https://doi.org/10.1016/j.tre.2017.07.003

On service network improvement for shipping lines under the one belt one road initiative of China

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Abstract

This paper aims to reconstruct the shipping service network between Asia and Europe by considering the improvement of New Eurasian Land Bridge rail services and Budapest-Piraeus railway. In particular, to reflect the decision making process in reality, a bi-level programming model is established to maximize the total profit of the liner shipping company in the upper level and meanwhile to minimize the total cost of the shippers in the lower level. Computational experiments considering different scenarios are conducted to obtain the new optimal networks under different cases. Several insightful findings are observed, further leading to useful managerial insights.

Key words: One belt one road initiative; Shipping network design; Bi-level optimization; Intermodal transshipment.

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1 Introduction

China has grown to the largest manufacturing and trading country in the world in the past two decades. However, it is recognized that China is now facing a big challenge, i.e., slowdown of domestic economy and trade [22]. To cope with this challenge, in March 2016, Chinese Government issued the "Action plan on the China-proposed Belt and Road Initiative", which aims to improve and reconfigure logistics and transportation networks along the One Belt One Road (OBOR) trade corridors and connectivity among the countries along the route [19]. Under this initiative, two main routes, the land-based "Silk Road Economic Belt" and ocean-going "Maritime Silk Road," are proposed to connect China and other Eurasia countries, as shown in Figure 1.

Figure 1: Map of the One Belt One Road Initiative[1]

Following this initiative, there are two important railway systems significantly impacting the current shipping service network from China to Europe. First, as an important part of the OBOR initiative, the railway along New Eurasia Land Bridge has achieved a quick development in recent years. The New Eurasia Land Bridge, also known as the Second Eurasia Land Bridge, is an international railway line connecting China and other Eurasia countries such as Kazakhstan, Russia, Belarus, and Poland. Through capitalizing on the New Eurasia Land Bridge, eleven Chinese

[1]Source: Eurasia Review

cities have successively opened direct railway container services to European cities, for example, Chongqing to Duisburg (Germany), Wuhan to Melnlk and Pardubice (Czech), Chengdu to Lodz (Poland), and Zhengzhou to Hamburg (Germany). By October 2015, 1070 trains in total have left China for Europe with cargoes, as the number of trains increased from 17 in 2011 to 623 in 2015. Thus, the cargo delivery service provided by this railway system is continuously increasing, leading to possibly extensive changes on the other cargo delivery services such as liner shipping.

Second, following the OBOR initiative, the railway system built to connect Southern European hub ports to their hinterland is also changing the current shipping network. In particular, in Figure 1, Venice and Piraeus (Athens) are highlighted as two gateway ports in Europe. In order to help build these two gateway ports and better utilize them to construct the liner shipping service network, a Chinese liner shipping company, i.e., COSCO, signed a concession agreement to operate Piraeus port with the Piraeus Port Authority in 2016, which provides COSCO with 67% shares of the port. Furthermore, COSCO is expected to invest more than half a billion euros (€552 million) in the Piraeus Port within the next five years and the investment aims "to make Piraeus the biggest transit port in the South Europe"[2].

With respect to the importance of these gateway ports in Central and Eastern Europe (CEE), besides COSCO's investment on the port construction, China also cooperated with CEE to construct a high-speed rail line (as shown in Figure 2) linking the Piraeus Port of Greece in the south to Budapest of Hungary in the north via Skopje of Macedonia and Belgrade of Serbia[3]. Upon its completion by 2018, the travel time by train between Southern and Central Europe will be significantly reduced. More importantly, the investment on these hub ports and the railway system linking the hub ports with other inland cities will tremendously reduce the cargo delivery time from China to other inland European cities through these ports and thereafter the railway.

Due to the improvement of these aforementioned two railway systems (i.e., the New Eurasia Land Bridge and the railway connecting Southern European hub ports to its hinterland), the corresponding transportation activities will change accordingly [18]. Therefore, it is of significance for the Chinese liner shipping companies such as COSCO, who merged China Shipping in 2016 and became a giant shipping line in China, to re-optimize their liner services from Asia to Europe by incorporating the increasing land-bridge rail services, the expansion of the Piraeus Port, and the construction of Piraeus-Budapest railway. To deal with this problem, in this paper, we propose an

[2] http://www.wsj.com/articles/china-cosco-to-invest-over-552-million-in-port-of-piraeus-1467789308

[3] http://thediplomat.com/2015/11/chinas-belt-and-road-reaches-europe/

Figure 2: Rail connect from Piraeus to Middle Europe

optimization model for Chinese liner shipping companies such as COSCO to re-construct their liner shipping service networks by considering the impacts from the aforementioned two railway systems. In particular, a bi-level optimization model is proposed to reflect the decision making of a static network design problem in practice, in which the liner shipping company decides which shipping routes to be operated and then the shippers decide the corresponding cargo amounts delivered by the chosen routes. Accordingly, in the upper level of our proposed bi-level programming model, the liner carrier's profit is maximized by deciding which routes are chosen and meanwhile the lower level problem minimizes the total cost of the shippers by deciding the cargo amounts corresponding to each available path. We reformulate the proposed bi-level mixed-integer programming model into a single level one by replacing the lower level problem with its Karush-Kuhn-Tucker (KKT) conditions since it is a convex problem when the upper level decision is fixed. To further improve the computational performance, we linearize the bilinear terms of the complementary slackness constraints in the KKT conditions and finally obtain a mixed-integer linear programming (MILP) model, which can be easily solved by a commercial optimization solver (e.g., CPLEX).

Furthermore, by respecting the expected development of the OBOR initiative, we construct eight cases in two separated scenarios by using the real data from COSCO to perform the computational experiments. Different indicators of the re-optimized network are compared with the current one to see the impacts brought by the OBOR initiative. Although the data is based on COSCO, the final results can be easily extended to other liner shipping companies for optimizing their shipping network when making strategies to follow the OBOR initiative. Meanwhile, the proposed bi-level optimization model and the corresponding solution approaches can also be applied in those companies. Finally, useful managerial insights are obtained from the analyses and detailed explanations are also provided.

This paper is a preliminary attempt to explore the impacts of the OBOR initiative, in particular the development of the rail systems mentioned above, on the shipping service change of one shipping line. The remaining part of our paper is organized as follows. Section 2 provides a comprehensive literature review and highlights the contribution of this paper. The notation and our proposed bi-level programming formulation are introduced in Section 3 in detail and the corresponding reformulation is described in Section 4. Section 5 presents the scenarios for analysis and discusses the results. Section 6 contains the final conclusion and policy and managerial implications.

2 Literature review

In recent years, there have been a number of quantitative studies on liner shipping network design, as reviewed in Christiansen et al. [5], Meng et al. [13], Tran and Haasis [24], and Lee and Song [10]. We classify the most relevant studies into three categories and analyze the relation of our study to the literature.

First, some works sought to develop sophisticated mathematical models and solution algorithms to design a container liner shipping network from scratch. Shintani et al. [20], Song and Dong [21], and Plum et al. [16] have examined the design of a single liner route that provides regular services. Gelareh et al. [7], Gelareh and Pisinger [8] and Zheng et al. [30, 31] have designed a set of liner routes that form a hub-and-spoke network. Agarwal and Ergun [1], Brouer et al. [3, 4], Mulder and Dekker [15], Plum et al. [17], Karsten et al. [9] have devoted efforts to design a general liner shipping network in which containers can be transshipped at any port. The designed routes and networks in the literature include information on the port rotations, ship deployment, and sometimes service schedule. Because shipping lines cannot completely reshuffle their shipping services, the designed networks may not be directly adopted by shipping lines. Furthermore, using mathematical algorithms to design port rotations cannot incorporate all practical considerations. For instance, since COSCO will operate Piraeus port, its ships will naturally call at Piraeus more frequently. The models in the first category of studies have taken into account this aspect when designing liner routes.

The second category of studies assumes that shipping lines already have a set of candidate services. The set of candidate services may include the ones that are being operated, the ones that were operated, the competitors' services, and the ones designed by various methods. Meng and Wang [12] chose a set of routes to operate from a much larger set of candidate routes. Wang et al. [27] provided an incremental network design approach that improves an existing network with minimum revision. The first and the second categories of research only consider the maritime part of the container transportation process, i.e., they assume that the container origins are ports and the container destinations are also ports. Moreover, they focus on one shipping company whose containerized cargo transportation demand is exogenous. In the context of OBOR, the container shipment demand for shipping services is endogenous as it depends on the relative attractiveness of shipping services and the New Eurasia Land Bridge.

The third category of study extends the above two categories by investigating the whole multimodal container transportation system in which the origins and destinations of containers are at inland locations. Meng et al. [14] worked on a global liner shipping network design problem with inland transportation services, multi-type containers and transit time requirements. Liu et al. [11] developed a decision support system for multimodal liner shipping network design. Tran et al. [25] designed a liner route that connects Europe and North America, incorporating the inland transportation of containers from/to the ports as well as inventory costs and CO_2 costs. The focus of this category of studies is still an ocean container shipping line. This liner provides door-to-door container transportation services by purchasing inland transportation services. The inland transportation services, including trucks, train, barges, and a combination of two or three modes, are purchased from inland transportation service providers. In our setting, although the New Eurasia Land Bridge is an inland transportation service, it attracts container shipment demand from the liner shipping company instead of assisting the liner shipping company to fulfill door-to-door transportation services.

In this paper, we study the liner shipping network design problem for an ocean container shipping company taking into consideration of OBOR effect. The concrete contribution of the study is three-folds and can be summarized as follows.

1. First, Maritime silk road and land silk road are two equally important parts in the OBOR initiative and they have not yet been examined together in the previous liner shipping network design literature. In our study, we extend the existing studies by incorporating the inland transportation including inland demand and rail of New Eurasia Land Bridge into our models.

2. Second, MILP formulations have been broadly applied in solving conventional problems for

liner shipping network design, however, it assumes that the demand is exogenous. In our study, the demand for shipping service is not fixed but depends on cost, time and capacities of the Maritime Silk Road and the New Eurasia Land Bridge. Consequently, the existing MILP formulations are no longer applicable. To address this new problem, we develop a bi-level programming formulation, which is very challenging for solution algorithm design. To solve the bi-level programming formulation, we propose an algorithm that first transforms the model into a single-level one using duality theory, and then linearize the single-level model into an MILP formulation. Such a formulation can be solved to optimality using existing optimization techniques.

3. Third, unlike most of the previous studies which applied randomly generated data, we conduct case studies based on realistic data collected from shipping companies. These shipping companies are regarded as potential beneficiaries from the OBOR initiative. The managerial insights obtained from case studies using real data is considered to be more valuable for practitioners.

3 Notation and formulation

In this section, we first introduce the notations used throughout this paper in Section 3.1 and then describe a mathematical optimization model that can provide the optimal solution of the network design in Section 3.2. In particular, we introduce a bi-level programming formulation, in which the liner shipping company (i.e., COSCO) maximizes its total profit in the upper level and the shipper minimizes its total cost in the lower level. Note here that without loss of generality, we combine all the shippers into one for brevity.

3.1 Notation

In the following, we introduce all the notations into three groups, i.e., sets, parameters, and decision variables.

Sets

We have the O-D pairs, shipping routes, railway routes, and legs in each route that will be defined as sets. We denote $\mathcal{P}$ as the set of all the O-D pairs whose demands should be satisfied, $\mathcal{R}_m$ as the set of all the possible shipping routes from Chinese ports to European ports, $\mathcal{R}_w$ as the set of all the existing railway routes (i.e., New Eurasian Land Bridge) connecting Chinese ports and

European ports, and $\mathcal{R}_0$ as the set of all the railway routes from European hub ports (e.g., Piraeus) to its inland ports (e.g., Budapest). As each route has a set of legs, we denote $\mathcal{L}$ as the set of all the individual legs in the network including routes $\mathcal{R}_m$, $\mathcal{R}_w$, and $\mathcal{R}_0$.

For each $od \in \mathcal{P}$, we denote $\mathcal{H}^m_{od}$ as the set of all the paths constructed by legs of the routes from $\mathcal{R}_m$ and $\mathcal{R}_0$ and denote $\mathcal{H}^w_{od}$ as the set of all the paths constructed by the legs in the routes from $\mathcal{R}_w$. Note that the shipping routes are run by the liner shipping company who needs to make the decisions on which shipping routes should be chosen for delivering the containers on each O-D pair. Meanwhile, the railway routes in $\mathcal{R}_w$ are essentially run by the competitor of the shipping company, trying to share the demand of each O-D pair for increasing its profit. For notation brevity, we let $\mathcal{R} = \mathcal{R}_m \cup \mathcal{R}_w \cup \mathcal{R}_0$, $\mathcal{H}^m = \cup_{\forall od \in \mathcal{P}} \mathcal{H}^m_{od}$, $\mathcal{H}^w = \cup_{\forall od \in \mathcal{P}} \mathcal{H}^w_{od}$, $\mathcal{H} = \mathcal{H}^m \cup \mathcal{H}^w$, and $\mathcal{H}_{od} = \mathcal{H}^m_{od} \cup \mathcal{H}^w_{od}$.

Parameters

Now we describe the notations of the parameters in the network. For each route $r \in \mathcal{R}$, we denote c_r as the fixed cost to operate it and Q^r as its capacity. For each $od \in \mathcal{P}$, we denote q^{od} as the corresponding amount of cargo demand and f_{od} (resp. f^w_{od}) as its freight rate if this od is delivered by maritime (resp. railway) paths. In order for a flexible schedule and to avoid low loading ratio for some route, the shipping company can ask its partner liner in the same alliance to ship a part (e.g., 5%) of the demand of each O-D pair. We call the percentage of this part as chartering ratio and denote its upper limit as k_{od} for each $od \in \mathcal{P}$ and let $\hat{f}_{od}$ represent the price for each $od \in \mathcal{P}$ for delivering this part of demand.

For each $h \in \mathcal{H}^m$, we denote c^m_h as its total operation cost, including loading, unloading, transshipment, and possible railway transportation (in Europe) cost, and p^m_h as its unit price for delivering one unit of cargo. Also, we denote p^w_h as the unit price for each path $h \in \mathcal{H}^w$ and t_h as the total time required when using path $h \in \mathcal{H}$. Moreover, we denote $\mathcal{L}_h$ as the set of legs constructing path h. For each leg $i \in \mathcal{L}$, we denote r_i as the route in which leg i is and let δ^h_i be 1 if leg i is used by path h and be 0 otherwise. For each leg, there is a corresponding shipping time over this leg for cargo delivery. Thus, the value of t_h is the summation of the time needed for each leg in set $\mathcal{L}_h$. In addition, we let V represent the value of time for calculating the cost and P^u (resp. P^d) represent the unit penalty cost for upper (resp. lower) level decision maker if the demand cannot be shipped for each $od \in \mathcal{P}$. Note here that generally we can obtain the estimated value of V in practices through communicating with the shipper. For instance, through investigation, we can easily obtain that how much more cost each shipper would like to pay if the cargoes can be delivered one day in advance. Alternatively, the value of V can be calculated mathematically through utilizing the approaches in the literature such as [28].

Decision variables

The decision variables correspond to all the decisions that need to be made in the model. In particular, our model includes the upper and lower level decisions, which are made by the liner shipping company and the shipper, respectively. For the corresponding notations, we let binary variable x_r represent the upper level decision, in which $x_r = 1$ if router $r \in \mathcal{R}$ is chosen to be in operation and 0 otherwise. For the lower level decision variables, we let continuous variable y_h represent the amount of cargoes delivered by path $h \in \mathcal{H}$, continuous variable w_{od} represent the amount of demand delivered by the partner liner of the shipping company for each $od \in \mathcal{P}$, and σ_{od} represent the amount of demand that cannot be shipped due to capacity limit corresponding to each $od \in \mathcal{P}$. Note here that for σ_{od}, it is in fact an auxiliary decision variable to indicate the amount of cargoes that are not delivered, which is the direct result based on the shipping company's decision x_r and the shipper's decision y_h; for w_{od}, it can be regarded as the amount of cargoes that the shipper asks the partner liner of the liner shipping company to deliver.

3.2 Mathematical formulation

Before describing the mathematical formulation, we introduce how the paths in set $\mathcal{H}$ are generated. As indicated in Section 3.1, essentially for each O-D pair $od \in \mathcal{P}$, we generate a set of paths (i.e., $\mathcal{H}_{od}$) that are divided into two groups, where one group is assigned to set $\mathcal{H}^m_{od}$ and another group is assigned to set $\mathcal{H}^w_{od}$.

For each $od \in \mathcal{P}$ whose origin is port o and destination is port d, in order to generate the paths in $\mathcal{H}^m_{od}$, we enumerate all the possible paths that can be constructed by all the legs of the routes in $\mathcal{R}_m$ and $\mathcal{R}_0$ such that all of these paths have an origin port o and a destination port d. Thus for each $h \in \mathcal{H}^m_{od}$, we have $p^m_h = f_{od}$ since the liner shipping company obtains revenue from them. Note here that we incorporate the development of the railway connecting the Southern European hub ports with the hinterland, as we use the legs of the routes in $\mathcal{R}_0$ to generate paths. Similarly, for each $od \in \mathcal{P}$, in order to generate the paths in $\mathcal{H}^w_{od}$, we enumerate all the possible paths that can be constructed by all the legs of the routes in $\mathcal{R}_w$ such that all of these paths have an origin port o and a destination port d. Since the railway routes along the New Eurasian Land Bridge are operated by the competitor of the liner shipping company, for each $h \in \mathcal{H}^w_{od}$, we have $p^w_h = f^w_{od}$, which indicates the operating cost of the O-D pair od when delivered by the railway paths, since the liner shipping company needs to pay this cost. Note here that we consider the effect from the railway routes along the New Eurasian Land Bridge when optimizing the liner shipping company's service network.

Therefore, with all the notations described above, the final bi-level programming formulation can be represented as follows and the detailed explanations are provided afterwards.

$$\max_{x} \quad \sum_{h\in\mathcal{H}^m} \left(p_h^m - c_h^m\right) y_h - \sum_{r\in\mathcal{R}_m} c_r x_r + \sum_{\forall od\in\mathcal{P}} \left(f_{od} - \hat{f}_{od}\right) w_{od} - \sum_{\forall od\in\mathcal{P}} P^u \sigma_{od} \tag{1a}$$

$$s.t. \quad x \in \{0,1\}^{|\mathcal{R}|},\ x_r = 1, \forall r \in \mathcal{R}_w \cup \mathcal{R}_0, \tag{1b}$$

$$\min_{y,w,\sigma} \sum_{\forall od\in\mathcal{P}} \left\{ (f_{od} + Vt_{od}) w_{od} + \sum_{h\in\mathcal{H}_{od}^m} \left(p_h^m + Vt_h\right) y_h + \sum_{h\in\mathcal{H}_{od}^w} \left(p_h^w + Vt_h\right) y_h + P^d \sigma_{od} \right\} \tag{1c}$$

$$s.t. \sum_{h\in\mathcal{H}} \delta_i^h y_h \leq Q^{r_i} x_{r_i},\ \forall i \in \mathcal{L}, \tag{1d}$$

$$\sigma_{od} + w_{od} + \sum_{h\in\mathcal{H}_{od}} y_h = q^{od},\ \forall od \in \mathcal{P}, \tag{1e}$$

$$\sum_{\forall od\in\mathcal{P}} w_{od} \leq k_{od} \sum_{\forall od\in\mathcal{P}} q^{od}, \tag{1f}$$

$$y_h \geq 0,\ \forall h \in \mathcal{H}, \tag{1g}$$

$$w_{od} \geq 0,\ \forall od \in \mathcal{P}, \tag{1h}$$

$$\sigma_{od} \geq 0,\ \forall od \in \mathcal{P}. \tag{1i}$$

The above formulation is a bi-level programming model because a minimization model is added as a constraint of the outer maximization model, as the maximization problem is called upper level problem and the minimization problem is called lower level problem. Note here that since we consider containerized cargoes, we generally choose P^u and P^d as very large numbers so that the amount of cargoes shipped by the shipper can be as large as possible. Also, we can easily observe that when P^u and P^d are large enough, the solution of y_h will not increase any more, which indicates that it is easy to choose the values of P^u and P^d. In the following, we explain the above formulation in detail.

Upper level model

In the upper level model, the objective function (1a) is to maximize the total profit that the liner shipping company obtains. The meaning of each term in (1a) is described as follows:

- $\sum_{h\in\mathcal{H}^m}(p_h^m - c_h^m)y_h$: the total revenue obtained from shipping cargoes using the paths in $\mathcal{H}^m$;

- $\sum_{r\in\mathcal{R}_m} c_r x_r$: the total cost for operating a certain number of shipping routes that are chosen from set $\mathcal{R}_m$ to be in operation;

- $\sum_{\forall od\in\mathcal{P}}(f_{od} - \hat{f}_{od})w_{od}$: the total revenue that the liner shipping company obtains through assigning part of the cargoes (i.e., w_{od}) to its partner liner, where $f_{od} - \hat{f}_{od}$ indicates the unit price that the liner shipping company obtains for each $od \in \mathcal{P}$;

- $\sum_{\forall od\in\mathcal{P}} P^u \sigma_{od}$: the total penalty cost induced by the amount of cargoes (i.e., σ_{od}) that are not delivered for all $od \in \mathcal{P}$.

Thus, basically (1a) indicates the total revenue minus the total cost.

For the constraints, we have one basic constraint (1b) showing that all the railway routes in set $\mathcal{R}_w \cup \mathcal{R}_0$ have to be chosen to be in the network since they are already in operation. For each shipping route $r \in \mathcal{R}_m$, the corresponding decision x_r runs freely in $\{0, 1\}$ and will be chosen to be in the final network as long as it is cost-effective. For the upper level model, we also need constraints to describe the relationship among y, w, and σ. This relationship is described through solving a lower level model as follows.

Lower level model

In the lower level model, the objective function (1c) is to minimize the total cost of the shipper when a certain number of shipping routes have been chosen to be in the network by the upper level decision maker (i.e., the liner shipping company). The meaning of each term in (1c) is described as follows:

- $\sum_{\forall od\in\mathcal{P}}(f_{od} + Vt_{od})w_{od}$: the total cost for delivering a part of cargoes (i.e., w_{od}) that the liner shipping company assigns to its partner liner.

- $\sum_{\forall od\in\mathcal{P}} \sum_{h\in\mathcal{H}^m_{od}}(p^m_h + Vt_h)y_h$: the total cost for delivering the cargoes by using the paths in $\cup_{\forall od\in\mathcal{P}}\mathcal{H}^m_{od}$, i.e., $\mathcal{H}^m$.

- $\sum_{\forall od\in\mathcal{P}} \sum_{h\in\mathcal{H}^w_{od}}(p^w_h + Vt_h)y_h$: the total cost for delivering the cargoes by using the paths in $\cup_{\forall od\in\mathcal{P}}\mathcal{H}^w_{od}$, i.e., $\mathcal{H}^w$.

- $\sum_{\forall od\in\mathcal{P}} P^d \sigma_{od}$: the total penalty cost induced by the amount of cargoes (i.e., σ_{od}) that are not delivered for all $od \in \mathcal{P}$.

For constraints that the shipper should respect, i.e., (1d) - (1i), we describe them in detail as follows:

- constraints (1d) indicate that the amount of cargoes delivered by one path cannot be larger than the capacity of any legs in this path, as the capacity of one leg is the capacity of the route to which this leg belongs;
- constraints (1e) describe the demand balance, indicating that for each $od \in \mathcal{P}$, the corresponding demand q^{od} should be satisfied either by some paths (i.e., $\sum_{h\in\mathcal{H}_{od}} y_h$) or by the partner liner (i.e., w_{od}) or by dropping out (i.e., σ_{od}) that leads to penalty;
- constraint (1f) indicates that only a part (i.e., at most k_{od}) of the demand can be shipped by the partner liner of the shipping company;
- constraints (1g) - (1i) describe the nonnegativeness of decision variables y, w, and σ.

In summary, we formulate our problem to be a bi-level mixed-integer program, which is very difficult to solve in general, and we show how we can solve it in the next section.

4 Reformulation and solution approach

In this section, to tackle the difficulty of solving a bi-level mixed-integer program, we reformulate our proposed bi-level programming formulation (1) to be a single-level mixed-integer linear programming (MILP) formulation, which can be solved directly by calling the commercial solvers like CPLEX. Basically we describe our solution approach in three steps as follows, i.e., using the KKT conditions to replace the lower level problem in the first step, reformulating the complementary slackness constraints in the second step, and strengthening the formulation in the third step.

Step 1: KKT conditions

Note that with given x, the lower level problem (i.e., (1c) - (1i)) is a linear programming formulation. Thus, we can replace it with its KKT conditions [6, 2]. Thus, we describe the KKT conditions of the lower level problem with the type of each constraint (i.e., primal feasibility constraints, dual feasibility constraints, complementary slackness constraints, and stationarity constraints) indicated in the left side as follows.

$$\text{(primal feasibility)} \qquad \sum_{h\in\mathcal{H}} \delta_i^h y_h - Q^{r_i} x_{r_i} \le 0,\ \forall i \in \mathcal{L}, \quad (\lambda_i) \tag{2}$$

$$\text{(primal feasibility)} \qquad \sigma_{od} + w_{od} + \sum_{h\in\mathcal{H}_{od}} y_h - q^{od} = 0,\ \forall od \in \mathcal{P}, \quad (\mu_{od}) \tag{3}$$

$$\text{(primal feasibility)} \qquad \sum_{\forall od\in\mathcal{P}} w_{od} - k_{od} \sum_{\forall od\in\mathcal{P}} q^{od} \le 0, \quad (\beta) \tag{4}$$

$$\text{(primal feasibility)} \qquad -y_h \leq 0,\ \forall h \in \mathcal{H}, \quad (\theta_h) \tag{5}$$

$$\text{(primal feasibility)} \qquad -w_{od} \leq 0,\ \forall od \in \mathcal{P}, \quad (\gamma_{od}) \tag{6}$$

$$\text{(primal feasibility)} \qquad -\sigma_{od} \leq 0,\ \forall od \in \mathcal{P}, \quad (\phi_{od}) \tag{7}$$

$$\text{(dual feasibility)} \qquad \lambda_i \geq 0,\ \forall i \in \mathcal{L}, \tag{8}$$

$$\text{(dual feasibility)} \qquad \beta \geq 0, \tag{9}$$

$$\text{(dual feasibility)} \qquad \theta_h \geq 0,\ \forall h \in \mathcal{H}, \tag{10}$$

$$\text{(dual feasibility)} \qquad \gamma_{od} \geq 0,\ \forall od \in \mathcal{P}, \tag{11}$$

$$\text{(dual feasibility)} \qquad \phi_{od} \geq 0,\ \forall od \in \mathcal{P}, \tag{12}$$

$$\text{(complementary slackness)} \qquad \lambda_i \Big(\sum_{\forall od \in \mathcal{P}} \sum_{h \in \mathcal{H}_{od}} \delta_i^h y_h - Q^{r_i} x_{r_i} \Big) = 0,\ \forall i \in \mathcal{L}, \quad (z_i) \tag{13}$$

$$\text{(complementary slackness)} \qquad \beta \Big(\sum_{\forall od \in \mathcal{P}} w_{od} - k_{od} \sum_{\forall od \in \mathcal{P}} q^{od} \Big) = 0, \quad (\delta) \tag{14}$$

$$\text{(complementary slackness)} \qquad \theta_h y_h = 0,\ \forall h \in \mathcal{H}, \quad (u_h) \tag{15}$$

$$\text{(complementary slackness)} \qquad \gamma_{od} w_{od} = 0,\ \forall od \in \mathcal{P}, \quad (v_{od}) \tag{16}$$

$$\text{(complementary slackness)} \qquad \sigma_{od} \phi_{od} = 0,\ \forall od \in \mathcal{P}, \quad (\kappa_{od}) \tag{17}$$

$$\text{(stationarity)} \qquad 0 = p_h^m + V t_h + \sum_{i \in \mathcal{L}} \lambda_i \delta_i^h + \mu_{od} - \theta_h,\ \forall od \in \mathcal{P}, h \in \mathcal{H}_{od}^m, \tag{18}$$

$$\text{(stationarity)} \qquad 0 = p_h^w + V t_h + \sum_{i \in \mathcal{L}} \lambda_i \delta_i^h + \mu_{od} - \theta_h,\ \forall od \in \mathcal{P}, h \in \mathcal{H}_{od}^w, \tag{19}$$

$$\text{(stationarity)} \qquad 0 = f_{od} + V t_{od} + \mu_{od} + \beta - \gamma_{od},\ \forall od \in \mathcal{P}, \tag{20}$$

$$\text{(stationarity)} \qquad 0 = P^d + \mu_{od} - \phi_{od},\ \forall od \in \mathcal{P}, \tag{21}$$

where we use $\lambda, \mu, \beta, \theta, \gamma$ and ϕ in the brackets of the right hand side of constraints (2) - (7) to represent their corresponding dual variables. Thus, by replacing the lower level problem (i.e., (1c) - (1i)) with constraints (2) - (21), we transform the original bi-level optimization problem (1) to an equivalent single-level maximization problem

$$\max\{(1a) : (1b), (2) - (21)\}. \tag{22}$$

Step 2: reformulating complementary slackness constraints

We can observe that complementary slackness constraints (13) - (17) are bilinear, which are not easily tractable. In order to further reformulate the mixed-integer bilinear program (22) to an MILP problem, we linearize constraints (13) - (17). To linearize them, we define binary variable z_i for each $i \in \mathcal{L}$, binary variable δ, binary variable u_h for each $h \in \mathcal{H}$, and binary variables v_{od}

and κ_{od} for each $od \in \mathcal{P}$, all of which are indicated in the right hand side of constraints (13) - (17). Then we replace constraints (13) - (17) with the following equivalent linear constraints to remove the bilinear terms.

$$\lambda_i \leq M(1 - z_i), \ \forall i \in \mathcal{L}, \tag{23}$$

$$-Mz_i \leq \left(\sum_{\forall od \in \mathcal{P}} \sum_{h \in \mathcal{H}_{od}} \delta_i^h y_h - Q^{r_i} x_{r_i} \right), \ \forall i \in \mathcal{L}, \tag{24}$$

$$\beta \leq M(1 - \delta), \tag{25}$$

$$-M\delta \leq \left(\sum_{\forall od \in \mathcal{P}} w_{od} - k_{od} \sum_{\forall od \in \mathcal{P}} q^{od} \right), \tag{26}$$

$$\theta_h \leq M(1 - u_h), \ \forall h \in \mathcal{H}, \tag{27}$$

$$y_h \leq M u_h, \ \forall h \in \mathcal{H}, \tag{28}$$

$$\gamma_{od} \leq M(1 - v_{od}), \ \forall od \in \mathcal{P}, \tag{29}$$

$$w_{od} \leq M v_{od}, \ \forall od \in \mathcal{P}, \tag{30}$$

$$\phi_{od} \leq M(1 - \kappa_{od}), \ \forall od \in \mathcal{P}, \tag{31}$$

$$\sigma_{od} \leq M \kappa_{od}, \ \forall od \in \mathcal{P}, \tag{32}$$

where M is an arbitrarily large positive number. To show the equivalence between constraints (13) - (17) and constraints (23) - (32), we take an example to show the equivalence between (13) and (23) - (24). For (13), for each $i \in \mathcal{L}$, at least one of λ_i and $(\sum_{\forall od \in \mathcal{P}} \sum_{h \in \mathcal{H}_{od}} \delta_i^h y_h - Q^{r_i} x_{r_i})$ will be zero. Thus, we can use binary variable z_i to indicate which one to be zero. For instance, in (23) - (24), if $z_i = 0$, then λ_i has to be zero due to (23) and $(\sum_{\forall od \in \mathcal{P}} \sum_{h \in \mathcal{H}_{od}} \delta_i^h y_h - Q^{r_i} x_{r_i})$ will be free due to (24); if $z_i = 1$, $(\sum_{\forall od \in \mathcal{P}} \sum_{h \in \mathcal{H}_{od}} \delta_i^h y_h - Q^{r_i} x_{r_i})$ has to be zero due to (24) and λ_i will be free due to (23). Thus, constraints (23) - (24) equivalently show the meaning of constraints (13). Similar demonstration can be made between constraints (15) - (17) and constraints (27) - (32) and is omitted here. Therefore, problem (1) can be further reformulated into an MILP model

$$\max\{(1a) : (1b), (2) - (12), (18) - (21), (23) - (32)\}. \tag{33}$$

Step 3: strengthening the formulation

To improve the computational performance of solving (33), we strengthen some constraints in (23) - (32). In particular, we replace each big M in constraints (24), (26), (28), (30), and (32) with a smaller number instead of using an arbitrarily large number, respectively. For instance, for constraints (24), we can observe that $(\sum_{\forall od \in \mathcal{P}} \sum_{h \in \mathcal{H}_{od}} \delta_i^h y_h - Q^{r_i} x_{r_i})$ is always greater than $-Q^{r_i}$, so we can replace the big M in (24) with Q^{r_i} so that we can get a tighter constraint (34) as follows. Similar analysis can be provided to strengthen (26), (28), (30), and (32) into constraints (35)-(38).

$$-Q^{r_i} z_i \leq \left(\sum_{\forall od \in \mathcal{P}} \sum_{h \in \mathcal{H}_{od}} \delta_i^h y_h - Q^{r_i} x_{r_i} \right), \ \forall i \in \mathcal{L}, \tag{34}$$

$$-\left(k_{od} \sum_{\forall od \in \mathcal{P}} q^{od} \right) \delta \leq \left(\sum_{\forall od \in \mathcal{P}} w_{od} - k_{od} \sum_{\forall od \in \mathcal{P}} q^{od} \right), \tag{35}$$

$$y_h \leq \min \left\{ Q^{r_i}, \forall i \in \mathcal{L}_h \right\} u_h, \ \forall h \in \mathcal{H}, \tag{36}$$

$$w_{od} \leq \min \left\{ q^{od}, \left(k_{od} \sum_{\forall od \in \mathcal{P}} q^{od} \right) \right\} v_{od}, \ \forall od \in \mathcal{P}, \tag{37}$$

$$\sigma_{od} \leq q^{od} \kappa_{od}, \ \forall od \in \mathcal{P}. \tag{38}$$

In summary, through the above three steps, our proposed bi-level programming model (1) can be finally reformulated as an MILP formulation as follows.

$$\max_{\substack{x,y,w,\sigma,\lambda,\beta,\theta,\\ \mu,\gamma,\phi,z,\delta,u,v,\kappa}} \sum_{h \in \mathcal{H}^m} \left(p_h^m - c_h^m \right) y_h - \sum_{r \in \mathcal{R}_m} c_r x_r + \sum_{\forall od \in \mathcal{P}} (f_{od} - \hat{f}_{od}) w_{od} - \sum_{\forall od \in \mathcal{P}} P^u \sigma_{od} \tag{39a}$$

$$s.t. \quad x, z, \delta, u, v, \kappa \in \{0, 1\}, \tag{39b}$$

$$(1b), (2) - (12), (18) - (21), (23), (25), (27), (29), (31), (34) - (38).$$

The final reformulation above enables us to solve it exactly and directly through calling commercial optimization solvers without developing any complicated algorithms such as heuristics. Note that it is exactly what the industrial practitioners desire to have since they prefer to solve the problem directly without investing too much on algorithms. Meanwhile, the advanced development of commercial optimization solvers provides the cost-effective opportunities to implement this model and solve their problems. In addition, the clean model (39) also provides us a convenient way to perform extensive scenario analysis, which is provided in the following section.

5 Data description and scenario analysis

In this section, we perform the computational experiments by using the realistic data from COSCO as input of model (39) and analyzing different scenarios for insightful findings. In particular, we first describe the data structure obtained from industrial practices in Subsection 5.1 and then introduce the case study results under different scenarios in Subsection 5.2. To solve model (39), we adopt CPLEX 12.5 as our commercial optimization solver and run all the instances at a personal computer with Intel Dual Core processors and 8G memory.

5.1 Data description

Most of the data used for our case studies are collected from available sources in COSCO or through survey with its line managers. Meanwhile, for a few data that are not available in COSCO, we obtain them through simulation based on known facts.

First, we describe the shipping route data. From the official website of COSCO[4], we obtain the detailed data of COSCO's current liner shipping network for Asia-Europe service as shown in Table 1, including available routes, the ship sizes, and shipping time for each individual legs and the whole route. In addition, due to the OBOR initiative leading to more focus on hub ports (e.g., Piraeus) and two railway systems mentioned in Section 1, we propose 19 new routes with help from two COSCO's line managers[5] so that the liner shipping company (i.e., COSCO) has more reasonable choices and the new routes can be added into the new network design after the optimization, which arguably increases the total profit for COSCO. Meanwhile, the involvement of COSCO in both the Piraeus's significant development and those two railway systems' progress strongly support the addition of these 19 new routes. Therefore, the new routes are basically generated based upon the current routes but incorporate the impacts from hub ports and railway systems, e.g., we replace one of the hub port of a current route with Piraeus to obtain a new route. Table 2 shows the new routes we propose.

Next, we describe the rail service data. We include into our model the currently existing ten rail service lines provided from China to East Europe. Note here that as mentioned in Section 1, there are eleven transcontinental rail service lines from China to East Europe now, but we notice that one of them goes through the Eurasian land bridge instead of the New Eurasian Land Bridge. Thus, this one is excluded from our model. For the capacity of each rail service line here, we assume it to be 100 TEU (i.e., Twenty-foot Equivalent Unit) per week for each line by considering the currently irregular frequency (e.g., once weekly or bi-weekly) of most of the rail service lines. In addition, we consider five ports called in COSCO's current liner shipping services (i.e., Antwerp, Rotterdam, Hamburg, Le Havre and Piraeus) as COSCO's hub ports for providing rail services from these hub ports to East Europe.

Finally, we describe the data for the remaining parameters. The loading and discharging costs of each port are collected from COSCO's line managers and the website of each studied port. The fixed cost of each route is calculated according to [23]. Moreover, the freight rate corresponding to

[4] http://www.coscon.com/ourservice/toService.do

[5] Their identities are hidden due to commercial confidentiality.

Table 1: Current shipping services of COSCO on Asia-Europe Service

No.	Ship Type	Ports of call
1	14000TEU	Hong Kong → Nansha → Kaohsiung → Yantian → HoChiMinh → Singapore → Rotterdam → Felixstowe → Hamburg → Antwerp
2	13000TEU	Xingang → Dalian → Qingdao → Shanghai → Ningbo → Singapore → Rotterdam → Hamburg → Antwerp
3	14000TEU	Kaohsiung → Shanghai → Ningbo → Taipei → Yantian → Tanjung Pelepas → Rotterdam → Felixstowe → Hamburg
4	13000TEU	Busan → Shanghai → Yantian → Singapore → Algeciras → Hamburg → Rotterdam
5	13000TEU	Xiamen → Ningbo → Shanghai → Shekou → Colombo → Piraeus → Felixstowe → Hamburg → Rotterdam → Antwerp
6	19000TEU	Qingdao → Shanghai → Ningbo → Xiamen → Yantian → Port Kelang → Felixstowe → Rotterdam → Hamburg
7	17700TEU	Tianjin → Dalian → Busan → Qingdao → Shanghai → Ningbo → Yantian → Port Kelang → Algeciras → Southampton → Dunkirk → Hamburg → Rotterdam → Le Havre
8	14000TEU	Shanghai → Ningbo → Yantian → HoChiMinh → Port Kelang → Le Havre → Rotterdam → Antwerp → Hamburg → Felixstowe

each O-D pair is obtained mainly from COSCO resources and partially from public data online at www.shippingcity.com and www.shippingchina.com. The demand corresponding to each O-D pair is calculated based on total shipping capacity of COSCO, its loading factor, and times of call on each port. Furthermore, with respect to the industrial practices, in our model we let $k_{od} = 5\%$ and $\hat{f}_{od} = 90\% f_{od}$ for each O-D pair $od \in \mathcal{P}$.

5.2 Scenario analysis and discussion

To understand different impacts on the shipping network from the improvement of the rail connecting Piraeus and East Europe hinterland (EEU rail) and the Eurasian Land Bridge rail (Eurasian rail), in this study we propose to analyze two separated scenarios with each one considering different levels of trade volumes. In particular, scenario one considers the same level (i.e., 100%) of trade volume as current practices and scenario two considers 120% of current trade volume in order to capture the effect from trade volume increase under the OBOR initiative. Furthermore, for each scenario with fixed trade volume, we further generate four cases under this scenario based on other variations of the input data as follows.

- Case 1: Current status;
- Case 2: EEU rail is improved;

Table 2: Proposed shipping services of COSCO on Asia-Europe Service

No.	Ship Type	Ports of call
9	14000TEU	Hong Kong → Nansha → Kaohsiung → Yantian → HoChiMinh → Singapore → Piraeus → Felixstowe → Hamburg
10	14000TEU	Hong Kong → Nansha → Kaohsiung → Yantian → HoChiMinh → Singapore → Piraeus → Felixstowe → Antwerp
11	14000TEU	Hong Kong → Nansha → Kaohsiung → Yantian → HoChiMinh → Singapore → Piraeus → Felixstowe → Hamburg → Antwerp
12	13000TEU	Xingang → Dalian → Qingdao → Shanghai → Ningbo → Singapore → Piraeus → Hamburg → Antwerp
13	13000TEU	Xingang → Dalian → Qingdao → Shanghai → Ningbo → Singapore → Piraeus → Rotterdam → Antwerp
14	14000TEU	Kaohsiung → Shanghai → Ningbo → Taipei → Yantian → Tanjung Pelepas → Piraeus → Felixstowe → Hamburg
15	14000TEU	Kaohsiung → Shanghai → Ningbo → Taipei → Yantian → Tanjung Pelepas → Piraeus → Rotterdam → Felixstowe
16	14000TEU	Kaohsiung → Shanghai → Ningbo → Taipei → Yantian → Tanjung Pelepas → Piraeus → Rotterdam → Hamburg
17	13000TEU	Busan → Shanghai → Yantian → Singapore → Piraeus → Algeciras → Hamburg
18	13000TEU	Busan → Shanghai → Yantian → Singapore → Piraeus → Algeciras → Rotterdam
19	13000TEU	Xiamen → Ningbo → Shanghai → Shekou → Colombo → Piraeus → Felixstowe → Rotterdam → Antwerp
20	13000TEU	Xiamen → Ningbo → Shanghai → Shekou → Colombo → Piraeus → Felixstowe → Hamburg → Antwerp
21	19000TEU	Qingdao → Shanghai → Ningbo → Xiamen → Yantian → Port Kelang → Piraeus → Felixstowe → Rotterdam
22	19000TEU	Qingdao → Shanghai → Ningbo → Xiamen → Yantian → Port Kelang → Piraeus → Felixstowe → Hamburg
23	17700TEU	Tianjin → Dalian → Busan → Qingdao → Shanghai → Ningbo → Yantian → PortKelang → Piraeus → Algeciras → Southampton → Dunkirk → Rotterdam
24	17700TEU	Tianjin → Dalian → Busan → Qingdao → Shanghai → Ningbo → Yantian → Port Kelang → Piraeus → Algeciras → Southampton → Dunkirk → Hamburg
25	14000TEU	Shanghai → Ningbo → Yantian → HoChiMinh → Port Kelang → Piraeus → Le Havre → Antwerp → Hamburg → Felixstowe
26	14000TEU	Shanghai → Ningbo → Yantian → HoChiMinh → Port Kelang → Piraeus → Le Havre → Rotterdam → Hamburg → Felixstowe
27	14000TEU	Shanghai → Ningbo → Yantian → HoChiMinh → Port Kelang → Piraeus → Le Havre → Rotterdam → Antwerp → Felixstowe

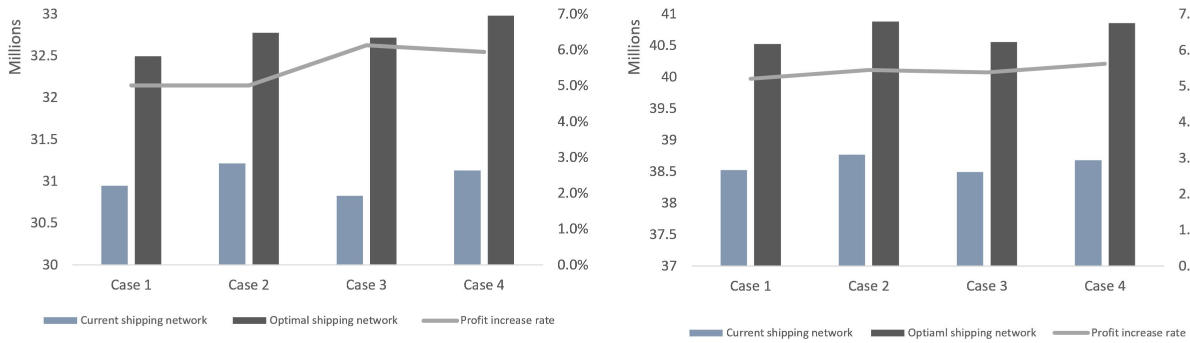
- Case 3: Eurasian rail is improved;
- Case 4: Both EEU rail and Eurasian rail are improved.

The first case applies the original collected data without further variations. Recently, COSCO and Greek railway operator, Trainose, aim to integrate the port and rail operations and provide quick and seamless shipping to the hubs in Hungary and Czech Republic. This makes the EEU rail a more viable route. Meanwhile, with significant development of the Piraeus port and the corresponding rail infrastructure connecting Piraeus and East Europe, EEU rail will have a sufficient capacity (higher than current level) to service the entire market in the Middle and East Europe[6]. Thus, in the second case, we assume that the capacity of the EEU rail (i.e., Piraeus-East Europe) increases from its current level (i.e., 100 TEU per week) to 800 TEU per week, which is a level of the hub ports on West Europe-East Europe rail line. Meanwhile, we also assume the corresponding rail cost is reduced by half (the EEU rail cost is currently very high since there is no regular rail service provided currently). In addition, with more China-Europe rail services being provided, in the third case, we assume that the weekly transportation capacity of Eurasian rail increases from 100 TEU to 500 TEU and its cost is reduced by around 16% from US$6000 per TEU to US$5000 per TEU. The fourth case combines the variations in both Cases 2 and 3. That is, both the EEU rail and Eurasian rail are improved in Case 4.

Now for each case of the two studied scenarios (i.e., scenario one with 100% trade volume and scenario two with 120% trade volume), we compare the current shipping network with the new shipping network provided by our optimization model (39) with the shipping services in both Tables 1 and 2 as input. We first report the results in Figure 3, which compares the profits from the new shipping network under different cases with the current shipping network. We can observe that the new network provided by our model leads to much higher profit for every case under both scenarios considered. Particularly, the profit of the new shipping network increases by approximately 5% to 6% on average, as compared to the current one.

In particular, we found that, under the scenario of current shipping network, the profits of Cases 2, 3, and 4 have no significant increase as compared to that of Case 1. The profit of Case 3 is even less than that of Case 1. It indicates that under the current shipping network, COSCO rarely benefits from the development of EEU rail and Eurasian rail and the development of Eurasian rail even brings negative impact to COSCO under certain circumstance. In contrast, the profits of

[6] https://www.europeanrailwayreview.com/29672/railway-extra/port-piraeus-railways-south-east-europe/



(a) Scenario One (100% trade volume) (b) Scenario Two (120% trade volume)

Figure 3: Comparison of profits between the new shipping network and current shipping network

Cases 2, 3, and 4 all become larger than that of Case 1 under the new shipping network. This implies that the new shipping network can take advantage of improvement of both EEU rail and Eurasian rail.

Next, in Table 3 we further report the results on several key indicators of the new shipping network with the current one. It is found, in both scenarios, only two or three routes out of eight in the current shipping network are kept in the new shipping network. For example, under scenario one, only routes of No. 1 and No. 7 in the current shipping network are included in the new shipping network in Case 1. On the other hand, there are more routes calling at port of Piraeus in the new shipping network. For example, as Table 4 illustrates, the port of Piraeus is called five times in the new shipping network rather than two times in the current shipping network under the Case 1 of Scenario one. In contrast, the number of port calls of the traditional hub ports in Western Europe like Rotterdam and Hamburg has been reduced from 8 to 5 and 4 times, respectively. This implies that Piraeus has the potential to be developed into a hub port for COSCO, which not only covers South Europe and Mediterranean region but also East Europe region, the usual hinterland of West Europe hub port. This can be evidenced by the fact that the EEU rail cargo volume increases to the upper limit of its capacity in all cases except for Case 3 (Eurasian rail development case) in the new shipping network, as shown in Table 3. The reason that in Case 3 the EEU rail has free capacity is that the improved Eurasian rail grabs the market share.

In addition, Table 3 shows that the loading factor (the column labeled "Loading Factor") of key legs[7] [26] and the weighted average usage[8] (the column labeled "Weighted Avg. Usage") are about

[7]The key leg of a long-haul liner service is the leg which the highest number of containers is carried. For instance, the leg after the last port of call in Asia in the head-haul leg for Asia-Europe service.

[8]For each leg in the network, it will be used by some paths and delivering a certain amount of cargoes. Thus, for

Table 3: Comparison of results between the new shipping network and current shipping network

Scenario one (100% trade volume)						
Current Network	**Selected Routes**	**Loading Factor**	**Weighted Avg. Usage**	**Transported Volume**	**Transported by Own**	**Chartering Ratio**
Case 1	1,2,3,4,5,7,8	100%	76%	102959	98900	3.94%
Case 2	1,2,3,4,5,7,8	100%	77%	102959	98924	3.92%
Case 3	1,2,3,4,5,7,8	100%	76%	102959	99724	3.14%
Case 4	1,2,3,4,5,7,8	100%	76%	102959	99700	3.17%
New Network	**Selected Routes**	**Loading Factor**	**Weighted Avg. Usage**	**Transported Volume**	**Transported by Own**	**Chartering Ratio**
Case 1	1,7,12,15,17,19,22	96%	77%	104968	100085	4.65%
Case 2	1,7,12,15,17,19,22	96%	77%	104968	100593	4.17%
Case 3	1,5,8,13,15,17,24	100%	78%	104968	99724	5.00%
Case 4	1,5,8,13,15,17,24	100%	75%	104968	99772	4.95%
Scenario two (120% trade volume)						
Current Network	**Selected Routes**	**Loading Factor**	**Weighted Avg. Usage**	**Transported Volume**	**Transported by Own**	**Chartering Ratio**
Case 1	1,2,3,4,5,6,7,8	100%	76%	123551	117972	4.51%
Case 2	1,2,3,4,5,6,7,8	100%	76%	123551	118001	4.49%
Case 3	1,2,3,4,5,6,7,8	100%	77%	123551	118801	3.84%
Case 4	1,2,3,4,5,6,7,8	100%	76%	123551	118902	3.76%
New Network	**Selected Routes**	**Loading Factor**	**Weighted Avg. Usage**	**Transported Volume**	**Transported by Own**	**Chartering Ratio**
Case 1	1,3,7,12,17,19,22,24	98%	76%	125962	119664	5.00%
Case 2	1,3,7,12,17,19,22,24	99%	77%	125962	120342	4.46%
Case 3	1,7,9,12,15,17,19,22	100%	78%	125962	119592	5.00%
Case 4	1,7,9,12,15,17,19,22	100%	79%	125962	119592	5.00%

Table 4: Comparison of ports' ship calls between two shipping networks

Ports		ROT	HAM	FEL	ANT	PIR	ALG	LEH	ZEE	SOU	DKK
Number of ship call	Current	8	8	5	4	2	2	1	1	1	1
	New	5	4	4	3	5	2	1	1	1	1

Remark: ROT:Rotterdam; HAM: Hamburg; FEL: Felixstowe; ANT: Antwerp; PIR: Piraeus; ALG: Algeciras; LEH: Le Havre; ZEE: Zeebrugge; SOU: Southampton; DKK: Dunkirk

96%-100% and 74%-78% respectively, which are consistent with the actual data. The differences of the two indicators between the two networks in both scenarios are minor, which suggests that the

each route including a set of legs, we define the weighted average usage of this route as the weighted average cargo amounts delivered by all the legs in this route over the time length of each leg.

new shipping network does not improve the ship utilization significantly. It is worth noting that the total transported volume (the column labeled "Transported Volume") and own transported volume (the column labeled "Transported by Own") in the new network both increase and this means transport capacity of the new network is distributed more reasonably across the O-D pairs thus more demand is met. Also, from Table 4, it is found that the port call is more evenly distributed among the ports which contribute to the increase. In addition, the chartering ratio, which indicates the slots chartered from partner liners in the same alliance increase approximately from 3% in the current shipping network to 4% in the new shipping network. The two factors contribute to the profit growth of the new shipping networks.

Finally, we report the comparison results of several key indicators of the rail usage under the new and current shipping networks. As shown in Table 5, for Case 1 in both scenarios, cargo volume of EEU only reaches its capacity in the new shipping network, which indicates that the EEU rail can be better utilized in the new shipping network under current status. What is more, in Case 1, the Eurasian rail usage increases from 20% in the current shipping network to 25% in the new shipping network under scenario one and from 27% in the current shipping network to 31% in the new shipping network under scenario two. This suggests that the new shipping network can also benefit the usage of the Eurasian rail although the usage rate is still relatively low. When the EEU rail is improved (Case 2), under both scenarios, the cargo volume of EEU rail will reach its capacity for both the current and new shipping networks while the cargo volume of Eurasian rail is almost unchanged. In comparison, cargo volume and the rail usage rate of the EEU rail in both shipping network are zero when the Eurasian rail is improved (Case 3). The cargo volume of Eurasian rail is unchanged when the trade is under the current level (Scenario one). It increases from 22% to 38% when the total trade volume increases by 20% from the current level (Scenario two). For Case 4, i.e., both the EEU rail and Eurasian rail are improved, the EEU rail are fully utilized under both scenarios, the cargo volume of Eurasian rail still only displays a modest increase when the total trade increase by 20%. These findings can provide some implications regarding the development of EEU rail and Eurasian rail. The development of EEU rail can lead to an immediate increase of its cargo volume while the cargo volume of the Eurasian rail barely increases despite its capacity development. This is because the price of Eurasian rail is still too high to be broadly accepted by the shippers [29]. It also reveals a plausible inverse relationship between the development of EEU rail and Eurasian rail, that is, if only the Eurasian rail is improved, there is no cargo being carried through the EEU rail while the sole development of EEU rail reduces the percentage of Eurasian rail usage.

Table 5: Comparison of indicators of rail usage

Scenario One (100% trade vol.)	**EEU rail cargo volume**		**EEU rail usage**		**Eurasian rail cargo volume**		**Eurasian rail rail usage**	
	Current	**New**	**Current**	**New**	**Current**	**New**	**Current**	**New**
Case 1	0	100	0%	100%	200	248	20%	25%
Case 2	800	800	100%	100%	224	248	22%	25%
Case 3	0	0	0%	0%	1024	1024	20%	20%
Case 4	800	800	100%	100%	1000	1072	20%	21%
Scenario Two (120% trade vol.)	**EEU rail cargo volume**		**EEU rail usage**		**Eurasian rail cargo volume**		**Eurasian rail rail usage**	
	Current	**New**	**Current**	**New**	**Current**	**New**	**Current**	**New**
Case 1	0	100	0%	100%	272	309	27%	31%
Case 2	800	800	100%	100%	301	287	30%	29%
Case 3	0	0	0%	0%	1101	1892	22%	38%
Case 4	800	800	100%	100%	1202	1892	24%	38%

6 Discussion and conclusion

As important parts of the OBOR initiative, the rail starting from China to Europe along New Eurasia Land Bridge has achieved fast development in the past two years. Meanwhile, COSCO successfully signed a concession agreement with the Piraeus Port Authority in 2016, which aims to transform this port into an important hub of Europe. This significant attempt is further supported by the investment from Chinese Government on the construction of a railway connecting Budapest and Piraeus via Skopje and Belgrade, which is expected to be completed in 2018. Against this background, this paper aims to explore the coping strategy for Chinese liner shipping company, taking into consideration of the impact of OBOR initiative, in particular, the rail development in East Europe and New Eurasian land bridge. A bi-level optimization model is established to realize this objective with real data collected from COSCO, the giant Chinese shipping line. In the upper level of the model, the liner carrier's profit is maximized, while the lower level minimizes the cost for the shipper. Two scenarios applying the current trade volume and 120% of the volume are proposed. For each scenario, four cases based on other variations of the input data are tested, which are the original case, East Europe rail improvement case, Eurasian land bridge rail improvement case, and both improvements case.

Our calculation reveals some interesting findings. First, we found the new shipping network could help COSCO to increase its profit by 5% to 6%. The new shipping network does not improve the ship utilization but can meet more O-D demand. Second, Piraeus port has the potential to be developed into a hub port which not only covers South Europe and Mediterranean region but also East Europe hinterland. Third, the improvement of East Europe rail and the Eurasian land bridge rail will bring significant benefit to the COSCO especially when COSCO keeps increasing its port calls to Piraeus. Fourth, the increased capacity and reduction of freight rate of East Europe rail will achieve an immediate increase of the cargo volume, in the meanwhile, the capacity usage rate in the new shipping network will also increase. By contrast, although the development of the Eurasian land bridge rail will improve its cargo volume, the increase is marginal and its usage rate will remain at a very low percentage, which can be explained by the high transport freight rate of the Eurasian land bridge rail. Fifth, there exists a plausible inverse relationship between EEU rail and land bridge rail. The development of Eurasian rail will bring a negative impact on EEU rail use and vice versa.

From the findings, we can reach some managerial insights. First, it is very necessary for COSCO to further develop the port of Piraeus by increasing its number of port calls and at the same time distributing the port calls more evenly among demand pairs. Second, the construction of Hungary-Serbia rail will benefit the current strategy of COSCO, namely, development of Piraeus. It offers a good opportunity to expand its influence in East Europe. COSCO should take advantage of this rail by guaranteeing reliable and regular rail service from Piraeus to East Europe hinterland. Third, although the Eurasian rail service attracts a lot of attention recently, it is noted that most of Eurasian rail cargo forwarders are now losing money and they survive on subsidies from government. Accompanying upgraded transport capacity and reduced freight rate, the transport cargo volume through the Eurasian Land Bridge rail will slightly increase. However, the usage rate of this route will still remain at a low percentage because the freight rate of the Eurasian land bridge rail is much higher than that of shipping. Thus, the central or local government should consider to support a few key routes; otherwise, all the rail service would likely remain unprofitable.

Due to limited data access, the authors recognize that there is still space to further study this topic. Potential directions include, but are not limited to the following topics. First, it is noted the chartering ratio increases approximately from 3% in the current shipping network to 4% in the new shipping network. This suggests that the COSCO should expand the collaboration with other shipping lines. With the launch of OCEAN shipping alliance including four giant shipping lines in the world (e.g., COSCO, Evergreen line, CMA CGA, and OOCL [Orient Overseas Container Line]) which own 34.86% of the market capacity on Asia-Europe trade lane, the collaboration scheme can be incorporated into the optimization model. Second, to explicitly understand the competition between liner carriers and the New Eurasia Land Bridge, a game theory model should be taken into consideration in the future study.

References

[1] R. Agarwal and Ö. Ergun. Ship scheduling and network design for cargo routing in liner shipping. *Transportation Science*, 42(2):175–196, 2008.

[2] S. Boyd and L. Vandenberghe. *Convex Optimization*. Cambridge University Press, 2004.

[3] B. D. Brouer, J. F. Alvarez, C. E. M. Plum, D. Pisinger, and M. M. Sigurd. A base integer programming model and benchmark suite for liner-shipping network design. *Transportation Science*, 48(2):281–312, 2013.

[4] B. D. Brouer, G. Desaulniers, and D. Pisinger. A matheuristic for the liner shipping network design problem. *Transportation Research Part E: Logistics and Transportation Review*, 72:42–59, 2014.

[5] M. Christiansen, K. Fagerholt, B. Nygreen, and D. Ronen. Ship routing and scheduling in the new millennium. *European Journal of Operational Research*, 228(3):467–483, 2013.

[6] J. Fortuny-Amat and B. McCarl. A representation and economic interpretation of a two-level programming problem. *Journal of the Operational Research Society*, 32(9):783–792, 1981.

[7] S. Gelareh, S. Nickel, and D. Pisinger. Liner shipping hub network design in a competitive environment. *Transportation Research Part E: Logistics and Transportation Review*, 46(6):991–1004, 2010.

[8] S. Gelareh and D. Pisinger. Fleet deployment, network design and hub location of liner shipping companies. *Transportation Research Part E: Logistics and Transportation Review*, 47(6):947–964, 2011.

[9] C. V. Karsten, D. Pisinger, S. Ropke, and B. D. Brouer. The time constrained multi-commodity network flow problem and its application to liner shipping network design. *Transportation Research Part E: Logistics and Transportation Review*, 76:122–138, 2015.

[10] C.-Y. Lee and D.-P. Song. Ocean container transport in global supply chains: Overview and research opportunities. *Transportation Research Part B: Methodological*, 95:442–474, 2017.

[11] Z. Liu, Q. Meng, S. Wang, and Z. Sun. Global intermodal liner shipping network design. *Transportation Research Part E: Logistics and Transportation Review*, 61:28–39, 2014.

[12] Q. Meng and S. Wang. Liner shipping service network design with empty container repositioning. *Transportation Research Part E: Logistics and Transportation Review*, 47(5):695–708, 2011.

[13] Q. Meng, S. Wang, H. Andersson, and K. Thun. Containership routing and scheduling in liner shipping: overview and future research directions. *Transportation Science*, 48(2):265–280, 2013.

[14] Q. Meng, S. Wang, and Z. Liu. Network design for shipping service of large-scale intermodal liners. *Transportation Research Record: Journal of the Transportation Research Board*, (2269):42–50, 2012.

[15] J. Mulder and R. Dekker. Methods for strategic liner shipping network design. *European Journal of Operational Research*, 235(2):367–377, 2014.

[16] C. E. M. Plum, D. Pisinger, J.-J. Salazar-González, and M. M. Sigurd. Single liner shipping service design. *Computers & Operations Research*, 45:1–6, 2014.

[17] C. E. M. Plum, D. Pisinger, and M. M. Sigurd. A service flow model for the liner shipping network design problem. *European Journal of Operational Research*, 235(2):378–386, 2014.

[18] J.-P. Rodrigue, C. Comtois, and B. Slack. *The Geography of Transport Systems*. Routledge, 2013.

[19] J. B. Sheu and T. Kundu. Forecasting time-varying logistics distribution flows in the One Belt-One Road strategic context. *Transportation Research Part E: Logistics and Transportation Review*, 2017.

[20] K. Shintani, A. Imai, E. Nishimura, and S. Papadimitriou. The container shipping network design problem with empty container repositioning. *Transportation Research Part E: Logistics and Transportation Review*, 43(1):39–59, 2007.

[21] D.-P. Song and J.-X. Dong. Long-haul liner service route design with ship deployment and empty container repositioning. *Transportation Research Part B: Methodological*, 55:188–211, 2013.

[22] H. Timmer, M. Bussolo, D. M. Gould, R. A. Letelier, T. C. Nguyen, G. L. Panterov, W. Shaw, E. Ushakova, A. Burns, I. V. Izvorski, M. A. Pigato, and C. Sanchez. The impact of China on Europe and Central Asia. *Europe and Central Asia economic update. Washington, D.C.: World Bank Group*, 2016.

[23] N. K. Tran and H.-D. Haasis. An empirical study of fleet expansion and growth of ship size in container liner shipping. *International Journal of Production Economics*, 159:241–253, 2015.

[24] N. K. Tran and H.-D. Haasis. Literature survey of network optimization in container liner shipping. *Flexible Services and Manufacturing Journal*, 27(2-3):139–179, 2015.

[25] N. K. Tran, H.-D. Haasis, and T. Buer. Container shipping route design incorporating the costs of shipping, inland/feeder transport, inventory and CO_2 emission. *Maritime Economics & Logistics*, 19(4):667–694, 2017.

[26] S. Wang. Optimal sequence of container ships in a string. *European Journal of Operational Research*, 246(3):850–857, 2015.

[27] S. Wang, Z. Liu, and Q. Meng. Segment-based alteration for container liner shipping network design. *Transportation Research Part B: Methodological*, 72:128–145, 2015.

[28] S. Wang, X. Qu, and Y. Yang. Estimation of the perceived value of transit time for containerized cargoes. *Transportation Research Part A: Policy and Practice*, 78:298–308, 2015.

[29] D. Yang and L. Jiang. Multi-criteria decision analysis in evaluation of container transport routes from East Asia to Europe. *Working Paper*, 2017.

[30] J. Zheng, Q. Meng, and Z. Sun. Impact analysis of maritime cabotage legislations on liner hub-and-spoke shipping network design. *European Journal of Operational Research*, 234(3):874–884, 2014.

[31] J. Zheng, Q. Meng, and Z. Sun. Liner hub-and-spoke shipping network design. *Transportation Research Part E: Logistics and Transportation Review*, 75:32–48, 2015.