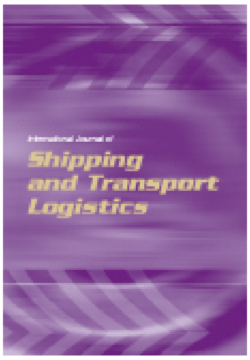


International Journal of Shipping and Transport Logistics

ISSN online: 1756-6525 - ISSN print: 1756-6517
https://www.inderscience.com/ijstl

Attraction and subsidy analysis of the 21st-Century Maritime Silk Road: A hub line location approach

Jianfeng Zheng, Lili Hou, Yao Wang, Rui Mei

Article History:

Received:	16 April 2019
Last revised:	28 July 2020
Accepted:	04 January 2021
Published online:	30 September 2022

Attraction and subsidy analysis of the 21st Century Maritime Silk Road: a hub line location approach

Jianfeng Zheng*, Lili Hou, Yao Wang and Rui Mei

Transportation Engineering College,
Dalian Maritime University,
Dalian, China
Email: jfzheng@dlmu.edu.cn
Email: hou17824835615@163.com
Email: 3023806498@qq.com
Email: 827972217@qq.com
*Corresponding author

Abstract: As a sea route corridor, the 21st Century Maritime Silk Road (TCMSR) has a potential impact on container routing between Asia and Europe. In this paper, all considered ports along this corridor are assumed to be hub ports. When transporting containers along the TCMSR, this paper considers the subsidy policy, represented by a subsidy factor. In order to explore the attraction and subsidy analysis of the TCMSR, a bilevel programming model is proposed. The upper level model aims to determine the optimal subsidy factor along the TCMSR, and the lower level model is formulated as a hub line location problem. By enumerating all different values of the subsidy factor, the bilevel programming model is reduced to the lower level model. Computational experiments show that, the attraction of the TCMSR mainly depends on the subsidy policies to be implemented along the TCMSR.

Keywords: liner shipping; hub line location; TCMSR; subsidy.

Reference to this paper should be made as follows: Zheng, J., Hou, L., Wang, Y. and Mei, R. (2022) 'Attraction and subsidy analysis of the 21st Century Maritime Silk Road: a hub line location approach', *Int. J. Shipping and Transport Logistics*, Vol. 15, Nos. 1/2, pp.91–110.

Biographical notes: Jianfeng Zheng is a Professor on Port and Shipping Logistics at Dalian Maritime University. His research interests include hub location, liner shipping network design, ship scheduling and port operation.

Lili Hou is a master student at Dalian Maritime University. Her research interests include hub location.

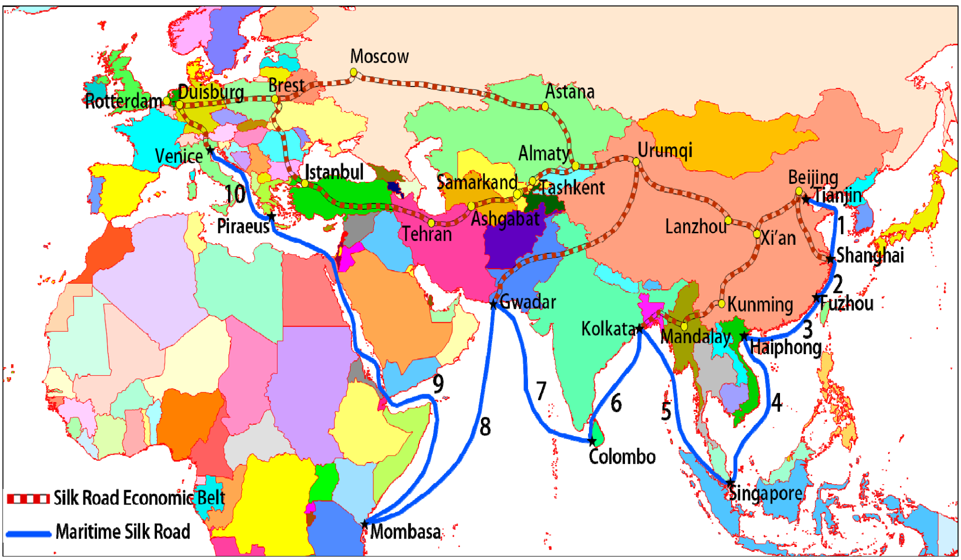
Yao Wang is a master student at Dalian Maritime University. Her research interests include hub location.

Rui Mei is a master student at Dalian Maritime University. Her research interests include location routing problem.

1 Introduction

In September and October 2013, Chinese Government proposed the cooperation initiative for the construction of the 'Silk Road Economic Belt' (SREB) and the '21st Century Maritime Silk Road' (TCMSR), known as the 'One Belt One Road' (OBOR), as shown in Figure 1.

Figure 1 The OBOR initiative (see online version for colours)



The SREB refers to the overland routes for road and rail transportation, including the New Eurasian Land Bridge (NELB), the China-Mongolia-Russia Corridor, the China-Central Asia-West Asia Corridor, the China-Indochina Peninsula Corridor, the Bangladesh-China-India-Myanmar Economic Corridor, and the China-Pakistan Economic Corridor. The TCMSR refers to the sea route corridors. It is a complementary initiative, as shown in Figure 1. Up to October 2018, the China Railway Express (CRE) has launched more than 11,000 trains (or trips) for serving 52 Chinese cities and 44 cities in 15 European countries. Evidently, the transportation freight rates between Asia and Europe are various with respect to different transportation modes (rail or sea). Take a 40-foot equivalent unit container for instance. The averaged freight rates are between 5,000 USD and 10,000 USD for railway operators, while for liner shipping companies the averaged freight rates are between 1,800 USD and 3,100 USD (Yang, 2019). Hence, subsidy policies are applied along the SREB, in order to compensate the difference of freight rates between different transportation modes.

From liner shipping companies' point of view, the OBOR initiative may have a potential impact on container routing between Asia and Europe, this is because of two important railway systems (Yang et al., 2018). Following the OBOR initiative, one important railway system is along the NELB. The other railway system connects Southern European hub ports to their hinterland. As shown in Figure 1, Venice and Piraeus are highlighted as two gateway ports in South Europe.

As will be shown in Section 2, the previous studies on OBOR focus on investigating liner shipping network design (Tu et al., 2018; Yang et al., 2018), security (Li et al., 2018; Gong and Lu, 2018), logistic and transportation infrastructure development (Chen et al., 2018a; Li, 2018; Sheu and Kundu, 2018; Shao et al., 2018; Tu et al., 2018; Zhao et al., 2018), etc. To the best of our knowledge, the subsidy analysis of the SREB and the TCMSR has not been investigated in the previous studies, although the subsidy is applied in practice. This paper investigates the attraction of the TCMSR considering the subsidy policies to be implemented along the TCMSR, following the subsidy policies applied along the SREB in practice. Moreover, this paper also considers the subsidy policies adopted on rail transportation between Venice and North Europe. In order to show potential importance of the TCMSR, all considered ports along the TCMSR are assumed to be hub ports in this paper. Hence, the TCMSR can be regarded as a hub line (Martins de Sá et al., 2015), similar to main line services in liner shipping. In order to explore the attraction and subsidy analysis of the TCMSR, this paper proposes a bilevel programming model. The upper level model aims to determine the optimal subsidy policy. The lower level model investigates whether the liner shipping company would like to adopt the TCMSR or to design a new hub line for container transshipment operations, leading to a hub line location problem.

The main motivation and contributions of this work are as follows:

1. the attraction and subsidy analysis of the TCMSR from the perspective of liner carriers have not been studied in the previous studies on OBOR, as shown in Section 2, and an optimisation problem is proposed to investigate the attraction and subsidy analysis of the TCMSR
2. a hub line location approach is presented to solve the proposed problem
3. new sub-tour elimination constraints are developed for our hub line location model, as shown in Section 4.

The rest of this paper is organised as follows. Section 2 provides literature review. Section 3 gives notation, assumptions and problem description. Section 4 proposes a bilevel programming model. Section 5 carries out numerical experiments. Finally, a summary is given in Section 6.

2 Literature review

This paper aims to investigate the attraction and subsidy analysis of the TCMSR from the liner carrier perspective. As mentioned before, the TCMSR is similar to main line services in liner shipping. Hence, the studied research topic is related to liner shipping network design (Brouer et al., 2014; Chen and Shmuel, 2013; Song and Dong, 2013; Wang and Meng, 2013; Zheng et al., 2014, 2015a, 2015b). In this paper, a hub line location model is presented to formulate the investigated problem. The hub location problem including hub node location, hub arc location and hub line location, is one of the most important research problems in liner shipping network design. The following related studies are reviewed on two aspects, i.e., the OBOR initiative and the hub location problem.

2.1 The OBOR initiative

Considering the significant impact of the OBOR initiative on the origins and destinations of freight flows, Sheu and Kundu (2018) presented a spatial-temporal logistics interaction model combined with Markov chain to forecast time-varying logistic distribution flows for a three-layer supply chain framework. Based a game theoretic approach, Liu et al. (2018) studied the cost-sharing decision problem of logistics service supply chain with large-scale customised service arising from the OBOR initiative. From the blueprint of the OBOR initiative, Li (2018) investigated yard storage planning for river terminals, which are critical nodes for connecting seaports with inland transportation. Li et al. (2018) addressed how the OBOR initiative can improve China's energy security based on the diversification strategy.

Shao et al. (2018) investigated the priority for transnational high-speed railway construction along the SREB. Results show that there are 18 sections along the SREB that satisfy the priority conditions for building a high-speed railway. Chen et al. (2018a) addressed the overseas port investment for China's central and local governments under the OBOR initiative. Zhao et al. (2018) solved the problems of the China railway network such as low load factor and profit margin, high pressure upon the government to subsidise the trains by evaluating potential cargo consolidation centres.

Zeng et al. (2018) focused on the evolution of hub ports by considering the Carat Canal, regarded as a potential new channel along the TCMSR. Yang et al. (2018) investigated shipping service network improvement by considering rail transportation along the SREB. Based on the current infrastructure development plan and expected future growth in demand, Tu et al. (2018) addressed the optimal design of the Indonesian shipping service network. Chen et al. (2018b) investigated the trends of manufacturing concentration and port shipping development along the TCMSR. By using the expert grading method, Gong and Lu (2018) studied the security assessment of different straits and canals along the TCMSR.

To the best of our knowledge, the subsidy analysis of the SREB and the TCMSR has not been addressed in the previous studies. In practice, the subsidy plays an important role in implementing the OBOR initiative. This paper aims to investigate the attraction and subsidy analysis of the TCMSR from both Chinese government and liner shipping companies' point of view. As shown in Section 4, a bilevel programming model is proposed to investigate our problem.

2.2 Hub location problem

The hub location problem was initiated by Goldman (1969), followed by O'Kelly (1986, 1987). Later, researchers presented many different hub location problems, including the p-hub median problem, the hub location problem with fixed costs, the p-hub centre problem and hub covering problems (Alumur and Kara, 2008). In addition, Yaman (2009) and Alumur et al. (2012) addressed the hierarchical hub location problems. Kim and O'Kelly (2009), Cui et al. (2010) and An et al. (2014) focused on investigating the reliable hub location problems. Recently, Sun and Zheng (2016), Zheng et al. (2018, 2019) developed different proper models for hub port location in liner shipping.

As compared with the hub location problems, there are fewer studies carried out on the hub arc location problems, which include additional decisions by selecting a series of hub arcs. For each selected hub arc, two endpoints are hubs. Campbell et al. (2005a, 2005b) studied the hub arc location problems by considering four special cases. Contreras and Fernández (2014) discussed how a general class of hub node and hub arc location problems can be stated as the minimisation of a real-valued supermodular set function. Martins de Sá et al. (2015) proposed the hub line location problem, which is a special case of the hub arc location problem. When all hubs are connected by means of a path (or line), the hub arc location problem is called hub line location problem.

As will be shown below, in order to explore the attraction and subsidy analysis of the TCMSR, a bilevel programming model is proposed in this paper. The upper level model aims to determine the optimal subsidy policy. The lower level model is formulated as a hub line location problem. There are two main differences between our hub line location problem and that proposed by Martins de Sá et al. (2015). Firstly, our hub line location problem aims to determine a new hub line while the TCMSR is regarded as a given hub line. Hence, the comparisons between the new hub line and the TCMSR should be investigated. Secondly, special sub-tour elimination constraints are proposed for our hub line location problem, as shown in Section 4.

3 Notation, assumptions and problem description

3.1 Hub ports and hub lines

Let $\mathcal{N}$ be a set of ports, which are further classified into two disjoint sets: a set of hub ports and a set of feeder ports. Containers can be consolidated and transshipped at hub ports, in order to benefit from economies of scale. Let $\mathcal{W}$ denote a set of origin-destination (OD) demand pairs, and let w_{ij} be weekly number of containers transported from origin port i to destination port j, $\forall (i, j) \in \mathcal{W}$.

Let $\mathcal{S}$ denote a set of all considered ports along the TCMSR, as shown in Figure 1. As mentioned before, in order to show the potential importance of the TCMSR, all ports in set $\mathcal{S}$ are assumed to be hub ports. Then, the TCMSR can be regarded as a given hub line, which can be expressed as follows:

Tianjin-Shanghai-Fuzhou-Haiphong-Singapore-Kolkata-
Colombo-Gwadel-Mombasa-Piraeus-Venice (1)

Following subsidy policies applied along the SREB, this paper considers similar subsidies, which are proportional to the transportation costs along the TCMSR. To proceed, let τ denote a subsidy factor when transporting containers along the TCMSR. In order to explore the attraction and subsidy analysis of the TCMSR, this paper proposes a bilevel programming model. The upper level model aims to determine the optimal subsidy factor. The lower level model investigates whether the liner shipping company would like to adopt the TCMSR or to design a new hub line for container transshipment operations, leading to a hub line location problem. Let $\mathcal{M}$ denote a set of candidate hub ports, which are used to determine the new hub line. In order to proceed, let hub line $l = 0$ represent the TCMSR, and let $l = 1$ represent the new hub line to be designed.

3.2 Assumptions

In order to formulate our problem, the following assumptions are considered:

1 The fixed container demand is considered.

2 The transportation cost is proportional to the distance.

3 We can benefit from economies of scale when transporting containers along the hub line, and let α denote the transportation discount factor to reflect economies of scale.

The above assumptions are often considered in the previous studies on hub location and hub line location (Alumur and Kara, 2008; Martins de Sá et al., 2015). In liner shipping, the bunker cost is a major component of ship operating cost. When sailing speed is fixed, the bunker cost is proportional to sailing distance. Hence, it is reasonable that the transportation cost is proportional to the distance.

3.3 Cost structure and container routing

When the TCMSR is used for container transshipments, the connection between Northern Europe and Venice is based on rail transportation, as shown in Figure 1. In order to describe the transportation cost considering different transportation modes, let δ_{ij}^{0} takes value 1 if rail transportation is used to connect between ports i and j, and 0 otherwise. Let δ_{ij}^{1} takes value 1 if maritime transportation is used to connect between ports i and j, and 0 otherwise. Let C_{ij}^{v} denote the cost for transporting one TEU container between ports i and j using transportation mode v, then we have

$$C_{ij}^{0} = \sigma \times c_{unit} \times Dis_{ij} \tag{2}$$

$$C_{ij}^{1} = c_{unit} \times Dis_{ij} \tag{3}$$

where Dis_{ij} is the distance between ports i and j, and σ ($\sigma \geq 1$) is a parameter used to control the difference between rail transportation cost and maritime transportation cost. As mentioned before, the parameter σ can be regarded as a subsidy factor applied along the SREB. Follow Zheng et al. (2019), the coefficient c_{unit} (USD/TEU × nautical mile) is set as 0.00825.

Without loss of generality, containers can be transported from their origin ports to their destination ports with or without considering container transshipment operations. When certain hub line is adopted, the total transportation cost for any certain OD demand w_{ij} includes five terms: the transportation cost from origin port i to the first hub port k using transportation mode v, the access cost at hub port k (denoted by C_{k}^{a}), the transportation cost from hub port k to hub port m along the adopted hub line, the exit cost at hub port m (denoted by C_{m}^{e}), and the transportation cost from hub port m to destination port j using transportation mode v. Here, the access cost and the exit cost can be calibrated by using transshipment costs at hub ports in liner shipping.

3.4 Problem description

In order to explore the attraction and subsidy analysis of the TCMSR, this paper proposes a bilevel programming model. The upper level model aims to determine the optimal subsidy factor along the TCMSR, by minimising the total subsidy while the utilisation of the TCMSR for routing containers is kept at certain level. The lower level model is formulated as a hub line location problem from liner carriers' perspective. For simplicity, this paper considers a single global liner carrier, and we determine the hub line location for this liner carrier. Note that the numerical results may be various when considering different liner carriers, because of different OD demands. The lower level model can be described as follows. Given the OD demand to be fulfilled and one given hub line (the TCMSR), we aim to design a new hub line and determine the routing of containers considering the selection of hub lines, in order to minimise the total transportation cost of transporting containers from their origin ports to their destination ports.

4 Model development

4.1 Decision variables

The decision variables of our bilevel programming model are listed as follows:

τ a subsidy factor used to describe the subsidy policy along the TCMSR

a_{ijk}^{l} fraction of OD demand w_{ij} collected from origin port i to hub port k along hub line l

x_{ijkm}^{l} fraction of OD demand w_{ij} routed via the first hub port k and then hub port m along hub line l

b_{ijm}^{l} fraction of OD demand w_{ij} delivered from hub port m along hub line l to destination port j

e_{ij} Fraction of OD demand w_{ij} directly transported origin port i to destination port j

z_{k}^{l} a binary variable which takes value 1 if port k is chosen to be a hub port along hub line l, and 0 otherwise

y_{km}^{l} a binary variable which takes value 1 if a hub arc is located between hub ports k and m along hub line l, and 0 otherwise;

T_k position of hub port k along the hub line to be designed.

4.2 Our bilevel programming model

Before providing our model formulation, we explain some decision variables and constraints.

In order to reduce the number of decision variables in our lower level model, i.e., the hub line location problem, following Martins de Sá et al. (2015), the hub arc related variables are defined as follows:

$$y_{km}^{0} \in \{0,1\},\ k < m,\ \forall k, m \in S \tag{4}$$

$$y_{km}^{1} \in \{0,1\},\ k < m,\ \forall k, m \in \mathcal{M} \tag{5}$$

All ports in set $\mathcal{S}$ are rearranged and ranked, according to port geographic location along the TCMSR. As shown in equation (1), Tianjin is regarded as the first port and Venice is the last port in set $\mathcal{S}$. Let p_i denote the index of the i^{th} hub port in set $\mathcal{S}$, and let $p_i < p_{i+1}$, then we have

$$y^0_{p_i, p_{i+1}} = 1, \quad \forall i = 1, ..., |S| - 1 \tag{6}$$

$$\sum_{g \in \mathcal{S}} \sum_{\substack{h > g, \\ h \in \mathcal{S}}} y^0_{gh} = 10 \tag{7}$$

where 10 is the number of hub arcs along the TCMSR. Similarly, all ports in set $\mathcal{M}$ are also rearranged and ranked according to port geographic location. When hub ports are properly located between Asia and Europe, a proper hub line can be simply obtained according to the geographic locations of hub ports, different from the hub line location problem in public transportation (Martins de Sá et al., 2015). Actually, container flows are often concentrated on some major waterways, as shown in Sun and Zheng (2016). Moreover, between Asia and Europe, hub ports are mainly located along the concentrated waterways. As a result, the rest hub ports along the hub line to be designed are almost located along the shortest path between the first hub port and the last hub port of the hub line. This phenomenon can be used to simplify the sub-tour elimination constraints in the hub line location problem, as shown below.

Different from the conventional sub-tour elimination constraints considered in Martins de Sá et al. (2015), we consider special sub-tour elimination constraints. Firstly, all ports in set $\mathcal{M}$ are rearranged and ranked, as mentioned before. By introducing auxiliary variables $\{T_k\}$ $(1 \le T_k \le p + 1, \forall k \in \mathcal{M})$, which denotes the position of hub port k along the new hub line to be designed, our sub-tour elimination constraints can be expressed as follows:

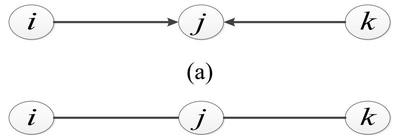
$$T_k + 1 + |\mathcal{M}| \times \left(y^1_{km} - 1\right) \le T_m, \; k < m, \forall k, m \in \mathcal{M} \tag{8}$$

$$T_m - 1 + |\mathcal{M}| \times \left(y^1_{km} - 1\right) \le T_k, \; k < m, \forall k, m \in \mathcal{M} \tag{9}$$

$$T_k - T_m \le 0, \; k < m, \forall k, m \in \mathcal{M} \tag{10}$$

Note that the above sub-tour elimination constraints borrow the ideals from the sub-tour elimination constraints adopted in the extended vehicle routing problems such as vehicle routing problem with time windows (Toth and Vigo, 2001). Both our sub-tour elimination constraints and the sub-tour elimination constraints adopted in vehicle routing problem with time windows cannot handle the situation of hub arc location, as shown in Figure 2(a). This is because the situation in Figure 2(b) is considered in the vehicle routing problem, rather than Figure 2(a). As shown in equation (5), the situation in Figure 2(a) is due to the reduction of the number of decision variables, and it is allowed in the hub line location problem (Martins de Sá et al., 2015). Interestingly, the situation in Figure 2(a) can be effectively avoided by ranking all ports in set $\mathcal{M}$, and then the above sub-tour elimination constraints (8)–(10) can be adopted in our model, as shown below.

Figure 2 An illustration of hub arc location for the violation of sub-tour elimination constraints



For our bilevel programming model, the upper level model aims to determine the optimal subsidy factor. The upper level model can be formulated as follows:

$$\min \sum_{(i,j)\in\mathcal{W}} \sum_{g\in\mathcal{S}} \sum_{\substack{h\neq g,\\ h\in\mathcal{S}}} \left(\tau\times\alpha\times C_{gh}^{1}\times x_{ijgh}^{0}\times w_{ij}\right) \tag{11}$$

subject to

$$\frac{\sum_{(i,j)\in\mathcal{W}}\sum_{g\in\mathcal{S}} a_{ijg}^{0}}{|\mathcal{W}|} \geq L; \tag{12}$$

$$\tau\in[0,1]. \tag{13}$$

where L is a parameter used to control the utilisation of the TCMSR for routing containers from origin ports to destination ports. The objective function (11) aims to minimise the total weekly subsidy, which is paid to certain liner carrier in order to improve the attractiveness of the TCMSR. Constraint (12) ensures that the utilisation of the TCMSR for routing containers should be kept at certain level. Note that the subsidy factor τ is the unique decision variable in the upper level model. $\{x_{ijgh}^{0}\}$ and $\{a_{ijg}^{0}\}$ are determined by solving the lower level model, which can be formulated as follows.

$$\begin{aligned}\min \sum_{(i,j)\in\mathcal{W}} w_{ij}\times\Bigg[&\sum_{k\in M}\left(C_{ik}^{1}+C_{k}^{a}\right)\times a_{ijk}^{1}+\sum_{k\in\mathcal{M}}\sum_{\substack{m\neq k,\\ m\in\mathcal{M}}}\alpha\times C_{km}^{1}\times x_{ijkm}^{1}\\ &+\sum_{m\in\mathcal{M}}\left(C_{mj}^{1}+C_{m}^{e}\right)\times b_{ijm}^{1}+\sum_{g\in\mathcal{S}}\left(\sum_{v\in\{0,1\}}\delta_{ig}^{v}\times C_{ig}^{v}+C_{g}^{a}\right)\times a_{ijg}^{0}\\ &+\sum_{g\in\mathcal{S}}\sum_{\substack{h\neq g,\\ h\in\mathcal{S}}}(1-\tau)\times\alpha\times C_{gh}^{1}\times x_{ijgh}^{0}\\ &+\sum_{h\in\mathcal{S}}\left(\sum_{v\in\{0,1\}}\delta_{hj}^{v}\times C_{hj}^{v}+C_{h}^{e}\right)\times b_{ijh}^{0}+C_{ij}^{1}\times e_{ij}\Bigg]\end{aligned} \tag{14}$$

subject to (6)–(10),

$$\sum_{k\in\mathcal{M}} a_{ijk}^{1}+\sum_{g\in\mathcal{S}} a_{ijg}^{0}+e_{ij}=1,\quad \forall(i,j)\in\mathcal{W}; \tag{15}$$

$$\sum_{m\in\mathcal{M}} b_{ijm}^{1}+\sum_{h\in\mathcal{S}} b_{ijh}^{0}+e_{ij}=1,\quad \forall(i,j)\in\mathcal{W}; \tag{16}$$

$$a^1_{ijk} + \sum_{\substack{m \neq k, \\ m \in \mathcal{M}}} x^1_{ijmk} = b^1_{ijk} + \sum_{\substack{m \neq k, \\ m \in \mathcal{M}}} x^1_{ijkm}, \forall (i, j) \in \mathcal{W}, \forall k \in \mathcal{M}; \tag{17}$$

$$a^0_{ijg} + \sum_{\substack{h \neq g, \\ h \in \mathcal{S}}} x^0_{ijhg} = b^0_{ijg} + \sum_{\substack{h \neq g, \\ h \in \mathcal{S}}} x^0_{ijgh}, \forall (i, j) \in \mathcal{W}, \forall g \in \mathcal{S}; \tag{18}$$

$$a^1_{ijk} \leq z^1_k, \forall (i, j) \in \mathcal{W}, \forall k \in \mathcal{M}; \tag{19}$$

$$b^1_{ijm} \leq z^1_m, \forall (i, j) \in \mathcal{W}, \forall m \in \mathcal{M}; \tag{20}$$

$$x^0_{ijgh} + x^0_{ijhg} \leq y^0_{gh}, \forall (i, j) \in \mathcal{W}, g < h, \forall g, h \in \mathcal{S}; \tag{21}$$

$$x^1_{ijkm} + x^1_{ijmk} \leq y^1_{km}, \forall (i, j) \in \mathcal{W}, k < m, \forall k, m \in \mathcal{M}; \tag{22}$$

$$\sum_{k \in \mathcal{M}} z^1_k = p + 1; \tag{23}$$

$$\sum_{k \in \mathcal{M}} \sum_{\substack{m > k, \\ m \in \mathcal{M}}} y^1_{km} = p; \tag{24}$$

$$\sum_{\substack{m > k, \\ m \in \mathcal{M}}} y^1_{km} + \sum_{\substack{m < k \\ m \in \mathcal{M}}} y^1_{mk} \leq 2z^1_k, \quad \forall k \in \mathcal{M}; \tag{25}$$

$$y^1_{km}, z^1_k \in \{0, 1\}, \quad k < m, \forall k, m \in \mathcal{M}; \tag{26}$$

$$\begin{aligned} &a^0_{ijg}, a^1_{ijk}, x^0_{ijgh}, x^1_{ijkm}, b^0_{ijh}, b^1_{ijm}, e_{ij} \geq 0, \\ &\forall (i, j) \in \mathcal{W}, k \neq m, \forall k, m \in \mathcal{M}, g \neq h, \forall g, h \in \mathcal{S}; \end{aligned} \tag{27}$$

$$T_k \in \{1, 2, ..., p+1\}, \forall k \in \mathcal{M}. \tag{28}$$

The objective function (14) is to minimise the total cost of transporting containers from origin ports to destination ports. Constraints (15) and (16) are used to determine whether the hub line is used or not for OD demand transported from their origin ports to their destination ports. Constraints (17) and (18) indicates the conservation of flow at hub port k $(\forall k \in \mathcal{M})$ or hub port g $(\forall g \in \mathcal{S})$, following Martins de Sá et al. (2015). The left side of constraints (17) (or (18)) represents the inflow at hub port k (or hub port g), and the right side gives the outflow. Constraints (19) mean that OD demand w_{ij} is allowed to enter the hub line from port k only when port k is a hub port. Constraints (20) ensure that OD demand w_{ij} is allowed to leave the hub line through port m only when port m is a hub port. Constraints (21) and (22) show that interhub container flows can only be routed through interhub connections. Constraints (23) and (24) ensure that the appropriate number of hub ports and hub arcs are selected. Constraints (25) are used for the design of the new hub line where each hub port is allowed to connect with at most two other hub ports. Constraints (26)–(28) are used to define the domain of decision variables.

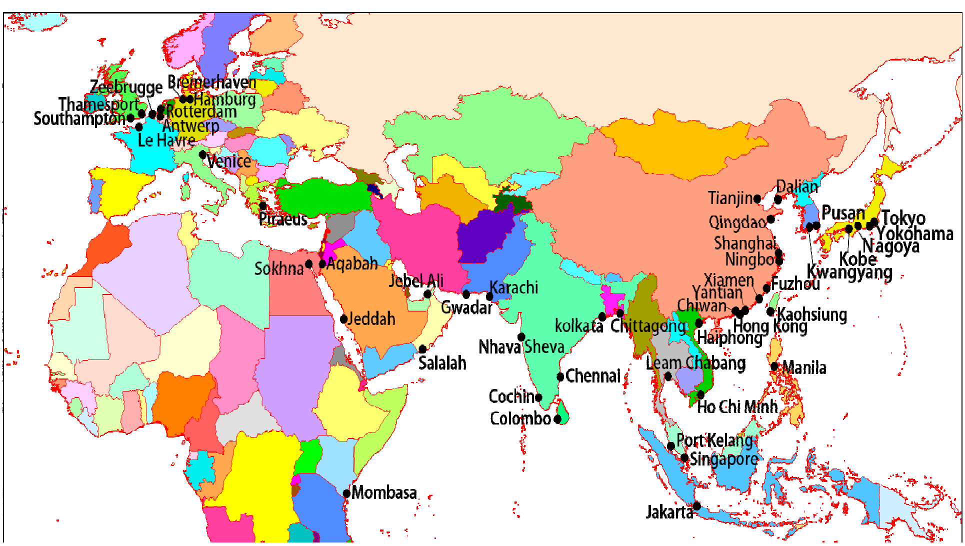
Since the subsidy factor as the unique decision variable of the upper level model, our bilevel programming model can be efficiently solved by enumerating all possible values of the subsidy factor. Hence, our bilevel programming model can be reduced to the lower level model, which is a mixed-integer linear program.

5 Numerical experiments

5.1 Data description

In this section, we provide the numerical results for an Asia-Europe shipping network with 48 ports, as shown in Figure 3. The OD container demand is provided by a global liner shipping company. Note that, from liner shipping company point of view, the TCMSR is not well operated yet in practice. Hence, from certain liner shipping company perspective, some ports along the TCMSR may do not have any associated containers to be loaded and/or discharged, including Mombasa, Venice, and among others. Based on the geographical location, we consider 14 candidate hub ports, ranked as follows: Pusan, Qingdao, Shanghai, Ningbo, Kaohsiung, Hong Kong, Singapore, Colombo, Jebel Ali, Salalah, Jeddah, Sokhna, Hamburg, Rotterdam and Southampton. For the number of hub ports along the new hub line, we mainly consider $p = 6$. It means that seven hub ports and six hub arcs are chosen to construct the new hub line. For each candidate hub port, the access cost and the exit cost are determined by using the transshipment cost provided by the liner shipping company. As mentioned before, our bilevel programming is reduced to the lower level model by enumerating all possible values of the subsidy factor. The lower level model is efficiently solved by using CPLEX implemented in a Windows 7 environment. Numerical experiments are performed on a 3.4 GHz Dual Core PC with 4 GB of RAM.

Figure 3 Ports in an Asia-Europe shipping network (see online version for colours)



5.2 Comparison between one hub line and two hub lines

In order to validate our proposed hub line location model, the results obtained via our model are compared with those based on the hub line location model proposed by Martins de Sá et al. (2015), which determines the location of one hub line. Obviously, our proposed hub line location model is similar to that in Martins de Sá et al. (2015), is containers are not routed via the hub ports along the TCMSR. The results for different values of α are mainly shown here. Let $\sigma = 1$, $\tau = 0.5$, and α is changed from 0.1 to 0.9.

Table 1 Comparison of hubbing probabilities (frequency) of candidate hub ports between two models

Ports	*Frequency*		*Ports*	*Frequency*	
	One line	*Two lines*		*One line*	*Two lines*
Qingdao	0	0.11	Colombo	1	1
Shanghai	1	1	Salalah	0.89	0.67
Ningbo	0	0.11	Jebel Ali	0.11	0.11
Hong Kong	0.89	0.78	Jeddah	1	1
Kaohsiung	0.11	0	Sokhna	0	0.67
Singapore	1	1	Rotterdam	1	0.33

To explore the potential hub locations, we consider the hubbing probability of any candidate hub port, which is defined as the frequency of this port based on the number of times to be selected as a hub port. Table 1 shows a comparison of hub probabilities of different candidate hub ports obtained by using our model and the model of Martins de Sá et al. (2015). In Table 1, column 'Two lines' represents our model, and column 'One line' represents the model of Martins de Sá et al. (2015). By using two different models, we can obtain identical hubbing probabilities for some candidate hub ports (e.g., Shanghai, Singapore, Colombo). For the candidate hub port (Rotterdam) in Europe, these two models can lead to different results. Based on the model of Martins de Sá et al. (2015), we can obtain that Rotterdam has a large probability to be a hub port. Based on our model, the hubbing probability of Rotterdam is quite small, as shown in Table 1. This is because of the effect of the TCMSR considered in our model. Based on our model, many containers are transported through the TCMSR, as well as the railway system connecting between North Europe and Venice. Such phenomenon is partly supported by Yang et al. (2018).

5.3 More results

Here, we provide more results on the TCMSR, and the results for $\alpha = 0.5$ are typically shown. Numerical experiments are mainly presented for different values of σ and τ. In order to explore the subsidy analysis of the TCMSR, let $\sigma = 1$, and τ is changed from 0.1 to 0.9.

Table 2 Hubbing probabilities (frequency) of candidate hub ports to be selected as hub ports

Ports	*Frequency (times)*	*Ports*	*Frequency (times)*
Shanghai	1 (9)	Salalah	0.89 (8)
Hong Kong	0.78 (7)	Jeddah	1 (9)
Singapore	1 (9)	Sokhna	0.78 (7)
Colombo	1 (9)	Southampton	0.33 (3)
Jebel Ali	0.22 (2)		

In Table 2, we show the hubbing porbabilities (frequency) of candidate hub ports to be selected as hub ports. Four candidate hub ports (Shanghai, Singapore, Colombo, Jeddah) are selected by nine times. Salalah is selected by eight times. Hong Kong and Sokhna are selected by seven times. Southampton is selected by three times, and Jebel Ali is selected by twice.

Figure 4 Hub line location for $\tau = 0.3$ (the solid line) and $\tau = 0.7$ (the dotted line) (see online version for colours)

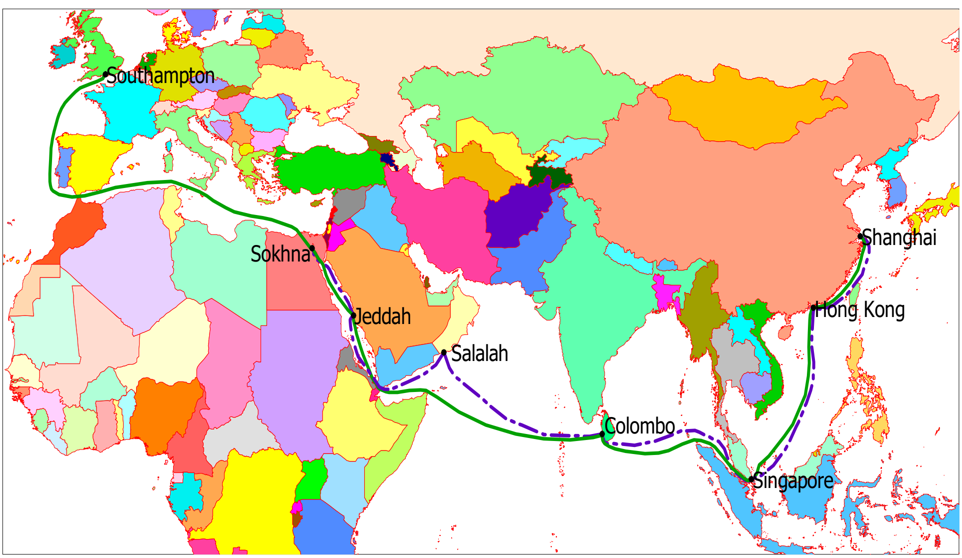


Figure 4 typically shows the results of hub line location for $\tau = 0.3$ and $\tau = 0.7$, respectively. For $\tau = 0.3$, the hub line is expressed as Shanghai-Hong Kong-Singapore-Colombo-Jeddah-Sokhna-Southampton. For $\tau = 0.7$, the hub line is given as Shanghai-Hong Kong-Singapore-Colombo-Salalah-Jeddah-Sokhna. Actually, when $\tau \leq 0.3$, Southampton is chosen to be a hub port in North Europe. When $\tau \geq 0.4$, no hub port is opened in North Europe. Containers originated from or delivered to ports in North Europe are prone to be transported by using the TCMSR and the railway system connecting between North Europe and Venice.

In order to further investigate the utilisation of the TCMSR for routing containers, let π_1 denote the proportion of OD demand pairs of considered liner carrier whose containers are transported along the TCMSR, and let π_2 denote the proportion of containers transported along the TCMSR. Then we have

$$\pi_1 = \frac{\sum_{(i,j)\in\mathcal{W}} \sum_{g\in\mathcal{S}} a_{ijg}^0}{|\mathcal{W}|} \tag{29}$$

$$\pi_2 = \frac{\sum_{(i,j)\in\mathcal{W}} \sum_{g\in\mathcal{S}} \left(a_{ijg}^0 \times w_{ij}\right)}{\sum_{(i,j)\in\mathcal{W}} w_{ij}} \tag{30}$$

Let *Sub* denote the weekly subsidy paid to the considered liner carrier, which is the objective value of the upper level model. As shown in Figure 6, π_1, π_2 and *Sub* increase when the subsidy factor τ increases. For any certain τ, π_1 and π_2 almost overlap. When $\tau < 0.2$, π_1, π_2 and *Sub* are approaching 0. In this case, the attractiveness of the TCMSR can be neglected. When $\tau \geq 0.2$, *Sub* increases linearly with respect to τ, given as follows

$$Sub = 637580 \times \tau - 129012, \quad \forall \tau \in [0.2, 1] \tag{31}$$

The above equation can be used to determine the optimal subsidy factor and the weekly subsidy to be implemented along the TCMSR.

In the upper level model, the utilisation of the TCMSR should be kept at certain level, as shown in equation (12). Let L_1 and L_2 denote two different levels. If $L_1 = 0.5$ and $L_2 = 0.9$, then the corresponding subsidy factor $\tau_1 = 0.3$ and $\tau_2 = 0.7$, and the resulting weekly subsidy Sub_1 = 62,262 (USD) and Sub_2 = 317,204 (USD) paid to the considered liner carrier, as shown in Figure 5. In order words, if the utilisation of the TCMSR is kept at level $L_1 = 0.5$, then the minimum weekly subsidy is Sub_1 = 62,262 (USD). If the utilisation of the TCMSR is kept at level $L_2 = 0.9$, then the minimum weekly subsidy is up to Sub_2 = 317,204 (USD).

Figure 5 π_1, π_2 and *Sub* versus the subsidy factor τ (see online version for colours)

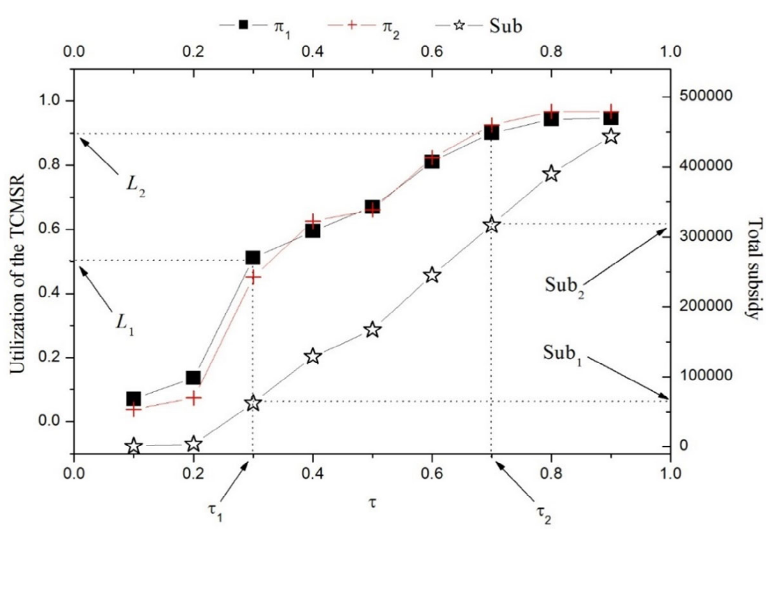
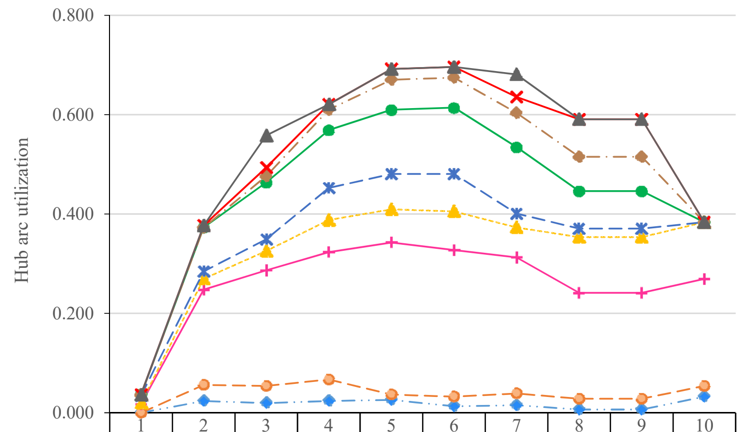


Figure 6 Hub arc utilisation for different subsidy factors (see online version for colours)



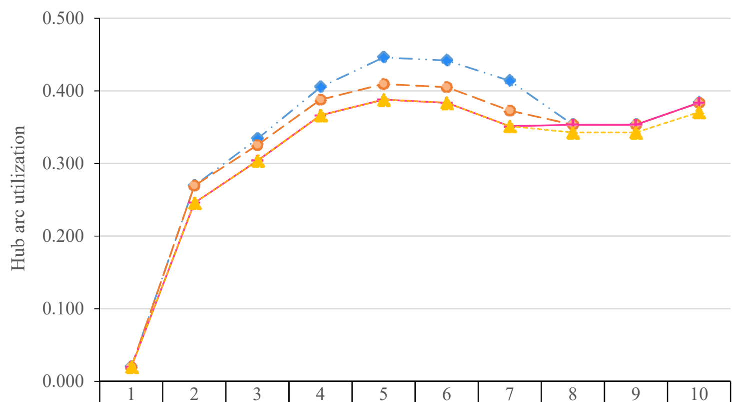
	1	2	3	4	5	6	7	8	9	10
τ=0.1	0.000	0.024	0.019	0.024	0.026	0.013	0.015	0.006	0.006	0.032
τ=0.2	0.000	0.056	0.054	0.067	0.037	0.032	0.039	0.028	0.028	0.054
τ=0.3	0.017	0.248	0.287	0.323	0.343	0.328	0.313	0.241	0.241	0.269
τ=0.4	0.019	0.269	0.325	0.388	0.409	0.405	0.373	0.353	0.353	0.384
τ=0.5	0.034	0.284	0.349	0.453	0.481	0.481	0.401	0.371	0.371	0.384
τ=0.6	0.037	0.373	0.463	0.569	0.610	0.614	0.534	0.446	0.446	0.384
τ=0.7	0.037	0.373	0.476	0.610	0.670	0.675	0.603	0.515	0.515	0.384
τ=0.8	0.037	0.377	0.494	0.621	0.692	0.696	0.636	0.591	0.591	0.384
τ=0.9	0.037	0.377	0.558	0.621	0.692	0.696	0.681	0.591	0.591	0.384

Next, we analyse the attractiveness of various hub arcs along the TCMSR, and the label of each hub arc is shown in Figure 1. Let π_i^3 denote the proportion of OD demand pairs whose containers are transported through the i^{th} ($1 \le i \le 10$) hub arc along the TCMSR. Then, we have

$$\pi_i^3 = \frac{\sum_{(k,j)\in \mathcal{W}} x^0_{kjp_ip_{i+1}}}{|\mathcal{W}|}, \quad i = 1, 2, \ldots, 10 \tag{32}$$

When the subsidy factor τ increases, hub arc utilisation (i.e., $\{\pi_i^3\}$) increases, as shown in Figure 6. Generally, as the increase of the label of hub arc, hub arc utilisation increases first, and then decreases. Two most utilised hub arcs are Singapore-Kolkata and Kolkata-Colombo. For any value of the subsidy factor τ, Gwadar-Mombasa and Mombasa-Piraeus always maintain identical utilisation. This is because, in our numerical experiments many hub ports including Gwadar and Mombasa along the TCMSR do not have any associated container demand, as mentioned before. Moreover, there is not any feeder port located close to Mombasa. Hence, there is not any container to be loaded, discharged or transshipped at Mombasa. In other words, it leads to a detour for the transportation of many containers between Asia and North Europe by using the TCMSR. This is why subsidy should be implemented along the TCMSR.

Figure 7 Hub arc utilisation for different values of parameter *p* (see online version for colours)



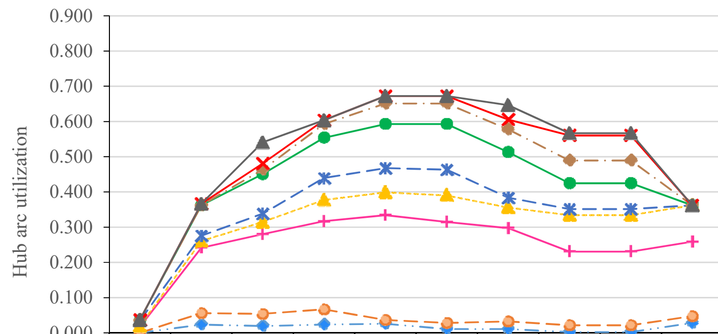
	1	2	3	4	5	6	7	8	9	10
p=5	0.019	0.269	0.334	0.405	0.446	0.442	0.414	0.353	0.353	0.384
p=6	0.019	0.269	0.325	0.388	0.409	0.405	0.373	0.353	0.353	0.384
p=7	0.019	0.246	0.304	0.366	0.388	0.384	0.351	0.353	0.353	0.384
p=8	0.019	0.246	0.304	0.366	0.388	0.384	0.351	0.343	0.343	0.371

In order to investigate the impact of the new designed hub line on the utilisation of the TCMSR, we explore hub arc utilisation for different values of parameter p. The parameter p is the number of hub arcs to be located for the new hub line. The results are shown in Figure 7, where the subsidy factor $\tau = 0.4$ is typically considered. When parameter p increases, more hub ports are opened along the new hub line. As a result, hub arc utilisation along the TCMSR decreases slightly. In other words, it does not have an obvious effect on hub arc utilisation along the TCMSR by considering different values of parameter p.

Generally, OD demand varies from week to week. Hence, we explore hub arc utilisation along the TCMSR for different OD demand cases. In case 1, all OD demands are decreased by 20% with probability 0.5. In case 2, all OD demands are increased by 20% with probability 0.5. The results of hub arc utilisation along the TCMSR for different subsidy factors in these two cases are shown in Figure 8, where parameter $p = 6$ is considered. Interestingly, it hardly affects hub arc utilisation along the TCMSR by considering different OD demand scenarios.

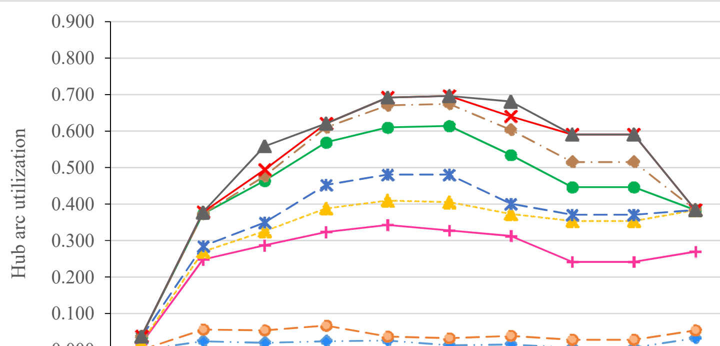
For the subsidy applied on rail transportation connecting between North Europe and Venice, we consider different values of parameter σ. The results of hub arc utilisation along the TCMSR are shown in Figure 9, where $p = 6$ and $\tau = 0.4$ are typically considered. As the increase of σ, the subsidy on rail transportation decreases, and then hub arc utilisation decreases obviously. Differences of hub arc utilisation among different value of σ are largest for the last two hub arcs, as compared with other hub arcs along the TCMSR. This is because the subsidy on rail transportation has a direct impact on the connection between North Europe and Venice, which can further affect the attraction of the TCMSR. In order to determine the optimal subsidy policy to be implemented along the TCMSR, we should consider subsidy policies applied along the NELB.

Figure 8 Hub arc utilisation for different subsidy factors in (a) case 1 and (b) case 2 (see online version for colours)



	1	2	3	4	5	6	7	8	9	10
τ=0.1	0.000	0.024	0.019	0.024	0.026	0.011	0.011	0.002	0.002	0.028
τ=0.2	0.000	0.056	0.054	0.067	0.037	0.028	0.032	0.022	0.022	0.047
τ=0.3	0.017	0.241	0.280	0.317	0.334	0.315	0.297	0.231	0.231	0.259
τ=0.4	0.019	0.261	0.315	0.377	0.399	0.390	0.356	0.334	0.334	0.362
τ=0.5	0.034	0.276	0.338	0.440	0.468	0.463	0.384	0.351	0.351	0.362
τ=0.6	0.037	0.362	0.450	0.554	0.593	0.593	0.513	0.425	0.425	0.362
τ=0.7	0.037	0.362	0.463	0.593	0.651	0.651	0.578	0.489	0.489	0.362
τ=0.8	0.037	0.366	0.481	0.603	0.672	0.672	0.606	0.560	0.560	0.362
τ=0.9	0.037	0.366	0.541	0.603	0.672	0.672	0.647	0.567	0.567	0.362

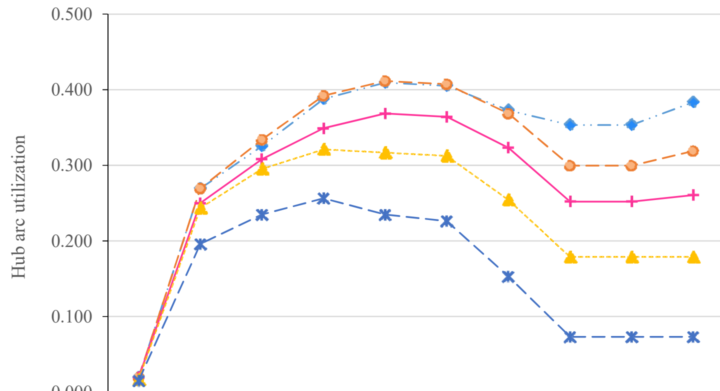
(a)



	1	2	3	4	5	6	7	8	9	10
τ=0.1	0.000	0.024	0.019	0.024	0.026	0.013	0.015	0.006	0.006	0.032
τ=0.2	0.000	0.056	0.054	0.067	0.037	0.032	0.039	0.028	0.028	0.054
τ=0.3	0.017	0.248	0.287	0.323	0.343	0.328	0.313	0.241	0.241	0.269
τ=0.4	0.019	0.269	0.325	0.388	0.409	0.405	0.373	0.353	0.353	0.384
τ=0.5	0.034	0.284	0.349	0.453	0.481	0.481	0.401	0.371	0.371	0.384
τ=0.6	0.037	0.373	0.463	0.569	0.610	0.614	0.534	0.446	0.446	0.384
τ=0.7	0.037	0.373	0.476	0.610	0.670	0.675	0.603	0.515	0.515	0.384
τ=0.8	0.037	0.377	0.494	0.621	0.692	0.696	0.640	0.591	0.591	0.384
τ=0.9	0.037	0.377	0.558	0.621	0.692	0.696	0.681	0.591	0.591	0.384

(b)

Figure 9 Hub arc utilisation for different values of parameter σ (see online version for colours)



	1	2	3	4	5	6	7	8	9	10
σ=1.0	0.019	0.269	0.325	0.388	0.409	0.405	0.373	0.353	0.353	0.384
σ=1.5	0.019	0.269	0.334	0.392	0.412	0.407	0.369	0.300	0.300	0.319
σ=2.0	0.019	0.250	0.308	0.349	0.369	0.364	0.323	0.252	0.252	0.261
σ=2.5	0.017	0.244	0.295	0.321	0.317	0.313	0.254	0.179	0.179	0.179
σ=3.0	0.015	0.196	0.235	0.256	0.235	0.226	0.153	0.073	0.073	0.073

6 Summary and final considerations

This paper has proposed and investigated the attraction and subsidy analysis of the TCMSR. The attraction of the TCMSR is mainly expressed by the utilisation of the TCMSR for routing containers. A bilevel programming model is formulated for our proposed problem. By enumerating all possible values of the subsidy factor, our bilevel programming model is reduced to the lower level model, which aims to design a new hub line, leading to a hub line location problem.

The main academic contributions of this paper are as follows:

1 an optimisation problem is proposed to investigate the attraction and subsidy analysis of the TCMSR

2 a hub line location approach is presented to solve the proposed problem

3 new sub-tour elimination constraints are developed for our hub line location model.

The main numerical findings are as follows. Numerical experiments show that, the utilisation of the TCMSR including the hub arc utilisation for routing containers mainly depends on the subsidy policies to be implemented along the TCMSR. We find a linear relationship between weekly subsidy to be implemented along the TCMSR and the subsidy factor. Based on this linear relationship, the optimal subsidy factor and weekly subsidy can be determined. Moreover, it seems to have an obvious effect on hub arc utilisation along the TCMSR by considering different subsidy policies applied on rail transportation connecting between North Europe and Venice. While the impact of different OD demand scenarios on hub arc utilisation along the TCMSR can be neglected.

There are some works we will investigate in the future. Firstly, we will investigate the subsidy policies of both the TCMSR and NELB. Secondly, we will investigate feeder service network design (or ship routing) integrated with the hub line location problem.

Acknowledgements

The authors are indebted to the anonymous reviewers for helpful comments. This paper is partly supported by National Natural Science Foundation of China (71871036, 72031005, 71831002, 71871130).

References

Alumur, S. and Kara, B.Y. (2008) 'Network hub location problems: the state of the art', *European Journal of Operational Research*, Vol. 190, No. 1, pp.1–21.

Alumur, S., Yaman, H. and Kara, B.Y. (2012) 'Hierarchical multimodal hub location problem with time-definite deliveries', *Transportation Research Part E*, Vol. 48, No. 6, pp.1107–1120.

An, Y., Zeng, B., Zhang, Y. and Zhao, L. (2014) 'Reliable p-median facility location problem: two-stage robust models and algorithms', *Transportation Research Part B*, Vol. 64, pp.54–72.

Brouer, B.D., Alvarez, J.F., Plum, C.E.M., Pisinger, D. and Sigurd, M.M. (2014) 'A base integer programming model and benchmark suite for liner-shipping network design', *Transportation Science*, Vol. 48, No. 2, pp.281–312.

Campbell, J.F., Ernst, A.T. and Krishnamoorthy, M. (2005a) 'Hub arc location problems: part I-introduction and results', *Management Science*, Vol. 51, No. 10, pp.1540–1555.

Campbell, J.F., Ernst, A.T. and Krishnamoorthy, M. (2005b) 'Hub arc location problems: part II-formulations and optimal algorithms', *Management Science*, Vol. 51, No. 10, pp.1556–1571.

Chen, J., Fei, Y., Lee, P.T.W. and Tao, X. (2018a) 'Overseas port investment policy for China's central and local governments in the Belt and Road initiative', *Journal of Contemporary China*, Vol. 28, No. 116, pp.196–215.

Chen, D., Luo, M. and Yang, Z. (2018b) 'Manufacturing relocation and port/shipping development along the Maritime Silk Road', *International Journal of Shipping and Transport Logistics*, Vol. 10, No. 3, pp.316–334.

Chen, J. and Shmuel, Y. (2013) 'Container slot co-allocation planning with joint fleet agreement in a round voyage for liner shipping', *Journal of Navigation*, Vol. 66, No. 4, pp.589–603.

Contreras I. and Fernández E. (2014) 'Hub location as the minimization of a supermodular set function', *Operations Research*, Vol. 62, No. 3, pp.557–570.

Cui, T., Ouyang, Y. and Shen, Z.J.M. (2010) 'Reliable facility location design under the risk of disruptions', *Operations Research*, Vol. 58, No. 4, pp.998–1011.

Goldman, A.J. (1969) 'Optimal location of centers in a network', *Transportation Science*, Vol. 3, No. 4, pp.352–360.

Gong, X. and Lu, J. (2018) 'Strait/canal security assessment of the Maritime Silk Road', *International Journal of Shipping and Transport Logistics*, Vol. 10, No. 3, pp.281–298.

Kim, H. and O'Kelly, M.E. (2009) 'Reliable p-hub location problems in telecommunication networks', *Geographical Analysis*, Vol. 41, No. 3, pp.283–306.

Li, K.X., Jin, M. and Shi, W. (2018) 'Diversification as an energy importing strategy for China under the Belt and Road Initiative', *International Journal of Shipping and Transport Logistics*, Vol. 10, No. 3, pp.335–354.

Li, M.K. (2018) 'Yard storage planning for river terminals on one belt one road', *International Journal of Shipping and Transport Logistics*, Vol. 10, No. 3, pp.299–315.

Liu, X., Zhang, K., Chen, B., Zhou, J. and Miao, L. (2018) 'Analysis of logistics service supply chain for the one belt and one road initiative of China', *Transportation Research Part E*, Vol. 117, pp.23–39.

Martins de Sá, E., Contreras, I., Cordeau, J.F., de Camargo, R.S. and de Miranda, G. (2015) 'The hub line location problem', *Transportation Science*, Vol. 49, No. 3, pp.500–518.

O'Kelly, M.E. (1986) 'The location of interacting hub facilities', *Transportation Science*, Vol. 20, No. 2, pp.92–106.

O'Kelly, M.E. (1987) 'A quadratic integer program for the location of interacting hub facilities', *European Journal of Operational Research*, Vol. 32, No. 3, pp.393–404.

Shao, Z.Z., Ma, Z.J., Sheu, J.B. and Gao, H.O. (2018) 'Evaluation of large-scale transnational high-speed railway construction priority in the belt and road region', *Transportation Research Part E*, Vol. 117, pp.40–57.

Sheu, J.B. and Kundu, T. (2018) 'Forecasting time-varying logistics distribution flows in the one belt-one road strategic context', *Transportation Research Part E*, Vol. 117, pp.5–22.

Song, D.P. and Dong, J.X. (2013) 'Long-haul liner service route design with ship deployment and empty container repositioning', *Transportation Research Part B*, Vol. 55, pp.188–211.

Sun, Z. and Zheng, J. (2016) 'Finding potential hub locations for liner shipping', *Transportation Research Part B*, Vol. 93, pp.750–761.

Toth, P. and Vigo, D. (2001) 'The vehicle routing problem', *Philadelphia: SIAM Monographs on Discrete Mathematics and Applications*, pp.157–160.

Tu, N., Adiputranto, D., Fu, X. and Li, Z.C. (2018) 'Shipping network design in a growth market: the case of Indonesia', *Transportation Research Part E*, Vol. 117, pp.108–125.

Wang, S. and Meng, Q. (2013) 'Reversing port rotation directions in a container liner shipping network', *Transportation Research Part B*, Vol. 50, pp.61–73.

Yaman, H. (2009) 'The hierarchical hub median problem with single assignment', *Transportation Research Part B*, Vol. 43, No. 6, pp.643–658.

Yang, D., Pan, K. and Wang, S. (2018) 'On service network improvement for shipping lines under the one belt one road initiative of China', *Transportation Research Part E*, Vol. 117, pp.82–95.

Yang, Z. (2019) 'Market structure, welfare analysis and strategic choice of China-Europe expresses', *Governance Studies*, Vol. 185, pp.97–103, in Chinese, https://doi.org/10.15944/j.cnki.33-1010/d.20181029.001.

Zeng, Q., Wang, G.W.Y., Qu, C. and Li, K.X. (2018) 'Impact of the carat canal on the evolution of hub ports under China's belt and road initiative', *Transportation Research Part E*, Vol. 117, pp.96–107.

Zhao, L., Zhao, Y., Hu, Q., Li, H. and Stoeter, J. (2018) 'Evaluation of consolidation center cargo capacity and locations for China railway express', *Transportation Research Part E*, Vol. 117, pp.58–81.

Zheng, J., Gao, Z., Yang, D. and Sun, Z. (2015a) 'Network design and capacity exchange for liner carriers with fixed and variable container demands', *Transportation Science*, Vol. 49, No. 4, pp.886–699.

Zheng, J., Meng, Q. and Sun, Z. (2015b) 'Liner hub-and-spoke shipping network design', *Transportation Research Part E*, Vol. 75, pp.32–48.

Zheng, J., Meng, Q. and Sun, Z. (2014) 'Impact analysis of maritime cabotage legislations on liner hub-and-spoke shipping network design', *European Journal of Operational Research*, Vol. 234, No. 3, pp.874–884.

Zheng, J., Qi, J., Sun, Z. and Li, F. (2018) 'Community structure based global hub location problem in liner shipping', *Transportation Research Part E*, Vol. 118, pp.1–19.

Zheng, J., Zhang, W., Qi, J. and Wang, S. (2019) 'Canal effects on hub location problem in liner shipping' *Transportation Research Part E*, Vol. 130, pp.230–247.