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# Computationally Simulating Intermodal Terminal Attractiveness and Market Demand

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**Abstract:**

Intermodal terminals represent a key element in most port logistic networks. They exploit economies of scale by pooling demand from surrounding areas and using rail to transport containers to and from ports. The main alternative of intermodal terminals is to truck containers through the road network. This is often the most convenient and quickest transport method for freight owners, however it increases congestion on often constrained roadways. To avoid such congestion, policy makers may try different incentives to increase the use of rail. This paper exploits various open and commercial datasets to build a model of the port logistics system, which not only includes the transportation network and service providers, but explicitly represents how the users of the system make decisions. This includes how the key service features of cost, timeliness, and reliability are valued by freight owners and forwarders. Such a model is critical in quantifying the effectiveness of different measures available to government policy makers. Furthermore, it can help intermodal terminals managers optimise their internal operations to improve their attractiveness to potential customers and maximise their returns. The paper's focus is on Sydney's Port Botany, however the methodology is generally applicable.

**Keywords:**

modelling transport networks, whole-city computational model.

## Introduction

Port Botany, located in Sydney's east, is the main container port in New South Wales (NSW). The Port's container throughput is predicted to increase substantially over the coming decades, potentially quadrupling to 13.6 million twenty foot equivalent unit (TEU) containers by 2040 [1]. This will put increasing pressure on the land side logistics chain and has the potential to cause significant congestion in the surrounding road network. Intermodal terminals help alleviate this road congestion by allowing containers to be moved between the port and intermodal terminal by rail. The intermodal terminal performs the transfer of containers between rail wagons and trucks, allowing a shorter drayage between the terminal and the container's origin/destination.

In 2014, there were 2.3 million movements of TEUs through Port Botany, split evenly between imports and exports. The land transportation of these containers was 2 million carried by truck and 0.3 million carried by rail, corresponding to a 14% share [3]. Improving this market share is a key objective for the NSW State Government [1] and NSW Ports, the managing consortium of the Port Botany precinct [3]. NSW Ports has set a target of moving three million TEUs by rail by the year 2045. Meeting this objective will require significant investment in new railway lines and intermodal terminals; however such steps will be critical in maintaining an efficient port logistics process for the State of NSW and ensuring Port Botany remains globally competitive.

Previous work into improving the usage of rail as a transport mode for containers moving in and out of Port Botany has focused largely on capacity considerations only [2]. Although having available capacity is necessary, it is not sufficient on its own to ensure that rail is competitive and can achieve a significant market share. An understanding of cost, timeliness and reliability of the entire logistics process, and how these are valued by shippers and freight forwarders, must be considered. The effects of major planning decisions, such as railway lines and large inland terminals, remain for decades and it is important that all possible alternatives are considered and compared in a consistent manner.

The key contribution of this work is the development of a new modelling framework to support such comparisons. Typically, such decisions are made by only considering the main constraints of capacity and aggregate demand. However, this ignores a key component of the problem regarding how market players make decisions. The proposed assessment framework explicitly considers how shippers choose between different transport service providers based on cost and quality of service, and how these service providers optimise their internal operations and price structure in response to market forces. This provides a holistic assessment methodology that can quantitatively predict the effects of different development trajectories.

**Datasets Covering the Port Logistics System**

Containerized trade through Port Botany supports the city of Sydney through imports, and regional NSW mainly through exports. Over 80% of import containers are delivered within a 40 kilometres radius of Port Botany [3]. It is noted that although the overall number of containers imported through Port Botany is approximately the same as the number exported, the majority of export containers are empty. Furthermore, the export of empties is predicted to increase to more than 74% by 2045, up from 62% in 2015 [3]. Due to these characteristics, only the transport of import containers into the Sydney metropolitan region will be considered here, the inclusion of exports is left for a future study.

The locations of Sydney's current and proposed intermodal terminals are shown in Figure 1. The two main transport options are depicted in Figure 2 and show a direct truck service (Option 1), and a combination of rail and truck via an intermodal terminal (Option 2).

***Option 1: Direct truck services***

1. Vessel arrives at the port, container unloaded from vessel and staked in the terminal yard
2. Truck arrives at the port, container loaded and transported to delivery location
3. Truck arrives at the delivery location and container unloaded.

***Option 2: Intermodal terminal services***

1. Vessel arrives at the port, container unloaded from vessel and staked in the terminal yard
2. Train arrives at the port, container loaded and transported to intermodal terminal
3. Train arrives at the intermodal terminal, container unloaded from train and staked in the terminal yard
4. Truck arrives at the intermodal terminal, container loaded and transported to delivery location
5. Truck arrives at the delivery location and container unloaded.

The remainder of this section describes datasets that cover the stages in these processes.

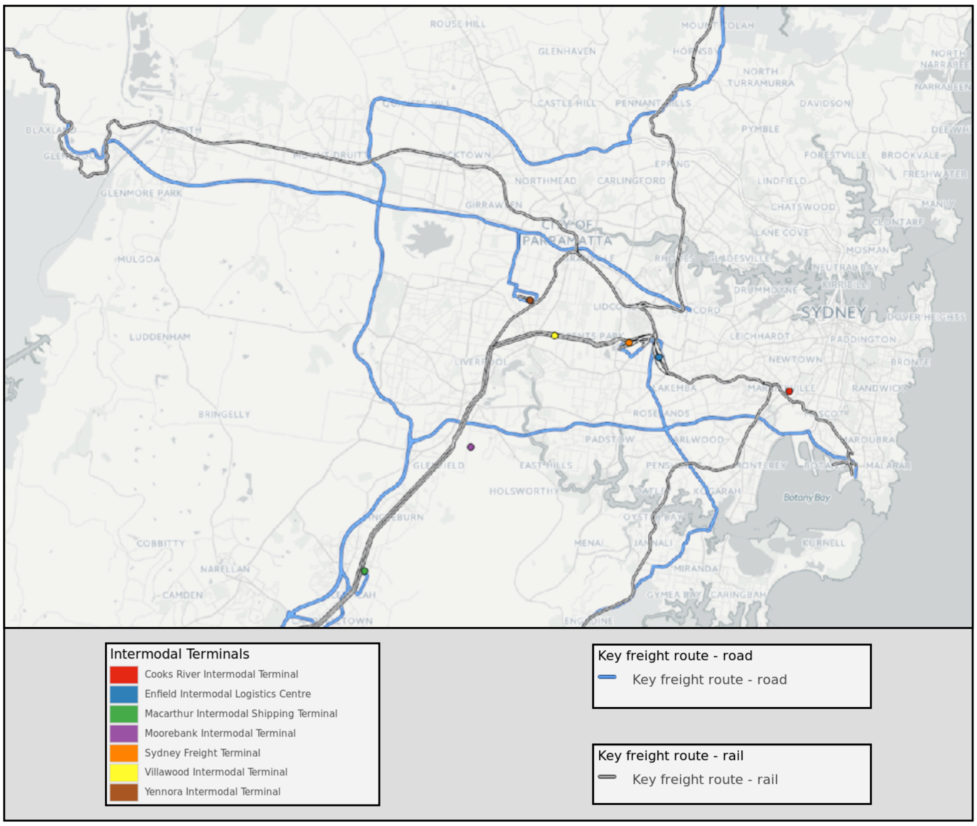


**Figure 1. Port logistics network. There are currently four operational intermodal terminals: Cooks River, Macarthur, Yennora and the Sydney Fright Terminal. Future terminals are planned at: Enfield, Moorebank, and Villawood.**

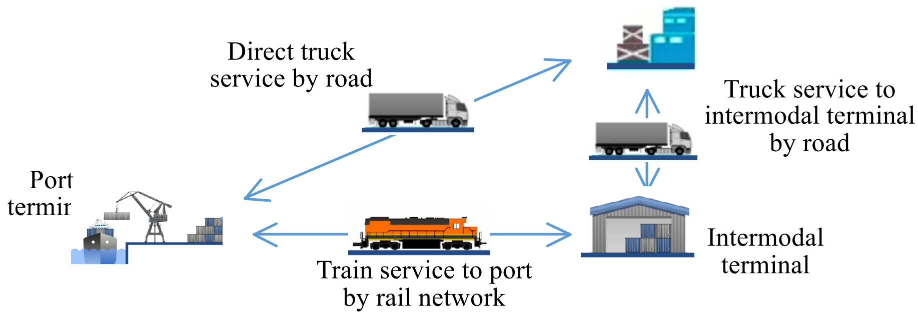


**Figure 2. The two main transportation options for containerized freight to and from Port Botany.**

*Port Botany Terminal Yard Storage Times*

Commercial data has been obtained regarding the movements of containers through the port terminals during the period 2013 to 2015. This comprises the detailed history of when each import container was unloaded from the vessel and the time it was picked up as part of the onward delivery chain. This defines the variation in wait times for containers based on their onward transport mode.

*Road Transport Times*

Travel times and road distances for vehicle movements through Sydney's road network has been obtained from Google's navigation service. This covers movements between each suburb in the Sydney metropolitan region and the port, and also each intermodal terminals.

*Rail Transport Times*

The freight rail network in the Sydney region has some dedicated freight lines and others that are shared with commuter services. Freight timetable information regarding the weekly schedules has been obtained the network operator: ARTC [4]. In addition to this schedule information, actual running times of all trains are collected by ARTC. Detailed information about the scheduled and actual running times have been acquired for a period in 2013. From this operational data, the nominal travel times for each link in the rail network have been computed. In addition, the actual delays that were experienced by trains travelling through the network have also been extracted.

*Road Transport Costs*

The retail price to deliver containers through Sydney directly by truck has been obtained from a road transport company. This commercially sensitive data is used to define the transport cost between the port or intermodal terminal and delivery destinations on the suburb scale. This is consistent with the price figures detailed in [5].

*Container Delivery Locations*

The Australian Bureau of Statistics has compiled information on the final delivery locations for containers imported through Port Botany [6]. This provides the total number of TEUs being transported from the Port through the logistics chain to each postcode. The data covers each month in the financial year ending 2010. The spatial distribution of the yearly total is depicted in Figure 3. In the future it is expected there will stay roughly the same, with some increase in the proportion of containers destined for Sydney's western and south-western suburbs. This will be driven by a combination of the availability of large parcels of land at lower prices, driving in turn the development of distribution centers in these areas [3].

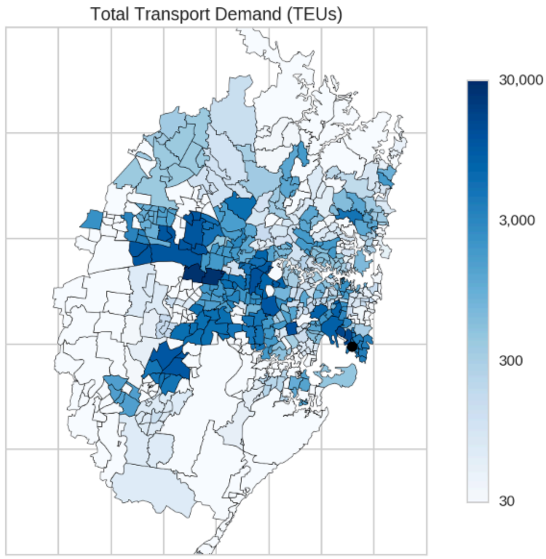


**Figure 3. Spatial distribution of the delivery locations of import containers into the Sydney metropolitan region (measured in TEUs per year for FYE 2010).**

## Economic Modelling Framework

In this section, an economic modelling framework is considered for the logistics system. The proposed framework represents all the key components in the network and explicitly models how the major market players make decisions. This allows the effects of proposed system modifications, such as the building of new rail infrastructure or the introduction of new intermodal terminals, to be quantified by explicit incorporating how the modifications will be exploited by the market players. This framework provides a holistic assessment methodology that goes well beyond simple capacity considerations. Furthermore, it incorporates the important factors of timeliness and reliability of the logistics process, and allows the effects of system modifications that influence these to be included. This is particularly important when considering incentive structures for rail, which historically has been slow and often experiences delays. The data related to 2014 has been used to parameterise and calibrate the model.

The main model components are depicted in Figure 4 and include (i) a decision model of the shippers and freight forwarders; (ii) the transport model of the direct truck service; and (iii) a model of the intermodal service providers. For the current analysis, the key output of the composite model is the throughput of each transport option. This allows the total mode share of rail and road to be predicted.

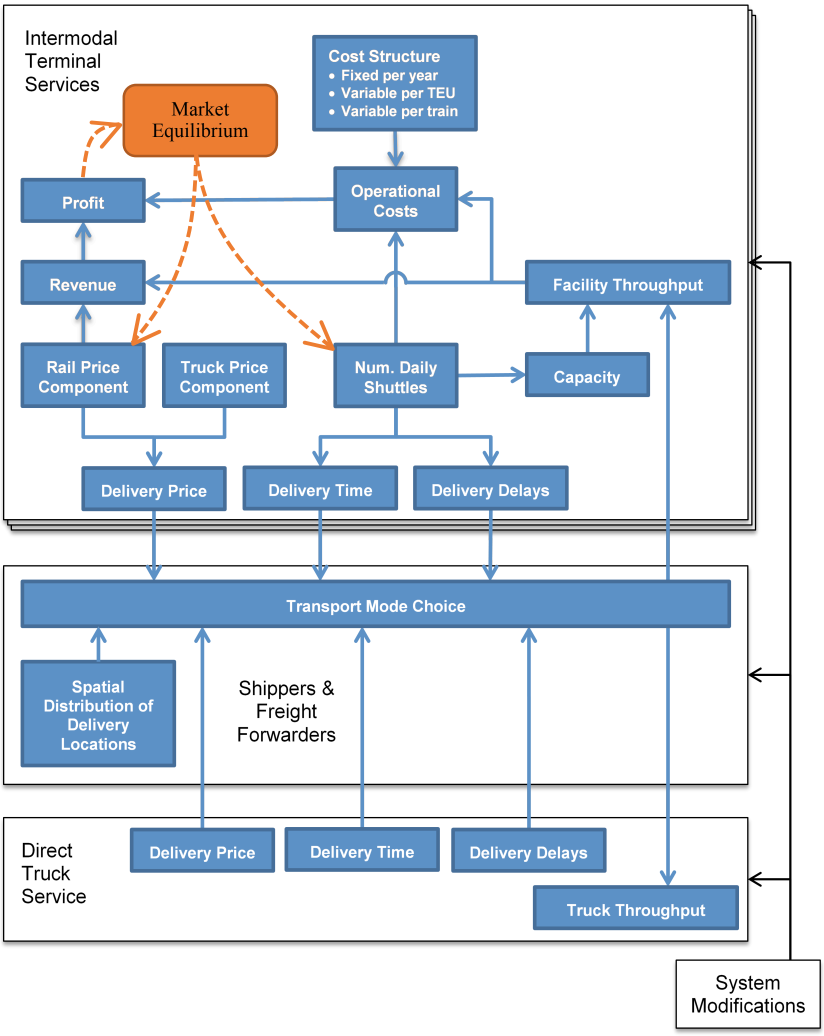


**Figure 4. Schematic of the main model components. Straightforward predictions of the throughput of each service can be generated with the blue components. A separate predictive analysis can be performed that includes the orange component. This determines the system's Nash equilibrium and sets appropriate prices and train schedules for the intermodal terminals to maximize the internal profit generated by each terminal.**

To allow predictions to be made in response to major market disruptions, such as the opening of new intermodal terminals, the market (Nash) equilibrium can be computed. This incorporates how intermodal operators may make decisions in the future to modify what they charge customers to use their service and how they schedule trains in order to maximise the profit they generate. In calculating the market equilibrium, it is assumed that the price structure of the direct truck service is fixed and is not changed by the entry of any new market players. This implies that the existing pricing structure offered by trucking companies is already very efficient due to the sufficiently large number of existing trucking companies.

*Understanding Transport Decisions*

It has been previously shown that a combination of price, transport time, and how often delays happen are all important to shippers. The work of Brooks *et al.* [7] presented a compelling case that all three have an integral part to play in modelling how decisions regarding model choice are made. Here, a similar discrete decision model is used that incorporates these important features and is based on a multinomial logit decision model [7]. This model is preferred over more complex models due to the ease at which the parameters of the model, once learned from the data, can be interpreted.

The specific multinomial logit decision model used in this work incorporates the three key features that are known to affect transportation decisions, namely: the total delivery price, the nominal (or mean) delivery time, and a reliability measure based on the 95th percentile buffer time. This last measure represents the additional time that must be added onto the mean delivery time to ensure 95% of the deliveries will arrive before the resulting time. This measure summarises the delays that a given transport option may experience.

For a given freight movement $m$ that a shipper needs to make, each available transport option $i$ is represented by the set of features: $p_{m,i}$, $t_{m,i}$, $r_{m,i}$, which corresponding to the price, time and reliability of the transport service. These features are combined into a single metric that represents the inherent utility to the shipper of that transport option (here utility refers to a von Neumann-Morgenstern utility function). This combination is performed by the linear function:

$$U_{m,i} = \beta_p p_{m,i} + \beta_t t_{m,i} + \beta_r r_{m,i} + \epsilon_{m,i}$$

The utility is parameterised by the coefficients: $\beta_p$, $\beta_t$, and $\beta_r$, which determine the intrinsic value of each feature to the shippers. The additional error term $\epsilon_{m,i}$ is assumed to be distributed according to a Type I extreme value density and represents other idiosyncratic effects on how shippers make decisions.

This model allows different transport options to be compared according to a single decision-theoretic metric. The option with the largest utility is assumed to be selected by the decision maker. It is noted however that as the model contains an explicit random term that is modelled probabilistically, the actual decision is not predicted, instead the probability distribution over each option is predicted.

Thus, for a given freight movement $m$, the resulting probability of choosing a particular transport mode $i \in O$ from a set of available transport options $O$ is given by

$$Pr(i|m,O) = \frac{exp(\sum_{f\in\{p,t,r\}} \beta_f f_{m,i})}{\sum_{j\in O} exp(\sum_{f\in\{p,t,r\}} \beta_f f_{m,j})}$$

This incorporates the three features of price, time and reliability of all the available transport options. The different options consisting of the direct truck service, and intermodal terminals are now considered, and their service features defined.

*Direct Truck Transport Service Features*

The critical features of cost, time and reliability for the direct truck service from Port Botany to an importer's premises is now considered. This combines the datasets related to the delivery cost, time, and delays outlined in the previous section above. Figure 5 plots the spatial variation in each feature, and the captured market share, for each suburb. The prediction of the market share is performed for the calibration scenario corresponding to the historical conditions of 2014.

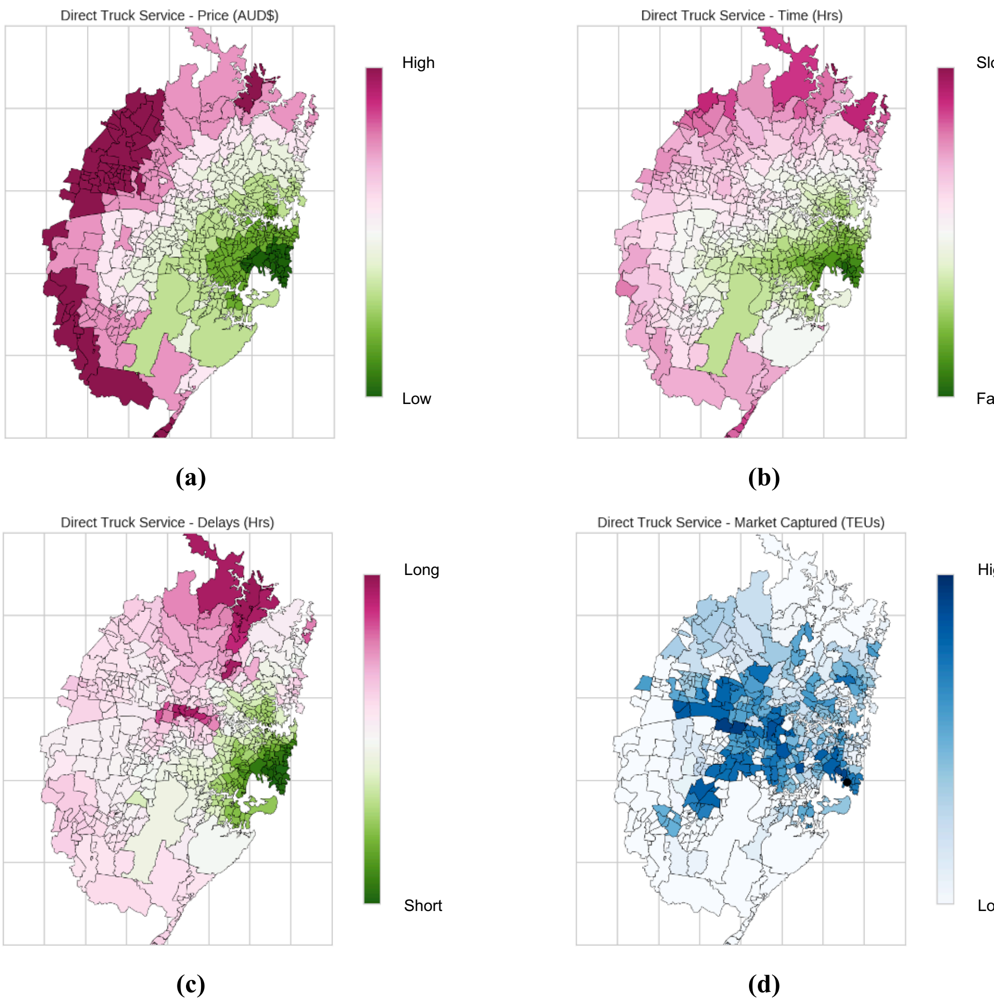


**Figure 5. Features of the direct truck service are depicted in (a) – (c). The total market that is captured by this service is depicted in (d).**

*Intermodal Terminal Transport Service Features*

The intermodal terminals are modelled as open access (and non-vertically integrated) facilities such that the road transport price is decoupled from the facilities operational costs that cover the container handling, storage and rail transport components. From [8] it is reported that the retail market price to cover rail transport and handling costs is likely to be in the order of $250. In addition to the price to cover the rail transportation and handling components, the road transportation component is modelled using the same trucking price information used for the direct truck service. The one difference is to adjust this to account for the reduced waiting and loading times that are typically experienced at an intermodal terminal. This adjustment is consistent with the recommendations made by [8]. Figure 6 considers the Yennora terminal and plots the spatial variation in each service feature, and the captured market share, for each suburb. Each service feature is plotted as a difference with respect to the direct truck service. The prediction of the market share is performed for the calibration scenario corresponding to 2014. Similar plots can be generated for the other terminals.

The internal operational model of an intermodal terminal includes the cost structure to operate the facility, the number of daily trains service the facility operates, and any capacity constraints. These allow the market equilibrium to be computed and are briefly covered next. More complex models, such as those described in [9] and [10], can be added in the future.

*Operational Costs of Intermodal Terminals*

The modelled operational costs of an intermodal terminal are completely determined by the facilities annual throughput and the number of daily train services. It includes three main components: (i) Fixed costs: this includes the total annual costs to operate the facility independent of the volume of containers moved through the facility. (ii) Variable cost per TEU: This represents the variable costs based on the number of TEUs moved through the facility per year, and may include individual labour and machinery costs. (iii) Variable cost per daily train service: This represents the costs per year to operator each daily train service that the terminal runs.

*Handling Capacity of Intermodal Terminals*

The handling capacity of an intermodal terminal is determined by two factors. The first is the intrinsic maximum capacity of the facility and is determined by the facility's size and layout. The second is a possible lower limit determined by the number of daily train services that runs between the port and the terminal. Based on the work of Guimarans *et al.* [2], it is assumed that the trains are all configured to be 650m long shuttles, with 32 wagons each, and have a maximum capacity of 96 TEUs.

**Example Analyses**

The modelling framework allows different scenarios and system configurations, corresponding to new infrastructure improvements or incentive payments/tolls, to be compared. This allows like for like comparisons to be made for how well an option can e.g, raise the rail mode share or reduce total distances travelled by trucks.

This section considers a base scenario corresponding to the calibration dataset available for 2014. During this year there was approximately 1.15 million TEUs imported into port Botany, with 80% of these delivered into the Sydney region, corresponding to 920,000 TEUs. The spatial distribution of delivery locations, shown in Figure 3 is used by first scaling match the required port throughput. Other scenarios have been configured but not reported here due to space limits.

*Response to System Modifications*

The following options to improve the rail mode share have been considered:

1. **Improving rail network delays:** This option considers a modification to how trains are scheduled and/or infrastructure improvements that causes a significant reduction in the delays that trains experience when travelling between Botany Gate and Cooks River.

2. **Improving port terminal storage times**: This option reduces the delays that rail experiences in moving containers out of the port terminal.

3. **Introduction of a port access fee for trucks**: Here the effect of directly incentivising rail through the introduction of a fee for trucks to access the port precinct. It is assumed that this is passed directly onto shippers. The fee is taken to be $20.

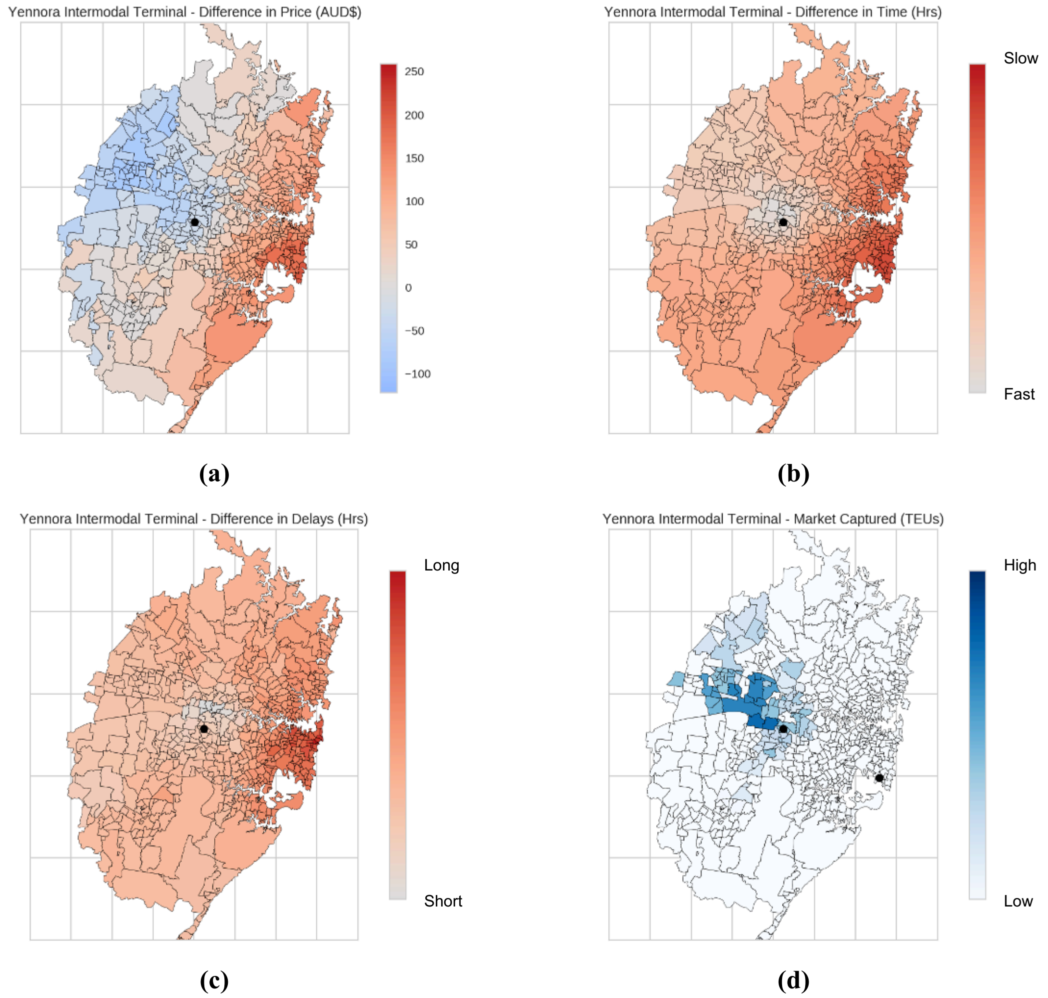


**Figure 6. Features of the Yennora Intermodal Terminal service, in relation to the direct truck service, are depicted in (a) – (c). Note: red represents less attractive feature values, blue more attractive. The total market share that is captured by this service is depicted in (d).**

The overall results for each of these options are summarised in Table 1. It is noted that the first two options both reduce the delays in the total delivery time associated with rail, leading to improved rail mode share. It is also noted that there is a reduction in the average distance travelled on the road network and the overall average delivery price paid by shippers. The last option also achieves an increase in the rail mode share, but this is at the expense of an overall increase in the average delivery price. It is noted that the effect of introducing a port access fee, considered in Option 3, has a side effect of allowing the intermodal terminals to also increase their price, causing an increase in the transportation costs across the board.

**Table 1. Effects of different system modifications on the overall up take of rail and the efficiency of the logistics system**

| | Average Rail Share (per cent) | Average Delivery Price Paid ($/TEU) | Average Road Distance Travelled (km/TEU) |
|---|---|---|---|
| Base | 13.9 | 649.1 | 28.2 |
| Option 1 | 14.2 | 649.0 | 28.1 |
| Option 2 | 18.6 | 648.5 | 26.9 |
| Option 3 | 20.1 | 664.8 | 26.5 |

## Discussion and Conclusions

This paper has described a novel framework to assess the value of different modifications and incentive structures for transport and logistics systems. The focus has been on Sydney's Port Botany and has considered how rail mode share can be increased. A holistic approach has been considered that moves away from simple capacity considerations and includes how the modifications will change the behaviour of the key market players. The model includes the port terminal, road transportation, the freight rail network, and intermodal terminals. Furthermore, it incorporates how freight owners and forwarders value different features of the logistics supply chain. This allows potential system modifications to be assessed by modelling how it will be exploited by the transportation service providers to allow them to better compete for market share.

Finally, there are several areas where the approach can be extended in the future:

- **Inclusion of export flows**: Incorporating the transportation of empty containers will allow additional benefits, such as co-locating empty container parks at intermodal terminals and other value added services, to be quantified.
- **Considering commodity level characteristics**: It is expected that shippers that handle different commodities have different needs and should be explicitly represented in the model.
- **Refinement of the delivery time and reliability features**: The existing model considers a single metric for each of the delivery time and reliability, and it is noted

that a greater granularity is likely to be needed to more accurately represent the true characteristics valued by shippers.

- **Transport decision model**: The multinomial decision model used in this work makes a number of assumptions, the main one being the homogeneity in the way that shippers value the different features of the transport options. This is unrealistic and should be improved. To support such refinement in the decision model, additional data is also needed. This may be direct observations of the transport decisions, or market surveys, e.g. as suggested by Brooks *et al.* [7].
- **Market dynamics and inertial**: There are often costs associated with changing the way things are currently done, e.g. from cognitive bias of the people making the decisions, through to the presence of long term contractual arrangements. These will limit the speed at which the system changes. Further work can be performed in the future to include these dynamics.

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