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Pricing Intermodal Freight Transport Services: A Cost-Plus-Pricing Strategy

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Abstract. This paper investigates transport services pricing problems faced by intermodal freight transport operators with fixed transport capacities in an intermodal freight transport network. We first present an optimal intermodal freight transport planning model to minimize the total transport cost. This model captures modality change phenomena, due time requirements, and the possibility to subcontract transport demands. A cost-plus-pricing strategy is proposed to determine the service price as the sum of the operational cost and the targeted profit margins of transport operators under different transport scenarios, i.e., self-transporting, subcontracting, and a combination of them. For the reference transport demand specified by a customer, a list of service packages with different due times, demand sizes, and the determined service prices will be offered to the customer. Based on the urgency of delivering containers and the prices of different service packages, the customer will make the final selection decisions. A case study is given to illustrate the planning model and our proposed pricing strategy.

Keywords: Intermodal freight transport planning, cost-plus-pricing strategy, subcontracting, transport service packages

1 Introduction

Port-hinterland freight transport has been facing challenges from increasing cargo volumes, limited capacities of transport infrastructures, traffic congestion on freeways around the port area, traffic emission issues, etc. The concept of intermodal freight transport provides an innovative solution for realizing efficient and sustainable hinterland transport systems for the deepsea ports, for instance the Port of Rotterdam [1]. Cranic and Kim [2] define intermodal freight transport as "the transportation of a load from its origin to its destination by a sequence of at least two transportation modes, the transfer from one mode to the next being performed at an intermodal terminal." By integrating and coordinating the use of different transport modes available in an intermodal freight transport network through an efficient ICT system, intermodal freight transport provides the opportunity to obtain an efficient use of the physical infrastructure as well as providing cost and energy efficient transport services. Apart from intermodal freight transport, a number of innovative concepts have been introduced in both the freight transport organization and the supply chain management, such as mode-free booking, extended gateway, synchromodal freight transport, and terminal haulage [1, 3–5].

The topic of intermodal freight transport has been studied intensively in literature [2, 6–11]. Quite a lot of research efforts have been investigating transport planning problem at the strategic, tactical, and operational decision-making levels. However, a successful implementation of intermodal freight transport and also other innovative concepts does not only depend on efficient transport planning, but also on an appropriate pricing strategy for intermodal freight services. Pricing intermodal freight transport services involves determining how much customers should be charged for each service with particular service-related characteristics i.e., origin, destination, the number of containers that have to be transported, and the due time for completing the movement. The pricing strategy will greatly affect the competitiveness of intermodal freight transport, and it also plays an important role in mode choice. Macharis and Bontekoning [6] point out that the pricing for intermodal transport is complicated since several actors are involved relating to different parts of the chain. It requires an accurate cost calculation and insight in the market situation.

The pricing strategies for intermodal freight transport services are often analyzed at two levels, the individual player in the intermodal chain, and the whole door-to-door intermodal freight transport service [11]. At the first, individual player level, pricing strategies for rail haul and drayage operators are evaluated in [12] and [13], respectively. Liu and Yang [14] combines slot allocation and dynamic pricing strategy in container intermodal transport. At the second, whole door-to-door service level, Tsai et al. [15] developed pricing strategies based on minimum logistics cost and logit demand functions for the whole intermodal transport chain. Li and Tayur formulated in [16] a medium-term planning model to jointly consider transport planning and service pricing in intermodal freight transport. Dandotiya et al. [17] developed a joint optimization model for the rail-truck terminal location policy and the pricing strategy for the DelhiMumbai freight corridor in India. This study aims to enhance the utilization of the railway infrastructure and shows the interrelation between terminal locations and the price sensitivities of customers while allowing for adequate profit for the railway. A bi-level programming model was proposed by Ypsilantis and Zuidwijk to jointly design the extended gateway services and determine the pricing scheme for profit maximization in [18]. This paper pointed out that for the port-to-door service the corresponding transport service price depends on the best alternative transport service offered by the competition and does not depend on the container transport routing in the network, while for the price of the port-to-port service this is not the case. The best alternative transport service is chosen from the shippers' perspective by evaluating a trade-off among major decision factors, such as transport cost, and transport time. Most of the research work on pricing strategy for intermodal freight transport in the literature is performed at the tactical level [8]. The research presented in the current paper combines the intermodal transport planning operation and the pricing strategy so that the pricing problem is considered in a more detailed level. Moreover, even through there are many cost-related pricing strategies, such as cost-plus pricing, market penetration pricing, discount pricing [12], the current paper will focus on using the basic concept of the cost-plus pricing strategy.

In the current paper we will consider an intermodal freight transport operator that provides port-to-port services in an intermodal freight transport network connecting deep-sea ports and inland terminals. The main contributions of this paper are a new intermodal freight transport network model for minimizing the transport cost of the intermodal freight transport operator and a cost-plus service pricing strategy for facilitating transport operators with given transport capacity in an intermodal freight transport network.This paper considers performing off-line pricing where all transport demands in the planning period are assumed to be known when the transport planning and pricing decisions are being made. It is noteworthy that some transport demands might be rejected by the operator in case that the determined prices of transport services for serving these transport demands are higher than the market prices. The proposed pricing strategy considers the operational cost and the targeted profit margins of intermodal freight transport operators, and also the market price for transporting freight. Therefore, an optimal intermodal freight transport planning model is first developed for representing the characteristic behaviors of the network (e.g., modality changes at intermodal terminals), to guarantee the due time requirements of transport demands, and to capture the possibility of using subcontracted transport services from other transport operators. The introduction of subcontracted transport services in the intermodal container transport network model was first proposed and investigated in [19, 20]. The network modeling approach in the current paper is based on the multi-node method that has been proposed and used in [21–23], which works at the tactical container flow level, while extensions are made in this paper to enable the network model to be capable of directly capturing the due time requirements of transport demands and the possibility of doing subcontracting at the operational container transport planning level. After that, the proposed cost-plus-pricing strategy determines intermodal freight transport service prices by adding up the transport operator's operational cost and the targeted profit margins while taking into account different transport scenarios, i.e., self-transporting, subcontracting, and a combination of these two. Moreover, for a reference transport demand a list of transport service packages with different due times, demand sizes, and the determined prices will be provided to the customer. The customer can make the final transport service selection according to his transport urgency and the service prices of different service packages.

The remainder of the paper is organized as follows. Section 2 briefly introduces intermodal freight transport networks and presents an optimal intermodal freight transport planning model. Our proposed cost-plus service pricing strategy is explained in detail in Section 3 under different transport scenarios. A simple case study is given in Section 4 to illustrate our proposed pricing approach. Conclusions and directions for future work are given in Section 5.

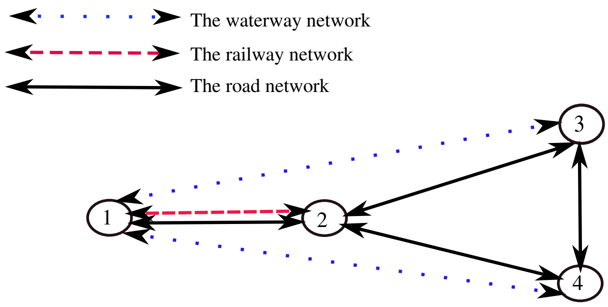

Fig. 1. A graph representation of an intermodal freight transport network. Each doubled-headed arc in the figure represents two directed links with opposite directions.

2 Planning intermodal freight transport

2.1 Intermodal freight transport networks

An intermodal freight transport network is a network of interconnected single-mode transport networks, for instance the road network, the railway network, the inland waterway network. The interconnected network consists of a set of intermodal terminals and a set of transport connections with different modalities among these terminals. Intermodal terminals function as the connecting points for multiple single-mode transport networks, and as the switching points for containers to switch from one modality to another. Unquestionably, certain amounts of transfer time and transfer cost will occur when containers switch among modalities.

By representing intermodal terminals and transport connections as nodes and links, an intermodal freight transport network can be abstracted as a directed graph. Figure 1 shows a graph representation of an intermodal freight transport network with 4 intermodal terminals, 8 freeway connections, 2 railway connections, and 4 inland waterway connections. Adopting the multiple node method used in [24], in [21] an intermodal terminal is modeled as a set of multiple nodes that correspond to each single-mode terminal and the storage yard at this intermodal terminal respectively. The use of multiple nodes enables the analysis of modality change phenomena at intermodal terminals in the same way as the transport connections. This paper will also adopt the multiple node method as used in [21].

Briefly speaking, an intermodal freight transport network can be modeled as a directed graph $\mathscr{G}(\mathscr{V},\mathscr{E},\mathscr{M})$. The node set $\mathscr{V}$ is generated using the multiple node method and on the basis of the structure of the physical network and the possibility of changing modalities at intermodal terminals. The node set $\mathscr{V} = \mathscr{V}_{\text{truck}} \cup \mathscr{V}_{\text{train}} \cup \mathscr{V}_{\text{barge}} \cup \mathscr{V}_{\text{store}}$ is a finite nonempty set with the sets $\mathscr{V}_{\text{truck}}$, $\mathscr{V}_{\text{train}}$, $\mathscr{V}_{\text{barge}}$, and $\mathscr{V}_{\text{store}}$ representing truck terminals, train terminals, barge terminals, and storage yards shared by different single-model terminals inside each intermodal terminal of the network, respectively. The modality change set $\mathscr{M}$ is constructed according to the available modalities in this network. This paper formulates the network model for three modalities (i.e., trucks, trains, and barges), but the network model can be extended to include more modalities. The mode change

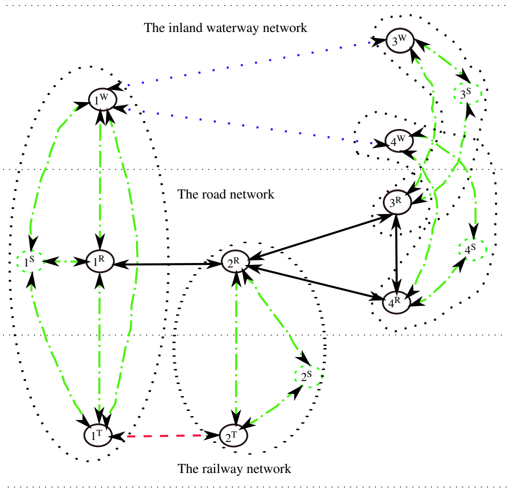

Fig. 2. The intermodal freight transport network model for the network shown in Figure 1. Each doubled-headed arc in the figure represents two directed links with opposite directions.

set $\mathscr{M} = \mathscr{M}_1 \cup \mathscr{M}_2$ indicates modalities and modality change types in the network with $\mathscr{M}_1 = \{\text{truck}, \text{train}, \text{barge}, \text{store}\}$ and $\mathscr{M}_2 = \{m_1 \to m_2 | m_1, m_2 \in \mathscr{M}_1 \text{ and } m_1 \neq m_2\}$. Note that the storage is considered as one type of virtual modality. The link set $\mathscr{E} \subseteq \mathscr{V} \times \mathscr{V} \times \mathscr{M}$ represents all available connections among nodes. The symbol $l^m_{i,j}$ is used to denote link $(i, j, m) \in \mathscr{E}$. All links in the network are categorized as either transport links or transfer links depending on whether a modality change happens on this link or not. Figure 2 gives the intermodal freight transport network model of the network shown in Figure 1. The dotted blue arcs, the solid black arcs, the dashed red arcs, and the dash-dotted green arcs indicate 4 transport links of the inland waterway network, 8 transport links of the road network, 2 transport links of the railway network, and 30 transfer links among nodes with different modalities in the intermodal freight transport network, respectively. The dashed green nodes indicate the storage nodes.

With the above multi-node method based network model, the paper [21] develops a generic intermodal freight transport network model in a discrete-time formulation from an aggregated container flow perspective for optimal container flow assignment. The optimal intermodal freight transport planing model proposed below is also in a discrete-time formulation but considers individual containers in the planning, and is therefore able to directly capture the due time requirements of transport demands ordered in the form of mode-free booking [3].

2.2 Optimal intermodal freight transport planning model

This section presents an optimal intermodal freight transport planning model for an intermodal freight transport operator. The transport operator has a fixed transport capacity on each link of the intermodal freight transport network and provides intermodal freight transport services to shippers. Shippers order transport services in a mode-free booking fashion, in which shippers only specify the characteristic information of their containers (i.e., the origin, the destination, the size, and the due time) while leaving the freedom to transport operators to choose appropriate modes of transport for transporting containers under the up-to-date network conditions. In order to guarantee the reliability of transport services, the transport operator strives to complete shippers' orders before their specified due times with the lowest total transport cost possible. Therefore, we choose to consider the due time requirements as hard constraints in the planning. Meanwhile, in practice there are situations that the transport operator does not have enough transport capacity available when some orders from a valued long-term business partners arrive. It is then really important for the transport operator to accept and finish these orders in order to establish a stable cooperation with the business partner. Therefore, we assume that the transport operator can subcontract a part or even the whole order to other transport operators in order to serve the order at the price of making less profit.

An order can be interpreted as a transport demand in the transport planning, and it is defined as a group of containers sharing the origin and destination nodes (e.g., (o,d)) and also a given due time (e.g., $\mathrm{T}_{o,d}$). The number of containers corresponding to transport demand $(o,d,\mathrm{T}_{o,d})$ (, which belongs to the set of all transport demands $\mathscr{O}_{\mathrm{odt}} \subseteq \mathscr{V} \times \mathscr{V} \times \mathscr{T}$) can be indicated by $d_{o,d,\mathrm{T}_{o,d}}$. The due time $\mathrm{T}_{o,d}$ is actually the latest time point for finishing transport demand $(o,d,\mathrm{T}_{o,d})$, for instance 5:00 pm on April 20, 2015. The proposed optimal intermodal freight transport planning model is a discrete-time model with a time step of T_{s} (h). The planning horizon of the intermodal freight transport is $N \cdot T_{\mathrm{s}}$ (h) with $N \in \mathbb{N}\backslash\{0\}$. The planning horizon should be large enough to include the due time of all transport demands. The objective, the constraints, and the optimization formulation of the proposed planning model will be explained in detail in the following subsections.

2.2.1 The objective of the planning model

For an intermodal freight transport operator with fixed transport capacities on transport connections in the network, the optimal transport planning consists in determining container routings and making subcontracting decisions by minimizing the total delivery cost while fulfilling the due time requirements of all transport demands in the network. In this optimal intermodal freight transport planning model, the total transport cost J_{total} is the sum of the storage cost, the transport/transfer cost, and subcontracting cost of transport demands in the network and is defined as follows:

$$J_{\mathrm{total}} = \sum_{(o,d,\mathrm{T}_{o,d})\in\mathscr{O}_{\mathrm{odt}}} \left[\sum_{k=1}^{N} \left[\sum_{i\in\mathscr{V}} x_{i,o,d,\mathrm{T}_{o,d}}(k) T_{\mathrm{s}} C_{i,\mathrm{store}} + \sum_{(i,j,m)\in\mathscr{E}} x^{m}_{i,j,o,d,\mathrm{T}_{od}}(k) T_{\mathrm{s}} C^{m}_{i,j,\mathrm{tran}} \right] + d^{\mathrm{sub}}_{i,o,d,\mathrm{T}_{o,d}}(1) C^{\mathrm{sub}}_{i,o,d,\mathrm{T}_{o,d}} \right], \tag{1}$$

where

- The value of $x_{i,o,d,\mathrm{T}_{o,d}}(k)$ (TEU) is the number of containers corresponding to transport demand $d_{o,d,\mathrm{T}_{o,d}}$ and staying at node i at time step k. The container storage cost at node $i \in \mathscr{V}$ is given as $C_{i,\mathrm{store}}$ (€/TEU/h).

- The value of $x^m_{i,j,o,d,\mathrm{T}_{od}}(k)$ (TEU) is the number of containers corresponding to transport demand $d_{o,d,\mathrm{T}_{o,d}}$ and traveling on link $l^m_{i,j}$ at time step k. The container transport/transfer cost on link $(i,j,m) \in \mathscr{E}$ is given by $C^m_{i,j,\mathrm{tran}}$ (€/TEU/h).
- The value of $d^{\mathrm{sub}}_{i,o,d,\mathrm{T}_{o,d}}(k)$ (TEU) is the number of containers corresponding to transport demand $d_{o,d,\mathrm{T}_{o,d}}$ that have to be subcontracted to other transport operators at time step k. The value of $d^{\mathrm{sub}}_{i,o,d,\mathrm{T}_{o,d}}(k)$ corresponds to a planning decision when $i = o$ and $k = 1$, and otherwise it is zero. Here we assume that the subcontracting decision is made about each transport demand only at the time when the demand enters the network. The price that has to be paid for subcontracting one TEU of the transport demand $d_{o,d,\mathrm{T}_{o,d}}$ is $C^{\mathrm{sub}}_{i,o,d,\mathrm{T}_{o,d}}$ (€/TEU).

2.2.2 The constraints of the planning model

The transport planning has to be performed with respect to multiple constraints on network dynamics, transport capacity, due time requirements, and subcontracting decisions. For each transport demand $d_{o,d,\mathrm{T}_{o,d}}$, the network dynamics include node dynamics and link dynamics, and can be formulated as:

$$\begin{aligned} x_{i,o,d,\mathrm{T}_{o,d}}(k+1) = x_{i,o,d,\mathrm{T}_{o,d}}(k) &+ \sum_{(j,m)\in\mathscr{N}_i^{\mathrm{in}}} q^{m,\mathrm{out}}_{j,i,o,d,\mathrm{T}_{o,d}}(k) \\ &- \sum_{(j,m)\in\mathscr{N}_i^{\mathrm{out}}} q^{m,\mathrm{in}}_{i,j,o,d,\mathrm{T}_{o,d}}(k) - d^{\mathrm{out}}_{i,o,d,\mathrm{T}_{o,d}}(k) \\ &+ \quad d^{\mathrm{in}}_{i,o,d,\mathrm{T}_{o,d}}(k) - d^{\mathrm{sub}}_{i,o,d,\mathrm{T}_{o,d}}(k), \end{aligned} \tag{2}$$

$$\begin{aligned} x_{i,o,d,\mathrm{T}_{o,d}}(k), d^{\mathrm{in}}_{i,o,d,\mathrm{T}_{o,d}}(k), d^{\mathrm{out}}_{i,o,d,\mathrm{T}_{o,d}}(k), d^{\mathrm{sub}}_{i,o,d,\mathrm{T}_{o,d}}(k) \in \mathbb{N}\backslash\{0\} \\ \forall (o,d,\mathrm{T}_{o,d}) \in \mathscr{O}_{\mathrm{odt}},\ \forall i,j \in \mathscr{V},\ \forall m \in \mathscr{M},\ \forall k, \end{aligned}$$

$$q^{m,\mathrm{out}}_{i,j,o,d,\mathrm{T}_{o,d}}(k) = q^{m,\mathrm{in}}_{i,j,o,d,\mathrm{T}_{o,d}}(k - T^m_{i,j}), \tag{3}$$

$$x^m_{i,j,o,d,\mathrm{T}_{od}}(k+1) = x^m_{i,j,o,d,\mathrm{T}_{od}}(k) + \left(q^{m,\mathrm{in}}_{i,j,o,d,\mathrm{T}_{o,d}}(k) - q^{m,\mathrm{out}}_{i,j,o,d,\mathrm{T}_{o,d}}(k)\right), \tag{4}$$

where

- The value of $q^{m,\mathrm{out}}_{i,j,o,d,\mathrm{T}_{o,d}}(k)$ (TEU) is the number of containers corresponding to transport demand $d_{o,d,\mathrm{T}_{o,d}}$ and leaving link $l^m_{i,j}$ to node j at time step k. The set $\mathscr{N}_i^{\mathrm{in}}$ is defined as

$$\mathscr{N}_i^{\mathrm{in}} = \{(j,m) \mid l^m_{j,i} \text{ is an incoming link for node } i\}.$$

- The value of $q^{m,\mathrm{in}}_{i,j,o,d}(k)$ (TEU) is the number of containers corresponding to transport demand $d_{o,d,\mathrm{T}_{o,d}}$ and entering link $l^m_{i,j}$ from node i at time step k. The set $\mathscr{N}_i^{\mathrm{out}}$ is defined as

$$\mathscr{N}_i^{\mathrm{out}} = \{(j,m) \mid l^m_{i,j} \text{ is an outgoing link for node } i\}.$$

- The transport time on each link $l_{i,j}^{m}$ is given by $T_{i,j}^{m}T_{\rm s}$ (h). Here the transport time on each link is assumed to be constant.
- The value of $d_{i,o,d,{\rm T}_{o,d}}^{\rm in}(k)$ (TEU) is the number of containers corresponding to transport demand $d_{o,d,{\rm T}_{o,d}}$ and entering node i from the outside of the network at time step k. The value of $d_{i,o,d,{\rm T}_{o,d}}^{\rm in}(k)$ equals $d_{o,d,{\rm T}_{o,d}} - d_{i,o,d,{\rm T}_{o,d}}^{\rm sub}(k)$ when $i = o$ and $k = 1$, and otherwise it is zero.
- The value of $d_{i,o,d,{\rm T}_{o,d}}^{\rm out}(k)$ (TEU) is the number of containers corresponding to transport demand $d_{o,d,{\rm T}_{o,d}}$ and arriving at the final destination node i at time step k. The value of $d_{i,o,d,{\rm T}_{o,d}}^{\rm out}(k)$ equals $\sum_{(j,m)\in\mathscr{N}_i^{\rm in}} q_{i,j,o,d,{\rm T}_{o,d}}^{m,{\rm in}}(k)$ when $i = d$ (here, we assume that containers coming from each transport demand will immediately leave the network once they arrive at their destinations), and otherwise it is zero.

The transport capacity of an intermodal freight transport operator on each link $l_{i,j}^{m}$, $C_{i,j}^{m}$ (TEU), is the maximum number of containers that can traverse within this link. The transfer capacity on each transfer link is basically determined by the equipment capacity and the operation of the intermodal terminal to which this link physically belongs. The transport/transfer capacity constraint on each link $l_{i,j}^{m}$ applies for the combination of all transport demands $d_{o,d,{\rm T}_{o,d}} \in \mathscr{O}_{\rm odt}$, and can be formulated as follows:

$$\sum_{(o,d,{\rm T}_{o,d})\in\mathscr{O}_{\rm odt}} x_{i,j,o,d,{\rm T}_{od}}^{m}(k) \leq C_{i,j}^{m}. \tag{5}$$

The due time requirements set the latest times before which the transport demands should be completed. It means that after the set due time of one transport demand its corresponding container flow at the nodes and on the links of the intermodal freight transport network should be zeros. Considering the network dynamics (2)–(4), the due time requirements can be simplified by only requiring the container flow of each transport demand in the network to be zeros at its due time. The due time requirements of all transport demands $d_{o,d,{\rm T}_{o,d}} \in \mathscr{O}_{\rm odt}$ are considered as hard constants in the transport planning, and can be formulated as:

$$x_{i,o,d,{\rm T}_{o,d}}(k_{o,d}) = 0, \qquad \forall i \in \mathscr{V}, \forall (o,d,{\rm T}_{o,d}) \in \mathscr{O}_{\rm odt}, \tag{6}$$

$$x_{i,j,o,d,{\rm T}_{o,d}}^{m}(k_{o,d}) = 0, \qquad \forall (i,j,m) \in \mathscr{E}, \forall (o,d,{\rm T}_{o,d}) \in \mathscr{O}_{\rm odt}, \tag{7}$$

where

- The time step $k_{o,d}$ corresponds to the due time of transport demand $(o,d,{\rm T}_{o,d})$ that is assumed to be a multiple of $T_{\rm s}$. The relation $k_{o,d}T_{\rm s} = {\rm T}_{o,d}$ holds.

This model allows the intermodal freight transport operator to subcontract transport demands to other operators in case of lacking transport capacity or for reducing the total transport cost for serving these transport demands. It is assumed that there is unlimited transport capacity from other operators for serving subcontracted transport demands. However, for each transport demand $(o,d,{\rm T}_{o,d}) \in \mathscr{O}_{\rm odt}$ the number of containers subcontracted to other operators should not be larger than the size of this transport demand.

Moreover, recalling the assumption that the subcontracting decision for each transport demand is only made when it enters the intermodal freight transport network at the origin node, the relation is guaranteed by the following constraints:

$$d^{\text{sub}}_{i,o,d,\mathrm{T}_{o,d}}(1) \le d_{o,d,\mathrm{T}_{o,d}}, \quad \forall (o,d,\mathrm{T}_{o,d}) \in \mathscr{O}_{\text{odt}} \tag{8}$$

2.2.3 The optimization formulation

The optimal intermodal freight transport planning problem can be formulated as the following optimization problem:

$$\min_{\tilde{x}_1,\tilde{x}_2,\tilde{q}^{\text{out}},\tilde{q}^{\text{in}},\tilde{d}^{\text{sub}}} J(\tilde{x}_1,\tilde{x}_2,\tilde{q}^{\text{out}},\tilde{q}^{\text{in}},\tilde{d}^{\text{sub}}) \tag{9}$$

$$\text{subject to } (2)-(8),$$

where

- $\tilde{x}_1$ contains all $x_{i,o,d,\mathrm{T}_{o,d}}(k)$, for $i \in \mathscr{V}, (o,d,\mathrm{T}_{o,d}) \in \mathscr{O}_{\text{odt}}, k = 1,\cdots,N$.
- $\tilde{x}_2$ contains all $x^m_{i,j,o,d,\mathrm{T}_{od}}(k)$, for $(i,j,m) \in \mathscr{E}, (o,d,\mathrm{T}_{o,d}) \in \mathscr{O}_{\text{odt}}, k = 1,\cdots,N$.
- $\tilde{q}^{\text{out}}$ contains all $q^{m,\text{out}}_{i,j,o,d,\mathrm{T}_{o,d}}(k)$, for $i \in \mathscr{V}, (j,m) \in \mathscr{N}^{\text{out}}_i, (o,d,\mathrm{T}_{o,d}) \in \mathscr{O}_{\text{odt}}, k = 1,\cdots,N$.
- $\tilde{q}^{\text{in}}$ contains all $q^{m,\text{in}}_{i,j,o,d,\mathrm{T}_{o,d}}(k)$, for $i \in \mathscr{V}, (j,m) \in \mathscr{N}^{\text{in}}_i, (o,d,\mathrm{T}_{o,d}) \in \mathscr{O}_{\text{odt}}, k = 1,\cdots,N$.
- $\tilde{d}^{\text{sub}}$ contains all $d^{\text{sub}}_{i,o,d,\mathrm{T}_{o,d}}(1)$, for $(o,d,\mathrm{T}_{o,d}) \in \mathscr{O}_{\text{odt}}$.

This problem (9)-10 is a linear integer optimization problem, which can be solved very efficiently using state-of-the-art solvers such as the intlinprog solver in Matlab, and CPLEX.

3 Pricing intermodal freight transport services

In this paper, we use a cost-plus-pricing strategy to determine the price of intermodal freight transport services. Before introducing the pricing strategy, some important assumptions and issues are listed as follows:

- For an intermodal freight transport service offered by the intermodal freight transport operator, there is always an market price for it and this market price is known to both transport operators and shippers. Therefore, the determined intermodal freight transport service price should not be more expensive than the corresponding market price.
- The intermodal freight transport operator has different targeted profit margins for different types of transport services, M_{self} for the self-operated services and M_{sub} for the subcontracted services. These two profit margins are preset by the transport operator according to its marketing objectives.

- For subcontracted intermodal freight transport services, the targeted profit margin M_{sub} is smaller than M_{self}. Because when the order is carried out by a subcontractor, the main job is done by the subcontractor and the transport operator will have less space to make profit.
- The intermodal freight transport service price is determined and charged at the moment when the order is made by the customer even if the actual execution of the container delivery changes later. For instance, the shipper pays the service price (determined by the operator) of finishing one order when the order is made. This order was planned to be served by trains at the beginning. But some or all containers of this order might be finally moved by trucks instead of the preplanned trains in case of unexpected situations during the container delivery process e.g., train cancellation due to bad weather conditions. In this case the actual operational cost of serving this order will increase since road transport is typically expected to be expensive than railway transport. However, the operator will not be able to charge the shipper any extra costs on this order.
- This paper works for the case of determining off-line pricing. It means that all transport demands in the planning period are known by the operator when he or she plans the freight transport and determines the service price.

With the above mentioned assumptions, our proposed cost-plus-pricing strategy determines the price of intermodal freight transport services as the sum of the operator's operational cost and the targeted profit margins. The operational cost includes the transport cost and the other related cost (e.g., the administration cost). The intermodal freight transport operator provides transport services by using its own transport capacity and subcontracting one part or the full order to other transport operators to serve the order with a predetermined negotiated price when necessary. The corresponding cost calculation and targeted profit margins are different from that of self-operated transport services. Therefore, the proposed pricing strategy should be tailored to take into account different transport scenarios, i.e., self-transporting, subcontracting, and a combination of them.

The optimal intermodal freight transport planning decisions for all transport demands are made by solving problem (9)–(10) in order to minimize the total transport cost. The operational cost and also the corresponding transport service price of each individual transport demand are then calculated and determined according to the transport cost, the other related cost, and the profit margins associated with it. The proposed pricing strategy will be subsequently illustrated for one transport demand in detail. For the sake of notation simplicity, the subscripts $o, d, \mathrm{T}_{o,d}$ for J, $C_{\text{other}}^{\text{self}}$, $C_{\text{other}}^{\text{sub}}$, M_{self}, M_{sub}, P, and P_{market} are omitted in the rest of this paper. For one order or transport demand $(o, d, \mathrm{T}_{o,d})$ with a size of $d_{o,d,\mathrm{T}_{o,d}}$, the operational cost is calculated as

$$C_{\text{cost}}^{\text{self}} = \frac{J}{d_{o,d,\mathrm{T}_{o,d}}} + C_{\text{other}}^{\text{self}}, \quad \text{for the self} - \text{operated case} \tag{10}$$

$$C_{\text{cost}}^{\text{sub}} = C_{i,o,d,\mathrm{T}_{o,d}}^{\text{sub}} + C_{\text{other}}^{\text{sub}}, \quad \text{fort the subcontracted case} \tag{11}$$

where

- The total transport cost J (€) for transport demand $(o,d,\mathrm{T}_{o,d})$ is obtained by solving the planing problem (9)–(10).
- The other cost is assumed to be proportional to the size of the order, but will be different for the self-operated transport service and the subcontracted transport service.

The profit margins for self-conducted transport services and subcontracted transport services are set as M_{self} and M_{sub}, respectively. There are three transport scenarios and the corresponding prices P (€/TEU) are calculated as follows:

– Scenario 1: The order is completely served by the intermodal freight operator itself, i.e., $d^{\text{sub}}_{i,o,d,\mathrm{T}_{o,d}}(1) = 0$. The price is:

$$P = C^{\text{self}}_{\text{cost}}\left(1 + M_{\text{self}}\right). \tag{12}$$

– Scenario 2: The order is served by both the intermodal freight operator and subcontractors, i.e., $0 < d^{\text{sub}}_{i,o,d,\mathrm{T}_{o,d}}(1) < d_{o,d,\mathrm{T}_{o,d}}$. The price is:

$$P_{\max} = \rho_{\text{self}}\left(\frac{J - C^{\text{sub}}_{i,o,d,\mathrm{T}_{o,d}} d^{\text{sub}}_{i,o,d,\mathrm{T}_{o,d}}(1)}{d_{o,d,\mathrm{T}_{o,d}} - d^{\text{sub}}_{i,o,d,\mathrm{T}_{o,d}}(1)} + C^{\text{self}}_{\text{other}}\right)\left(1 + M_{\text{self}}\right) + \rho_{\text{sub}} C^{\text{sub}}_{\text{cost}}\left(1 + M_{\text{sub}}\right) \tag{13}$$

where ρ_{self} and ρ_{sub} are the percentage of the self-operated containers in the transport demand $(o,d,\mathrm{T}_{o,d})$ and that of the subcontracted containers.

– Scenario 3: The order is served by subcontractors, i.e., $d^{\text{sub}}_{i,o,d,\mathrm{T}_{o,d}}(1) = d_{o,d,\mathrm{T}_{o,d}}$. The price is:

$$P = C^{\text{sub}}_{\text{cost}}\left(1 + M_{\text{sub}}\right). \tag{14}$$

The market price of the transport service to serve the order or transport demand $(o,d,\mathrm{T}_{o,d})$ is P_{market}. In case that the determined price $P > P_{\text{market}}$, the order is not in this transport operator's targeted marketing areas and the transport operator will either recommend another related service packages (e.g., service packages with a longer due time) or decline the order.

Considering the practical booking process, the intermodal freight transport operator will provide several service packages to customers according to their inexplicit reference order information and let the customers select the final service package. The transport service booking procedure is as follows: the customers first specify the reference size of the order in number of containers, the origin and destination pair of the order, and a reference due time. The transport operator will provide the customers with a list of transport service packages with different due times, demand sizes, and determined prices by solving the transport planing problem (9) in multiple times. Generally speaking, a shorter due time or a bigger order size would leads to a higher price. Taking into account the urgency to finish the order and also the price, the customers will determine which transport service package will be selected.

4 Case study

The case study considers a simple intermodal freight transport network, consisting of three different types of transport networks that are connected at four intermodal terminals. Figure 1 shows the network topology and the four nodes 1, 2, 3, and 4 represent Rotterdam, Tilburg, Nijmegen, and Venlo, respectively. The corresponding network model is given in Figure 2. The network parameters, i.e., transport time, transport cost, transport capacity on links and storage cost and storage capacity at nodes are given in Table 1 and Table 2, respectively. The network is considered to be initially empty. Profit margins for self-operated transport services and subcontracted transport services are $M_{\text{self}} = 5\%$ and $M_{\text{sub}} = 2\%$. The other costs for the self-operated transport service and the subcontracted transport service are $C^{\text{self}}_{\text{other}} = 0.5$ (€/TEU), and $C^{\text{sub}}_{\text{other}} = 0.001$ (€/TEU).

This case study assumes that transport capacity from subcontracting intermodal freight transport services is unlimited. The intermodal freight transport is planned for a period of $N = 24$ hours for different transport demand scenarios by solving the linear integer optimization problem (9). In this paper, we use the dual simplex algorithm in the intlinprog solver in Matlab to solve the optimization problem (9). The simulation experiments are done in a desktop computer with an Intel® Core$^{\text{TM}}$ i5-2400 CPU with 3.10 GHz and 4 GB RAM.

The reference transport demand information (i.e., origin, destination, the number of containers, and due time) and the corresponding subcontracting information (i.e., subcontracting cost, and subcontracting capacity) are presented in Table 3. A list of four transport service packages is provided to the customer in Table 4. This table presents the operational cost of the four different transport service packages and their corresponding intermodal freight transport service price resulted from the proposed pricing strategy in Section 3. It is clear from Table 4 that the demand size and the due time in the transport service packages influence the determined transport service price from the proposed pricing strategy. For transport service packages designed for transport demands with the same size the determined transport service prices decrease significantly as the due times become longer. For instance, for transport service package of 100 TEU the corresponding service price drops 29.1% from 19.996 (€/TEU) for a due time of 6 hours to 14.175 (€/TEU) for a due time of 12 hours. Meanwhile, the enlargement of the size of transport demand may require more expensive transport service packages. This is because the transport operator may encounter a lack of transport capacity and has to do subcontracting, which is typically expensive. For example, for transport service packages tailed to transport demands with a due time of 12 hours the corresponding transport service prices are 14.175 (€/TEU) and 14.569 (€/TEU) for the size of 100 TEU and 200 TEU, respectively. There is a 2.8% rising in the service price. The case study shows that the transport demand with a larger size and/or a shorter due time might require an higher priced service packages.

5 Conclusions

This paper proposes a cost-plus-pricing strategy to determine the price of intermodal freight transport services by adding together the operational cost of the transport op-

Table 1. Network parameters: links. The symbols in the second column, e.g., 1r, correspond to the labels of nodes in the intermodal freight transport network model presented in Figure 2.

Link type	OD pair	Transport time (h)	Transport cost (€/h/TEU)	Transport capacity (TEU)
Road	1r-2r	2	5	20
	2r-3r	1	5	20
	2r-4r	1	5	20
	3r-4r	1	5	20
Rail	1t-2t	2	2	30
Water	1w-3w	6	1	50
	1w-4w	10	1	50
Modality – modality	any	2	2	1000
Modality – storage	any	1	1	1000

Table 2. Network parameters: nodes. The symbols in the first row, e.g., 1s, correspond to the labels of nodes in the intermodal freight transport network model in Figure 2.

	1s	1w	1r	1t	2r	2t	2s	3w	3r	3s	4w	4r	4s
Storage cost (€/h/TEU)	0	0	0	0	0	0	0	0	0	0	0	0	0
Storage capacity	1000	10	10	10	10	10	1000	10	10	1000	10	10	1000

Table 3. Transport demand and subcontracting information. The symbol "/" in the table means either. For instance, the notation "100/200" means that the size of the transport demand could either be 100 TEUs or 200 TEUs.

Origin	Destination	Number (TEU)	Due time (h)	Subcontracting cost (€/TEU)	Subcontracting capacity (TEUs)
1w	4r	100/200	6/12	20/15	unlimited

Table 4. A list of four transport service packages with different operational costs and determined service prices for serving different transport demands (i.e., the number of containers, and the due time).

Demand (TEU)	Due time (h)	Subcontracting cost €/TEU	Demand served (TEU) overall/itself/subcontract	Total transport cost €	Operational cost €/TEU	Price €/TEU
100	6	20	100	1940	–	19.996
			20	340	17.5	
			80	1600	20.001	
	12	15	100	1300	13.5	14.175
			100	1300	13.5	
			0	0	15.001	
200	6	20	200	3940	–	20.198
			20	340	17.5	
			180	3600	20.001	
	12	15	200	2740	–	14.569
			130	1690	13.5	
			70	1050	15.001	

erator and also its targeted profit margins under different transport scenarios, i.e., self-transporting, subcontracting, and a combination of them. The transport cost is one important part of the transport operator's operational cost and is minimized by optimizing transport planning based on a discrete-time network model. It assumed that the reference transport demand information such as origin, destination, the number of containers, and due time are given by the customers, and that the transport operator will provide a list of transport service packages with different due times, demand sizes, and also the determined prices to the customer. Based on the urgency of delivering containers and the prices of different service packages, the customer will make the final selection decisions. The simulation results indicate that a shorter due time or a lack of capacity could result in the requirement of transport service with a higher price.

For the future work, we will investigate the application of the proposed pricing strategy for performing on-line dynamic pricing. For the case of dynamic pricing, only transport orders that have already been confirmed earlier are known when the current transport planning and pricing decisions are being made, and other transport orders will arrive later and the transport planning and pricing decisions for the newly arrived orders have to be adjusted accordingly by then. In addition, an integrated approach including joint consideration of intermodal freight transport planning and service pricing will be implemented to investigate the effect of demand response to the transport service price.

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References

1. Port of Rotterdam Authority, "Port vision 2030: Port compass," Dec. 2011. [Online]. Available: http://www.portofrotterdam.com/en/Port/port-in-general/port-vision-2030/Documents/Port-Vision-2030.pdf
2. T. Crainic and K. Kim, "Intermodal transportation," in *Transportation*, ser. Handbooks in Operations Research and Management Science, C. Barnhart and G. Laporte, Eds. Elsevier, 2007, vol. 14, ch. 8, pp. 467–537.
3. T. Groen, T. Groen, W. Hofman, R. Janssen, J. V. Meijeren, M. Oonk, and et al, *Implementatieroadmap Synchromodaliteit*. The Netherlands: TNO, Connekt & Dinalog commissioned by the Ministry of Infrastructure and Environment, 2011.
4. A. Veenstra, R. Zuidwijk, and E. van Asperen, "The extended gate concept for container terminals: Expanding the notion of dry ports," *Maritime Economics and Logistics*, vol. 14, no. 1, pp. 14–32, 2012.
5. Europe Container Terminal, *The future of freight transport*. Rotterdam, The Netherlands: Europe Container Terminal, Oct. 2011.
6. C. Macharis and Y. M. Bontekoning, "Opportunities for OR in intermodal freight transport research: a review," *European Journal of Operational Research*, vol. 153, no. 2, pp. 400–416, 2004.
7. I. Jarzemskiene, "The evolution of intermodal transport research and its development issues," *Transport*, vol. 22, no. 4, pp. 296–306, 2007.

8. A. Caris, C. Macharis, and G. Janssens, "Planning problems in intermodal freight transport: accomplishments and prospects," *Transportation Planning and Technology*, vol. 31, no. 3, pp. 277–302, 2008.
9. ——, "Decision support in intermodal transport: A new research agenda," *Computers in Industry*, vol. 64, no. 2, pp. 105–112, 2013.
10. M. SteadieSeifi, N. Dellaert, W. Nuijten, T. V. Woensel, and R. Raoufi, "Multimodal freight transportation planning: A literature review," *European Journal of Operational Research*, vol. 233, no. 1, pp. 1–15, 2014.
11. Y. Bontekoning, C. Macharis, and J. Trip, "Is a new applied transportation research field emerging? – a review of intermodal rail-truck freight transport literature," *Transportation Research Part A: Policy and Practice*, vol. 38, no. 1, pp. 1–34, 2004.
12. S. Yan, D. Bernstein, and Y. Sheffi, "Intermodal pricing using network flow techniques," *Transportation Research Part B*, vol. 29, no. 3, pp. 171–180, 1995.
13. L. N. Spasovic and E. K. Morlok, "Using marginal costs to evaluate drayage rates in rail-truck intermodal service," *Transportation Research Record*, no. 1383, 1993.
14. D. Liu and H. Yang, "Dynamic pricing model of container sea-rail intermodal transport on single OD line," *Journal of Transportation Systems Engineering and Information Technology*, vol. 12, no. 4, pp. 122–127, 2012.
15. J. F. Tsai, E. K. Morlock, and T. E. Smith, "Optimal pricing of rail intermodal freight: models and tests," University of Pennsylvania, Tech. Rep., 1994.
16. L. Li and S. Tayur, "Medium-term pricing and operations planning in intermodal transportation," *Transportation Science*, vol. 39, no. 1, pp. 73–86, 2005.
17. R. Dandotiya, R. Nath Banerjee, B. Ghodrati, and A. Parida, "Optimal pricing and terminal location for a rail–truck intermodal service–a case study," *International Journal of Logistics Research and Applications*, vol. 14, no. 5, pp. 335–349, 2011.
18. P. Ypsilantis and R. A. Zuidwijk, "Joint design and pricing of intermodal port-hinterland network services: Considering economies of scale and service time constraints," ERIM Report Series Research in Management, Tech. Rep., 2013.
19. B. van Riessen, R. R. Negenborn, G. Lodewijks, and R. Dekker, "Impact and relevance of transit disturbances on planning in intermodal container networks using disturbance cost analysis," *Maritime Economics & Logistics*, pp. 1–24, 2014.
20. B. Van Riessen, R. R. Negenborn, R. Dekker, and G. Lodewijks, "Service network design for an intermodal container network with flexible transit times and the possibility of using subcontracted transport," *International Journal of Shipping and Transport Logistics*, vol. 7, no. 4, pp. 457–478, 2015.
21. L. Li, R. R. Negenborn, and B. De Schutter, "A general framework for modeling intermodal transport networks," in *Proceedings of the 10th IEEE International Conference on Networking, Sensing and Control (ICNSC 2013)*, Paris, France, Apr. 2013, pp. 579–585.
22. ——, "A sequential linear programming approach for flow assignment in intermodal freight transport," in *Proceedings of the 16th IEEE International Conference on Intelligent Transport Systems (ITSC 2013)*, The Hague, The Netherlands, Oct. 2013, pp. 1124–1230.
23. ——, "Receding horizon approach for container flow assignment in intermodal freight transport," *Transportation Research Record*, vol. 2410, pp. 132–140, 2014.
24. B. Boardman, E. Malstrom, D. Butler, and M. Cole, "Computer assisted routing of intermodal shipments," *Computers and Industrial Engineering*, vol. 33, no. 1-2, pp. 311–314, 1997.