Transportation Management
Operational Networks

Chris Caplice
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Agenda

- Economic vs Traditional Modes
- Operational Networks
  - One to One
  - One to Many
  - Many to Many
- Example of Approximate Analysis
Traditional Transport Modes (US)

<table>
<thead>
<tr>
<th>Mode</th>
<th>2003 revenue ($B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trucking</td>
<td>610</td>
</tr>
<tr>
<td>Rail</td>
<td>36</td>
</tr>
<tr>
<td>Intermodal</td>
<td>8</td>
</tr>
<tr>
<td>Pipeline</td>
<td>27</td>
</tr>
<tr>
<td>Air Freight</td>
<td>13</td>
</tr>
<tr>
<td>Barge</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>702</td>
</tr>
</tbody>
</table>

Note that these modes are all technology based – according to the type of power unit and guideways used.
The Transportation Product

Four Primary Transportation Components
- Loading/Unloading
- Line-Haul
- Local-Routing (Vehicle Routing)
- Sorting

Basic Forms of Consolidation
- Vehicle
- Temporal
- Spatial

Driving Influences
- Economies of Scale
- Economies of Scope (Balance)
- Economies of Density
The Transportation Product

Loading/Unloading
- Key drivers:
  - Number of items
  - Time
  - Stowability (Packaging)
- Not always symmetric

Linehaul
- Key drivers:
  - Distance
  - Balance / Backhaul
- Impacted by network
  - Congestion
  - Connectivity
Regression of Long Haul TL Rates

<table>
<thead>
<tr>
<th>Independent Variable</th>
<th>Coefficient Value</th>
<th>95% Confidence Limits</th>
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</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>116.84</td>
<td>107.57</td>
</tr>
<tr>
<td>Distance</td>
<td>1.10</td>
<td>1.097</td>
</tr>
<tr>
<td>OutBound Flag</td>
<td>9.04</td>
<td>5.48</td>
</tr>
<tr>
<td>Private Fleet Dist</td>
<td>(0.17)</td>
<td>(0.21)</td>
</tr>
<tr>
<td>Spot Mkt Dist</td>
<td>0.29</td>
<td>0.26</td>
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<tr>
<td>Intermodal Dist</td>
<td>(0.29)</td>
<td>(0.30)</td>
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<tr>
<td>Expedited Dist</td>
<td>0.15</td>
<td>0.13</td>
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<td>High Frequency Flag</td>
<td>(72.49)</td>
<td>(78.44)</td>
</tr>
<tr>
<td>Monthly Flag</td>
<td>(60.96)</td>
<td>(64.44)</td>
</tr>
<tr>
<td>Quarterly Flag</td>
<td>(36.33)</td>
<td>(38.96)</td>
</tr>
<tr>
<td>$100M Buy Flag</td>
<td>(19.2840)</td>
<td>(23.85)</td>
</tr>
<tr>
<td>Regional Values</td>
<td>XXX</td>
<td>XX</td>
</tr>
</tbody>
</table>

Explains ~77%

Explains ~ 2%

Explains ~ 7%
The Transportation Product

Vehicle Routing

- **Key drivers:**
  - Number/Density of stops
  - Vehicle Capacity
  - Time

- **Origin or Destination**
  - One to Many
  - Many to One
  - Interleavened
The Transportation Product

Sorting

- Key drivers:
  - Stowability (Packaging)
  - Number of items
  - Timing (Banking)

Inbound unloading

Outbound loading

Inbound vehicles

Outbound vehicles

Cross-Dock Terminal

From A

From B

From C

To D

To E

To F

Material Adapted from Yossi Sheffi
The Transportation Product

- Four Primary Transportation Components
  - Loading/Unloading
  - Line-Haul
  - Local-Routing (Vehicle Routing)
  - Sorting
- Basic Forms of Consolidation
  - Vehicle
  - Temporal
  - Spatial
- Driving Influences
  - Economies of Scale
  - Economies of Scope (Balance)
  - Economies of Density
Economies of Scale

For an individual shipment –
- Captures allocation of fixed costs over many items
- Follows lot sizing logic – drives mode selection

Across a network – this is less clear
- Volume on all lanes increase in the same proportion
- It depends on directionality (mainly direct carriers)
- Consolidated carriers have more fixed costs - more terminals
Economies of Scope (Balance)

- Reverse flow mitigates the cost of repositioning.
- Strong for direct carriers – but present in all
  - Subadditivity - the costs of serving a set of lanes by a single carrier is lower than the costs of serving it by a group of carriers
  - Cost Complementarity - the effect that an additional unit carried on one lane has on other lanes
Economies of Density

Strong for Consolidated Carriers

- Location Density
  - Number of customers per unit area

- Shipment Density
  - Average number of shipments at a customer location
  - Daily average volume is critical

Which is better?
Economic Modes

Consolidated Carrier’s Core Activities

Direct Carrier’s Core Activities
Economic Modes

Consolidated operations (CO)
- Bus/rail transit
- LTL
- Rail
- Airlines
- Ocean carriers/liner service
- Package delivery

Direct operations (DO)
- Taxi
- TL
- Unit trains
- Charter/private planes
- Tramp services
- Courier

DO conveyances on CO carriers (sub-consolidation)
- Rail cars
- Ocean containers
- Air “igloos”
Operational Network (ONW) Structure

- **One to One**
  - Direct Network

- **One to Many / Many to One**
  - Direct with Milk Runs
  - Consolidation within the Vehicle

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**One to Many**

**Pool / Zone Skipping**

- **M21 w/Tranship**

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**P - Pickup Location**

**D - Delivery Location**
Operational Network (ONW) Structure

Many to Many
- No Transhipment Point
  - Direct with Milk Runs
- With Transhipment Point
  - Direct with DC (Cross Docking)
  - Direct with Milk Runs

Direct w/ DC

Direct w/ Milk Runs

Hub w/ Directs

P - Pickup Location  D - Delivery Location

Many to Many

M2M Interleaved

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Decisions – Contract Type

What type of relationship do you need to establish with your carriers?

Continuum of relationships from one-off to ownership
- Ownership of Assets versus Control of Assets
- Responsibility for utilization
- On-going commitment / responsibilities
- Shared Risk/Reward – Flexible contracts

Spot Market | Alternate Carriers | Core Carriers | Dedicated Fleet | Private Fleet

Use for random & distressed traffic
Use for most reliable and steady flows
Solution Approaches for ONW

**Math Programming / Algorithmic Approach**
- Develop detailed objective function and constraints
- Requires substantial data
- Solve MILP to optimality

**Simulation Approach**
- Develop detailed rules and relationships
- Simulate the expected demand patterns
- Observe results and rank different scenarios

**Approximation Approach**
- Develop a Total Cost Function that incorporates the relevant decision variables
- Obtain reasonable results with as little information as possible in order to gain insights
- Detailed data can actually make the optimization process harder
Total Cost Per Item Function

Cost per item = Holding Costs + Moving Costs
= (Inventory Cost) + (Transport Cost + Handling Cost)

\[ TC(Q) = vD + A \left( \frac{D}{Q} \right) + rv \left( \frac{Q}{2} \right) \]

\[ CostPerItem = \frac{TC(Q)}{D} = v + A \frac{Q}{Q} + rv \left( \frac{T}{2} \right) \]

Nomenclature

- \( A \): Fixed order cost ($/shipment)
- \( r \): Inventory holding cost ($/yr)
- \( v \): Purchase cost ($/item)
- \( Q \): Shipment size (items)
- \( T \): Shipment frequency (yr) = \( Q/D \)
- \( c_f \): Fixed transport cost ($/shipment)
- \( c_v \): Variable transport cost (#/item)
- \( c_s \): Fixed cost per stop ($/stop)
- \( c_d \): Cost per distance ($/distance)
- \( c_{vd} \): Marginal cost / item / distance
- \( c_{vs} \): Marginal cost / item / stop
- \( n_s \): Number of delivery stops
One to One System

TotalCPI = \( rv \left( \frac{T}{2} + L \right) + c_s \left( \frac{1+n_s}{Q} \right) + c_d \left( \frac{d}{Q} \right) + c_{vs} \)
Handling Costs

Handling Costs ($/item)
- Loading items into boxes, pallets, containers, etc.
- If handled individually – linear with each item
- If handled in batches – fixed & variable components
- Generally subsumed w/in transportation (move) costs as long as \( Q >> Q_{h\text{MAX}} \) (total shipment size is greater than pallet)

\[
\text{Handling Cost} = c_{fh} + c_{vh} Q_h \\
\text{Movement Cost} = c_f + \left( c_v + c_{vh} + \frac{c_{fh}}{Q_{h\text{MAX}}} \right) Q \\
\text{Transport & Handling} = c_s \left( \frac{1+n_s}{Q} \right) + c_d \left( \frac{d}{Q} \right) + \left[ c_{vs} + c_{vh} + \frac{c_{fh}}{Q_{h\text{MAX}}} \right]
\]
One to Many System

**Single Distribution Center:**
- Products originate from one origin
- Products are demanded at many destinations
- All destinations are within a specified Service Region
- Ignore inventory (service standards given)

**Assumptions:**
- Vehicles are homogenous
- Same capacity, $Q_{\text{MAX}}$
- Fleet size is constant

Based on Hernandez MLOG Thesis 2003

Figure by MIT OCW.
One to Many System

**Finding the estimated total distance:**
- Divide the Service Region into Delivery Districts
- Estimate the distance required to service each district

Based on Hernandez MLOG Thesis 2003

Figure by MIT OCW.

Based on Hernandez MLOG Thesis 2003
One to Many System

Route to serve a specific district:
- Line haul from origin to the 1st customer in the district
- Local delivery from 1st to last customer in the district
- Back haul (empty) from the last customer to the origin

Based on Hernandez MLOG Thesis 2003
An Aside: Routing & Scheduling

Problem:
- How do I route vehicle(s) from one or many origins to one or many destinations at a minimum cost?
- A HUGE literature and area of research

Traveling Salesman Problem / Vehicle Routing Problem
- One origin, many destinations, sequential stops
- Stops may require delivery & pick up
- Vehicles have different capacity (capacitated)
- Stops have time windows
- Driving rules restricting length of tour, time, number of stops

Discussed next lecture – Dr. Edgar Blanco
One to Many System

Find the estimated distance for each tour, $d_{TOUR}$

- Capacitated Vehicle Routing Problem (VRP)
- Cluster-first, Route-second Heuristic

$$d_{TOUR} \approx 2d_{\text{LineHaul}} + d_{\text{Local}}$$

$d_{\text{LineHaul}}$ = Distance from origin to center of gravity (centroid) of delivery district
$d_{\text{Local}}$ = Local delivery between $c$ customers in district (TSP)
One to Many System

What can we say about the expected TSP distance to cover n stops in district of area X?

- Hard bound and some network specific estimates:

\[ E[d_{TSP}] \leq 1.15\sqrt{nX} \]
\[ E[d_{TSP}] \approx k\sqrt{nX} \]

For n>25 over Euclidean space, k=.7124
For grid (Manhattan Metric), k=.7650

Density, \( \delta \), number of stops per area
Average distance per stop, \( d_{stop} \)

\[ \delta = \frac{n}{X} \]
\[ d_{stop} = \frac{d_{TSP}}{n} = k \cdot \frac{\sqrt{nX}}{n} = \frac{k}{\sqrt{\delta}} \]

http://web.mit.edu/urban_or_book/www/book/index.html, see section 3.87
One to Many System

- Length of local tours
  - Number of customer stops, \( c \), times \( d_{\text{stop}} \) over entire region
  - Exploits property of TSP being sub-divided –
    - TSP of disjoint sub-regions \( \geq \) TSP over entire region

Figure by MIT OCW.
One to Many System

Finding the total distance traveled on all, \( l \), tours:

\[
E[d_{\text{TOUR}}] = 2d_{\text{LineHaul}} + \frac{ck}{\sqrt{\delta}}
\]

\[
E[d_{\text{AllTours}}] = lE[d_{\text{TOUR}}] = 2ld_{\text{LineHaul}} + \frac{nk}{\sqrt{\delta}}
\]

Minimize number of tours by maximizing vehicle capacity

\[
l = \left[ \frac{D}{Q_{\text{MAX}}} \right]^+
\]

\[
E[d_{\text{AllTours}}] = 2\left[ \frac{D}{Q_{\text{MAX}}} \right]^+ d_{\text{LineHaul}} + \frac{nk}{\sqrt{\delta}}
\]

\([x]^+ \) is lowest integer value greater than \( x \) – a step function

Estimate this with continuous function:

\[
E([x]^+) \sim E(x) + \frac{1}{2}
\]
One to Many System

So that expected distance is:

\[
E[d_{AllTours}] = 2 \left[ \frac{E[D]}{Q_{MAX}} + \frac{1}{2} \right] d_{LineHaul} + \frac{E[n]k}{\sqrt{\delta}}
\]

Note that if each delivery district has a different density, then:

\[
E[d_{AllTours}] = 2 \sum_i \left[ \frac{E[D_i]}{Q_{MAX}} + \frac{1}{2} \right] d_{LineHaul_i} + k \sum_i \frac{E[n_i]}{\sqrt{\delta_i}}
\]

For identical districts, the transportation cost becomes:

\[
\text{TransportCost} = c_s \left[ E[n] + \frac{E[D]}{Q_{MAX}} + \frac{1}{2} \right] + c_d \left( 2 \left[ \frac{E[D]}{Q_{MAX}} + \frac{1}{2} \right] d_{LineHaul} + \frac{E[n]k}{\sqrt{\delta}} \right) + c_{vs} E[D]
\]
One to Many System

Fleet Size

- Find minimum number of vehicles required, \( M \)
- Base on, \( W \), amount of required work time
  - \( t_w \) = available worktime for each vehicle per period
  - \( s \) = average vehicle speed
  - \( l \) = number of shipments per period
  - \( t_l \) = loading time per shipment
  - \( t_s \) = unloading time per stop

\[
M t_w \geq W = \frac{d_{\text{AllTours}}}{s} + l t_l + n t_s
\]

\[
W = \left( \frac{2d_{\text{LineHaul}}}{s} + t_l \right) \left[ \frac{E[D]}{Q_{\text{MAX}}} + \frac{1}{2} \right] + E[n] \left( \frac{k}{s \sqrt{\delta}} + t_s \right)
\]
One to Many System

Note that $W$ is a linear combination of two random variables, $n$ and $D$

$$E[aX + bY] = aE[X] + bE[Y]$$
$$Var[aX + bY] = a^2Var[X] + b^2Var[Y] + 2abCov[X,Y]$$

Substituting in, we can find $E[W]$ and $Var[W]$

$$a = \left( \frac{2d_{LineHaul}}{s} + t_l \right) \left[ \frac{1}{Q_{MAX}} \right]$$
$$b = \left( \frac{k}{s\sqrt{\delta}} + t_s \right)$$

Given a service level, CSL

$$P[W<M_{tw}] = CSL$$
Thus,

$$M = \frac{(E[W] + k(CSL) \text{ StDev}[W])}{t_w}$$
Questions?