Locating urban and regional container terminals in a competitive environment: An entropy maximising approach

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Sydney (Source: The Australian, 2016)
Sydney Freight Problem

- Port close to Sydney suburbs
  - Limited space for expansion
  - Competing land uses (residential use)
- Road network expansion – limited to Westconnex
Promising Solution: Urban IMT

- Intermodal transport = Rail + Road
- Combined strengths of rail and road modes

Intermodal Terminal (IMT)

Place of transfer between trains and trucks

Flexible & accessible

High carrying capacity, low cost

Destinations
Promising Solution: Regional IMT

- Efficient transport of goods produced & consumed domestically
- Involves the use of two intermodal terminals

Warehouse in region A

Pre-leg

Main leg

Post-leg

Warehouse in region B
Two main markets for IMTs

— Usage through the choice of **metropolitan intermodal transport**

— Usage through the choice of **regional intermodal transport**
Other Use of IMTs

— Empty Container Park
  — Efficient management of empty containers

— Warehousing & Distribution
  — Warehousing activities
  — Consolidation of loads for export
  — Distribution centres for manufacturers and retailers
**Key Research Question addressed here**

Which IMT locations provide shippers with maximum benefit?

**Metropolitan intermodal transport**

**Regional intermodal transport**
Main Contributions of the Paper

– Formulation of an IMT location problem that maximises shipper surplus

– It is shown that, as entropy maximisation subject to certain constraints delivers a logit mode choice model and as the logit mode choice model delivers expected mode choice probabilities that maximise consumer (shipper) surplus, therefore entropy maximisation can be used to find IMT locations that maximise shipper surplus leading to a single level facility location problem

– Lagrangian relaxation is used to facilitate solution of the problem

– This approach may be used to solve any facility location problem where the interests of the facility locator are aligned with the interests of the facility user (like public transport)
Why is IMT location key?

It is crucial in determining the usage of the terminals.
Why is the location key?

It is crucial in determining the usage of the IMTs.
IMT location problem v Conventional facility location problem

IMT location: Maximise expected shipper utility

- Many decision makers
- Maximise expected shipper utility

IMT Demand
- By Metropolitan intermodal transport
- By Regional intermodal transport

Multiple user mode choice decision
IMT Location Problem: 3 problem layers

IMT Location Decisions

Candidates locations

Best Location

Mode Choice

Terminal Choice

influenced by:
Decision variables and unit transport costs

— The decision variables of the model are
  — Regional intermodal transport demand \( W_{istj} \)
  — Metropolitan intermodal transport demand \( V_{itj} \)
  — Road transport demand \( U_{ij} \)
  — Location variables \( Y_t \)

— The unit transport costs are
  — Regional intermodal transport \( c_{istj} \)
  — Metropolitan intermodal transport cost \( c_{itj} \)
  — Road transport costs \( c_{ij} \)
  — Average weighted transport cost over all modes \( c \)
Unit transport cost composition

— Regional intermodal transport costs:

\[ c_{ijst} = c_{is} + c_{s} + c_{st} + c_{t} + c_{tj} ; \forall i \in \mathcal{O}, j \in \mathcal{D}, s \neq t, s, t \in \mathcal{T} \]

— \( c_{is} \) is the road cost from cargo origin \( i \in \mathcal{O} \) to IMT \( s \in \mathcal{T} \)

— \( c_{st} \) is the rail cost from IMT \( s \in \mathcal{T} \) to IMT \( t \neq s \in \mathcal{T} \) and takes into account the economies of scale of using rail

— \( c_{tj} \) is the road cost from IMT \( t \in \mathcal{T} \) to cargo destination \( j \in \mathcal{D} \)

— \( c_{is} \) and \( c_{t} \) are terminal usage cost for IMT \( s \) and \( t \) respectively. These costs are assumed to include the fixed cost of IMT location and operation costs passed on to the shipper or user, who then decides whether or not to use the terminal

— Metropolitan transport cost

\[ c_{itj} = c_{it} + c_{t} + c_{tj} ; \forall i \in \mathcal{O}, j \in \mathcal{D}, t \in \mathcal{T} \]
Decision variables and unit transport costs

— Road transport cost generally expressed in terms of fixed and variables cost;

\[
c_{ij} = \phi + \theta \ast GT_{ij}
\]

— where \( \phi \) is the fixed cost (\$/per TEU),

— \( \theta \) is the cost sensitivity parameter of truck generalised time between two locations on the network and \( GT_{ij} \) is the generalised truck travel time between location \( i \) and \( j \) on the network and can generally be expressed as:

\[
GT_{ij} = time_{ij} + (voc / vot) \ast dist_{ij}
\]

— where \( time_{ij} \) and \( dist_{ij} \) are the congested truck travel time (min) and distance respectively, \( voc \) is the vehicle operating cost (\$/per km), \( vot \) is truck driver’s value of time (\$/per minutes).
Basic Entropy Maximisation Model

Max $S = Z / \prod_{i \in O} \prod_{j \in D} (X_{ij}) (\prod_{t \in T} V_{itj})$

Subject to:

1. $\sum_{s \in T} \sum_{t \neq s \in T} W_{istj} + \sum_{s \in T} V_{itj} + X_{ij} = q_{ij}$

2. $\sum_{i \in O} \sum_{s \in T} \sum_{t \neq s \in T} \sum_{j \in D} c_{listj} W_{istj} + \sum_{i \in O} \sum_{t \in T} \sum_{j \in D} c_{itj} V_{itj}$

3. $\sum_{i \in O} \sum_{j \in D} \sum_{s \neq t \in T} W_{istj} + \sum_{i \in O} \sum_{j \in D} \sum_{s \neq t \in T} W_{itsj} + \sum_{i \in O} V_{itj}$

4. $\sum_{t \in T} Y_{lt} = p$

5. $Y_{lt} \in \{0, 1\}; t \in T$

6. $W_{istj} \geq 0; V_{itj} \geq 0; X_{ij} \geq 0; W_{issj} = W_{isttj} = 0; \forall s, t \in T; \forall i \in O; j \in D$
Solving the Entropy Maximisation Problem

Applying Stirling's Approximation to the entropy function:

\begin{align*}
\ln S &\approx \sum_{i \in O} \sum_{j \in D} U_{ij} \{1 - \ln U_{ij}\} + \sum_{i \in O} \sum_{t \in T} \sum_{j \in D} V_{itj} \{1 - \ln V_{itj}\} \\
&\quad + \sum_{i \in O} \sum_{s \in T} \sum_{t \neq s \in T} \sum_{j \in D} W_{istj} \{1 - \ln W_{istj}\}
\end{align*}

Shannon entropy of road transport demand
Solving the Entropy Maximisation Model: Relaxation

Max $\Lambda \approx \sum_{i \in \mathcal{O}} \sum_{j \in \mathcal{D}} U_{ij} \{1 - \ln U_{ij}\} + \sum_{i \in \mathcal{O}} \sum_{t \in \mathcal{T}} \sum_{j \in \mathcal{D}} V_{itj} \{1 - \ln V_{itj}\} + \sum_{i \in \mathcal{O}} \sum_{s \in \mathcal{T}} \sum_{t \neq s \in \mathcal{T}} \sum_{j \in \mathcal{D}} W_{istj} \{1 - \ln W_{istj}\}$

Subject to:

1. $\sum_{s \in \mathcal{T}} \sum_{t \neq s \in \mathcal{T}} W_{istj} + \sum_{s \in \mathcal{T}} V_{itj} + X_{ij} = q_{ij}$

2. $\sum_{i \in \mathcal{O}} \sum_{s \in \mathcal{T}} \sum_{t \neq s \in \mathcal{T}} \sum_{j \in \mathcal{D}} c_{istj} W_{istj} + \sum_{i \in \mathcal{O}} \sum_{t \in \mathcal{T}} \sum_{j \in \mathcal{D}} c_{itj} V_{itj}$

3. $\sum_{i \in \mathcal{O}} \sum_{j \in \mathcal{D}} \sum_{s \neq t \in \mathcal{T}} W_{istj} + \sum_{i \in \mathcal{O}} \sum_{j \in \mathcal{D}} \sum_{s \neq t \in \mathcal{T}} c_{istj} V_{itj}$

4. $\sum_{t \in \mathcal{T}} Y_{tl} = p$

5. $Y_{tl} \in \{0, 1\}; \ t \in \mathcal{T}$

6. $W_{istj} \geq 0; \ V_{itj} \geq 0; \ X_{ij} \geq 0; \ W_{issj} = W_{isttj} = 0; \forall s, t \in \mathcal{T}; \forall i \in \mathcal{O}; j \in \mathcal{D}$
Solving the Entropy Maximisation Model: Lagrangian relaxation

\[ \text{FLP : Max } \Lambda \downarrow \text{FLP} = \sum_{t \in \mathcal{T}} (\psi_{\downarrow t} b_{\downarrow t}) Y_{\downarrow t} \]

Subject to:

\[
(4) \sum_{t \in \mathcal{T}} Y_{\downarrow t} = p \\
(5) Y_{\downarrow t} \in \{0, 1\}; \ t \in \mathcal{T}
\]
Solving the Entropy Maximisation Model

FLP : Max \( \Lambda \downarrow \text{FLP} = \sum_{t \in T} \psi_{\downarrow t} Y_{\downarrow t} \)

Subject to (4) and (5)

Problem decomposed into FLP and Mode choice problem (MCP) :
\( \Lambda = \Lambda \downarrow \text{FLP} + \Lambda \downarrow \text{MCP} \).

MCP : Max \( \Lambda \downarrow \text{MCP} = \sum_{i \in O} \sum_{j \in D} \{1 - \ln U_{ij}\} + \sum_{i \in O} \sum_{t \in T} \sum_{j \in D} \{1 - \ln V_{\downarrow itj} - \psi_{\downarrow t}\} + \sum_{i \in O} \sum_{s \in T} \sum_{t \neq s \in T} \sum_{j \in D} \{1 - \ln W_{\downarrow istj} - \psi_{\downarrow s} - \psi_{\downarrow t}\} \),

Subject to (1), (2), (3) with terminal locations fixed, and (6)
Solving the Facility location problem (FLP)

FLP : Max $\Lambda_{FLP} = \sum_{t \in T} \psi t b t Y t$

Subject to (4) and (5)

Given $\psi t \geq 0; \forall t \in T$, the FLP can be solved by identifying the $p$ largest elements of $(\psi t b t); \forall t \in T$ and setting the corresponding values of $Y t$ equal to 1.

Let the set $K$ with cardinality $p$, be the set of located IMTs, which then goes into the MCP as input.

Note that for sufficiently large IMTs with $\psi t = 0; \forall t \in T$, the objective value ($\Lambda_{FLP}$) of the FLP will be zero and the selection of the best IMTs will only be based on the value of $\Lambda_{MCP}$.
Solving the MCP

MCP : Max Λ ↓ MCP = \[ \sum_{i \in \mathcal{O}} \sum_{j \in \mathcal{D}} \{ 1 - \ln U_{ij} \} + \sum_{i \in \mathcal{O}} \sum_{t \in \mathcal{T}} \sum_{j \in \mathcal{D}} \{ 1 - \ln V_{itj} - \psi_{it} \} + \sum_{i \in \mathcal{O}} \sum_{s \in \mathcal{T}} \sum_{t \neq s \in \mathcal{T}} \sum_{j \in \mathcal{D}} \{ 1 - \ln W_{istj} - \psi_{is} - \psi_{it} \} \]

Subject to (1), (2), (3) with IMT locations fixed, and (6)

Enforcing the Karush-Kuhn-Tucker (KKT) optimality conditions

\[-\ln W_{istj} - \beta c_{istj} - \eta_{ij} - \psi_{is} - \psi_{it} = 0; \forall s \in \mathcal{K}, t \neq s \in \mathcal{K} \] With respect to regional intermodal transport demand

\[-\ln V_{itj} - \beta c_{itj} - \eta_{ij} - \psi_{it} = 0; \forall t \in \mathcal{K} \] With respect to metropolitan intermodal transport demand

\[-\ln U_{ij} - \beta c_{ij} - \eta_{ij} = 0 \] With respect to road transport intermodal demand
Overall Solution showing Nested Choices

Facility Location Problem (FLP)

Mode Choice Problem (MCP)

Mode choice

Decision maker

Mode

choice

Road alone

Intermodal transport

Intermodal transport choice

Regional

Urban

IMT Choice

T1-T2

T1-T3

... T(T-1)-T

T1

T2

... T
Case Study: NSW as study area

- The study area is Sydney Metropolitan Area (SMA), Australia.

- The study area was divided into 79 container destination zones.

- The container movement data were obtained from Australian Bureau of Statistics (ABS) and comprises of import containers and delivery post codes within the study area.

- Truck congested travel times and distances were skimmed from an existing transport model of the study area (METROSCAN-TI) and were used to construct the generalised costs of each mode.
Case Study: NSW as study area and cargo distribution

Data Source: ABS, 2011 (Information Paper: Experimental Statistics on International Shipping Container Movements)
Case Study: Key cargo destinations in the Study Area

- Liverpool: 6%
- Penrith: 4%
- Blacktown: 13%
- Parramatta & Holroyd: 9%
- Auburn: 6%
- Fairfield: 10%
- Bankstown: 9%
- Campbelltown: 6%
Case Study: Distribution of candidate IMTs
Mode Choice Problem: Generalize Cost ($)

Intermodal transport cost ($) : 3 components

\[ c_{itj} = c_{it} + c_{tj} + c_t \]

1. Rail cost ($ per TEU) to each IMT

\[ c_{it} = \delta + \theta d_{it} \approx \tilde{\delta} \quad \tilde{\delta} = $150 \]

2. Road cost ($ per TEU) from the port or each IMT to container destination

\[ c_{tj} = \psi + \rho t_{tj} \]

\[ \rho = 2.04 ($/\text{min}) \]

\[ \psi = $156 \]

Fixed cost

Variable cost as function of travel time

3. Terminal user cost ($ per TEU) \( C_t \)

Data Source: Access Economics & Maunsell, 2003
Demand for candidate IMTs

Candidate locations

- Camellia, 159,981
- Eastern Creek, 170,857
- Yennora, 61,337
- Eastern Creek, 170,857
- Moorebank, 7,660
- Ingleburn, 51,862
- Minto, 50,454
- Villawood, 10,419
- Chullora, 2,102
- Enfield, 1,287
Location problem: Best IMT location

Data Source: ABS, 2011 (Information Paper: Experimental Statistics on International Shipping Container Movements)
Reduction in truck kilometres travelled due to Eastern Creek

<table>
<thead>
<tr>
<th></th>
<th>No IMT (TEU-KM)</th>
<th>IMT (TEU-KM)</th>
<th>% Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16,576,456</td>
<td>15,181,841</td>
<td>8.41%</td>
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</tbody>
</table>
Sensitivity Testing IV : Selecting Two IMTs

Share of Key Markets

<table>
<thead>
<tr>
<th>Location</th>
<th>Camillia</th>
<th>Eastern Creak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bankstown</td>
<td>84%</td>
<td>16%</td>
</tr>
<tr>
<td>Auburn</td>
<td>85%</td>
<td>15%</td>
</tr>
<tr>
<td>Holroyd</td>
<td>72%</td>
<td>28%</td>
</tr>
<tr>
<td>Parramatta</td>
<td>82%</td>
<td>18%</td>
</tr>
<tr>
<td>Penrith</td>
<td>37%</td>
<td>63%</td>
</tr>
<tr>
<td>Fairfield</td>
<td>51%</td>
<td>49%</td>
</tr>
<tr>
<td>Blacktown</td>
<td>29%</td>
<td>71%</td>
</tr>
</tbody>
</table>

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Sensitivity Testing IV: Selecting 1-4 IMTs

- Over 90% of import containers have their destinations
  - 25% to Eastern Creek
  - 22% to Yennora, Camellia, Eastern Creek
  - 47% to Camellia, Eastern Creek
  - 42% to Yennora, Camellia, Eastern Creek
  - 33% to {Camellia, Eastern Creek}
  - 39% to {Yennora, Camellia, Eastern Creek}
  - 7% to {Yennora, Camellia, Eastern Creek, Ingleburn}

% Share

- Eastern Creek: 100%
- {Camellia, Eastern Creek}: 53% (47% Camellia, 6% Eastern Creek)
- {Yennora, Camellia, Eastern Creek}: 42% (32% Camellia, 7% Eastern Creek)
- {Yennora, Camellia, Eastern Creek, Ingleburn}: 39% (32% Camellia, 7% Eastern Creek, 0% Ingleburn)
Case Study: Optimal IMT charges for Eastern Creek

% Drop in revenue due to increase in terminal changes

Optimal terminal change of $60

\[ C_{itj} = C_{it} + C_{tj} + C_t \]

IMT Charges ($/TEU)

Demand
Revenue

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Conclusions

- This paper proposes an entropy maximizing for locating competitive multi-shipper IMTs.

- The overall problem was decomposed using Lagrangian relaxation into a facility location problem and a mode choice problem.

- Two algorithms were proposed to solve the linked facility location and mode choice sub-problems; complete enumeration and a heuristic algorithm.

- The running time of the heuristic grows linearly as the number of facilities to locate ($\rho$) increases for a fixed number of candidate IMT locations $\tau$.

- This approach is appropriate where other situations where facility locator and facility user interests are aligned, like public transport.
Decision support system for locating urban intermodal container terminals

1. Upload cost file
   - Choose file

2. Upload IMT data
   - Choose file

Intermodal markets:
- Export and import
- Number of terminals to locate: 1

Click to run!

QUESTIONS?