Chapter 17

A multiobjective programming model for comparing existing and potential corridors between the Indian Ocean and China

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1 Introduction

1.1 Background

With the rapid development of China in the past four decades, today's China has a greater interest in establishing a stronger connectivity with the rest of the world than in the past, which is an important aim of the Belt and Road Initiative (BRI). This initiative is a great plan involving political, economic and regional development, and environmental factors around the world. It is of utmost importance to ensure the smoothness and safety of the connectivity for China's and regional economic development in a sustainable and efficient manner. The Malacca Strait, as a connectivity link between the Indian Ocean and the South China Sea, is vital to the Chinese economy since about half of Chinese cargo transport goes through it and enters the Indian Ocean. As an important country of global trade, China needs ensure the safety and smooth flow of cargo transport between the Indian Ocean region and China.

At present, the vast majority of maritime cargo transport between China and the Indian Ocean must pass through the Malacca Strait, often called the "Asian throat," and the performance of the Strait has a huge impact on China's marine transport lines and China's economy. It is because of this that China has to identify alternative transport corridors to move their cargoes smoothly and safely between the Indian Ocean region and China. Therefore, the implementation and boost of the BRI is targeted at establishing transport lines or logistics corridors between the Indian Ocean region and China.

The BRI's "Vision and Action" mentions the China-Pakistan Economic Corridor (CPEC), and China-Myanmar-Bangladesh-India (CMBI) Economic

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Corridor, which are under construction or discussion. These two corridors will offer new opportunities or alternatives to China's maritime transport lines going through the Malacca Strait. The idea of constructing the Kra Canal in Southern Thailand has been discussed widely in Southeast Asia and in the rest of the world (Lau and Lee, 2016; Heng and Yip, 2018; Gao and Lu, 2019). If it is to be built, it would provide a direct alternative to the Malacca Strait.

In the literature, there is a great deal of work on evaluating these corridors or their alternatives from the political, economic, environmental, and other perspectives. Here is a brief overview of the literature on this topic.

1.2 Literature review

Having been stimulated by a real-life application, Caramia and Guerriero (2009) propose a multiobjective model to investigate a long-haul freight transport problem, where the two objectives, respectively associated with travel time and transport cost, are to be minimized together with the maximization of transportation mean sharing index. Vehicle capacity, time windows, and transportation jobs have to obey additional constraints related to mandatory and forbidden nodes. A heuristic algorithm is applied to solve their problem. Yang et al. (2011) present an intermodal network model to examine the competitiveness of 36 alternative routes for freight transport from China to and beyond the Indian Ocean, and a goal programming approach is proposed to handle the formulated model with multiple and conflicting objectives, such as minimizing transport cost, transit time, and variability of transit time simultaneously. Zhou (2012) proposes a logistics network method for a two-level logistics network with fixed topology, considering the determination of the capacity of each transport line to seek the optimal logistics network utilization, constrained by traffic distribution plan and the logistics node and transport line capacity. Shaikh et al. (2016) evaluate the current timetable, cost, energy consumption, and greenhouse gas emissions of existing and proposed oil supply routes from the Middle East and Africa to the border of China. They estimate the Capital Expenditure (CAPEX), Operating Expense (OPEX), and average cost per barrel of the pipeline along the CPEC based on a weighted model. Chen (2018) proposes four transport corridors for the trade between China and Europe, including the Maritime Silk Road, the Central European Banley, the Gwadar Port Iron-Sea Transport, the Ice Silk Road, and systematically compares their development trends, current situation, and potentials, and certain advantages and limitations of each of these corridors are identified and discussed.

The Indian Ocean region is an important region for the implementation of BRI to strengthen the connectivity between Africa/Europe and the Far East. In this context, the China-Pakistan Economic Corridor, the China-Myanmar-Bangladesh-Indian Corridor, and the Kra Canal proposal have been discussed widely, as transport or logistics corridors running parallel to the Malacca Strait. The investigations in the existing literature generally focus on a corridor only with analysis of the impacts on the local economy and environment if it runs. It is time to move on for us to carry out a comparative study of these alternative transport corridors between the Indian Ocean region and the Far East after we have reached a reasonable understanding of these corridors. This comparison will benefit further discussions on planning, constructing, and operating, as well as academically investigating these corridors.

When we plan these three alternatives running parallel to the Malacca Strait, it is necessary to consider the split of goods among them as well as the investment plus the rate of return.

1.3 Intellectual merits of this research with scenario settings

This chapter is to propose a multiobjective optimization model while different types of cargoes are transported along the corridors of interest between the Indian Ocean region and China. For the convenience of exposition, the cargoes are assumed to move separately from Saudi Arabia and South Africa to China or from China to Saudi Arabia and South Africa through the aforementioned four corridors, as illustrated in Fig. 1, in which the bottom route of the right side of the map is the existing one going through the Malacca Strait and the other three are potential ones. On the map in Fig. 1, routes 1–4 are also known as routes A, B, C, and D, respectively.

The proposed model has four objectives, respectively associated with transport cost, energy consumption, greenhouse emissions, and safety. In the model to be formulated, all the four objectives appear in one single objective function

FIG. 1 Illustration of the four routes between China and Indian Ocean. *(Modified from Google Maps.)*

in the form of a weighted sum of them. Though, we still use "multiobjective programming model" in the title of the chapter. The solution to the model offers a satisfactory cargo (volume) allocation over the four corridors. The formulated model can be used as a tool of decision-making support since the results from it may provide meaningful suggestions for policy makers.

Table 1 lists the cargoes the four corridors of interest may transport. The key reason to choose Saudi Arabia as an end of the transport corridors is that a large amount of crude oil is transported to the Far East from this region and the main reason we choose South Africa as an end of the corridors is that a lot of iron ores are transported to the Far East from this place. The products from China to Saudi Arabia or South Africa are mainly electronic ones. It is noteworthy that all these cargoes may be transported via all these corridors.

1.4 Structure of this chapter

The rest of this chapter is organized as follows. Section 2 introduces a multiobjective programming model to capture the distribution of cargoes over the four transport corridors under discussion. Section 3 applies the formulated model to make a comparison of these corridors. Section 4 investigates the rate of return on investment in the three potential corridors. Section 5 gives a brief discussion on the regional impacts of transport from the analysis carried out in this chapter. Section 6 concludes the chapter.

2 Methodology

The resulting cargo allocation model consists of two components: objective system and constraints. The objective system consists of four objectives or indicators for each corridor, i.e., transport cost, energy consumption, greenhouse emissions, and safety. In this work, we use VLCCs of 200 million barrels to transport oil and full 40-foot containers for other cargoes.

2.1 Objective system

2.1.1 Transport cost

Transport cost mainly includes the cost incurred in the process of moving cargoes from their origin to their destination, regardless of other indirect activities, such as marketing, packaging, information support, and general administration. We consider freight rate, inventory cost, shipment-handling cost, and insurance cost in the transport cost.

First, the freight rate is defined as follows:

$$F_i = \sum_{n=1}^{3} d_{in} \cdot V \cdot x_i \tag{1}$$

where F_i is the total freight rate from origin to destination along route i by transport mode n (n = 1, 2, 3, respectively corresponding to marine, rail and

TABLE 1 Description of the cargoes transported.

Cargoes	Origins	Destinations	Corridors	Transport modes
Crude oil	Damman	Guangzhou	Malacca Strait	Marine
		Guangzhou	Kra Canal	Marine
		Kashgar	CPEC[a]	Marine cum pipeline
		Kunming	CMBI[b]	Marine cum pipeline
Iron ores	Cape Town	Guangzhou	Malacca Strait	Marine
		Guangzhou	Kra Canal	Marine
		Kashgar	CPEC[a]	Marine cum rail
		Kunming	CMBI[b]	Marine cum rail
Electronic products	Guangzhou	Jeddah	Malacca Strait	Marine
			Kra Canal	Marine
			CPEC[a]	Marine cum rail
			CMBI[b]	Marine cum rail
	Guangzhou	Damman	Malacca Strait	Marine
			Kra Canal	Marine
			CPEC[a]	Marine cum rail
			CMBI[b]	Marine cum rail
	Guangzhou	Cape Town	Malacca Strait	Marine
			Kra Canal	Marine
			CPEC[a]	Marine cum rail
			CMBI[b]	Marine cum rail

[a] *China to Pakistan Economic Corridor.*
[b] *China-Myanmar-Bangladesh-India Economic Corridor.*

pipeline), d_{in} is the unit freight rate to transport a full 40-foot container or same volume of cargo by route i, V is the total cargo volume, and x_i is the ratio of cargo volume for route i to the total cargo volume.

The three different modes of transport are considered because not all the four alternative corridors use the same transport modes.

Second, according to Min (1990), the inventory cost occurs in three places: the consignor, in-transit, and the consignee. The inventory costs to the consignor and the consignee are generally considered as parts of the cost of manufacture and sale, respectively. The cost of in-transit inventory is considered a crucial part of the cost in the whole transport. For simplicity, we only need treat the in-transit inventory cost as the inventory cost (IIC_i), which is related to the total freight value on route i and transport time and written mathematically in the following expression:

$$IIC_i = FV_i \cdot \sum_{n=1}^{3} T_{in} \cdot IR_n \tag{2}$$

where T_{in} denotes the total time for cargoes to be transported on route i by transport mode n, IR_n is the inventory-holding cost rate (in percentage) in mode n, and FV_i represents the total value of freight moving on route i and is defined below:

$$FV_i = fv \cdot V \cdot x_i \tag{3}$$

where fv denotes the production value of a cargo in a full 40-foot container or a full barrel.

The total time for cargoes to be transported from origin to destination on route i by transport mode n is given by the ratio of distance to speed, i.e.:

$$T_{in} = \frac{D_{in}}{v_n} \tag{4}$$

where D_{in} and v_n denote the distance and velocity on route i by transport n, respectively.

Third, the insurance cost of transport is similar to the inventory cost and related to the freight value, transport time, and the insurance cost rate β_n (%):

$$IS_i = FV_i \cdot \sum_{n=1}^{3} T_{in} \cdot \beta_n \tag{5}$$

where β_n varies according to mode n, which is classified into marine, rail and pipeline transport.

The fourth type of the transport cost is shipment-handling cost, which mainly occurs in the process of loading and unloading and is related to the total freight value and the cargo volume:

$$H_i = FV_i \cdot \sqrt[3]{V} \cdot x_i \cdot \eta \tag{6}$$

where η represents the specified factor of the shipment-handling cost.

To sum up, the total cost (C_i) to the transport of a cargo can be written as follows:

$$C_i = F_i + IIC_i + H_i + IS_i \tag{7}$$

In particular, for oil transport, F_i is just defined as marine cost, and varies as a route differs, depending on the distance between two ports of route i (D_i). As the proposed corridors currently remain conceptual, we are short of data related to them. The marine cost per barrel is estimated by means of the known marine cost (F_A) and the distance of route 1 (denoted as D_A). The freight rate for the other routes (i) is calculated as in Eq. (8) and it is assumed that the pipeline cost is $4.00/barrel of ESPO pipeline, irrespective of the pipeline length.

$$F_i = \frac{D_i}{D_A} \times F_A \tag{8}$$

2.1.2 Energy consumption and GHG emissions

The energy consumption (E_i) and GHG emissions (G_i) are estimated respectively by means of the following expressions, which are proposed on the basis of the work in Shaikh (2016):

$$E_i = V \cdot x_i \cdot m \cdot \sum_{n=1}^{3} \phi_{En} \cdot D_{in} \tag{9}$$

$$G_i = V \cdot x_i \cdot m \cdot \sum_{n=1}^{3} \phi_{Gn} \cdot D_{in} \tag{10}$$

where m means the weight of a full 40-foot container or a full barrel oil, φ_{En} and φ_{Gn} represent respectively the standard values per unit energy consumed and per GHG emitted in transporting 1-ton cargo for the distance of 1 km by mode n.

It is noted that the standard values may differ from one transport mode to the other.

2.1.3 Safety

In this chapter, the risk value is adopted to evaluate safety, which implies that the higher risk value represents the lower safety level of a route. To calculate the risk of a route, the following kinds of risk events that may occur to transport have been assumed:

(1) Natural disasters, such as lightning, tsunami, earthquake, flood.
(2) Traffic accidents, mainly happening to sea transportation, such as stranding, collision, explosion, capsize.
(3) General extraneous risks, such as stealing by pirates, cargo clash and rust in the process of transportation, natural damage of pipe.
(4) Special extraneous risks, such as war, man-made damage of hardware facilities, and closure of corridors due to political disputes among the neighboring countries.

The resulting risk value can be calculated in the following equation:

$$R_i = \sum_{n=1}^{3} \left(D_{in} \cdot \sum_{r=1}^{4} L_{irn} \cdot P_{irn} \right) \tag{11}$$

where L_{irn} means the loss when risk r happens to transport mode n on route i (the percentage of the total freight value on route i), and P_{irn} is the probability of risk r happening to transport mode n on route i.

2.2 Resulting model

A mathematical programming model can be formulated for our problem and written in the following form:

$$\min Z = w_1 C_i + w_2 E_i + w_3 G_i + w_4 R_i \tag{12}$$

for all $i = 1, 2, 3, 4$ ··Subject to:

$$\begin{cases} \sum_{i=1}^{4} x_i = 1, \\ x_i \geq 0, \qquad i = 1,2,3,4 \end{cases} \tag{13}$$

where the objective function in Eq. (12) minimizes the weighted sum of total transport cost, energy consumption, greenhouse gas emissions, and risks, with the degree of priority of each type of costs indicated by the weights w_j ($j = 1$, 2, 3, 4), and C_i, E_i, G_i and R_i given in Eqs. (7), (9)–(11), respectively.

In addition, the sum of w_j for $j = 1$, 2, 3, and 4 is equal to 1.

3 Model application and analysis

The previously formulated mathematical programming model (12) and (13) is a nonlinear programming problem. Since the objective function of the model contains four components with different units and scales, we normalize the four components by dividing each of them with their respective potential maximum values. Considering that the four components exhibit significantly different distributions, such a normalization procedure retains their respective original distributions and transforms the value of each of the four components into a range between 0 and 1. Our model is solved by means of Cplex and Yalmip.

3.1 Scenario settings

To proceed, we are making the following assumptions:

(1) The original weight vector for the objective function in Eq. (12) is set to be:

$$(w_1, w_2, w_3, w_4) = (0.4, 0.25, 0.25, 0.1)$$

(2) The unit freight value (*fv*) of a full 40-foot container or a full barrel of crude oil is assumed to be US\$800.00.

(3) The inventory cost rate and insurance cost rate both vary from one transport mode to the other and are set respectively as follows:

$$IR_n = \begin{bmatrix} 0.025 & 0.015 & 0.01 \end{bmatrix}$$
$$\beta_n = \begin{bmatrix} 0.015 & 0.02 & 0.01 \end{bmatrix}$$

(4) The shipment-handling cost rate is set to be 2.5% on both routes 1 and 2, and 3.75% for the others.

(5) The probability of risk r by transport mode n is assumed as follows:

$$P_{rn} = \begin{bmatrix} 0.3 & 0.4 & 0.6 \\ 0.4 & 0.3 & 0.05 \\ 0.2 & 0.2 & 0.15 \\ 0.1 & 0.1 & 0.2 \end{bmatrix}$$
$$P_{arn} = P_{brn}, \quad a \neq b$$

3.2 Scenario analysis

The cargo volume allocation given by the previously formulated model may vary as the total volume varies. In this section, we will carry out a series of numerical experiments to test the sensitivity and robustness of the cargo volume allocation to the changes in various parameters. For the sake of exposition, we take cargo transport from South Africa to China as a case with sensitivity analysis of the cargo volume allocation to the weights and safety cost in the objective function (12).

3.2.1 *Sensitivity to the weight* w_j

An increase in the weight of a cost component will inevitably lead to a reduction in other weights since their sum is equal to one. The objective function of the previously formulated model (12)-(13) can be rewritten in the following form:

$$\min Z = \sum_{i=1}^{I}\sum_{j=1}^{J} w_j f_{ij} \tag{14}$$

where $f_{ij} = \sum_{r} K_{ij}^{r}, r$ denotes one of the four alternative routes, K indicates a cost component; K represents C, E, G and R when $j = 1, 2, 3, 4$. If w_{j_0} increases by θ then a new set of weights is given by $w_{j_0}^{'} = w_{j_0} + \theta$ and

$$w_j^{'} = w_j - \theta/3 \ \text{ at } \ j \neq j_0 \tag{15}$$

Figs. 2–5 show the results of a series of experiments regarding the sensitivity of the cargo volume allocation over the four routes to the weight w_j. It can be seen from Fig. 2 that, as the decrease of w_1 makes route 3 undertake more and more cargo volume and even all cargo when w_1 falls down to 0.1, which implies that the economic factor is an inferior strength of route 3 (China to Pakistan Economic Corridor). In other words, route 3 may be the most costly one among the four ones in terms of the transport cost.

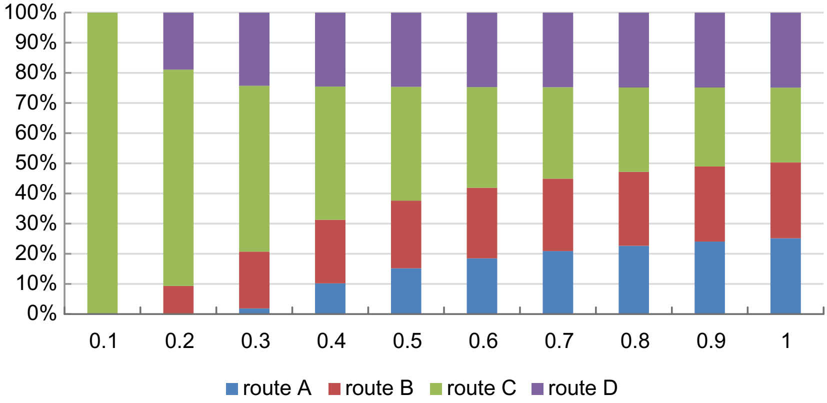


FIG. 2 Volume ratio variation as the weight associated with the transport cost varies.

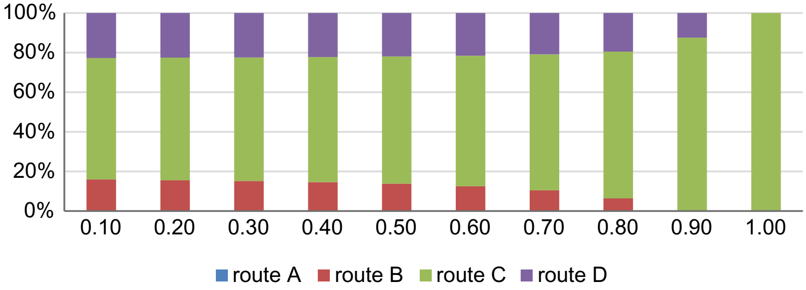


FIG. 3 Volume ratio variation as the weight associated with the energy consumption varies.

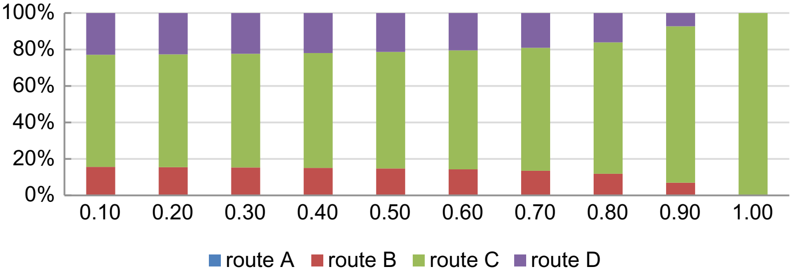


FIG. 4 Volume ratio variation as the weight associated with the GHG emissions changes.

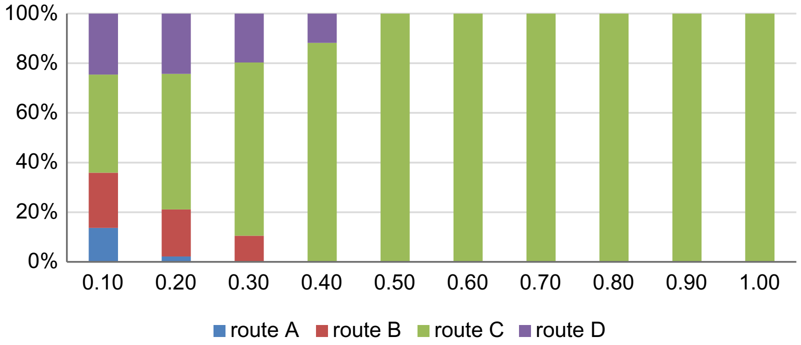


FIG. 5 Volume ratio variation as the weight associated with the safety changes.

As shown in Figs. 3 and 4, energy consumption and GHG emissions have a similar effect on the four routes. While w_2 =1 or w_3=1, the CPEC is an absolutely preferred alternative. As w_2 or w_3 increases from 0, the volume allocated over the CPEC increases gradually. The volume onto the CPEC, on the other hand, is still quite high (more than 50%) even though w_j (j=2, 3) approaches zero. This implies that the CPEC is a good choice in the sense of sustainability (energy consumption, GHG emissions). As for safety, the CPEC is in a relative dominant position. Before w_4 approaches 0.5, route 3 has taken up all cargo volume, which implies that it dominates the other three alternatives in terms of safety in the given set of scenario settings. However, to have more convincing opinions of this, we need more real-life data to make our set scenario more like the real-life one.

3.2.2 Sensitivity to the safety cost

The probability of occurrence of each risk is assumed, based on the data from the existing corridors of the type. It is noteworthy that the variation in the probability may lead to different results. The maintenance cost of railways and pipelines in response to various risks is not too small to be counted. Hence, the sensitivity analysis in this subsection mainly considers two factors: the probability of occurrence of risks and the maintenance cost of pipelines.

3.2.2.1 The probability of risks to occur

The CPEC and the CMIB both consist of marine and pipeline transport. Since the pipeline is more vulnerable and subject to more unpredictable challenges, we are carrying out the sensitivity analysis of the cargo volume allocation to the probability of each risk to occur while oil transport is carried out by pipeline. Figs. 6 and 7 show the results from the variation in the probability of risks to occur to the pipeline transport.

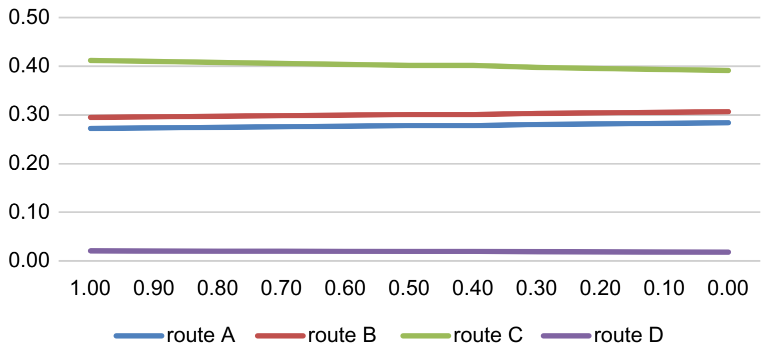
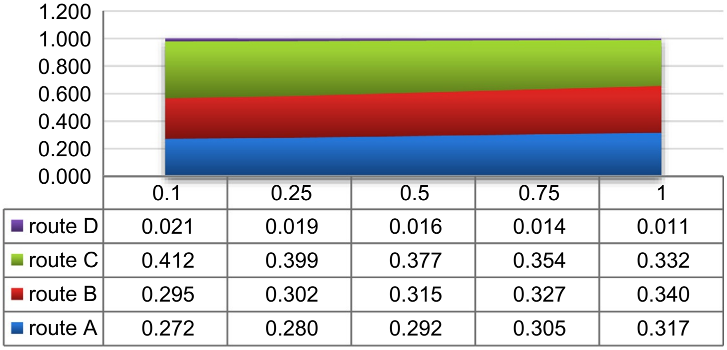


FIG. 6 Volume ratio variation as risk 1 varies.



	0.1	0.25	0.5	0.75	1
🟪 route D	0.021	0.019	0.016	0.014	0.011
🟩 route C	0.412	0.399	0.377	0.354	0.332
🟥 route B	0.295	0.302	0.315	0.327	0.340
🟦 route A	0.272	0.280	0.292	0.305	0.317

FIG. 7 Volume ratio variation as the pipeline maintenance cost varies.

It is readily seen that the probability of occurence of risks has a little effect on the volume allocation, so the variation trend is stable and negligible.

3.2.2.2 The maintenance cost of pipeline

Due to the unavailability of exact pipeline maintenance cost, a certain proportion of the freight value is proposed to be the maintenance cost, and denoted by the value of lost freight. Keep the maintenance cost of marine L_{ir1} as constant and make the pipeline maintenance cost set as follows:

$$L_{ir3} = 0.1FV_i,\ L_{ir3} = 0.25FV_i,\ L_{ir3} = 0.5FV_i,\ L_{ir3} = 0.75FV_i,\ L_{ir3} = FV_i$$

We may then solve the model under these settings and compare the results, which are displayed in Fig. 7.

It can be seen that the increase in the percentage of lost freight value (i.e., maintenance cost of pipelines) has a great effect on volume allocation, and that the volume allocated onto the CPEC has just decreased slightly, eliminating inaccuracy due to data inevitability.

4 Analysis of return on investment

Except the Malacca Strait, the other three transport corridors have not been built or not completed yet. The necessity of building these alternatives has always been a controversial issue. It has not yet been decided in favor of the Kra Canal, after having been discussed for decades. It is undoubted that many factors have affected the process, but getting sufficient funds to complete this mega-project is a problem that cannot be avoided at all. In addition, the CPEC and the CMBIEC are the two important corridors proposed in the context of the BRI, which certainly needs a huge amount of financial investment along the Belt and/or Road. Therefore, it is imperial to investigate the rate of return on investment in these corridors.

It is assumed that the CPEC will be completed in 2030, so we choose 2030 as a time point for investment to start to return. For the sake of exposition, this analysis only considers three typical cargoes being transported between China and Saudi Arabia or South Africa, which are respectively crude oil from Dammam to China, iron ores from Cape Town to China, and plastic products from Guangzhou to Cape Town.

4.1 Predicting volume of imports and exports

From 2000 to 2017, as shown in Figs. 8–10, the volume of imports and exports of China's foreign trade has witnessed a rising trend, which could be approximately considered a linear rise. Therefore, this chapter assumes to make

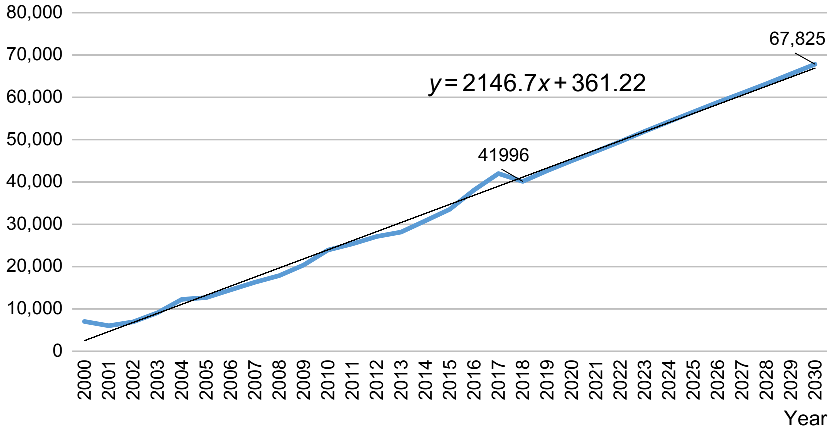


FIG. 8 China's crude oil imports up to 2030 (10 k tons).

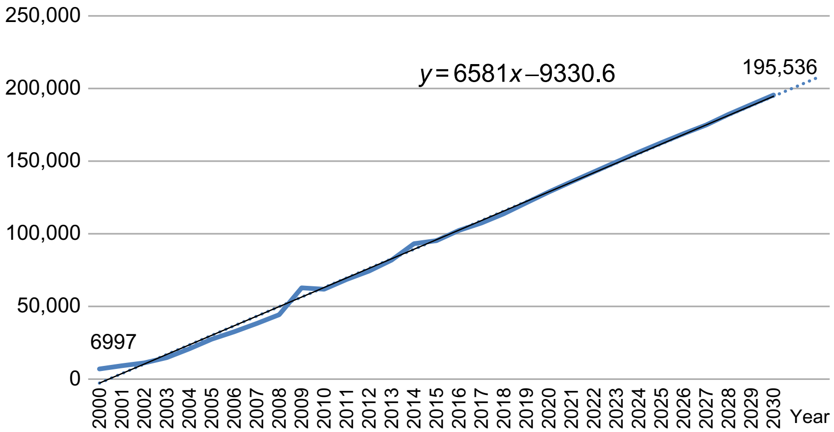


FIG. 9 China's iron ore imports up to 2030 (10 k tons).

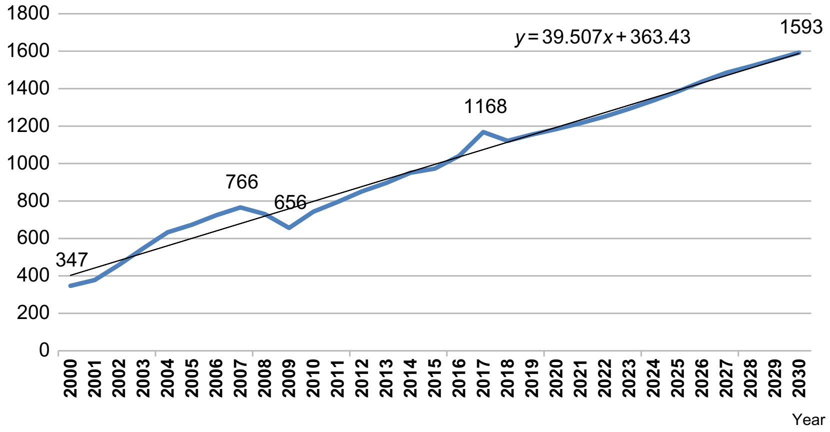


FIG. 10 China's plastic product exports up to 2030 (10 k tons).

a linear prediction for the volume of imports and exports of China in 2030 (see Figs. 8–10 again).

It is assumed that the percentage of crude oil imports from Saudi Arabia to the three cities of China will be up to 12%, and that 8% of the total iron ores will be transported from South Africa to China. Plastic product exports from Guangzhou to Cape Town account for 80% of the total.

4.2 Optimal volume allocation

According to the sensitivity analysis in the previous section, it is known that the impact of risks on the volume allocation results is negligible. In addition, the inventory cost rates, insurance cost rates, and shipment-handling cost rates

TABLE 2 The optimal cargo volume allocation.

Cargo	Crude oil	Iron ores	Plastic products
Volume ratio	0.03:0.17:0.62:0.18	0.21:0.41:0.28:0.10	0:1:0:0

are all very small, whose variations play only a minor role in the calculation of the transport cost. Therefore, keep the values of those parameters in transport cost and safety the same as in the previous assumptions. In addition, the different weights of the four components in the objective function (12) will lead to different results. We have seen that the weight of transport costs plays the most sensitive role in the cargo volume allocation, and that the effects of rest of the cost components are not very large. Therefore, in investment analysis, the weight of transport cost is assumed to be 0.4, and the weights for the rest of the costs are all set to 0.2.

Moreover, the freight value of a full 40-foot container is different when different cargoes are loaded. Combining the information found, we assume that a full barrel of crude oil *as* is worth 50 US dollars, and that a full 40-foot container of plastic products is worth 500 US dollars. In addition, it is known that the price per ton of iron ores is about $76, so the *fv* of a full 40-foot container filled with iron ores can be set as $1950. Considering the reality of imports and exports, the total cargo volume of a full year is simply divided into 12 for 12 months. Therefore, the volume in the formulated model is the value equal to the annual total forecast volume divided by 12.

Based on the aforementioned assumptions, the results of three types of cargo volume allocation are listed in Table 2.

4.3 Analysis of return on investment

In order to display more intuitively the superiority of optimal allocation from the previously formulated model, we make a comparison of these corridors in terms of the aforementioned performance indices (i.e. four cost components in the objective function) between pre and postoptimization. The values of the indices are given in Tables 3–5.

It is suggested that almost all the four cost components have been improved more or less, and especially for crude oil, the values of the three out of the four have been improved by 50% or so. Although for the other two cargoes, the improvements of the four objectives are not so large, there have still been significant advantages in most cases because of the very large basis value.

In the transport cost evaluation, this chapter adds transport time cost so the transport cost not only includes economic cost but also time cost, which leads to the larger value of transport cost. It is known that the completed construction of

TABLE 3 A comparison of crude oil before and after optimization.

Route	Ratio	Transport cost ($\times10^{7}$ US$)	Energy consumption ($\times10^{11}$ KJ)	GHG emissions ($\times10^{10}$ g)	Safety ($\times10^{11}$ US$)
Route 1	0.03	2.5	4.6	3.6	2.7
Route 2	0.17	68.0	23.3	18.3	14.0
Route 3	0.62	1360.0	33.7	27.2	11.0
Route 4	0.18	208.0	20.3	16.0	11.0
After (total)	1	1638.5	81.9	65.1	38.7
Before	–	2270.0	153.0	12.0	91.5
Optimization value	–	631.5	71.1	54.9	52.8
Optimization rate	–	38.5%	46.5%	45.8%	57.7%

TABLE 4 A comparison of iron ores before and after optimization.

Route	Ratio	Transport cost ($\times 10^8$ US$)	Energy consumption ($\times 10^{11}$ KJ)	GHG emissions ($\times 10^{10}$ g)	Safety ($\times 10^{11}$ US$)
Route 1	0.21	1.6	5.2	4.1	6.7
Route 2	0.41	4.0	9.6	7.5	12.3
Route 3	0.28	5.5	5.4	3.7	6.6
Route 4	0.10	3.1	2.3	1.7	3.0
After (total)	1	14.2	22.5	17.0	28.6
Before	–	16.3	22.2	17.3	32.4
Optimization value	–	2.1	−0.3	0.3	3.8
Optimization rate	–	14.8%	−1.3%	1.8%	13.3%

TABLE 5 A comparison of plastic products before and after optimization.

Route	Ratio	Transport cost ($\times 10^7$ US$)	Energy consumption ($\times 10^{12}$ KJ)	GHG emissions ($\times 10^{11}$ g)	Safety ($\times 10^{11}$ US$)
Route 1	0	0	0	0	0
Route 2	1	9.8	3.1	2.4	1.2
Route 3	0	0	0	0	0
Route 4	0	0	0	0	0
After (total)	1	9.8	3.1	2.4	1.2
Before	–	10.4	3.3	2.6	1.3
Optimization value	–	0.6	0.2	0.2	0.1
Optimization rate	–	6.1%	6.5%	8.3%	8.3%

the CPEC is expected to invest \$46 billion, and that \$28 billion will be invested in constructing the Kra Canal. It is defined that the rate of return on investment in the three corridors is the total optimization value of transport cost, so the return rate is approximately 50%. This chapter only considers three types of cargoes, and for more cargoes there must be more cost advantages. Therefore, under the premise of comprehensively considering economic cost and time cost, the rate of return on investment in the three corridors is a little higher, to some extent. The transport time is an important aspect in the process of foreign trade that we need consider. Based on our inevstigation in this chapter, it may be feasible and rational to invest in the three corridors so that cargo imports and exports can be finished more effectively and economically.

5 Transport and regional impacts

The rapid development of China's economy in the past four decades itself is a good evidence of positive impacts of transportation development on economic growth. Having made a long-lasting great success by building roads before making more wealth, China took the initiative in 2013 and proposed the BRI, which is another practice of this idea. That is, it is hoped that the BRI will promote more transportation infrastructure to be built or improved so that this world or the regions the Belt or the Road goes through may be connected in a better way, which promotes economic development due to lower transport cost and better, inspiring, efficiency.

If all three new corridors that are discussed in this paper are built, South Asia will certainly be more connected, so that the logistics cost will be reduced significantly and resources or products can be transported in a more efficient and effective manner. Then, a business operator may optimize his or her business in a wider area.

6 Concluding remarks

This chapter proposes a mathematical programming model to allocate a set of given cargoes over the four transport corridors or routes of interest between China and Saudi Arabia or South Africa in the Indian Ocean region, which handles the four objectives: minimized transport cost, minimized energy consumption, minimized GHG emissions, and maximized safety by means of a weighted sum of them. Then a scenario analysis is carried out to test and verify the newly proposely model, and the sensitivity analysis of the cargo volume allocation over the four alternative routes to the weights and safety factor in the formulated model is carried out to identify the degrees of influence of each type of objectives.

A series of experiments show that the resulting cargo volume allocation from the formulated model may be greatly affected by the weights of the four objectives, especially by the weight of transport cost, whose variation can make a big difference to the resulting cargo allocation among the corridors. Moreover, as the parameter values in the safety definition vary, the allocation results have been almost unaffected. Subsequently, the rate of return on investment in the three potential corridors is analyzed. This work may not provide a good or final set of suggestions for policy makers, but certainly will promote the implementation of Belt and Road Initiative and encourage more convining analysis of potential ideas or projects related to this initiative.

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