A REVENUE-BASED SLOT ALLOCATION AND PRICING FRAMEWORK FOR MULTIMODAL TRANSPORT NETWORKS

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ABSTRACT

This paper analyses the operational integration between different multimodal transport services and proposes a slot allocation and pricing model for multimodal transport networks to maximize revenue and utilize capacity. The methodology entails a revenue-based optimal two-stage approach. Firstly, a slot allocation model is formulated by using stochastic integer programming for long-term contract market sale where the predetermined or negotiated price tariffs are used for regular orders. Secondly, a stochastic nonlinear programming is formulated to solve the slot allocation and dynamic pricing on short-term spot market sale for temporal as well as last-minute orders. Finally, a case study is provided to demonstrate an efficient and effective use of the proposed model.

INTRODUCTION

The changing structure of the transport business driven by high cost efficiency, increased competition, demand pressure, less pollution, strict traffic and customs regulations has led shippers to immediately use multimodal freight transport services (Kayikci, 2014). The one hand, shippers seek the cost efficient, quality effective and faster services, on the other hand multimodal transport service providers (MTPs) offer the services timely and faster with appropriate slot allocation and pricing strategy in order to maximize revenue. Multimodal transport describes a multi-unit transport chain in which transport are conveyed with at least two different transport modes (i.e. rail-road, river-road, sea-road, sea-rail) on the basis of a multimodal transport contract from a place (origin) in one country at which transport units are taken in charge by the multimodal transport providers in transport means (e.g. RoRo vessel, RoLa train) to a designated place (destination) for delivery in a different country (UN, 1980). A typical transport chain consists of three separated segments: pre-haulage, main-haulage and end-haulage. The sections for pre- and end-haulage refer short-distance and transport units (e.g. RoRo-units, containers, trailers) are mostly transported by road between customers and terminals/ports and vice versa, while main-haulage refers long-distance and transport units are shipped by vessels from one port to another and/or transported by rail from one terminal to another. Main-haulage consists of the combination of several sea-rail connections or modal shifts (transshipments), where MTPs establish often a consortium (e.g. liner shipping provider, railway freight provider) and this is responsible for the performance of entire haulage contract from origin to destination (OD) and also capacity management of transport means. Also, an MTP, which is mainly liner shipping provider, can rent block train services as a company train rather than using public train services of other railway freight providers and it offers a seamless trip between OD to the shippers by taking the whole trip responsibility. Block train enables MTPs that all storage units are shipped from the same point and arrive at the same destination, so that trip can be realized without having any transshipment within OD, uninterrupted and faster. This research focuses on the main-haulage part of transport network.

The development of the multimodal transport system relies on the construction of networked comprehensive cargo hub (multimodal hub) system. These cargo hubs provide transport mode transfer for the multimodal transport services. They usually have stockyard for stacking transport units, as well as dispatching and configuration of freight trains, vessels or vehicles. Meanwhile, they have good highway connections, railway facilities, seaport and well-tuned information systems, which are essential for the freight transport services and helpful for tracking, managing and controlling the freight flow (Lowe, 2005). Beside this, the capacity management including route planning and vessel/train scheduling is likely to be a crucial success factor for the sustainability of multimodal transport (Kayikci, 2014). Inadequate capacity utilization may cause dramatic losses for MTPs. Therefore, a high level of collaboration and seamless integration is significant. The capacity of freight trains and vessels is generally being utilized at a rate of over 70% per trip (Kayikci, 2014). In this respect, revenue management (RM) strategies and technologies may help MTPs to improve load factor (capacity utilization rate) and margins of their services.

The context of multimodal freight transport has been extensively studied in literature (SteadieSeifi, et al. 2014). A large number of research efforts have been focused on transport planning problems at the strategic, tactical and operational decision-making levels. However, a successful implementation of multimodal freight transport and also other innovative transport solutions not only depend on efficient transport planning and control, but also on an appropriate slot allocation and pricing strategy for multimodal freight services (Li et al., 2010; Cho et al., 2012; Tao, 2013). In the multimodal transport industry, like in airline industry, in practice there are two different as well as related components of multimodal transport revenue maximization (Belobaba et al., 2009): *differential pricing:* various shipper products ("fare products") are offered at different price categories (dynamic or fixed price options) with different characteristics for freight transport in the same OD route; *revenue management:* This process determines the number of slots (space occupied by a transport unit in a vessel or a train) to be made available to each shipper class ("fare class" for booking a slot) on a transport means, by setting booking limits (capacity control) on fare slots. The pricing strategy has a great impact on the profitability as well competitiveness of multimodal freight services and also it plays an important role for the shippers to decide on transport mode. A pricing strategy based on a single price for all available slots is an imperfect compromise to maximize revenue, therefore the price segmentation should be applied. A pricing strategy depends mainly on transport cost, price sensitivity, and competition (Reis et al., 2013; Li et al., 2010), but also there are many factors for pricing multimodal freight transport involved in determining how much shippers should be charged by using each service with specific service-related characteristics such as origin node (loading), destination node (discharging), type of transport means, the number and type of transport units, transport time, delivery time and also time of reservation. Usually one or more of these factors vary significantly across market segments. The purpose of this research is to present a dynamic slot allocation and pricing framework for MTPs which operate together.

The rest of the paper is organized as follows: First, a revenue-based slot allocation and pricing model is described, then the solution model is developed, afterwards a case study is applied into the model, finally the paper is completed with findings and conclusion.

A REVENUE-BASED SLOT ALLOCATION AND PRICING MODEL

A revenue-based slot allocation and pricing model is depicted in Figure 1. This model solely considers sea and rail transport in a multimodal transport network, whereas road transport is kept out of the model. Although in the practice the pricing strategies for each transport mode are mainly determined as fixed pricing according to km-distance to be travelled between OD, in this model, we used shipper classes in order to determine pricing strategies. Three shipper classes are identified, namely (Kayikci, 2014): (1) *contractual shipper* regularly ships large quantities of transport units and is characterized with a fixed-commitment contract and negotiated market price; a certain slot allotment (protect slots) is reserved on transport means over a period of time where the orders of major shippers and forwarders have priority to get fulfilled (Lee, et al, 2007). (2) *ad-hoc shipper* buys slot with spot market price; this type of shippers is temporal and this fare is offered only for a certain sales time period (i.e. until one-two weeks before the departure date of vessel or train). (3) *urgent shipper* typically seeks a free slot in the last minute and is willing to pay a high fare for the last-minute freight services. The highest spot market rate in the sales time period is preferably allocated to the urgent shippers. The contractual shippers make an agreement with consortia on the number of shipped transport units per year, therefore there are protected slots at each vessel and rail to reserve for contract market sale. Since the ad-hoc and urgent orders generates higher revenue, it is optimal to accept as many orders for spot market sale as possible (Lee, et al. 2007). Because of this predictable behaviour, the freight demand of contractual shipper is certain, whereas the demand is uncertain for urgent and ad-hoc shippers. The price strategy depends on the relationship between the supply capacity (the number of available slots) and demand forecast (number of shipper orders). If the demand is greater than the supply, there is a shortage. If the supply increases, the price decreases, and if the supply decreases, the price increases.

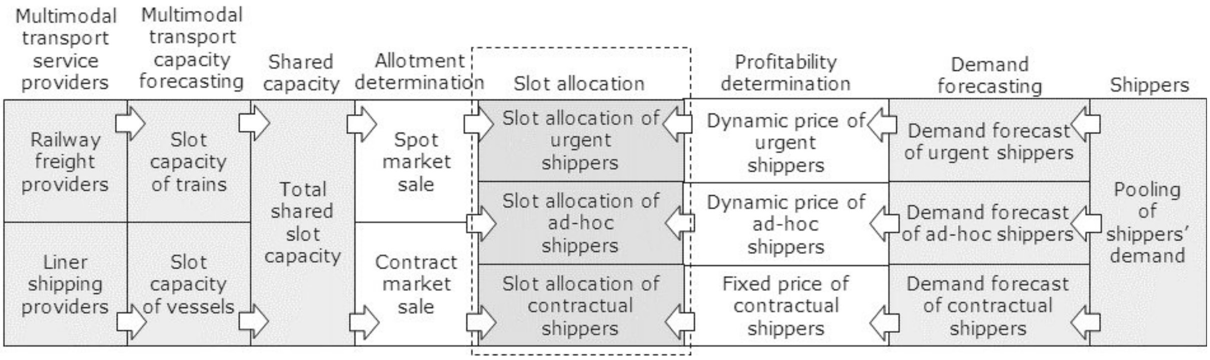

Figure 1: A revenue-based slot allocation and pricing model in multimodal transport

The total shared slot capacity indicates the total available slots on transport units, e.g. on both train and vessel. Operationally, capacity of transport units depends on the density of booked shipments and their shapes as well as the dead weight restriction. Also, the transport unit mix in relation to movable decks, internal ramps, lane heights etc., can be a limiting factor as to how much cargo in a vessel or train wagon can accommodated. In the model, it is also necessary to determine how much slot capacity should be allocated to the contractual shippers for contract market sale. For that the MTPs make decision on the limitation of allotments, as this would affect also the profitability. The seasonality of cargo movements (peak and low season), directional cargo imbalances (import vs. export), minimum scale (the number and size of vessels and/or trains) and so on play important role to decide on the percentage of allotments.

METHODOLOGY

The methodology entails a revenue based optimal two-stage approach. Firstly, a slot allocation model is formulated by using stochastic integer programming for long-term contract market where the pre-determined price tariffs are used for regular customer class. Secondly, a stochastic nonlinear programming is formulated to solve the slot allocation and dynamic pricing for spot market.

Assumptions:
Supply capacity for shared slots and demand forecasts are equal.
All transhipments are loaded freights.
Only semi-trailers are shipped as transport unit.
All trips which made either vessels or rails are round trips, different prices can be assigned for every OD direction due to importing/exporting freight. The freight rate is calculated according to combined sea-rail legs, there is no separate calculation.
There is no additional cargo demand (semi-trailer) available for loading from the cargo-hub (H) to vessel and train.
The average freight rate of each OD node pair for contractual shippers is determined in advanced on negotiation.

There are no cancellations and no-shows.

Indices and parameters:
i = the index of loading node (origin node) of the freight flow, $i = 1,2, \dots, m$
j = the index of discharging node (destination node) of the freight flow, $j = 1,2, \dots, n$
V = the index of nodes for seaport terminal, $V = \{v_i | i = 1, \dots, n\}$
R = the index of nodes for railway inland terminal, $R = \{r_j | j = 1, \dots, n\}$
E= the edge from/to OD pair, $E = \{(v_i, r_j)/(r_i, v_j) | v_i \in V, r_j \in R\}$
k = the index of trip for vessel or train, $k = 1,2, \dots, l$. Each trip is constrained by the maximum serviceable capacity
Q = the total slot capacity of multimodal line, $Q = Q^v + Q^r$
Q^v = the slot capacity of vessel
Q^r = the slot capacity of train
Q_k^v and Q_k^r = the available slot capacity of k^{th} trip for vessel or train
MA = the maximum slot allotment of contractual shippers (protect slots)
p_{ij}^c and p_{ji}^c = slot price for contractual shippers at the t^{th} booking period of contract market sale from/to OD pair respectively for outward (v_i, r_j) and return trip (r_i, v_j)
P_{ijt}^{su} and P_{jit}^{su} = upper price limit at the t^{th} booking period of spot market sales from/to OD pair respectively for outward (v_i, r_j) and return trip (r_i, v_j)
P_{ijt}^{sl} and P_{jit}^{sl} = lower price limit at the t^{th} booking period of spot market sales from/to OD pair respectively for outward (v_i, r_j) and return trip (r_i, v_j)
p_{ijt}^s and p_{jit}^s = slot price at the t^{th} booking period of spot market sales from/to OD pair respectively for outward (v_i, r_j) and return trip (r_i, v_j), where the slot price for $t = 1, 2, \dots, T - 1$ is allocated for ad-hoc shippers, whereas $t = T$ for urgent shippers
T = booking period for spot market sales, $t = 1,2, \dots, T - 1, T$, which can be divided into the sub-periods e.g. days, weeks.

Decision variables:
x_{ij}^c and x_{ji}^c = slot demand for contractual shippers at the t^{th} booking period of contract market sale from/to OD pair respectively for outward (v_i, r_j) and return trip (r_i, v_j).
x_{ijt}^s and x_{jit}^s = slot demand at the t^{th} booking period of spot market sale from/to OD pair respectively for outward (v_i, r_j) and return trip (r_i, v_j), where the slot demand for $t = 1, 2, \dots, T - 1$ is allocated for ad-hoc shippers, whereas $t = T$ for urgent shippers.
We assumed that the demand function is linear $x_{ijt}^s = a_{ijt} - b_{ijt} . p_{ijt}^s, a_{ijt}, b_{ijt} > 0, \forall t$ and $x_{jit}^s = a_{jit} - b_{jit} . p_{jit}^s$, $a_{jit}, b_{jit} > 0, \forall t,$ where the demand function coefficients, a and b are estimated for each t^{th} booking period using statistical methods (e.g. regression analysis) for round-trip (Thiele, 2006). The demand in spot market is uncertain and fluctuated randomly, therefore dynamic price need to be included. Actual value of demand function coefficients a_{ijt} and b_{ijt} is denoted with $\tilde{a}_{ijt}$ and $\tilde{b}_{ijt}$ for OD pair as to outward (v_i, r_j) and return trip (r_i, v_j), $\tilde{a}_{ijt} \in [a_{ijt} - \hat{a}_{ijt}, a_{ijt} + \hat{a}_{ijt}]$, $\tilde{b}_{ijt} \in [b_{ijt} - \hat{b}_{ijt}, b_{ijt} + \hat{b}_{ijt}]$ sowie $\tilde{a}_{jit} \in [a_{jit} - \hat{a}_{jit}, a_{jit} + \hat{a}_{jit}]$, $\tilde{b}_{jit} \in [b_{jit} - \hat{b}_{jit}, b_{jit} + \hat{b}_{jit}]$, where $\hat{a}$ and $\hat{b}$ indicate the variation in coefficients. Deviation degrees for $\alpha_{ijt}, \beta_{ijt} \in [-1,1]$between the actual value $\tilde{a}_{ijt} | \tilde{b}_{ijt}$ and the estimated value $a_{ijt} | \, b_{ijt}$are included, which makes $\tilde{a}_{ijt} = a_{ijt} + \hat{a}_{ijt} \alpha_{ijt}, \tilde{b}_{ijt} = b_{ijt} + \hat{b}_{ijt} \beta_{ijt}$. The absolute value of the differences between actual and nominal demand at the t^{th} booking period is $\tau_{ijt}^s = \hat{a}_{ijt} \alpha_{ijt} - \hat{b}_{ijt} \beta_{ijt} . p_{ijt}^s$ for outward trip (v_i, r_j), similar $\tau_{jit}^s = \hat{a}_{jit} \alpha_{jit} - \hat{b}_{jit} \beta_{jit} . p_{jit}^s$for return trip (r_i, v_j). The lesser the τ value, the higher the demand function involvement from MTPs. This $\min \tau$ is added in the objective function for spot market sale.
V_{ijk}^c = trip length; $V_{ijk}^c = 1$, if vessel trip k is the part of OD pair for outward trip (v_i, r_j) in contractual market sale, otherwise $V_{ijk}^c = 0, \forall k$.
V_{jik}^c = trip length; $V_{jik}^c = 1$, if vessel trip k is the part of OD pair for return trip (r_j, v_i) in contractual market sale, otherwise $V_{jik}^c = 0, \forall k$.
R_{ijk}^c = trip length; $R_{ijk}^c = 1$, if rail trip k is the part of OD pair for outward trip (v_i, r_j) in contractual market sale, otherwise $R_{ijk}^c = 0, \forall k$.

R_{jik}^{c} = trip length; $R_{jik}^{c}=1$, if rail trip k is the part of OD pair for return trip (r_j, v_i) in contractual market sale, otherwise $R_{jik}^{c}=0, \forall k$.
V_{ijk}^{s}= trip length; $V_{ijk}^{s}=1$, if vessel trip k is the part of OD pair for outward trip (v_i, r_j) in spot market sale, otherwise $V_{ijk}^{s}=0, \forall k$.
V_{jik}^{s} = trip length; $V_{jik}^{s}=1$, if vessel trip k is the part of OD pair for return trip (r_j, v_i) in spot market sale, otherwise $V_{jik}^{s}=0, \forall k$.
R_{ijk}^{s} = trip length; $R_{ijk}^{s}=1$, if rail trip k is the part of OD pair for outward trip (v_i, r_j) in spot market sale, otherwise $R_{ijk}^{s}=0, \forall k$.
R_{jik}^{s} = trip length; $R_{jik}^{s}=1$, if rail trip k is the part of OD pair for return trip (r_j, v_i) in spot market sale, otherwise $R_{jik}^{s}=0, \forall k$.

Objective functions
The objective function of the model is to maximize the total freight contribution for contract and spot market sale.

$$Max\ Z = Max\ Z\ (contract) + Max\ Z\ (spot) \tag{1}$$

Contract market sale: The objective function of the model for contract market sale is to maximize the total freight contribution from the shipment of contractual shippers for round trip. This is represented in equation (2).

$$Max\ Z\ (contract) = \sum_{i=1}^{m}\sum_{j=1}^{n} p_{ij}^{c}.x_{ij}^{c} + \sum_{j=1}^{n}\sum_{i=1}^{m} p_{ji}^{c}.x_{ji}^{c} \tag{2}$$

Spot market sale: The objective function of the model for spot market sale is to total freight contribution from the shipment of ad-hoc shippers as well as urgent shippers. This is represented in equation (3).

$$Max\ Z\ (spot) = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{t=1}^{T-1} p_{ijt}^{s}.x_{ijt}^{s} + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{t=1}^{T-1} p_{jit}^{s}.x_{jit}^{s} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{t=T-1}^{T} p_{ijt}^{s}.x_{ijt}^{s} + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{t=T-1}^{T} p_{jit}^{s}.x_{jit}^{s} \tag{3}$$

$$Max\ Z\ (spot) = (\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{t=1}^{T-1} p_{ijt}^{s}\left(a_{ijt} - b_{ijt}\ .p_{ijt}^{s}\right) + \min \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{t=1}^{T-1} p_{ijt}^{s}\left(\hat{a}_{ijt}\alpha_{ijt} - \hat{b}_{ijt}\beta_{ijt}.p_{ijt}^{s}\right)) + \cdots$$

Constraints:

(a) Vessel constraints:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{l} x_{ij}^{c}\, V_{ijk}^{c} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{t=1}^{T}\sum_{k=1}^{l} x_{ijt}^{s} V_{ijk}^{c} \ \le \sum_{k=1}^{l} Q_k^{v} = Q^{v}, \forall k \tag{4}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{l} x_{ji}^{c}\, V_{jik}^{c} + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{t=1}^{T}\sum_{k=1}^{l} x_{jit}^{s} V_{jik}^{c} \ \le \sum_{k=1}^{l} Q_k^{v} = \ Q^{v}, \forall k \tag{5}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{l} x_{ij}^{c}\, V_{ijk}^{c}\ and\ \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{l} x_{ji}^{c}\, V_{jik}^{c} \le MA \tag{6}$$

(b) Train constraints:

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{l} x_{ij}^{c}\, R_{ijk}^{c} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{t=1}^{T}\sum_{k=1}^{l} x_{ijt}^{s} R_{ijk}^{c} \ \le \sum_{k=1}^{l} Q_k^{r} = Q^{r}, \forall k \tag{7}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{l} x_{ji}^{c}\, R_{jik}^{c} + \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{t=1}^{T}\sum_{k=1}^{l} x_{jit}^{s} R_{jik}^{c} \ \le \sum_{k=1}^{l} Q_k^{r} = \ Q^{r}, \forall k \tag{8}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{l} x_{ij}^{c}\, R_{ijk}^{c}\ and\ \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{l} x_{ji}^{c}\, R_{jik}^{c} \le MA \tag{9}$$

(c) Total slot capacity constraint for multimodal freight transport:
The total allocated slot number for contract and slot market sale cannot exceed the total slot capacity of multimodal freight transport, as shown in equation (10), total slot capacity is the sum of the available shared capacity of the total vessel operational capacity and train operational capacity, seen in equation (11).

$$\sum_{i=1}^{m}\sum_{j=1}^{n} x_{ij}^{c} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{t=1}^{T} x_{ijt}^{s} \leq Q \tag{10}$$

$$Q = \sum_{k=1}^{l} Q_k^v + \sum_{k=1}^{l} Q_k^r \tag{11}$$

(d) Freight demand constraint:
The allocated slots to each OD leg must be set between the interval of the lower and upper bound of freight price at the t^{th} booking period of spot market sales for outward (v_i, r_j) and return trip (r_i, v_j) respectively, seen in equation (12) and (13). The price for spot market sale cannot be lower than the price for contact market sale. This also helps to keep the capacity utilization at certain rate.

$$P_{ijt}^{sl} \leq x_{ijt}^{s} \leq P_{ijt}^{su} \ \forall i, j \text{ and } t \tag{12}$$

$$P_{jit}^{sl} \leq x_{jit}^{s} \leq P_{jit}^{su} \ \forall i, j \text{ and } t \tag{13}$$

CASE STUDY

An Istanbul based consortium of MTPs provides a number of sea and rail transport services to shippers and has a fixed transport capacity on each link of the multimodal network. Shippers search slots for semi-trailers to reserve available space on vessel and rail. MTPs allocate shared slots capacity for the three classes of shippers with three legs from Istanbul (v_1) to Salzburg (r_1) and Ludwigshafen (r_2) through sea-rail transhipment. Transshipment takes place in Trieste (H).

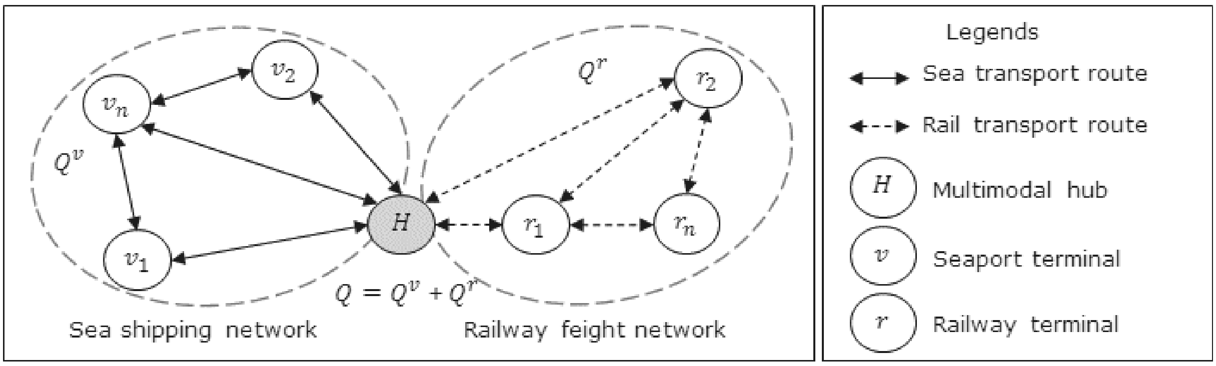

Figure 2: The multimodal freight transport network

The multimodal transport network is arranged in several railway legs and sea shipping voyages as shown in Figure 2. This network can be defined through a graph, i.e. $M = (H, V, R, E)$ that models the network structure, where V is a set of nodes for seaport terminal, $V = \{v_i | i = 1, \dots, n\}$, R is a set of nodes for railway inland terminal (hinterland), $R = \{r_j | j = 1, \dots, n\}$ and H denotes the cargo hub for multimodal transport where both loading and discharging operations of vessels and trains are carried out. In a multimodal transport network, many cargo hubs can be operated for modal shift. A combination of one railway node and one sea shipping node refers an OD pair of multimodal freight flow which is shown with edge $E = \{(v_i, r_j) | v_i \in V, r_j \in R\}$. Railway freight provider operates rail services (i.e. RoLa, ISU) to/from the ports/terminals, which are specially designed wagons to carry wheeled cargo by rail. Liner shipping provider has a fleet of vessels (i.e. RoRo), which are specially types of ships designed to carry wheeled cargo. Their transport units can be trucks, semi-trailer trucks, trailers, automobiles, railroad cars, project cargo, and maritime containers on MAFIs or cassettes. The railway freight provider operates round-trip daily

RoLa train service with six/leg from cargo hub to two railway inland terminals $(H - r - H)$. The train capacity (Q_k^r) is 32 semi-trailers/trip. The liner shipping provider operates round-trip daily RoRo vessel service with one/line from seaport to cargo hub $(v - H - v)$. The vessel capacity (Q_k^v) is 240 semi-trailers/trip. The maximum shared capacity from one port to other terminal for each trip is 192 and each trip is completed via sea and rail transport. There is one sea trip and four rail trips between $(v_1 - r_1)$, whereas there is one sea trip and two rail trip between $(v_1 - r_2)$ for both outward and return legs.

Booking periods of spot market sale	OD	$t = 1$	$t = 2$	$t = 3$
Estimation of demand function coefficients a_{ijt} and b_{ijt} for outward trip	$v_1 - r_1$	150, 0.053	85, 0.022	33, 0.013
	$v_1 - r_2$	90, 0.047	45, 0.015	20, 0.008
Variation of demand function coefficients $\hat{a}_{ijt}$ and $\hat{b}_{ijt}$ for outward trip	$v_1 - r_1$	15, 0.005	15, 0.005	15, 0.005
	$v_1 - r_2$	10, 0.005	10, 0.005	10, 0.005
Estimation of demand function coefficients a_{jit} and b_{jit} for return trip	$r_1 - v_1$	130, 0.048	102, 0.019	21, 0.008
	$r_2 - v_1$	53, 0.041	28, 0.016	13, 0.006
Variation of demand function coefficients $\hat{a}_{ijt}$ and $\hat{b}_{ijt}$ for return trip	$r_1 - v_1$	15, 0.005	15, 0.005	15, 0.005
	$r_2 - v_1$	10, 0.005	10, 0.005	10, 0.005

Table 1: Estimation and variation of demand function coefficients in booking periods

Node Pair $(v_i, r_j)(r_i, v_j)$	contractual shipper (no t limitation)		ad-hoc shipper $(t = 1, \dots, T - 1)$				urgent shipper $(t = T)$	
time period	$t = 0$		$t = 1$		$t = 2$		$t = 3$	
OD	Price	Demand	Price	Demand	Price	Demand	Price	Demand
$v_1 - r_1$	1628	40	1863	68	1900	13	2023	7
$v_1 - r_2$	1488	13	1813	42	1928	7	1968	2
$r_1 - v_1$	1628	35	1948	71	2030	18	2115	4
$r_2 - v_1$	1488	18	1898	34	1998	8	2061	4
Revenue	€ 168.228		€ 405.670		€ 90.720		€ 34.801	
Total	**€ 699.419**							

The transport unit price of semi-trailer is in Euro. Maximum allotment for contract market sale is 30%. Trip capacity is 100%.

Table 2: Differentiated scenario: slot allocation and pricing strategy according to dynamic pricing conditions in booking period t

Node Pair $(v_i, r_j)(r_i, v_j)$	contractual shipper (no t limitation)		ad-hoc shipper $(t = 1, \dots, T - 1)$				urgent shipper $(t = T)$	
time period	$t = 0$		$t = 1$		$t = 2$		$t = 3$	
OD	Price	Demand	Price	Demand	Price	Demand	Price	Demand
$v_1 - r_1$	1628	40	1863	68	1863	13	1863	7
$v_1 - r_2$	1488	13	1813	42	1813	7	1813	2
$r_1 - v_1$	1628	35	1948	71	1948	18	1948	4
$r_2 - v_1$	1488	18	1898	34	1898	8	1898	4
Revenue	€ 168.228		€ 405.670		€ 87.158		€ 32.051	
Total	**€ 693.107**							

Table 3: Basic scenario: Slot allocation and pricing strategy according to same price conditions in booking period t

It is assumed that the booking period of spot market sale is divided into three average time periods $t = 1,2,3$, where $t = 3$ represents the greatest time period of booking and offers higher prices for urgent shipper. The demand function coefficients for estimation and variation are determined via using statistical analysis, seen in Table1. The optimization software LINGO 14.0 is used to solve the model. The maximum allotment (MA) for contract market sale is kept around 30%, where fixed prices are used for the booking orders of contractual shippers. These shippers have a long term contractual agreement with MTPs to secure the reservation priority. The rest of slot capacity are allocated according to dynamic pricing strategy. The lowest and highest prices ($P_{ijt}^{sl}, P_{ijt}^{su}, P_{jit}^{sl}, P_{jit}^{su}$) per outward and return trip are calculated according to Equation (3) seen in Table 2, here the value of dynamic price rates should be higher than the rates of contractual shipper.

FINDINGS AND CONCLUSION

The model is run by using LINGO software, which obtains the total revenue data from operated routes. According to differentiated pricing scenario, seen in Table 2, the price and demand are allocated and the total revenue is calculated as € 699.419. Table 3 shows the basic scenario, where the same pricing strategy is pursued for spot market sale, so that the total revenue is obtained as € 693.107. The comparison of results of two tables showed that the total revenue for multimodal transport operations in this case will increase about 1% by applying dynamic pricing strategy through the proposed model. This provides the evidence that dynamic pricing applications in multimodal freight transport will boost the revenue maximization and the capacity utilization.

In this research, road transport is kept out of the model and the booking period of spot market sales is limited with three time phases. Furthermore, model included only three legs (one port and two hinterland terminals) in order to demonstrate the simplicity of the network system. An extended version of the model will map out a larger network and it can be expanded by applying also road transport and adding additional time phases respond to seasonal demand fluctuations.

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