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Optimal location of open access urban container terminals under elastic cargo demand

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Abstract

The lack of investment in inland transport infrastructure coupled with increase in ship size and growth of alliances has resulted in congestion, safety and environmental problems in the vicinity of ports and urban centres, especially centres close to the sea port. The development of urban container terminals with interface to road, rail or waterway networks is seen as a promising solution to these problems. The terminals are expected to be common user facilities, where each shipper has the choice of using it through the choice of rail or barge transport in the moving the containers between the port and terminal, and truck to/from the destination/origin or alternatively using truck only between the port and the origin/destination. The terminals are also expected to perform auxiliary activities such as warehousing and empty container storage thereby allowing these activities to be relocated to the terminals to provide extra revenue. This study employs an entropy framework to embed distribution and model choice models within a facility location problem such that the mode and distribution models influence the location choice of terminals, which in turn conditions the choice of mode and cargo destinations. The overall model was decomposed using Lagrangian relaxation techniques and is solved to optimality. Key features of the model were demonstrated using NSW, Australia, as a case study and data on import containers. The model reveals the key factors governing the distribution of containers in urban areas and the influence of the distribution on the optimal location for intermodal terminals.

1. Introduction

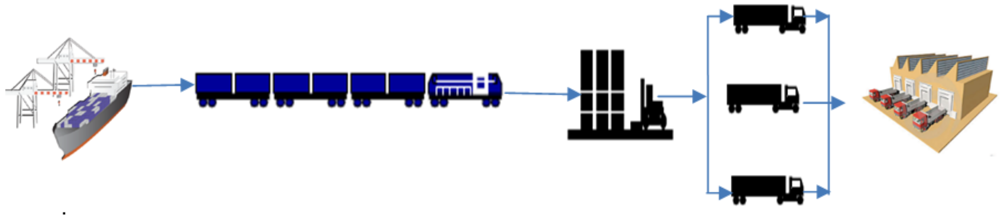
The concept of urban intermodalism is a relatively new intermodal transport concept, considered as promising and sustainable solution to congestion, safety, environmental and other related problems that city ports have on the urban fabric (Meyrick 2007). These problems are compounded for city ports like Sydney experiencing continuous growth in containerised trade, with little room for physical expansion and lack of adequate and efficient transport systems connecting the port and container origins/destinations in the urban region. These problems also have negative impacts on port operations and significantly worsen the cost and reliability of cargo delivery to/from the port (DoFD, 2011). Inefficient port operations have the potential of negatively affecting a nation's foreign trade and its ability to compete in global markets, since the port is largely considered the transit point for the greater part of this trade in volumes (Teye Bell & Bliemer, 2015). The search for efficient transport solutions to the above problems led to the development of urban intermodal container terminals that interface with road and rail or waterway networks to promote the use of urban intermodal transport to shippers.

Urban intermodal transport, also known as IMEX (import/export) intermodal system (Meyrick, 2007), involves the combined use of a high carrying capacity mode (rail or barge) to transport the containers between the port and intermodal terminals (IMTs) and trucks between customer locations and the IMTs. Thus, containers arriving at the port (imported containers) can be transported efficiently by rail (advantage of economies of scale) to the terminals and then transferred onto trucks (advantage of flexibility and accessibility) for onward movement to various destinations in the urban region (Teye, Bell & Bliemer 2015b; Meyrick 2007). Similarly, export containers can first be consolidated at an intermodal terminal before been transported to the port by rail for export as shown in Figure 1. The key element in the promotion of urban intermodal transport is the IMTs, which are equipped with the required facilities for seamless transfer of containers between modes (e.g., trucks and rail) (Slack, 1998). These terminals are expected to be open user facilities for multiple users where users have the choice of routing their containers through the terminals as part of an intermodal transport chain or use trucks only for the transport task. Thus, the location of a new IMT adds another mode of transport (intermodal transport) and hence increases the modal options for shippers. Promoting the use of this mode (urban intermodal) of transport is expected to create significant extra handling capacities at ports as fewer yard spaces will be required for the storage, sorting and movement of containers within ports and also improve congestion problems around the port. Further, a significant shift to the use of intermodal transport is expected to lead to less damage to the road infrastructure, reduction in accidents and other road fatalities and reduction in greenhouse gas emissions due to the expected reduction in the number of truck trips and the total kilometres travelled on the road network.

The first model for locating urban or IMEX intermodal terminals (UITLP) was proposed by Teye, Bell & Bliemer (2015) using mixed inteher programming (MILP) formulation of the problem with Lagrangian heuristics for solving it. They observed that the MILP formulation leads to all-or-nothing assignment of demand between competing modes for each origin-destination pair, resulting in possibly unintuitive results under forecasting and policy testing. For instance, if a certain transport option is only marginally more expensive, then the model predicts that it will not be used at all. This limitation motivated a new formulation by Teye, Bell & Bliemer (2016), where they replaced the linear programming (LP) part of the formulation with a nonlinear entropy maximising framework which allows a (logit) discrete choice model to be embedded within the facility location model. The solution to the model generates interlinked facility location model (FLM) and a mode and IMT choice model (MITP) suitable for explaining mode choice behaviour by shippers, forecasting IMT usage and policy testing. However, the proposed entropy model was only tested on toy examples, making it not suitable for supporting intermodal-oriented policies. Additionally, this model and other existing models on ITLP assume known and fixed origin-destination demand of cargo. As stated earlier this assumption has a severe limitation on the location and financial viability of the located IMTs since there is no way of accessing the potential of the located IMTs to attract warehousing and other auxiliary activities to them (the IMTs). Several studies (e.g., DoFD, 2011; Meyrick, 2006) have shown the importance of revenue generated from activities in the viability and sustainability of urban IMTs and it is unrealistic to use fixed matrices to determine the best IMT locations in urban areas.

This paper extends the work by Teye, Bell & Bliemer (2016) in three main directions. First, this paper embeds a variable cargo distribution model within the entropy framework and links it to the mode and IMT choice model (MITP). This is achieved through accessibility measures such that changes in modal and IMT decisions can influence the distribution of containers whilst the distribution of containers conditions the choice of mode and IMT. Secondly, algorithms for solving the overall model and estimation of relevant parameters are proposed and tested. Thirdly, the model is applied using the state of New South Wales (NSW), Australia, as a case study. The model reveals the key factors governing the distribution of containers in urban areas and hence the location of IMTs. The suitability of the model in forecasting and testing of intermodal-oriented policies and gauging their impact on intermodal transport usage are demonstrated.

Figure 1: Urban intermodal transport: Import market (Export market is the reverse)



2. Methodology

The study area (e.g., the urban region) is assumed to be segmented into freight analysis zones where cargo can be seen as originating from one zone and destined to another zone. The zones are connected to both the rail and highway networks so that cargo can be transported from one zone to another using at least one mode of transport. This paper considers two main modes of transport available to each decision maker; intermodal transport mode resulting from the combined use of trains and trucks and road direct transport using trucks alone.

2.1. Notation

The notations used in the models are defined as follows: $\mathcal{O}$ is the set of cargo origin zones indexed by i; $\mathcal{D}$ is the set of cargo destination zones indexed by j; T is the set of candidate IMT sites indexed by t where the indicator variable Y_t equals 1 if an IMT is located at location t and 0 otherwise; f_t is the fixed cost ($ per day) of locating an IMT at t; b_t is the maximum handling capacity of IMT t (in TEUs per day) and p is the required number of IMTs to be located. The variable Q_{ij} represent the quantity of cargo (in TEUs per day) transported from cargo origin zone i to destination zone j; the quantity of Q_{ij} transported intermodally (in TEUs per day) through IMT t is represented by X_{itj} with associated unit cost c_{itj} (in $ per TEU per day) and the quantity transported by road direct (in TEUs per day) is represented by W_{ij} with associated unit cost ω_{ij} (in $ per TEU per day), q_i is the observed quantity of cargo (in TEUs per day) produced or originating from origin zone i, and d_j the observed quantity of cargo (in TEUs per day) attracted or destined to zone j,$\mathbb{Z}$ is the total cargo (in TEUs per day) in the system.

2.2. The Principle of Entropy Maximisation

The principle of maximum entropy (PEM) could be considered as a generalisation to the random utility maximization theory (McFadden 1974). Unlike the random utility maximisation where the analyst make some assumptions about the error terms (missing information), the PEM requires no assumption about the missing information (error terms) but rather all possible states (values) of the variable of interest are considered and the most likely state consistent with the evidence available is selected.

The problem under consideration is to find the best sites in the urban region to locate p IMTs. What is 'best', however, depends on the application and the chosen objective. Assume that the objective is to maximise demand or usage and also justify the construction and other relevant costs of locating and operating them. The demand for the IMTs directly relates to the demand for intermodal transport mode. However, since we do not have complete information on the intermodal transport information, we propose a probabilistic description of the system in order to account for all the missing information. In fact, even if we have complete information on the system, many of them (the information) cannot be quantified and included in the decision process (McFadden, 1974).

The question therefore moves away from 'finding the best p IMT locations with the assumption of complete and precise information' to 'finding the most likely p IMT locations based on the information available'. The key question that arises is: what is the best way of combing the diverse pieces of contextual information or evidence to construct a probability distribution of IMT usage with the least possible bias? The answer to this question is based on the principle of maximum entropy (Jaynes, 1957; Shannon, 1948; Wilson, 1970; Fisk 1983). The principle asserts that the most unbiased probability distribution possible will be the distribution constructed by considering all possible states (or values) of IMT demand and selecting the most likely state consistent with all the evidence we have. Fisk (1983) noted that any other distribution would imply having more and above knowledge about the system than what is supplied by the evidence available.

The PEM approach was successfully applied in Teye, Bell & Bliemer (2016) to locate urban cargo terminals under fixed origin-destination cargo matrices leading to a facility location model linked to probability distributions of modal demand and IMT demand. The extension to include a cargo distribution model is proposed in Section 2.2. The overall objective is to find the most likely values of intermodal flows (X_{itj}) and road direct flows (W_{ij}) consistent with available information on cargo distribution and other relevant properties of the intermodal transport system, which according to Teye, Bell & Bliemer (2016) can be expressed as:

$$-\sum_{i\in\mathcal{O}}\sum_{t\in T}\sum_{j\in\mathcal{D}}\left(X_{itj}\ln(X_{itj})-X_{itj}\right)-\sum_{i\in\mathcal{O}}\sum_{j\in\mathcal{D}}\left(W_{ij}\ln(W_{ij})-W_{ij}\right) \qquad (1)$$

We can then maximize the above entropy subject to the information available expressed in constraints.

2.2. The Available Evidence about the intermodal system

2.2.1 Cargo Distribution

To incorporate a cargo distribution model into the entropy framework, we make some assumption about the quantity of cargo (in TEUs) attracted to each destination zone and how they (TEUs per day) can be expressed as a function of the overall attractiveness of the zone. Let A_j be a vector of K variables describing the attractiveness of destination j as cargo destination zone and let vector α be the associated parameters revealing the importance or weight of each $k \in K$ variable in the cargo attraction process. If the quantity cargo arriving at a destination zone $Q_j = \sum_i Q_{ij}$ is assumed to follow a Poisson distribution with the mean expressed as

$$\mathbb{E}\left[Q_j|A_j\right] = d_j = exp\left(\sum_{k\in K}\alpha_k A_{jk}\right) = exp\left(A_j{}'\alpha\right)$$

then it can be shown that the optimal values of α under the Karush-Kuhn-Tucker (KKT) condition satisfy the following equation:

$$\sum_i\sum_j Q_{ij}\,A_{jk} = \sum_j d_j A_{jk} \quad ;\forall k \in K \qquad (2)$$

2.2.2 Other Available Evidence about the intermodal system

In addition to constraint (2), other available information on the intermodal system can be summarised as follows:

1. *Conservation of cargo flow constraint*. This information is added as constraint (3). It ensures that for each origin-destination pair, the sum of cargo transported intermodally and by road direct equals the total number of cargo associated with this origin-destination pair.

$$\sum_{t \in T} X_{itj} + W_{ij} = Q_{ij} \quad \forall\, i \in \mathcal{O}; j \in \mathcal{D} \tag{3}$$

2. *Budget constraint*. This evidence is added as constraint (4). The first component captures the weighted cost of using intermodal transport, the second captures the weighted cost of using road direct transport (e.g. truck only) and the third component represents the fixed costs of locating the required number of IMTs, which should not exceed the total budget (C).

$$\sum_{i \in O} \sum_{t \in T} \sum_{j \in D} c_{itj} X_{itj} + \sum_{i \in O} \sum_{j \in D} \omega_{ij} W_{ij} + \sum_{t \in T} f_t Y_t \leq C \tag{4}$$

3. *Capacity constraint*. Information on cargo handling capacity of each candidate IMT is added as constraint (5)

$$\sum_{i \in \mathcal{O}} \sum_{j \in \mathcal{D}} X_{itj} \leq Y_t b_t \quad \forall t \in T \tag{5}$$

4. *Definitional constraint*. The information on the required number of IMTs to locate is presented by constraint (6)

$$\sum_{t \in T} Y_t = p \tag{6}$$

5. *Demand constraints*. Constraints (7) guarantee that the total quantity of cargo originating from a given cargo origin zone must equal the sum of all cargo arriving at all destination zones from that origin:

$$\sum_{j \in \mathcal{D}} Q_{ij} = q_i \quad \forall\, i \in \mathcal{O} \tag{7}$$

Based on the above constraints, the proposed entropy facility location model (EMFLM) can be summarised follows:

$$EM: \ \mathbb{F} = Max \left\{ - \sum_{i \in \mathcal{O}} \sum_{t \in T} \sum_{j \in \mathcal{D}} X_{itj} \big(\ln(X_{itj}) - 1 \big) - \sum_{i \in \mathcal{O}} \sum_{j \in \mathcal{D}} W_{ij} \big(\ln(W_{ij}) - 1 \big) \right\}$$

Subject to constraint (2) to (7) and the following integer and non-negativity constraints:

$$Y_t \in \{0,1\}; \ \forall t \in T \tag{8}$$

$$X_{itj} \geq 0\, ; W_{ij} \geq 0 \ ; \quad \forall\, i \in \mathcal{O}; j \in \mathcal{D}; t \in T \tag{9}$$

$$Q_{ij} \geq 0\, ; \forall\, i \in \mathcal{O}; j \in \mathcal{D} \tag{10}$$

3. Solution to the EMFLM

3.1. Introduction

The general problem under consideration is NP hard (Sorensen, Vanovermeire & Busschaert 2012), which implies that it is unlikely to find an efficient algorithm for solving every instance of the problem (Garey & Johnson 1979). However, Teye Bell & Bliemer (2016) noted that since there are few plausible places in an urban region to place IMTs, complete enumeration (CE) algorithms could be employed to solve the problem in a reasonable amount of time. To do this, the hard constraints in the problem which are associated with the location variables ($Y_t, t \in T$) have to be separated from the rest. This can be achieved by relaxing constraints (4) and (5) of the PEM model resulting in two sub-models; the facility location problem (FLP):

$$FLP:\ Z_{LP}(Y,\beta,\psi) = Min\left\{\sum_{t\in T}(\beta f_t - \psi_t b_t)Y_t\right\}$$

Subject to constraints (6) & (8)

and Cargo Flow Model (CFM)

$$CFM: Z_{CFM} = Max\left\{\sum_{i\in\mathcal{O}}\sum_{t\in T}\sum_{j\in\mathcal{D}} X_{itj}\{1-\ln(X_{itj})-\psi_t\} + \sum_{i\in\mathcal{O}}\sum_{j\in\mathcal{D}} W_{ij}\{1-\ln(W_{ij})\} \quad +\beta C \right.$$
$$\left. -\ \beta\left(\sum_{i\in\mathcal{O}}\sum_{t\in T}\sum_{j\in\mathcal{D}} c_{itj}X_{itj} + \sum_{i\in\mathcal{O}}\sum_{j\in\mathcal{D}}\omega_{ij}W_{ij}\right)\right\}$$

Subject to constraints (2), (3), (7), (9) and & (10)

3.2. Solution to FLP

Given $\psi_t \geq 0;\ \forall t \in T$ and $\beta \geq 0$, FLP can be easily solved by identifying the p smallest elements of $(\beta f_t - \psi_t b_t), \forall t \in T$, and setting the corresponding values of Y_t equal to 1. Conversely, for a given set of located IMTs, $\mathcal{T} \in T$ with size p, the Lagrangian multipliers $\beta, \psi_t; \forall t \in \mathcal{T}$ can be computed by solving the CFM. Once we know $\mathcal{T} \in T$ the CFM can be solved as outlined in the next subsection.

3.3. Solution to CFM

Problem CFM can be solved by constructing a Lagrangian equation comprising of the objective function and the constraints and enforcing the KKT or first order optimality conditions with respect to X_{itj}, W_{ij} and Q_{ij} are respectively given as:

$$-\ln(X_{itj}) - \psi_t - \eta_{ij} - \beta c_{itj} = 0; \forall\, i \in \mathcal{O}; j \in \mathcal{D}; t \in \mathcal{T} \qquad (11)$$

$$-\ln(W_{ij}) - \eta_{ij} - \beta\omega_{ij} = 0;\ \forall\, i \in \mathcal{O}; j \in \mathcal{D}; t \in \mathcal{T} \qquad (12)$$

$$\eta_{ij} + \sum_{k\in K}\xi_k A_{jk} - \gamma_i = 0\ ;\ \forall\, i \in \mathcal{O}; j \in \mathcal{D} \qquad (13)$$

where $\eta_{ij} \geq 0$; are Lagrangian multipliers for the origin-destination cargo flow constraints (3) and the vectors $\beta, \psi, \xi, \gamma \in \mathbb{R}$ (set of real numbers) are Lagrangian multipliers for constraints

(4), (5), (2) and (7) respectively. The reader is referred to the paper by Teye, Bell & Bliemer (2016) for detail derivation of the mode and IMT distribution models (X, W). It can be shown that with some algebraic manipulation, the container distribution from equation (13) can be expressed as:

$$Q_{ij} = q_i \frac{exp\left(\lambda_D I_{ij} + \sum_{k\in K} \xi_k A_{jk}\right)}{\sum_{j\in\mathcal{D}} exp\left(\lambda_D I_{ij} + \sum_{k\in K} \xi_k A_{jk}\right)} \quad (14)$$

where I_{ij} is the expected maximum utility (also referred to as the logsum) from the mode & IMT choice models (see Teye, Bell & Bliemer, 2016). The Lagrangian parameters $\xi_k; k \in K$ associated with the zonal attributes can then be estimated using Poisson Quasi-Maximum Likelihood Estimator (QMLE) or other appropriate estimators.

3.4. Complete Enumeration (CE) for solving overall problem

Once the EMTLP is decomposed into the sub-problems, and each solved to optimality, the CE algorithm is used to solve the overall problem. Note that the size of the set $\Psi,$ of locating p IMTs from the candidate set of T is polynomially bounded by:

$$|\Psi| = \binom{\tau}{p} = \frac{\tau!}{p!\,(\tau - p)!} = O(\tau^p) \;; \quad \tau = |T| \quad (15)$$

.

For example, if the analyst is interested in locating two IMTs, then the number of possible evaluations of the MCP is bounded by $\tau(\tau - 1)$. Let Z_D be the total demand of intermodal transport or total usage of the located IMTs and $\mathcal{T}$ the set of located IMTs. Note that only feasible intermodal flows satisfying the budget and all other constraints are returned, else Z_D is set to zero. The CE algorithm is presented as follows:

CE Algorithm

1. Initialization: $\mathcal{T}^* = \{0\}, Z_D{}^* = -L,$ where L is a large positive number, $\mathcal{T}^*$ the set with the optimum IMT sites with associated value $Z_D{}^*$
2. For each subset $\mathcal{T} \in \Psi$ with associated total fixed cost of *p* IMTs, where the location variable $Y_t = 1;\ \forall t \in \mathcal{T}\ ;\ Y_t = 0\ \forall t \notin \mathcal{T}$ do:
   - 2.1. Solve the CFM and store the optimal value as Z_D
   - 2.2. If $Z_D > Z_D{}^*$, then $Z_D{}^* = Z_D$ and $\mathcal{T}^* = \mathcal{T}$
3. Repeat step (2) for all subsets of Ψ and stop
4. Return $Z_D{}^*$ and $Y_t = 1, \forall\ t \in \mathcal{T}^*$ and $Y_t = 0, \forall\ t \notin \mathcal{T}^*$

4. Case Study

4.1. Introduction

The proposed model was implemented using Sydney Metropolitan Area (SMA), Australia as the study area. 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-IT) and were used to construct the generalised costs of each mode. In this study, 8 plausible IMT locations were identified primarily based on their proximity to the rail network and their spatial distribution as shown in Figure 3 (Meyrick, 2007). Data on employment by industry and occupation were obtained from ABS business counts. Key features of the IMTs such as fixed setup cost, handling capacity and total cost (lift on/off plus storage) incurred at terminals were all assumed to be the same across them (the candidate IMTs) and were derived from the national intermodal study (Meyrick, 2007). The distribution of import containers in the study area is shown in Figure 2 where about 90% of the cargos have their destinations within 50km from the port. Figure 3 shows the top container destination areas within the study area with Blacktown alone accounting for about 13%.

The cargo distribution model is explained by four main variables: natural logarithm of the number of employees (labourers) in manufacturing as a proxy to the access to manufacturing businesses and agglomeration; the natural logarithm of number of people employed in warehousing and storage industry, which is expected to quantify the benefits of performing warehousing activities at the located IMTs. The third variable (accessibility) captures access to key markets which in this study were identified as zones in the two main central business districts (CBDs), Sydney and Parramatta and three regional centres (Penrith, Liverpool and Campbelltown). The fourth variable is the expected utility from the mode choice model as an indicator to access to multiple modes of transport.

Fig 2: Over 90% of import cargos have their destinations within 50km from the port

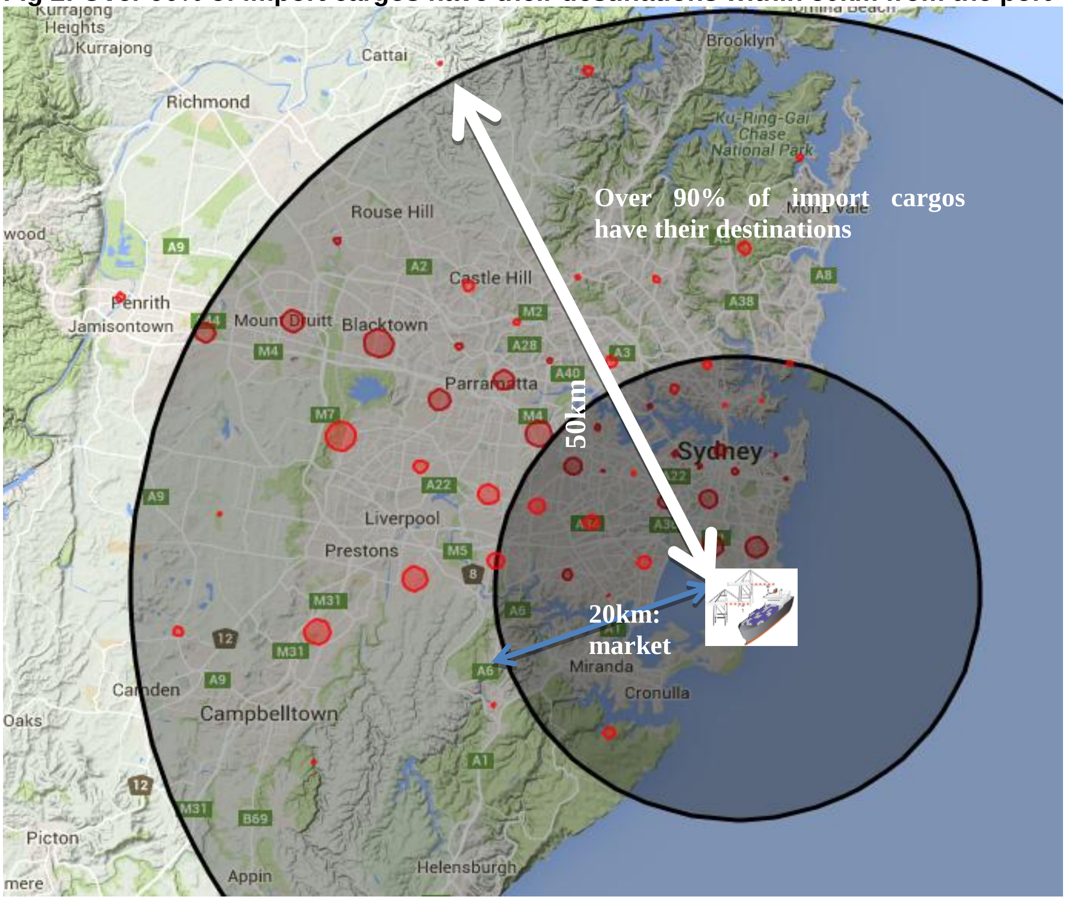
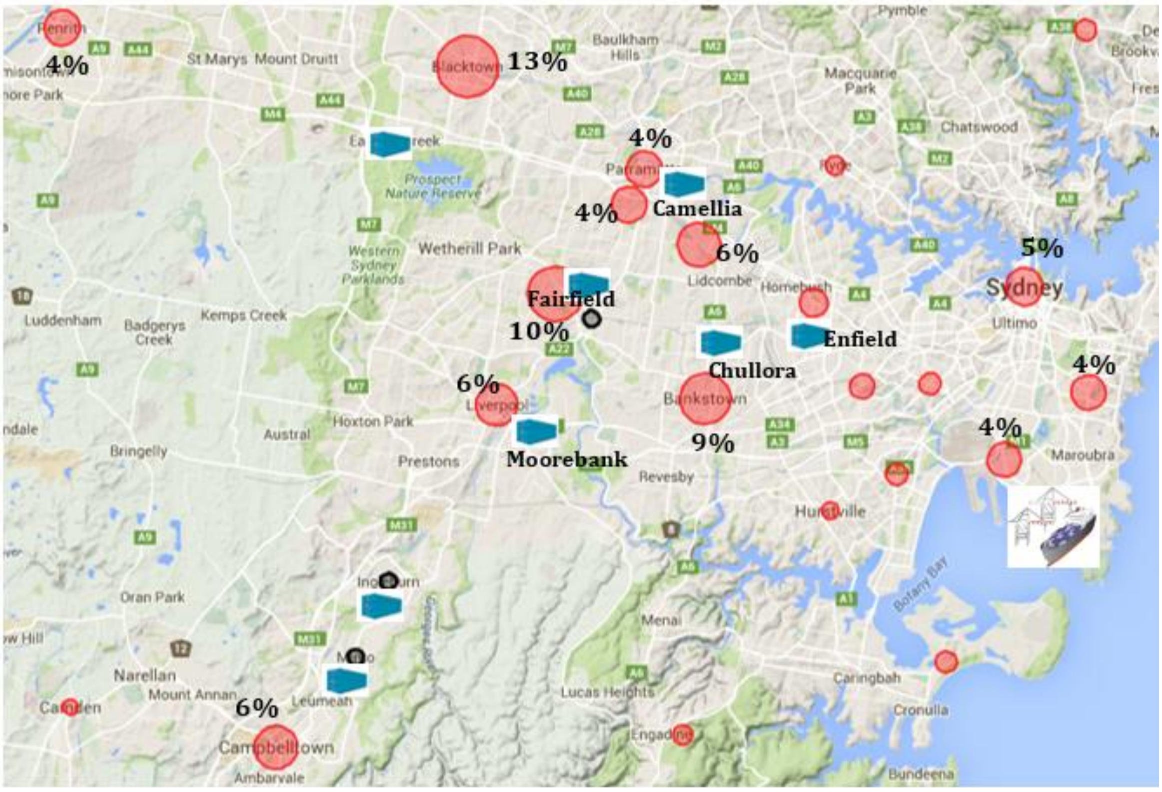


Fig 3: Key Cargo Destinations



5. Analysis of Results

5.1. Key factors governing container distribution and mode choice

The generalised cost coefficient or sensitivity parameter β governing the choice of mode and IMT was estimated to be -0.016555 with associated estimated average trip length of 265.6232 compared with the observed trip length of 265.6232 showing that increasing the modal options for shippers did not increase the average transport cost of container movements over all modes. This adds to the safety, environmental and congestion reduction benefits associated with reducing the number of trucks on the road network.

Table 1 presents the estimated results for the cargo distribution model. All the presented estimated parameters are significant at 95% confidence interval. The results showed expected positive marginal utilities for increasing access to manufacturing and warehousing businesses, accessibility to the key markets and multiple modes of transport (mode choice logsums). For example, the positive value (0.77) associated with manufacturing indicates that zones with high manufacturing jobs are more likely to be container destinations and may be indicating the existence of agglomeration of freight related businesses in the area. This is also true for zones with high warehousing and storage jobs. The accessibility to the CBDs variable is also positive (0.246) indicating that all things being equal zones with easy access to the key markets (5 CBDs in Sydney) are more attractive container destinations. This analysis is also true for zones with access to multiple modes of transport derived from the mode choice model.

Looking at the magnitude of the estimated variables, access to manufacturing businesses has the biggest influence on the distribution of containers in the urban region and hence the location and use of IMTs. The second most important factor is the access to warehousing and storage businesses, which together with access to manufacturing may be revealing the agglomeration effect associated with the containerised trade. This makes agglomeration or access to freight-related business the key driver in the choice and usage of intermodal terminals. Access to key markets and multiple modes are very important and should be considered in the decision process but with relatively smaller weights.

Table 1: Factors governing container distribution

Meaning	Coefficient	tstats
Access to Manufacturing	0.7748	
t stats		6
Access to Warehousing & Storage	0.3017	
t stats		4
Access to key Markets	0.2457	
t stats		4
Access to Multiple Modes	0.1631	
t stats		2
No of Estimated Parameters	4	
Number of Observations	79	

5.2. Selecting the best IMT location

Here, we used the proposed model to determine the best IMT location among the 8 candidate locations. The result of this analysis is shown in Figure 4 where Eastern Creek (location number 4) immerged as the best location followed by Camellia. An IMT located at Eastern Creek is expected to attract almost 59,000 TEUs per annum as a transfer node representing about 8% of the annual import containers. Figure 5 shows the key markers for Eastern Creek IMT, with 43% of its demand expected to come from containers destined to Blacktown, 14% from Fairfield and 11% from Penrith. These results are expected considering the proximity of Eastern Creek to Blacktown and Penrith relative to the other candidate IMTs. Additionally, Blacktown is the biggest container destination accounting for over 13% of all import containers.

To test the robustness of the results, l2, 3 and 4 IMTs were located in turn with the results presented in Figure 6. The test supports Eastern Creek and Camellia as the most promising IMT locations. For the 3 located IMTs, Eastern Creek is expected to capture 42% of the intermodal market, followed by Camellia with 33% and then Yennora with 25% share.

Fig 4: Eastern Creek is the best IMT Location

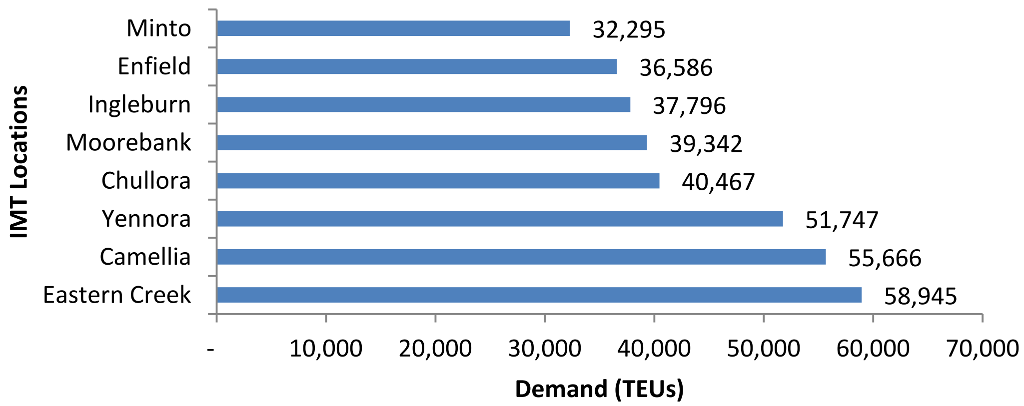


Fig 5: Key market of the Eastern Creek IMT

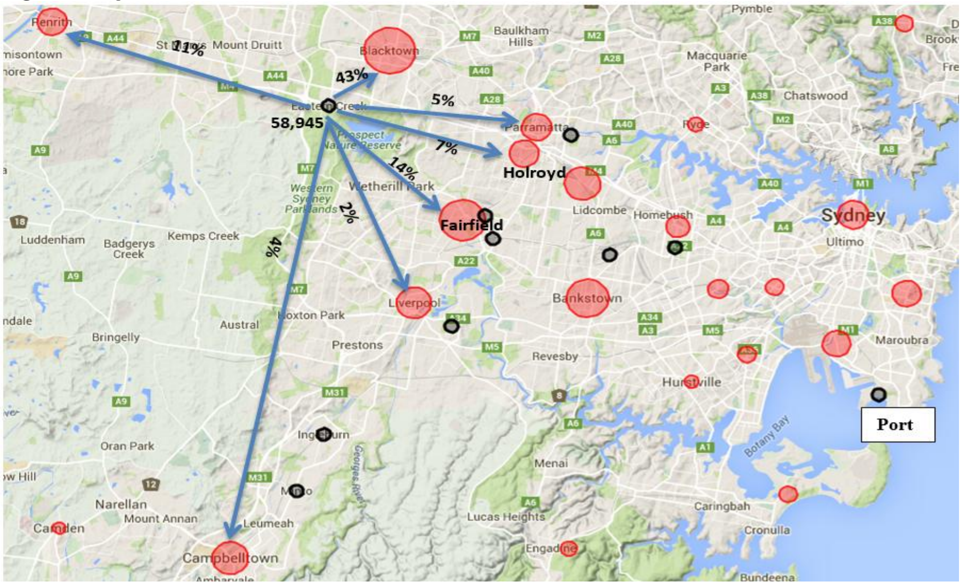
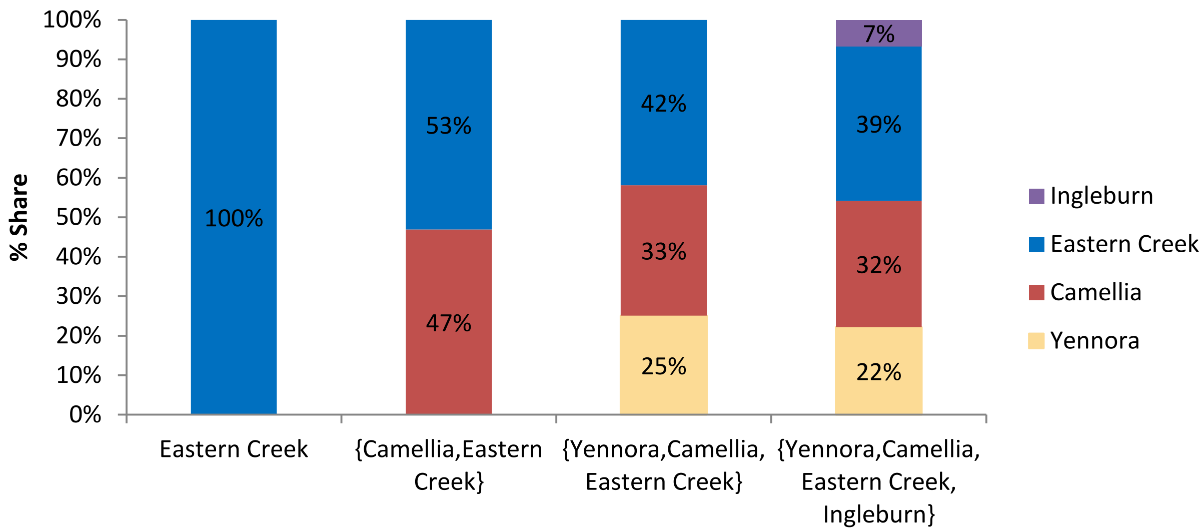


Figure 6: Robustness of optimal IMT selection



5.3. Policy Testing

The study tested two important policies and investigated their impacts on the located Eastern Creek IMT. The first is to estimate the likely revenue from warehousing activities at the IMT. To do this we increase the warehousing units in a container destination zone closest to Eastern Creek IMT. This zone was identified to be South East of Blacktown. The warehousing units were approximated by the number of employees working in warehousing, which is the variable used in the cargo distribution model. The results after increasing the number of warehousing employees by +5%, +10%, +15%, 20% and 25% in turn, are shown in Figure 7. The results show that a 5% increase will increase the use of the Eastern Creek IMT for transfer purposes by about 0.3% and a further 1.3% increase due to re-location of warehousing activities to the IMT. Similar conclusions can be drawn for the +10%,15% and +20% scenarios. The relatively high demand due to warehousing is expected considering the high land value and scarcity of land for these (warehousing) purposes in the study area (Sydney metropolitan).

The second policy looks at the impact of urban congestion or road pricing on the located IMT. This policy was tested by increasing the road transport costs to zones within the two main central business districts (Sydney and Parramatta) by +5%, +10%, +15%, to

50% in turn. As expected the results show a marginal increase in the use of Eastern Creek from the base to the 50% scenario. For example, the demand for the use Eastern Creek IMT for transfer purposes increased by 1.3% under the 5% scenario to about 26% under the 50% scenario. These results suggest a positive future outlook for the IMT as congestion to these two CBDs is set to set worse in the future. In other words, the cost of transporting containers by trucks to the CBDs is set to go up significantly either due to congestions or through some form of road pricing. It is also expected that an increase in the cost reaching the CBDs can trigger re-distribution of containers and may have positive impacts on the located IMTs.

Fig 7: Investigating the benefits of performing warehousing activities at the IMT

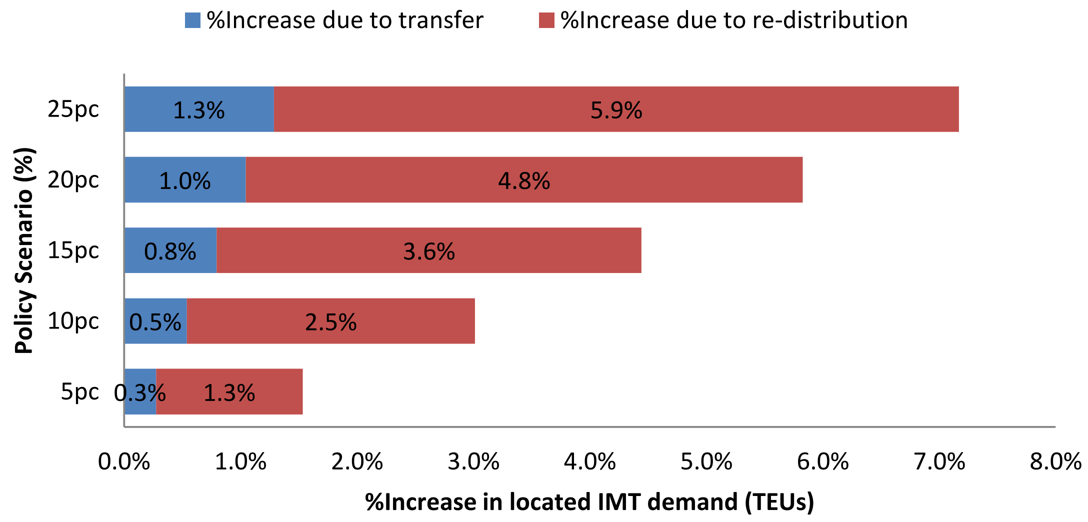
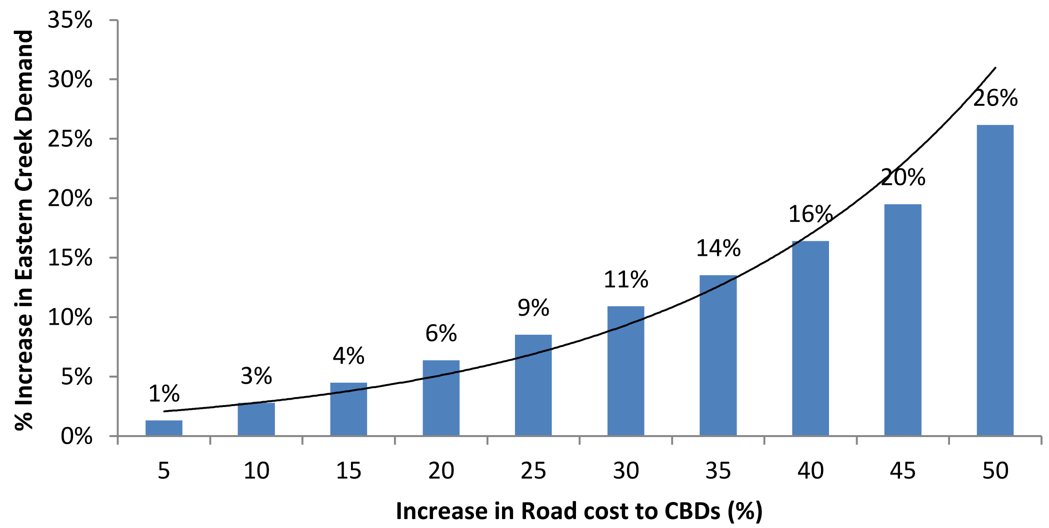


Fig 8: Impact of IMT demand due to worsening accessibility to CBDs



6. Policy Implications

The results of the models have several implications for policy makers. Perhaps most importantly, the effect of container distribution on urban intermodal location and usage, accounted for through the cargo distribution model. The distribution model has been shown to be governed by four important policy variables, two (access to manufacturing and warehousing variables) of which reveal the existence of agglomeration (i.e., clusters of industries in a single location) associated with containerized trade. The results suggest that the access to manufacturing has the biggest impact on the distribution of containers in the urban region. This result is consistent with recent study by Chandler et al. (2015) who provided empirical evidence of the strong relationship between the number of manufacturing businesses and the location of intermodal freight terminals in the US. Thus the catchment area (market) of a located intermodal terminal is likely to be in close proximity to manufacturing businesses.

Also of importance to policy makers are the results that container destinations must have convenient access to key markets. The accessibility to key market variable, measured as function of truck travel time from container destination to the key markets immerged with positive value and statistically significant, suggesting that easy access from container destination to key markets is essential. Finally, proximity and convenient access to multiple modes of freight transport also has significant effect on container destinations, although its impact is relatively small compared with access to manufacturing or warehousing businesses. There is strong evident to suggest that the best place to locate intermodal terminal is in Eastern Creek due to its proximity to a major container destination (Blacktown) and hence its access to manufacturing and warehousing businesses. The results show that performing auxiliary activities such as warehousing at the terminal will provide a significant source of revenue due to potential container re-distribution and increase in the use of intermodal transport. Policy testing shows a positive future outlook for the located IMT as intermodal terminal use is set to go up significantly due to worsening traffic congestion in the study area especially around the CBDs. Plausible policies to promote intermodal transport use include subsidising the cost of IMT usage as transfer node and road pricing especially around the port. Other important policies include encouraging freight related businesses like manufacturing and warehousing to be located around the IMTs.

7. Conclusion

This study employs an entropy framework to successfully embed a distribution model and mode and IMT choice models in a facility location problem such that the choice of mode hence IMT influences the container distributions, which in turn influence location choice of intermodal terminals. The overall model was decomposed using Lagrangian relaxation techniques and solved to optimality. Key features of the model were demonstrated using Sydney Metropolitan Area (SMA) as case study and import containers to the state of NSW, Australia. The model has been shown to produce intuitive and realistic results both in terms of locating the facilities and testing of various policy instruments.

The study identified four key variables governing the distribution of containers in the urban region, which in turn influence the location choice of intermodal terminals. The study has also demonstrated the use of the model for testing of various instruments to promote the use of the located IMTs. The policies include possible government subsidies on the use of the terminals as transfer node and road pricing especially around the port. Both policies proved to be very effective in promoting the use of intermodal transport. Other useful policies are encouraging the clustering of freight related business around the IMTs.

The models presented deals with the location of urban container terminals. The model can be extended to deal with container flows between regions (e.g., Sydney and Melnourne) which require the use of two intermodal terminals along the intermodal transport chain. The study area for this intermodal system is usually large with significantly high number of plausible places to locate the IMTs. This will therefore require the development of a more efficient algorithm or heuristics for solving such problems.

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