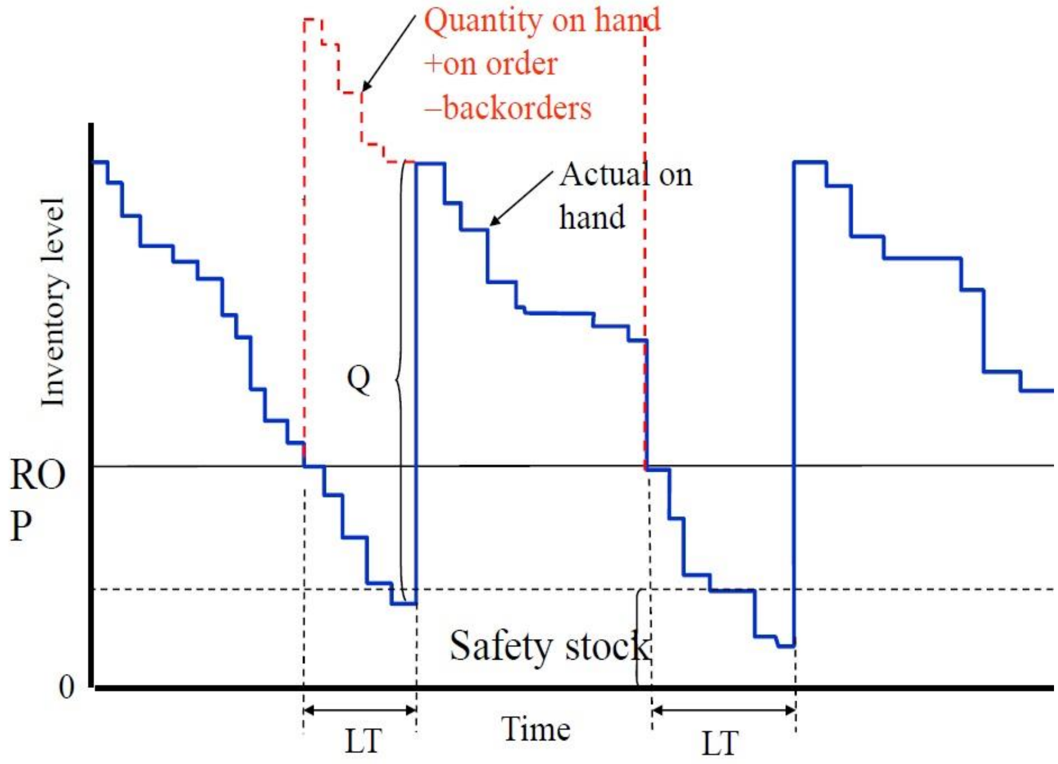
damage

+

Inventory in-Transit

+

Safety Inventory



Florida Statewide Model – 1 (Total cost)

$$G_{mnql} = \beta_{0ql} + \beta_1 \times \left(\frac{Q}{q}\right) + T_{mnql} + \beta_2 \times j \times v \times Q + \beta_3 \times t_{mnl} \times j \times v \times \frac{Q}{365} + (\beta_4 + \beta_5 \times v) \times \frac{q}{2} + v \times a \times \sqrt{(LT \times {\sigma_Q}^2) + (Q^2 \times {\sigma_{LT}}^2)}$$

Ordering Cost | Transport and Handling Cost | Damage Cost | Inventory in-transit cost | Carrying Cost | Safety Stock Cost

Variable or Parameter	Description or Interpretation (of Parameters)	Source
G_{mnql}	Logistics cost (shipper m and receiver n with shipment size q and logistics chain l)	Calculated in the model
Q	Annual flow in tons	FAF
q	Shipment size in tons	Variable
β_{0ql}	Alternative-specific constant	Parameter to be estimated
β_1	Constant unit per order	Parameter to be estimated
T	Transport and intermediate handling costs	network skims, survey data
β_2	Discount rate	Parameter to be estimated
j	Fraction of shipment that is lost or damaged	Survey data or assumed value
v	Value of goods (per ton)	FAF data
β_3	Discount rate of goods in transit	Parameter to be estimated
t	Average transport time (days)	Lookup table (or skims), survey data
β_4	Storage costs per unit per year	Parameter to be estimated
β_5	Discount rate of goods in storage	Parameter to be estimated
a	Constant, set safety stock a fixed prob. of not running out of stock	Survey data or assumed value
LT	Expected lead time (time between ordering and replenishment)	Lookup table (or skims) , survey data
σ_Q	Standard deviation in annual flow (variability in demand)	Survey data, assumed value
σ_{LT}	Standard deviation of lead time	Lookup table (or skims), survey data

Equation modification

$$G_{mnql} = \beta_{0ql} + \beta_1 \times \left(\frac{Q}{q}\right) + T_{mnql} + \beta_2 \times j \times v \times Q + \beta_3 \times t_{mnl} \times j \times v \times \frac{Q}{365} + (\beta_4 + \beta_5 \times v) \times \frac{q}{2} + a \times \sqrt{(LT \times {\sigma_Q}^2) + (Q^2 \times {\sigma_{LT}}^2)}$$

Ordering Cost | Transport and Handling Cost | Damage Cost | Inventory in-transit cost | Carrying Cost | Safety Stock Cost

- ✓ Term "j" is redundant *(the fraction of shipment that is lost or damaged)*
- ✓ Unit = tons (safety inventory level), should be multiplied by the cost of holding safety inventory.
- ✓ Only "Transport", "Inventory in-transit" and "Safety stock" costs are reliant on "cost" and "time" from skims (the model performs the shipment size choice before mode choice).

$$G_{mnql} = \beta_{0ql} + T_{mnql} + \beta_3 \times t_{mnl} \times v \times \frac{Q}{365} + \beta_5 \times v \times a \times \sqrt{(LT \times {\sigma_Q}^2) + (Q^2 \times {\sigma_{LT}}^2)}$$

Transport and Handling Cost | Inventory in-transit cost | Safety Stock Cost

Florida Statewide Model – 1 (Product and Supply Chain Types)

Safety Stock Cost

- Depends on product type
- Depends on supply chain type and service level
- Depends on product demand patterns

Functional Products	Innovative Products
Mature product	Early life cycle stage
Low product variety	High product variety
Predictable demand	Unpredictable demand
minimize inventory	Deploy significant buffer stocks
Greater reliance on low cost modes	Greater reliance on fast and reliable modes

Categorizing commodities

Different parameters

	Functional Product	Innovative Product
Efficient Supply Chain	MATCH	MISMATCH
Responsive Supply Chain	MISMATCH	MATCH

Florida Statewide Model – 1 (Model Run Comparisons)

Commodity	**Wood Products**		Origin FAF	**129** *(Florida, remainder)*
Segment	**Internal - Internal**		Destination FAF	**123** *(Florida, Orlando)*

Cost type ($)	Formula	Truck	Rail	Air	Water
B_0	*Constant*	2,788.9	2,739.9	99,999,999	99,999,999
Transport	$Q*C$	247.7	266.3	4,406.4	N/A
Inventory in-transit	$B_3*(t/(24*60))*v*Q/365$	0.4	0.7	0.5	N/A
Safety Stock	$B_5*v*a*((LT)*(Q_{sd})\wedge^2)+(Q\wedge^2+(LT_{sd})\wedge^2))\wedge^{0.5})$	1,314.5	1,452.7	1,378.4	N/A
Ordering	$B_1*(Q*2000/q)$	50.0	50.0	50.0	50.0
Damage	$B_2*j*v*Q$	1.2	1.2	1.2	1.2
Carrying	$(B_4+(B_5*v))*((q/2000)/2))$	15,581.6	15,581.6	15,581.6	15,581.6
	TOTAL COST ($)	**19,984**	**20,092**	**N/A**	**N/A**
Shipment Characteristics	*c ($)*	*39.9*	*42.9*	*709.7*	*N/A*
	t (min)	*1,602.6*	*3,284.8*	*2,380.2*	*N/A*
	Q (tons)	*6.2*	*6.2*	*6.2*	*6.2*
	GCD (mile)	*89.5*	*89.5*	*89.5*	*89.5*
	Value ($)	*2,365.3*	*2,365.3*	*2,365.3*	*2,365.3*
	v ($/ton)	*380.9*	*380.9*	*380.9*	*380.9*
	LT (days)	*11.1*	*12.3*	*11.7*	*N/A*

Florida Statewide Model – 1 (Model Run Comparisons)

Commodity	**Electronics**	Origin FAF	**123** *(Florida, Orlando)*
Segment	**Internal - External**	Destination FAF	**379** *(North Carolina, remainder)*

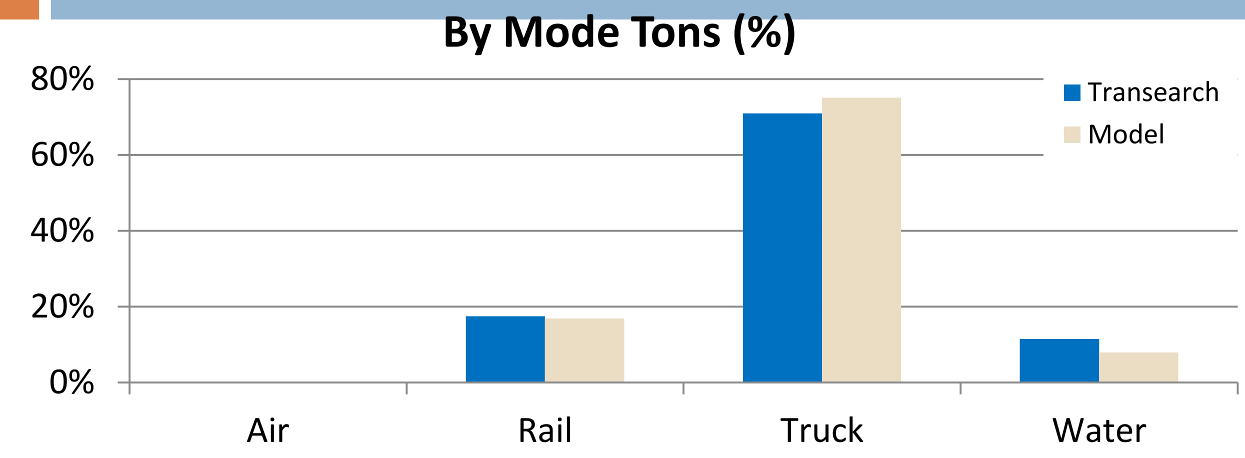
Cost type ($)	Formula	Truck	Rail	Air	Water
B_0	*Constant*	2,309.6	5,122.6	846.2	99,999,999
Transport	$Q*C$	17.8	22.2	777.9	N/A
Inventory in-transit	$B_3*(t/(24*60))*v*Q/365$	3.3	26.1	13.6	N/A
Safety Stock	$B_5*v*a*((LT)*(Q_{sd})\wedge^2)+(Q\wedge^2+(LT_{sd})\wedge^2))\wedge^{0.5})$	31,485.8	39,791.6	35,245.5	N/A
Ordering	$B_1*(Q*2000/q)$	776.0	776.0	776.0	776.0
Damage	$B_2*j*v*Q$	30.3	30.3	30.3	30.3
Carrying	$(B_4+(B_5*v))*((q/2000)/2))$	160.0	160.0	160.0	160.0
	TOTAL COST ($)	**34,783**	**45,929**	**37,850**	**N/A**
Shipment Characteristics	*c ($)*	*45.9*	*57.2*	*2,005.0*	*N/A*
	t (min)	*578.3*	*4530.2*	*2,367.2*	*N/A*
	Q (tons)	*0.39*	*0.39*	*0.39*	*0.39*
	GCD (mile)	*518.5*	*518.5*	*518.5*	*518.5*
	Value ($)	*12,105.9*	*12,105.9*	*12,105.9*	*12,105.9*
	v ($/ton)	*31,201.5*	*31,201.5*	*31,201.5*	*31,201.5*
	LT (days)	*10.4*	*10.4*	*10.4*	*10.4*

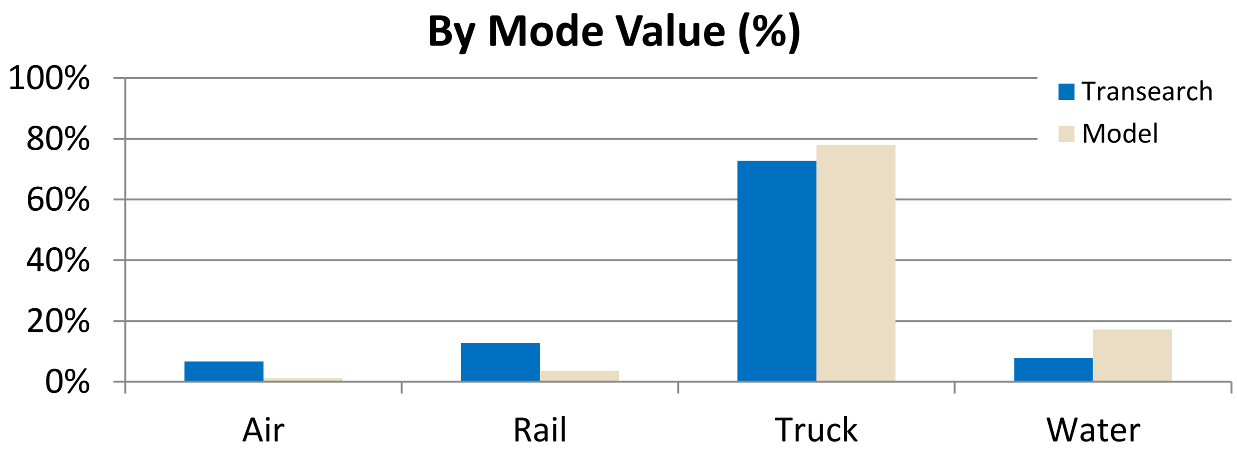
Florida Statewide Model – 1 (Model Run Comparisons)

Commodity	**Pharmaceuticals**	Origin FAF	**139** *(Georgia, remainder)*
Segment	**External - Internal**	Destination FAF	**129** *(Florida, remainder)*

Cost type ($)	Formula	Truck	Rail	Air	Water
B_0	*Constant*	2,194.2	903.5	1,268.0	99,999,999
Transport	$Q*C$	1.5	2.2	74.7	N/A
Inventory in-transit	$B_3*(t/(24*60))*v*Q/365$	0.3	3.0	1.7	N/A
Safety Stock	$B_5*v*a*((LT)*(Q_{sd})\wedge^2)+(Q\wedge^2+(LT_{sd})\wedge^2))\wedge^{0.5})$	3,814.5	4,781.8	4,318.8	N/A
Ordering	$B_1*(Q*2000/q)$	50.0	50.0	50.0	50.0
Damage	$B_2*j*v*Q$	3.7	3.7	3.7	3.7
Carrying	$(B_4+(B_5*v))*((q/2000)/2))$	287.3	287.3	287.3	287.3
TOTAL COST ($)		**6,352**	**6,031**	**5,877**	**N/A**
Shipment Characteristics	*c ($)*	*36.7*	*53.2*	*1,801.9*	*N/A*
	t (min)	*470.8*	*4,242.3*	*2,285.6*	*N/A*
	Q (tons)	*0.04*	*0.04*	*0.04*	*0.04*
	GCD (mile)	*342.0*	*342.0*	*342.0*	*342.0*
	Value ($)	*1,477.2*	*1,477.2*	*1,477.2*	*1,477.2*
	v ($/ton)	*36,061.1*	*36,061.1*	*36,061.1*	*36,061.1*
	LT (days)	*10.3*	*10.3*	*11.6*	*10.3*

Florida Statewide Model – 1 (Mode Choice Validation Results)





Calibration of the mode choice model resulted in a relatively good match to the mode choice shares observed in the Transearch data