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

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Abstract

A flexible and policy-oriented model based on the principle of entropy maximisation is proposed for locating competitive multi-user freight facilities in general and inland multi-user intermodal container terminals (IMTs) in particular in a context where multiple users have choices which include whether or not to use the facilities. The overall problem is decomposed into a linked facility location problem (FLP) and a mode choice problem (MCP). The MCP is cast as a three-level nested probability model for determining modal and IMT demands. It was shown that for terminals with sufficiently large handling capacities, the objective function of the overall problem reduces to that of the MCP, the result is a single level mathematical program, which locates facilities to maximise shippers' expected utility or consumer surplus. The model is suitable for urban or regional planning, but may also be used by terminal operators to estimate shipper demand for given locations. Algorithms for solving the model, principal features of the algorithms and the model are also presented.

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Keywords: Intermodal container terminals; Entropy; Intermodal transport; Inland terminals; Lagrangian relaxation.

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1. Introduction

The development of inland intermodal transport is increasingly seen as a promising and sustainable means to alleviate congestion, safety, road damage and environmental problems associated with the use of road alone mode (e.g., trucks) in the movement of cargo between origins and destinations in the hinterland (Arnold et al. 2004; Bontekoning et al. 2004; Nierat 1997). Intermodal transport by definition involves combining the strengths of two or more modes of transport (e.g., rail, air, inland waterway, sea and road) in a single seamless journey (Nierat 1997; Slack 1998). This study investigates ways to efficiently combine the strengths of rail (or barge) and road to form a competitive and more sustainable alternative to road alone transport (e.g., trucks). The competitive advantage of intermodal transport is based on exploiting the economies of scale and distance of rail whilst taking advantage of the flexibility and accessibility of trucks for pickups and deliveries. The key elements in any intermodal transport system are the intermodal terminals (IMTs) and their geographical locations with respect to cargo origins and destinations (Salucci 2006). The European Commission (Salucci 2006) defined an IMT as the place equipped with the required facilities for the seamless transfer of intermodal units (e.g., containers) between two modes (e.g., between trucks and rail). Thus, locating a new IMT adds another mode of transport (intermodal transport) as an option for shippers. The level of user benefits or attractiveness of the new transport mode critically depends on where the IMT is located with respect the cargo origins and destinations (Meyrick 2007; Salucci 2006).

Two inland intermodal transport systems can be identified in the literature (Teye et al. 2017a; Meyrick 2007; Arnold et al. 2001), namely the regional intermodal transport system (RITS) and the urban intermodal transport system (UITS). The RITS involves the use of two IMTs in the movements of cargo between a given origin-destination pair. In this system (see Figure 1) the cargo is first consolidated at an IMT close to the cargo origins using trucks and then transported by a high capacity mode (e.g. rail or barge) to another terminal close to the cargo destinations for final distribution by trucks. In this system, both economies of scale and distance are key drivers in the location and use of IMTs (Park et al. 1995; Arnold et al. 2001; Arnold et al. 2004; Lin, et al. 2014).

The UITS involves the use of one IMT along the intermodal transport chain and mainly captures two main markets; the import market and the export market. For the import market, cargo arriving at the port is first transported by a high capacity mode such as rail or barge to an IMT (taking advantage of economies of scale) and then transferred to trucks for onward movement to destinations in the urban region (Teye et al. 2017a; Meyrick 2007). Conversely, for the export market, cargo is first consolidated at an IMT before been transported to the port by rail or barge for export as shown in Figure 1. Promoting the use of this intermodal option is expected to create significant extra handling capacity at ports while significantly reducing congestion and related safety and environmental problems associated with the use of trucks. 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 to container origins/destinations in the hinterlands. As noted in Teye et al. (2017a), these problems can also affect a nation's foreign trade and ability to compete in global markets, as the gateway for the greater part of this trade.

As noted earlier, in the UITS the benefits are derived mostly from the economies of scale offered by the use of high capacity mode and the reduction in road congestion and related costs, so decisions on the location of IMTs in this system must fully account for these benefits. Similarly, economies of scale and distance with respect to cargo origins and destinations are the two key factors driving the use of IMTs in the RITS (Meyrick 2007; Arnold et al. 2004). In both systems, the locations of the IMTs are crucial for their usage and hence the demand for intermodal transport. The key difference between RITS and UITS is the number of IMTs involved in the transport task. For UITS, the involvement of the port means only one IMT is required along the intermodal transport chain whilst for RITS exactly two IMTs are involved. Both RITS and UITS benefit from economies of scale, but the economies of distance also play a key role in the choice of intermodal transport in RITS with some studies recommending minimum distances (usually between 400-600km) above which regional intermodal transport is considered competitive against road alone transport (NCHRP586 2007; Piyatrapoomi et al. 2006; Klink and van den Berg 1998). The competitiveness of intermodal transport in the UITS is largely based on the economies of scale and savings in transport costs achieved by avoiding congestion around ports and between ports and delivery centres in the hinterlands or the urban region.

In areas where sufficient volume or markets for both systems exist, separate IMTs can be located for each system (UITS and RITS). This option appears to be the case in practice according to several studies on the subject (see Meyrick 2007; NCHRP586 2007; Arnold et al. 2004 for example of each IMT system in practice). For example, studies on locating IMTs for the RITS can be found in Park et al. (1995), Arnold et al. (2001), Arnold, et al. (2004)