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Impacts of the Belt and Road Initiative on the China-Europe Trading Route Selections[1]

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Abstract: This paper investigates the potential of Belt and Road economic corridors to serve as China-Europe trading route alternatives. By constructing a new Route Utility Function considering cost, environmental impact, mode reliability & security, transit time, and infrastructure reliability, we demonstrate the remarkable advantages of the corridors over the traditional ocean route and their heterogeneous impacts on different regions of China. The importance of considering infrastructure reliability for trading route selections is highlighted. More importantly, the analyses of this study could generate insightful implications for proper logistics planning under the development of other economic cooperation and trading agreements throughout the world.

Keywords: Belt and Road Initiative; Economic corridors; China-Europe trading; Route selection.

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1. Introduction

1.1 Problem background

China has become the largest manufacturing center and trading entity since the Chinese Reform and Opening-up in the 1970s (Cullinane et al., 2018). Among the trading partners, Europe plays the most significant role in the Chinese export industry, with the highest percentage (18.5%) of Chinese exported cargos being delivered into its market (NBSC, 2017). However, due to the under-developed connectivity between China and its neighboring countries, China heavily relies on ocean transportation for international freight delivery (Lanteigne, 2008). Therefore, the development of the export market of China is heterogeneous. As reported by NBSC (2017), the coastal regions in East and South China generate the highest export values (e.g., 654.14 billion USD for Guangdong and 330.96 billion USD for Jiangsu) owing to the geographical proximity to the key ocean terminals, while the inland regions derive much lower contribution (e.g., 0.47 billion USD for Tibet and 0.36 billion USD for Qinghai) due to the long extra transportation distance from product origins to coastal ports.

Currently, the ocean trading route between China and Europe starts from the coastal ports of East or South China, passing through the South China Sea, the Strait of Malacca, the Indian Ocean, the Red Sea, the Mediterranean, and finally arrives at the European countries through more than twenty thousand kilometers sailing. Therefore, the existing China-Europe trading route greatly relies on the Strait of Malacca, a well-known traffic bottleneck due to the heavy traffic flow and unstable political environment (Evers & Gerke, 2006). Consequently, China has long concerned about the reliability of this lifeline due to the potential blockages and territorial disputes, which is the so-called *Malacca Dilemma* (Zhang, 2011). Besides, ocean shipping is reported to be of low mode reliability[6] and disadvantageous in low speed and long delivery time[7].

With the aim of reducing the impact of the existing transportation barriers and improving the international trading efficiency (especially for the European market), the Chinese government launched the ambitious Belt and Road Initiative (BRI) in 2013 (SCPRC, 2015).The initiative involves the development of various economic corridors to enhance the diversity and connectivity of the international logistics network of China, through various infrastructure projects like railway/highway/port construction or upgrading projects. These economic corridors provide various

[6] The “mode reliability” in this paper refers to the reliability of transportation modes (i.e., ocean vessels, road trucks, and trains).
[7] https://freighthub.com/en/blog/modes-transportation-explained-best/.

potential routes linking China and Europe to alleviate the dependence of China-Europe trading on the Strait of Malacca.

The establishment of the BRI brings huge benefits for China and the partnering countries. From the perspective of economics, the Chinese export companies could benefit from the potential shortened distances, the resulting reduction in delivery times, and the improved transportation mode reliability and security with the application of the new BRI routes, which is beneficial to the development of the China-Europe trading market. Since the initiation in 2013, the merits brought by the BRI have emerged. As reported by the Ministry of Commerce of People's Republic of China[8], the trades between China with the Belt and Road countries experienced a rapid growth in 2017. Taking Europe as an example, the trading volume between China and European countries witnessed a remarkable increase of 15.2% in that year.

Despite the observed big success, the BRI is facing with diverse challenges. The major one is the uncertain reliability of the transportation infrastructures along the economic corridors. For example, the change of regime or government policies may suspend or even terminate the previously signed cooperation contracts on the construction, maintenance, or pass-through permission of the transportation infrastructures. In addition, as many infrastructure projects pass through disputed, terrorism-threatened, or extreme-climate regions, the associated instability and volatility should not be underestimated. Therefore, the uncertain infrastructure reliability has become a major threat for the future success of the BRI.

1.1.1 The significance of the trading route selection problem in the BRI strategic context

From the discussion above, it could be concluded that the BRI brings great opportunities and remarkable challenges for the China-Europe trading market simultaneously. Moreover, the diverse BRI-proposed economic corridors are featured with different characteristics (i.e., distances, transportation modes applied), leading to heterogeneous impacts on various parts of China. Therefore, the selection for the optimal trading route from the BRI-enhanced logistics network becomes extremely crucial for Chinese export companies to maintain profitability and competitiveness in the fast-developing and intensively competitive market. However, although the importance of the trading route selection problem in the BRI era has been realized, there is little research exploring the unique characteristics of

[8] http://english.mofcom.gov.cn/article/statistic/lanmubb/ChinaEU/201803/20180302718751.shtml.

each BRI-proposed economic corridor and analytically investigating their heterogeneous impacts on the decision making for the export companies located in China. Consequently, the benefits and challenges of the BRI-proposed economic corridors are not clearly known by decision makers, causing under-utilization and a restricted success of the initiative.

1.2 Literature review & research gaps

In the literature, there are two main streams of research (quantitative research and qualitative research) related to the BRI. We review them as follows.

1.2.1 Quantitative research for the BRI

From the perspective of operations management, one research stream quantitatively analyzes the BRI-related supply chain management problems. For instance, motivated by the increasing demands for customized logistics services in the Belt and Road region, Liu et al. (2018) investigate the impact of a cost sharing contract on the optimal pricing and customization decisions for the service supply chain members who operate under a mass customization program. Regarding the supply chain network construction in the BRI era, Shao et al. (2017) develop a model which incorporates the factors like national cooperation and political stability into the model to evaluate the priority of the construction projects in the transnational high-speed railway network. Yang et al. (2017) investigate the reconstruction problem of the shipment service network for the Asia-Europe trading system. Besides, electricity flows are applied to simulate and forecast the increasingly time-varying logistics distribution flows led by the BRI in the work of Sheu and Kundu (2017). Their case results generate insightful suggestions for the development tactics for the policy makers and practitioners. Recently, Chen and Yang (2018) and Zeng et al. (2017) explore the logistics hub problem in the Belt and Road supply chain. To be specific, Chen and Yang (2018) propose a genetic algorithm to evaluate the impact of capacity limits and industry transfer on port clustering, while Zeng et al. (2017) study the effect of the potential Carat Canal on the evolution of hub ports. Furthermore, from the aspect of overseas investment strategies, Duan et al. (2018) build a fuzzy integrated assessment model to analyze the energy investment risks for fifty countries along the Belt and Road. They conclude that countries like Russia and Pakistan are the most ideal destinations for the Chinese energy investments. Besides, Jiang et al. (2018) examine the hinterland patterns of China Railway Express under the BRI according to the binary logit model. The authors show that the China Railway Express cost could be reduced by 60 percent if the government offers subsidies to the operators. Furthermore, Li et al. (2018) firstly evaluate the contribution of BRI logistics infrastructures for the economic growth of countries along the belt and road by building an error correction model with panel data from the year of 2003 to 2014.

Therefore, it is identified that the existing quantitative research on the BRI mainly focuses on supply chain management problems like network construction, logistics distribution flow forecasts, logistics hub problems, and investment decisions. However, little attention has been paid to the impact of the BRI economic corridors and the new trading route selection problem in the BRI era.

1.2.2 Qualitative research for the BRI

In addition to the quantitative research reviewed above, some researchers are devoted to studying the BRI issues from a qualitative aspect. For example, Ferdinand (2016) reviews the BRI from the economic dimensions and geopolitical implications, and concludes that the BRI shows a new stage of the Chinese foreign policies that the geopolitical considerations are becoming increasingly significant. Besides, Yu (2017) and Huang (2016) examine the motivation of the BRI, while Lee et al. (2018) propose several future research trends. In addition, Wang (2017) evaluates a new dispute resolution mechanism for the potential conflicts led by the BRI. Differently, Zeng (2016) conducts a conceptual analysis to compare the BRI with the traditional strategic concepts like the partnership arrangement, regional economic integration, and community of common destiny. The author concludes that the BRI is a new form of global governance which integrates regional economic integration and partnership arrangement.

In conclusion, the BRI-related qualitative research generally studies the economic and political implications and motivations of the initiative, while few studies investigate the characteristics of the diverse BRI-proposed economic corridors and their potential to serve as China-Europe trading route alternatives.

1.2.3 Research gaps

Table 1 summarizes the two streams of literature regarding the BRI in terms of research topics and major findings. In conclusion, the following research gaps could be obtained. First, despite the remarkable economic significance, the BRI-related research is still underdeveloped. Second, none of the previous studies have analyzed the full potential of the diverse BRI economic corridors in serving as a trading route alternative between China and Europe. Third, there is little research examining the advantages and merits of the BRI economic corridors over the traditional ocean route for the China-

Europe trading market analytically. Fourth, to the best of our knowledge, no research has mathematically analyzed the heterogeneous impacts of the various BRI economic corridors on the trading route decisions of the export companies located in different regions of China. Last, although the infrastructure reliability is crucial for the route decisions, limited research has investigated its impact especially in the context of the BRI. In this work, we construct a Route Utility Function which integrates the factors of transportation cost, environmental impact, transit time, mode reliability, mode security[9], together with infrastructure reliability to evaluate the utilities of the diverse route alternatives arising with the BRI.

Table 1. Summary of selected studies of the two main streams research related to the BRI.

Stream	Literature	Research topic	Major findings
Quantitative	Liu et al. (2018)	Supply chain coordination	It is beneficial to enhance BRI logistics services.
	Shao et al. (2017)	High-speed railway construction	Results show that 18 areas in the BRI region have priority conditions.
	Yang et al. (2017)	Service network improvement	New optimal networks under different cases are identified.
	Sheu and Kundu (2017)	Forecasting logistics distribution flows	Developmental strategies are proposed to optimize logistics decisions.
	Chen and Yang (2018)	Port cluster problem	The growth in port cluster benefits social welfare and manufacturing industry.
	Zeng et al. (2017)	Evolution of hub ports	Results show that the opening of the Carat Canal shifts traffic flow from the Strait of Malacca.
	Duan et al. (2018)	Energy investment risk assessment	Resource potential and Chinese factors are main determinants of energy investment risks.
	Jiang et al. (2018)	Hinterland patterns of China Railway Express	Results show that China Railway Express cost could be reduced by 60 percent with subsidies.
	Li et al. (2018)	Logistics as driving forces for economic growth	Telecommunication and airway transportation are important for developing BRI countries.
Qualitative	Ferdinand (2016)	Economic dimensions and geopolitical implications	Chinese foreign policies enter a new stage, and the geopolitical issues are more important.
	Yu (2017)	Motivation investigation	The BRI could change the landscape of Asia.
	Huang (2016)	Motivation investigation	The initiative faces diverse barriers.
	Lee et al. (2018)	Overview of the initiative	Various research trends are proposed.
	Wang (2017)	Dispute resolution mechanism	An alternative dispute resolution mechanism is examined.
	Zeng (2016)	Conceptual analysis	The BRI is a new form of global governance.

1.3 Contribution statement

We summarize and highlight the managerial insights generated from this work and the incremental

[9] The term "mode security" in this paper refers to "transportation mode security". Unless otherwise specified, throughout this paper, the term "mode" represents "transportation mode".

contributions for the literature and practice as follows.

First, considering the significant impact of transportation infrastructure reliability on the route selection decisions, especially in the strategic context of the BRI, we firstly propose to integrate the factor of infrastructure reliability into the decision framework. In the freight transportation planning literature, factors such as cost, transit time, mode reliability, mode security, and environmental impact are generally considered in the route & mode selections (e.g., Arencibia et al., 2015; Cullinane & Toy, 2000; Danielis & Marcucci, 2007; Jeffs & Hills, 1990). However, the reliability issue of transportation infrastructures is largely ignored in the existing studies. As illustrated by our analyses on the various routes in the BRI-enhanced logistics network, the transportation infrastructures involved are threatened by diverse risks and uncertainties. Therefore, we construct a new Route Utility Function which integrates the infrastructure reliability factor to evaluate the route alternatives. By generating seven scenarios where the transportation infrastructure reliability declines and analyzing the resulting adjustments in the optimal routes, the significant impact of infrastructure reliability on the trading route decisions is illustrated. Therefore, the importance of integrating this critical factor into the freight transportation planning and mode selection decision framework is uncovered. Accordingly, it is suggested that the government should take efforts in maintaining the infrastructure reliability of the proposed economic corridors to achieve sustainable benefits and advantages of the BRI.

Second, through reviewing and analyzing the transportation projects of the BRI economic corridors, we identify that four of them (New Eurasia Land Bridge Economic Corridor, China-Mongolia-Russia Economic Corridor, China-Pakistan Economic Corridor, and China-Indochina Peninsula Economic Corridor) have the potential to serve as China-Europe trading route alternatives to enhance the Chinese international logistics network, while the other two (China-Central Asia-West Asia Economic Corridor and Bangladesh-China-India-Myanmar Economic Corridor) demonstrate little prospect currently. Therefore, the export companies in China could pay more attention to the four potential economic corridors to enjoy their advantages through the enhancement of transportation connectivity between China and Europe.

Third, based on the delivery of a general product in a basic scenario where the impact of infrastructure reliability is excluded, we demonstrate the remarkable advantages of the BRI economic corridors over the traditional ocean route for the China-Europe trading business, especially when the delivery time requirement is strict. Specifically, the BRI-proposed new trading routes could dominate the traditional ocean route for most regions of China with tight time requirements, while the traditional ocean route could be preferable for some coastal regions only if a loose time requirement is proposed.

Fourth, the heterogeneous impacts of the diverse BRI economic corridors on the route decisions of the export companies located in different regions of China are demonstrated. To be specific, we find that the New Eurasia Land Bridge Economic Corridor and China-Mongolia-Russia Economic Corridor are the most desirable substitutions for the traditional ocean route for the majority part of the country, while the China-Pakistan Economic Corridor may be advantageous for the western region (i.e., Xinjiang Province). Besides, the China-Indochina Peninsula Economic Corridor shows little influence on the route decisions, but it could help enhance the diversity of the Chinese international logistics network. This managerial insight provides important and useful guidelines for export companies in deciding the applications of the diverse BRI-proposed trading routes by considering their locations.

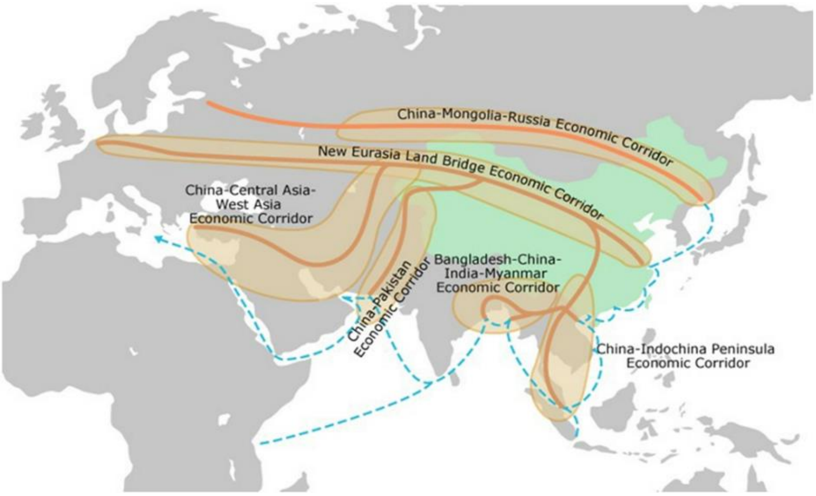
Fifth, we propose three insightful developmental suggestions to help maximize the benefits of the BRI. Briefly, it is suggested that more Urumqi-originated China-Europe freight trains based on the New Eurasia Land Bridge Economic Corridor could be established. Next, several strategies to alleviate the one-way Belt and Road trading dilemma are proposed. Besides, more stops along the China-Europe freight trains are recommended. These suggested strategies are believed to not only help enlarge the impact of the BRI, but also benefit the economic development of the involved regions, which could stimulate more future research on the BRI.

In summary, this paper incrementally contributes to i) the route selection literature by investigating a novel logistics problem arising with the BRI, and ii) the BRI-related literature by generating insights regarding the application of the BRI-proposed economic corridors. Furthermore, this paper is also an important contribution for the practical utilization of the BRI-proposed trading routes through providing insightful guidance and developmental suggestions, which benefits both the export companies and governments significantly. More importantly, this paper positions itself as the first study which contributes to the logistics and transportation management literature on demonstrating and highlighting the significance to integrate the factor of infrastructure reliability into the route selection decision framework. It lays the foundation for future studies in related areas under different trading agreements.

This study is organized as follows. First, the transportation infrastructure projects of the BRI economic corridors are analyzed in Section 2. Then, Section 3 builds the BRI-enhanced logistics network and formulates the Route Utility Function. Numerical analyses are demonstrated in Section 4, followed by the developmental suggestions in Section 5. Finally, Section 6 draws conclusions for this work.

2. The BRI economic corridors

As discussed, the BRI proposes diverse economic corridors to enhance the international logistics network of China, as shown in Figure 1. According to the proposal of the Chinese government (SCPRC, 2015), on land, the initiative concentrates on the construction of the New Eurasia Land Bridge Economic Corridor, China-Mongolia-Russia Economic Corridor, China-Indochina Peninsula Economic Corridor, and China-Central Asia-West Asia Economic Corridor by utilizing the international transport routes, core cities, and major economic industrial parks along the Belt and Road. At sea, the China-Pakistan Economic Corridor and Bangladesh-China-India-Myanmar Economic Corridor are proposed to connect the pivotal sea ports along the Belt and Road. In this section, we briefly introduce the economic corridors with a special emphasis on the transportation connectivity projects that facilitate the corridors to serve as a trading route between China and Europe. Besides, the risks and uncertainties associated with the transportation infrastructures are discussed.



- NELBEC: China-Europe (*by land*).
- CMREC: China-Europe (*by land*).
- CIPEC: Kunming-Singapore (*by land*)-Europe (*by sea*).
- CCAWAEC: Xinjiang-Central and Western Asia (*by land)*.
- CPEC: Kashgar-Gwadar Port (*by land*)-Europe (*by sea*).
- BCIMEC: Kunming-Kolkata (*by land*).

Figure 1. The six economic corridors proposed by the BRI[10].

2.1 New Eurasia Land Bridge Economic Corridor

With the completion of China's North Xinjiang Rail Line linking Alataw Pass / Horgos Pass with Urumqi, the railway systems of Kazakhstan and China realize seamless connection, thereby forming

[10] This figure is extracted from Hong Kong Trade Development Council through http://china-trade-research.hktdc.com/business-news/article/The-Belt-and-Road-Initiative/The-Belt-and-Road-Initiative/BRI/en/1/1X000000/1X0A36B7.htm.

the New Eurasia Land Bridge. Through the New Eurasia Land Bridge Economic Corridor (NELBEC), many cities in China could connect with major European cities directly by train through western and central Asian countries. Therefore, the application of the NELBEC could significantly enhance the transportation efficiency between China and Europe (Lin, 2011).

Since 2011, the Chinese government has established many regular China-Europe freight trains along the NELBEC. We show some examples based on the China-Hamburg freight trains in Figure 2. For instance, the Zhengzhou-Hamburg freight train runs around ten thousand kilometers with 15 days (through Alataw Pass or Horgos Pass), while the counterpart starting from Xiamen requires 16 days with a length of 11866 km (through Alataw Pass).

The main risks and uncertainties associated with the NELBEC arise from the issues like the relations between China with the countries along the rail line and the political instability of the related countries. Besides, as there are increasing China-Europe freight trains being launched along the NELBEC, the capacity of the New Eurasia Land Bridge rail line is becoming a significant limitation for the NELBEC's advantages.

2.2 China-Mongolia-Russia Economic Corridor

In order to align the development strategies of the three neighboring countries of China, Russia, and Mongolia, the governments inked a strategic contract to construct an economic corridor (named as the China-Mongolia-Russia Economic Corridor (CMREC)) to enhance the transnational transportation connectivity (Deepak, 2017; Zhang & Zhang, 2017).

For the CMREC, we mainly consider the First Eurasia Land Bridge rail line which is similar to the New Eurasia Land Bridge rail line introduced in Section 2.1, linking China with Europe through countries like Russia and Mongolia. Similarly, various China-Europe freight trains based on the CMREC have been established, crossing the Chinese border through either Erenhot Pass or Manchuria Pass. Some examples are shown in Figure 2. For instance, Shenyang, a major city in Northeast China, is operating a freight train to Hamburg through Manchuria Pass which takes 13 days of transportation time.

The risks and uncertainties of the CMREC are similar to those of the NELBEC, including political unreliability and capacity limitations.

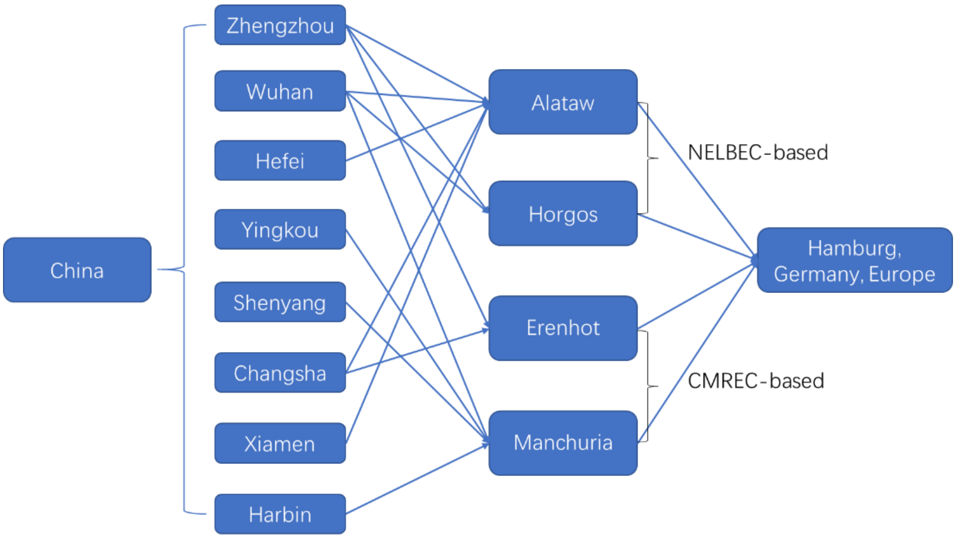


Figure 2. Example China-Europe freight trains with Hamburg as the destination[11].

2.3 China-Indochina Peninsula Economic Corridor

China and Indochina Peninsula are connected by land with close cultural, economic, and geographical ties. The China-Indochina Peninsula Economic Corridor (CIPEC) starts from Kunming, crossing Viet Nam, Lao PDR, Cambodia, Thailand, Myanmar, and Malaysia, and finally ends at Singapore. The CIPEC is a bridge to promote the co-operations between China and the ASEAN countries through an upgraded transportation network (Luft, 2016).

The major connectivity project of the CIPEC, the Kunming-Singapore Railway, is proposed to connect China with Singapore through a three-direction railway system based on the existing rail network in the region (see Figure 3, the yellow lines represent the current missing links): i) West via Mandalay, Yangon, and Bangkok; ii) central via Vientiane and Bangkok; iii) East via Hanoi, Ho Chi Minh, Phnom Penh, and Bangkok. With the implementation of the CIPEC, the cargos produced in Southwest China could be delivered to Singapore Port directly by train for subsequent ocean shipment to Europe.

However, the construction of the CIPEC is impeded by the tense relations and political instability of the involved countries. For example, Thailand has delayed and changed some contracted projects for several times[12], while the Malaysian prime minister announced that he would reconsider the feasibility of the collaboration agreements[13]. Therefore, the full implementation of the Kunming-Singapore

[11] http://www.amiue.com/p/2178#%E8%87%B32018%E5%B9%B44%E6%9C%88%E4%B8%AD%E6%AC%A7%E7%8F%AD%E5%88%97%E7%8F%AD%E6%AC%A1%E6%95%B0%E6%8D%AE

[12] https://www.bangkokpost.com/news/general/1477265/talks-hit-wall-over-delay-clause.

[13] https://economictimes.indiatimes.com/news/defence/malaysia-gives-a-big-jolt-to-chinas-one-belt-one-road-projects/articleshow/64620929.cms.

Railway is far from realization. However, considering that most part of the China-Indochina Peninsula rail network in China has been completed, and this corridor could benefit the development of the ASEAN countries, it is believed that the CIPEC has the potential to perform as a trading route alternative upon its completion.

Figure 3. Kunming-Singapore Railway[14].

2.4 China-Central Asia-West Asia Economic Corridor

The China-Central Asia-West Asia Economic Corridor (CCAWAEC) stretches from Xinjiang to central and western Asian countries like Kazakhstan and Kyrgyzstan. The most significant advance of this economic corridor is the Third China-Central Asia Co-operation Forum held in Shandong in June 2015, where China and five Central Asia countries inked a joint declaration on multilateral co-operations. However, the CCAWAEC is positioned as an energy corridor with diverse pipeline construction projects such as the Central Asia-China Gas Pipeline program.

2.5 China-Pakistan Economic Corridor

As the flagship program of the BRI, the China-Pakistan Economic Corridor (CPEC) links Kashgar (Xinjiang, China) with Gwadar Port (Pakistan) through highway/railway network construction and upgrading projects (see Figure 4), bringing significant benefits for the associated countries (Boyce, 2017; Hali et al., 2015). This corridor greatly shortens the distance between Arabian Sea and West China, implying a sharp reduction in the trading route between West China and Europe. Therefore, the CPEC generates huge potential to open West China to the world with an enhanced logistics efficiency (Shaikh et al., 2016).

[14] This figure is extracted from https://en.wikipedia.org/wiki/Kunming%E2%80%93Singapore_railway.

Currently, the China-Pakistan transnational highway and railway systems are under construction and upgrading. However, as these infrastructures pass through regions with high mountains (e.g., Karakoram Mountains and Hindu Kush Mountains) and extreme climates (e.g., Pamirs Plateau), the complex geological conditions like snow avalanche, landslide, rockfall and road icing impose great challenges on the reliability of these facilities. Besides, the politically unstable Kashmir disputed district also increases the uncertainties of the CPEC.

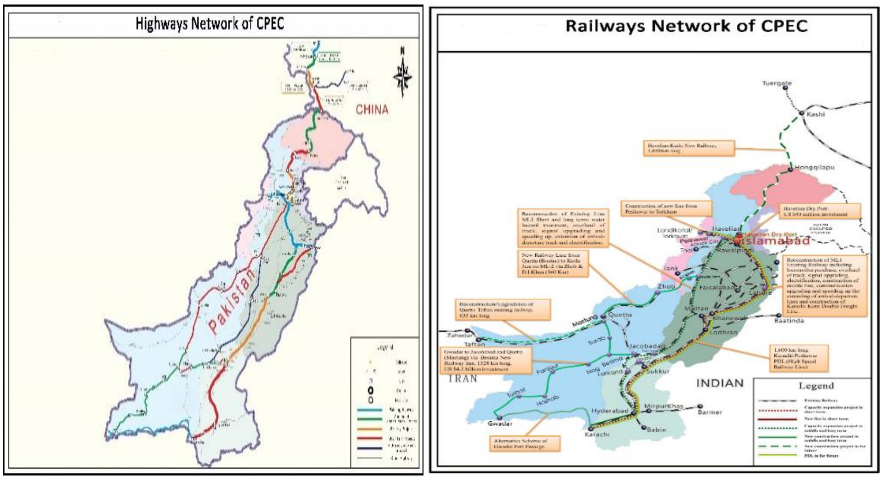


Figure 4. The construction map of the CPEC[15].

2.6 Bangladesh-China-India-Myanmar Economic Corridor

The Bangladesh-China-India-Myanmar Economic Corridor (BCIMEC) was proposed in May 2013 (Deepak, 2017). The first Joint Working Group of the BCIMEC was held in Kunming in Dec 2013 where the official representatives of the four involved countries discussed the collaboration mechanisms along the corridor. As planned, this corridor begins from Kunming and ends at Kolkata. However, due to the regional disputes like the Rohingya Refugee Crisis, the transportation infrastructure development projects are still under discussion and have little progress.

In summary, Table 2 highlights the comparisons among the six BRI-proposed economic corridors, regarding the major BRI transportation connectivity infrastructures and their potential to serve as a China-Europe trading route. It is concluded that the NELBEC, CMREC, CIPEC, and CPEC demonstrate feasibility and potential to serve as a trading route alternative between China and Europe. Besides, the last column of Table 2 summarizes the major risks and uncertainties faced by the potential route alternatives. Therefore, we concentrate on investigating the impacts of these four economic

[15] The figures are extracted from the official website of the CPEC through http://cpec.gov.pk/maps.

corridors on the China-Europe trading route decisions.

Table 2. The summary and comparison of the six BRI-proposed economic corridors.

Corridor	Major BRI connectivity infrastructure		China-Europe trading route		Remarks	Risks
	In use	In construction	In use	Potential		
NELBEC	NELBEC-based China-Europe freight trains		√			Political unreliability; Capacity
CMREC	CMREC-based China-Europe freight trains		√			Political unreliability; Capacity
CIPEC		Kunming-Singapore Railway		√		Political unreliability
CCAWAEC					Positioned as an energy corridor	
CPEC		China-Pakistan highway and railway systems		√		High mountains and extreme climates; Political unreliability
BCIMEC					Infrastructure development projects are under discussion	

3. The Route Utility Function for the BRI-enhanced logistic network

With the implementation of the diverse BRI economic corridors, the logistics network between China and Europe is greatly expanded. Therefore, a new China-Europe trading route selection problem has emerged. In this section, we firstly illustrate the BRI-enhanced logistics network based on an example. Next, we mathematically formulate a Route Utility Function to evaluate the route alternatives in order to improve the decision making of the Chinese export companies.

3.1 An example of the BRI-enhanced logistics network

The example is based on a company located in Nanjing which produces a general product[16] to be exported in a 40ft standard container to Hamburg, as shown in Figure 5.

[16] A general product refers to a generic product without specifying the product category.

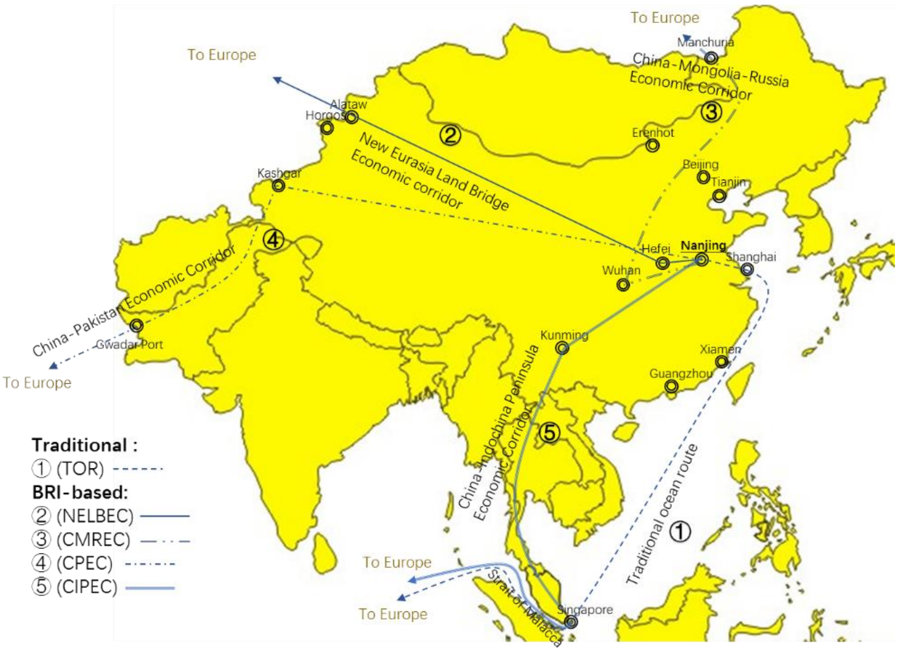


Figure 5. An example of the BRI-enhanced logistics network[17].

The major trading routes in the enhanced network are summarized as follows. First, through the traditional ocean route (TOR), the product should be delivered to Shanghai Port (the nearest sea port) by rail or road for ocean shipping through the Strait of Malacca. Second, through the NELBEC, the Hefei-Hamburg freight train (the nearest NELBEC train) could be applied to carry the cargos to Europe through Alataw Pass. But the container should be transported to Hefei from Nanjing first by rail or road. Third, through the CMREC, the company could apply the Wuhan-Hamburg freight train (the nearest CMREC train) through Manchuria Pass. Similarly, domestic transportation (rail or road) is required from Nanjing to Wuhan. Fourth, if the CPEC is selected, the delivery (rail or road) from Nanjing to Kashgar is necessary, followed by the transportation to Gwadar Port through railway or roadway, where the cargos could be shipped to Hamburg by ocean vessels. Last, the container could start its ocean tour from Singapore if the CIPEC is applied and the cargos are delivered to Singapore through the Kunming-Singapore Railway. Besides, rail and road could be utilized for the movement from Nanjing to Kunming. In this network, Shanghai, Hefei, Wuhan, Kashgar, and Kunming are the transfer stations for the product origin (Nanjing) to connect with the TOR, NELBEC, CMREC, CPEC, and CIPEC, respectively. In summary, considering the infrastructures and corresponding transportation modes available for each section, totally 12 trading route alternatives are available for Nanjing-Hamburg trading businesses in the BRI-enhanced logistics network of Figure 5. They are: 1) TOR-1: Nanjing-*rail*-Shanghai-*ocean*-

[17] This example is constructed by the authors according to the existing industrial practices and the proposals of the BRI economic corridors.

Hamburg; 2) TOR-2: Nanjing-*road*-Shanghai-*ocean*-Hamburg; 3) NELBEC-1: Nanjing-*rail*-Hefei-*rail*-Hamburg; 4) NELBEC-2: Nanjing-*road*-Hefei-*rail*-Hamburg; 5) CMREC-1: Nanjing-*rail*-Wuhan-*rail*-Hamburg; 6) CMREC-2: Nanjing-*road*-Wuhan-*rail*-Hamburg; 7) CPEC-1: Nanjing-*rail*-Kashgar-*rail*-Gwadar-*ocean*-Hamburg; 8) CPEC-2: Nanjing-*rail*-Kashgar-*road*-Gwadar-*ocean*-Hamburg; 9) CPEC-3: Nanjing-*road*-Kashgar-*rail*-Gwadar-*ocean*-Hamburg; 10) CPEC-4: Nanjing-*road*-Kashgar-*road*-Gwadar-*ocean*-Hamburg; 11) CIPEC-1: Nanjing-*rail*-Kunming-*rail*-Singapore-*ocean*-Hamburg; 12) CIPEC-2: Nanjing-*road*-Kunming-*rail*-Singapore-*ocean*-Hamburg.

3.2 The Route Utility Function

Similar to the freight transportation planning and mode selection literature, we propose a Route Utility Function which is the weighted sum of diverse factors to evaluate the route alternatives in the enhanced logistics network (Arencibia et al., 2015; Danielis & Marcucci, 2007). In the literature, cost, transit time, overall transportation mode reliability, and overall transportation mode security (the safety of cargos) for a route are crucial factors in the determination of delivery strategies (Cullinane & Toy, 2000; Danielis & Marcucci, 2007; Jeffs & Hills, 1990; Murphy et al., 1997; Reis, 2014). To be specific, transportation mode reliability refers to the probability of cargos being transported to the destination within a given time by the mode (Reis, 2014), while transportation mode security represents the probability that the cargos remain undamaged during delivery (Kim et al., 2017). For instance, trucks could be easily affected by traffic, road conditions, and bad weather, leading to low mode reliability and mode security. Besides, environmental impacts are gaining increasing attention all around the world (Chan et al., 2013; Chan et al., 2016; Choi et al., 2012; Chung et al., 2018). More importantly, as discussed, the ocean line of the TOR is restricted by the Malacca Dilemma, while the BRI economic corridors are threatened by various risks and uncertainties. Therefore, the transportation connectivity infrastructures are facing the possibility to be cut off. Consequently, in this work, we firstly propose to integrate the factor of infrastructure reliability (the probability of the transportation infrastructure not being cut off) into the decision framework, enabling the decision makers to consider the impact of transportation infrastructures in the trading route decisions. Following the literature, the infrastructure reliability for a route is inserted into the Route Utility Function as an independent factor with a weight, like other traditional factors (e.g., cost).

The enhanced logistics network is denoted by $G\sim(N, A)$, where N represents the set of nodes (including a source node acting as the product origin, a sink node performing as the export destination, and intermediate nodes representing the transfer stations), while A stands for the set of arcs in the network. The set of transportation infrastructures is denoted by F (indexed by f), while that of transportation modes by M (indexed by m)[18]. For each arc, we use two binary variables, x_{ij}^{f}, and x_{ij}^{m}, to stand for whether the infrastructure f and mode m are applied for the delivery from node i to node j, respectively. A feasible path starting from the source node to the sink node in the network represents a possible export trading route (R). The aim of the route selection problem is to identify the optimal path with the highest utility from all the feasible paths in the network. The details of the route utilities are explained as follows.

First, the cost for route R (c_R) equals the sum of the costs incurred by the arcs (c_{ij}^{m}) contained in R (see Eq. (1)). Second, the environmental impact of a route (e_R) is the overall carbon emissions generated by all the involved arcs (e_{ij}^{m}), as shown in Eq. (2). Third, the overall mode reliability for route R (ur_R) is the arithmetic product of the reliability level of the mode applied for each arc contained in R (ur_{ij}^{m}) like Eq. (3). Similarly, the overall mode security of a route (s_R) is the arithmetic product of the security level of the mode applied for each arc in R (s_{ij}^{m}), as in Eq. (4). Last, for the overall infrastructure reliability of a route (ir_R), it equals the arithmetic product of the reliability level of the infrastructure utilized for each arc in R (ir_{ij}^{f}). To illustrate the meaning and details of Eq. (3) to Eq. (5), we use a simple numerical example based on a route consisting of two arcs as shown in Table 3.

$$c_R = \sum_{(i,j)\in R} \sum_{m\in M} x_{ij}^{m} c_{ij}^{m}, \tag{1}$$

$$e_R = \sum_{(i,j)\in R} \sum_{m\in M} x_{ij}^{m} e_{ij}^{m}, \tag{2}$$

$$ur_R = \prod_{(i,j)\in R} \sum_{m\in M} x_{ij}^{m} ur_{ij}^{m}, \tag{3}$$

$$s_R = \prod_{(i,j)\in R} \sum_{m\in M} x_{ij}^{m} s_{ij}^{m}, \tag{4}$$

$$ir_R = \prod_{(i,j)\in R} \sum_{f\in F} x_{ij}^{f} ir_{ij}^{f}. \tag{5}$$

Besides, shippers generally impose a restriction on transit time (i.e., the product should be delivered to the destination within w days). The total transit time required by route R (t_R) is the summation of the time required by the arcs (t_{ij}^{m}) in R (Eq. (6)). A penalty cost will be incurred if the time restriction is violated. Eq. (7) calculates the length of time violated by route R (et_R). If the delivery

[18] Each transportation mode is related to an infrastructure. To be specific, if trains, trucks, or ocean vessels are applied, the corresponding infrastructures adopted are rail line, road, and ocean line, respectively.

time is equal to or smaller than w, et_R equals zero, causing no penalty. On the contrary, et_R is equal to the total transit time t_R minus w if the time requirement is not satisfied. The time-violation penalty cost for route R (pt_R) then equals et_R multiplying the unit penalty cost β_e, as given in Eq. (8).

$$t_R = \sum_{(i,j)\in R} \sum_{m\in M} x_{ij}^m t_{ij}^m, \tag{6}$$

$$et_R = \max\{0, (t_R - w)\}, \tag{7}$$

$$pt_R = et_R * \beta_e. \tag{8}$$

Table 3. An example of the mode reliability & security and infrastructure reliability for a route.

Route: Nanjing-*rail*-Shanghai-*ocean*-Hamburg			Arc mode reliability	Route mode reliability	Arc mode security	Route mode security	Arc infrastructure reliability	Route infrastructure reliability
Arc	Mode	Infrastructure	ur_{ij}^m	ur_R	s_{ij}^m	s_R	ir_{ij}^f	ir_R
Nanjing-Shanghai	Train	Rail line	0.91	0.91*0.83 =0.7553	0.94	0.94*0.92 =0.8648	0.95	0.95*0.75 =0.7125
Shanghai-Hamburg	Ocean vessel	Ocean line	0.83		0.92		0.75	

To summarize the crucial factors that determine the route utility, Table 4 is used to show the specific features of the six factors. Besides, all of these factors are continuous variables.

Table 4. The characteristics of the factors considered in route utility.

Factor[#]	Explanation	Notation	Unit
Cost	Monetary expenditure of the route	c_R	USD
Environmental impact	The pollution emitted by the route, measured by CO_2 emission	e_R	gram (CO_2)
Mode reliability	The overall probability to deliver in time by the modes applied in the route	ur_R	Probability
Mode security	The overall probability to keep cargos safe by the modes applied in the route	s_R	Probability
Infrastructure reliability	The overall probability of the transportation infrastructures applied in the route not being cut off	ir_R	Probability
Transit time	Transit time requirement violation penalty cost of the route	pt_R	USD

[#]All the factors listed in this table are for a route, instead of for an individual arc.

Although we have obtained the mathematical expressions of the factors, their measurement scales are different, causing infeasibility to simply add them together. Therefore, we utilize the normalized forms of these attributes. Specifically, $\widetilde{c_R}, \widetilde{e_R}, \widetilde{ur_R}, \widetilde{s_R}, \widetilde{ir_R}$, and $\widetilde{pt_R}$ represent the normalized transportation cost, environmental impact, mode reliability, mode security, infrastructure reliability, and time-violation penalty cost of route R, respectively. The normalization function is shown in Eq. (9), where the notation with a line on top represents the maximum value of the factor, while that with a line in the bottom stands for the minimum. We use a numerical example regarding the factor of cost to illustrate the mechanism of normalization. Consider the logistics network in Figure 5, a total of 12 trading route alternatives are available. Assume that the maximum cost among the 12 alternatives is 100USD (normalized as 1), while the minimum cost is 50USD (normalized as 0). Then, consider a route with the cost of 60USD. The normalized cost for this route is then equal to (60-50)/(100-50)=0.2. After normalization, all factors are valued in [0,1].

$$\tilde{Y} = \frac{Y-\underline{Y}}{\overline{Y}-\underline{Y}},\ Y = c_R, e_R, ur_R, s_R, ir_R, pt_R. \tag{9}$$

Route Utility Function: $$U_R = \theta_{ir}\widetilde{ir_R} + \theta_{ur}\widetilde{ur_R} + \theta_s\widetilde{s_R} - \theta_c\widetilde{c_R} - \theta_e\widetilde{e_R} - \theta_t\widetilde{pt_R}. \tag{10}$$

Finally, the Route Utility Function is formulated in Eq. (10), where $\theta_{ir}, \theta_{ur}, \theta_s, \theta_c, \theta_e,$ and θ_t are the non-negative weight parameters for infrastructure reliability, mode reliability, mode security, transportation cost, environmental impact, and time-violation penalty cost, respectively. Specifically, the route utility is composed of two parts: i) A positive component of the weighted sum of infrastructure reliability, mode reliability, and mode security; ii) a negative component of the weighted sum of transportation cost, environmental impact, and time-violation penalty cost. The weightings are decided by the export companies based on various considerations like the nature of products to be delivered, company profitability, and governmental policies. For instance, the emphasis on transit time for the delivery of fresh fruits & flowers is much higher than that for cereals. Besides, with rigorous regulations on carbon emissions imposed by governments, companies pay much attention to the environmental issue of the route selections.

4. Analyses

This section evaluates the impacts of the BRI economic corridors on the China-Europe trading route selection decisions through numerical analyses based on the delivery of a 40ft standard container of a general product (equal emphases are laid on the route factors, i.e., $\theta_{ir}, \theta_{ur}, \theta_s, \theta_c, \theta_e,$ and $\theta_t = 1$). The cargo weight is the payload capacity (27.6 ton)[19]. First, Section 4.1 constructs the BRI-enhanced logistics network by determining the export destination in Europe, the product origins in China, and the transfer stations. Then, the necessary transportation data is collected in Section 4.2. Next, the significant advantages of the BRI economic corridors over the TOR, and the heterogeneous impacts of the diverse corridors on different regions of China[20] are investigated in Section 4.3. Finally, the impact of

[19] The data is obtained from http://www.dsv.com/sea-freight/sea-container-description/dry-container.

[20] The Hong Kong Special Administrative Region and Macau Special Administrative Region are excluded from analyses in this paper because they are not included in the China Statistical Yearbook 2017 (NBSC, 2017).

infrastructure reliability is evaluated and the importance to integrate this factor into the decision framework is emphasized in Section 4.4.

4.1 Construction of the enhanced logistics network

First of all, this section constructs the BRI-enhanced logistics network for analysis by determining the export destination in Europe, the product origins in China, and the transfer stations for each product origin to connect with the TOR and BRI economic corridors.

4.1.1 Destination.

Hamburg is selected as the export destination in this work. Among the European countries, Germany is the largest market for Chinese goods. It is reported that there were more than 65 billion USD value of goods being transported to Germany from China in 2016, which ranked the highest in Europe at that time. Besides, Hamburg Port is the largest seaport of Germany, and the Chinese government has established various China-Europe freight trains that end at Hamburg (see Figure 2). As a result, Hamburg is nominated as the product destination in our analysis.

4.1.2 Product origins.

As China is the third largest country in the world with fast-developing economy, there could be numerous schemes to divide the country into various sub-regions for analyses (e.g., by industrial clusters, domestic infrastructures, areas, major hubs, and provinces). In this work, our study is based on the delivery of a general product, ignoring the specific characteristics of different categories of products. Besides, our main purpose is to investigate the advantages of the BRI route alternatives over the traditional ocean route regarding the China-Europe international trading (instead of evaluating the selections of domestic infrastructures). Therefore, we propose to divide China (including 31 provinces and municipalities[21]) into 14 sub-regions (denoted as S1 to S14) according to provinces and geographical proximity (which are common considerations in the literature like Li et al. (2018)) to demonstrate the effects of the corridors. Then, a representing city is assigned to be the product origin within each sub-region, as shown in Table 5. The second column of the table summarizes the provinces/municipalities involved in each sub-region, while the third column lists the representing city. The fourth and fifth columns demonstrate the total area and export value generated by each sub-region,

[21] For ease of expression, the autonomous regions (Xinjiang, Inner Mongolia, Ningxia, Guangxi, and Tibet) and municipalities (Beijing, Tianjin, Shanghai, and Chongqing) are named as “provinces” in this work.

respectively, while the major sea ports located in the sub-regions are stated in the last column. The partitioning principle is explained as follows. First, Xinjiang, Tibet, and Inner Mongolia, as the three largest provinces of China (each occupies more than 10% of the national territory), form S1, S2, and S3, respectively. The respective capital of the three provinces is selected as the representing city for each sub-region. Secondly, as mentioned, the eastern and southern coastal sectors of China contribute the highest export values due to the proximity to the major port terminals. Thus, we define the costal sub-regions according to the key sea ports and geographical proximity. The major ports applied here are the six largest sea ports of China (Ningbo Port, Shanghai Port, Tianjin Port, Guangzhou Port, Qingdao Port, and Dalian Port) (NBSC, 2017). For example, with the support of Guangzhou Port, Guangdong is the most important export province in China. Geographically, Guangxi and Hainan are close to Guangdong. Therefore, these three provinces are combined to form sub-region S4. Regarding the representing city of this sub-region, the capital of the province that generates the highest export value is nominated. Consequently, Guangzhou, the capital of Guangdong Province, is then the representative product origin of S4. Similarly, according to the locations of the other five major ocean ports, S5 (Shanghai, Jiangsu, and Anhui), S6 (Zhejiang, Fujian, and Jiangxi), S7 (Shandong and Henan), S8 (Tianjin, Beijing, and Hebei), and S9 (Liaoning, Jilin, and Heilongjiang) are defined. Besides, Nanjing, Hangzhou, Jinan, Shijiazhuang, and Shenyang are appointed as the corresponding representative product origins of S5-S9. Lastly, for the remaining inland provinces, S10, S11, S12, S13, and S14 are constructed by combining the adjacent provinces. Figure 6 depicts the determined sub-regions, key cities, and major ports.

Table 5. Characteristics of the divided sub-regions of China.

Sub-region	Province/municipalities contained	Representing city*	Area (% of the country)	Export (% of the country)	Major sea port
S1	Xinjiang	Urumqi (Xinjiang)	17.27%	0.66%	
S2	Tibet	Lhasa (Tibet)	12.78%	0.02%	
S3	Inner Mongolia	Hohhot (Inner Mongolia)	12.31%	0.25%	
S4	Guangdong	Guangzhou (Guangdong)	1.87%	31.18%	Guangzhou Port
	Guangxi		2.46%	0.60%	
	Hainan		0.35%	0.17%	
	Sub-total		4.68%	31.95%	
S5	Shanghai		0.07%	7.93%	

	Jiangsu	Nanjing (Jiangsu)	1.07%	15.78%	Shanghai Port
	Anhui		1.45%	1.24%	
	Sub-total		2.59%	24.95%	
S6	Zhejiang	Hangzhou (Zhejiang)	1.06%	13.04%	Ningbo Port
	Fujian		1.26%	4.16%	
	Jiangxi		1.74%	1.15%	
	Sub-total		4.06%	18.35%	
S7	Shandong	Jinan (Shandong)	1.60%	6.88%	Qingdao Port
	Henan		1.74%	2.16%	
	Sub-total		3.34%	9.04%	
S8	Tianjin	Shijiazhuang (Hebei)	0.12%	1.99%	Tianjin Port
	Beijing		0.17%	1.21%	
	Hebei		1.95%	2.10%	
	Sub-total		2.25%	5.30%	
S9	Liaoning	Shenyang (Liaoning)	1.52%	2.14%	Dalian Port
	Jilin		1.95%	0.23%	
	Heilongjiang		4.73%	0.23%	
	Sub-total		8.20%	2.60%	
S10	Qinghai	Yinchuan (Ningxia)	7.52%	0.02%	
	Gansu		4.73%	0.09%	
	Ningxia		0.69%	0.10%	
	Sub-total		12.94%	0.21%	
S11	Shanxi	Xi'an (Shaanxi)	1.63%	0.60%	
	Shaanxi		2.14%	0.75%	
	Sub-total		3.77%	1.35%	
S12	Sichuan	Chongqing (Chongqing)	5.01%	1.25%	
	Chongqing		0.86%	1.60%	
	Sub-total		5.87%	2.85%	
S13	Yunnan	Kunming (Yunnan)	3.99%	0.42%	
	Guizhou		1.83%	0.19%	
	Sub-total		5.82%	0.61%	
S14	Hunan	Changsha (Hunan)	2.20%	0.68%	
	Hubei		1.93%	1.18%	
	Sub-total		4.14%	1.86%	

*The province that the representing city belongs to is shown in the bracket.

4.1.3 Transfer stations.

With the product origins and export destination determined, we then decide the transfer stations for each product origin to connect with the economic corridors or the TOR. For the CPEC and CIPEC, the transfer stations are fixed as Kashgar and Kunming, respectively, while those for the TOR, NELBEC, and CMREC are determined according to the nearest principle. Take S9 as an example. Since Dalian Port is the closest sea terminal for the representing product origin (Shenyang), it is selected as the transfer port of the TOR for S9. Besides, Zhengzhou is the nearest city that operates the NELBEC-based China-Hamburg freight train for Shenyang. Therefore, Zhengzhou is nominated as the transfer station of the NELBEC-based route for S9. Additionally, as Shenyang itself operates a CMREC-based China-Hamburg freight train, there is no need to deliver the cargos to other transfer stations for the utilization of the CMREC. The decided transfer stations for each sub-region are summarized in the 2nd, 5th, 8th, 11th, and 14th columns of Table 11 (please see Appendix).

Figure 6. The sub-regions, key cities, and major ports in the analysis.

4.1.4 Available routes.

With the determination of transfer nodes, the BRI-enhanced China-Hamburg logistics network is constructed. As there might be multiple transportation modes available for some arcs in the network (i.e., both rail and road could be applied to the domestic transportation from product origins to transfer stations), we use suffixes to represent the different mode applications. For example, NELBEC-1 represents that the arc from product origin to the transfer station of the NELBEC applies railway transportation, while NELBEC-2 stands for the utilization of roadway in that arc. The same logic applies to the TOR, CMREC, and CIPEC. Differently, for the CPEC, as railway and roadway are available for both the product origin-Kashgar arc and the Kashgar-Gwadar Port arc, four suffixes are given to the CPEC. Specifically, CPEC-1 and CPEC-2 stand for the application of railway in the former arc, while the latter uses railway and roadway, respectively. Differently, CPEC-3 and CPEC-4 mean the employment of roadway in the former arc, with the latter using railway and roadway, respectively. Additionally, for the representing cities that themselves are the originating stations of the TOR or the proposed corridors, no suffix is assigned to the corresponding route (including the CMREC of S9, the TOR of S4, the CIPEC of S13, and the NELBEC and CMREC of S14). We show the available trading routes in the enhanced logistics network in Table 6 using S4 as an example.

Table 6. An example of available trading routes in the BRI-enhanced logistics network.

<table>
<tr><th>Origin</th><th>Available routes</th><th colspan="5">Route details</th><th>Destination</th></tr>
<tr><td rowspan="11">Guangzhou (S4)</td><td>TOR</td><td colspan="5">ocean</td><td rowspan="11">Hamburg</td></tr>
<tr><td>NELBEC-1</td><td>rail</td><td rowspan="2">Transfer station: Xiamen</td><td colspan="3" rowspan="2">rail</td></tr>
<tr><td>NELBEC-2</td><td>road</td></tr>
<tr><td>CMREC-1</td><td>rail</td><td rowspan="2">Transfer station: Changsha</td><td colspan="3" rowspan="2">rail</td></tr>
<tr><td>CMREC-2</td><td>road</td></tr>
<tr><td>CIPEC-1</td><td>rail</td><td rowspan="2">Transfer station: Kunming</td><td rowspan="2">rail</td><td rowspan="2">Singapore</td><td rowspan="2">ocean</td></tr>
<tr><td>CIPEC-2</td><td>road</td></tr>
<tr><td>CPEC-1</td><td rowspan="2">rail</td><td rowspan="2">Transfer station: Kashgar</td><td>rail</td><td rowspan="4">Gwadar</td><td rowspan="4">ocean</td></tr>
<tr><td>CPEC-2</td><td>road</td></tr>
<tr><td>CPEC-3</td><td rowspan="2">road</td><td rowspan="2">Transfer station: Kashgar</td><td>rail</td></tr>
<tr><td>CPEC-4</td><td>road</td></tr>
</table>

4.2 Data collection

In order to facilitate the evaluation of the diverse trading route alternatives, it is essential to collect all the necessary transportation data for the enhanced logistics network as follows.

4.2.1 Distance.

The distances among the product origins to the transfer stations of the TOR, NELBEC, and CMREC by rail or road are collected in Table 11 in Appendix (the 3rd, 4th, 6th, 7th, 9th, and 10th columns), while the distance information of the NELBEC-based and CMREC-based China-Hamburg freight trains is summarized in the 7th column of Table 12 (Appendix). Besides, the lengths of sea travel from Chinese ports to Hamburg Port are elaborated in the second column of Table 13 (Appendix). For the routes along the CIPEC or CPEC, the products produced in each sub-region should be transported by rail or road to Kunming or Kashgar first, the distances of which are demonstrated in the 12th, 13th, 15th, and 16th

columns of Table 11 (Appendix). In addition, as the transportation infrastructures are still under construction, the on-land transportation distance data of the CIPEC and CPEC are estimated as follows: Kunming to Singapore (Rail: 3900km)[22], Kashgar to Gwadar Port (Rail: 3000km, Road: 2808km)[23]. Finally, the ocean section from Singapore Port to Hamburg Port in the CIPEC and that from Gwadar Port to Hamburg Port in the CPEC are shown in the last two rows of Table 13 (Appendix).

4.2.2 Carbon emissions.

The environmental impact of the transportation modes is collected from the Guidelines for Measuring and Managing CO_2 Emission from Freight Transport Operations published by the European Chemical Industry Council[24]. From this guideline, it is reported that among the considered transportation modes, road trucks generate the highest level of carbon dioxide (62 g/ton-km), followed by freight trains (22 g/ton-km). The deep-sea container vessel is the most environmentally friendly mode, emitting only 8g carbon dioxide per ton per kilometer.

4.2.3 Speed.

Generally, the speed of road trucks is the highest among the three modes, followed by railway and ocean vessels. Regarding the roadway speed, according to the traffic safety regulations of China, the maximum and minimum speeds for trucks on highways are 100 and 60 km/h, respectively. Accordingly, an average of 80 km/h is applied for road transportation. Regarding the railway speed, as the Kunming-Singapore Railway and the Kashgar-Gwadar Railway are under construction, we use the average speed of 35.6 km/h which is estimated for the freight trains in China[25]. On the other hand, the speeds of the China-Hamburg freight trains are estimated based on the distance and transit time information collected in Table 12 (Appendix). To be specific, an average of 29.92 km/hour is obtained for the NELBEC-lines and 33.49 km/hour for the CMREC-lines. For ocean shipping, the normal speed of 16 knots is applied.

4.2.4 Cost.

Overall, ocean shipment is the most cost-efficient transportation mode, while roadway is the most expensive one, followed by railway. In the analysis, the ocean shipping fee for a 40ft container is approximated as 0.16 USD per nautical mile according to the quotations of ocean freighters (P.S.: the details are shown in Table 13). Regarding the road freight cost, we utilize 0.058 USD/ton-km which is

[22] https://en.wikipedia.org/wiki/Kunming%E2%80%93Singapore_railway.
[23] https://en.wikipedia.org/wiki/Karakoram_Highway; https://globalmaritimehub.com/wp-content/uploads/attach_435.pdf.
[24] https://www.ecta.com/resources/Documents/Best%20Practices%20Guidelines/guideline_for_measuring_and_managing_co2.pdf.
[25] https://www.statista.com/statistics/278404/speed-of-freight-trains-in-china/.

estimated from a Chinese road freight price quotation website[26]. Besides, the rail freight rate for a 40ft standard container, as shown in Eq. (11), is obtained from the rate standard regulated by the Ministry of Railways of the People's Republic of China[27]. Specifically, the total rail expense from node i to node j (c_{ij}^{rail}) equals the summation of a fixed cost (ϵ_{rail}=99 USD) and a variable cost that is the product of the unit variable cost (τ_{rail}=0.4 USD/km) and the distance between the two nodes (d_{ij}^{rail}).

Railway cost function: $$c_{ij}^{rail} = \epsilon_{rail} + \tau_{rail} * d_{ij}^{rail}. \quad (11)$$

4.2.5 Mode reliability and security.

Among the three modes, railway is reported to be the most reliable one, while road trucks could be easily affected by traffic, road conditions, and bad weather. Besides, weather also imposes significant influence on the reliability of ocean vessels[28]. Regarding the cargo security, it is concluded that the water transport and rail transport provide higher security levels than road transport[29]. Therefore, the reliability levels of trains, road trucks, and ocean vessels are randomly selected from the range of [0.90, 1.00], [0.80, 0.90], and [0.80, 0.90], respectively. Additionally, the security levels of the three modes are randomly generated from [0.90, 1.00], [0.80, 0.90], and [0.90, 1.00], respectively. Table 7 summarizes the obtained reliability and security levels of the three modes.

Table 7. The generated mode reliability and security levels.

Mode	Reliability	Security
Railway	0.91	0.94
Road truck	0.82	0.86
Sea vessel	0.83	0.92

4.3 Demonstration: The heterogeneous impacts of the BRI economic corridors

This section evaluates the benefits of the BRI economic corridors over the TOR, and investigates the heterogeneous impacts of the BRI economic corridors on the trading route selection decisions for the export companies located in different regions of China. A basic scenario where the reliability levels of all transportation infrastructures in the enhanced logistics network are set as one to exclude the influence of infrastructure reliability. In addition, three cases with different delivery time requirements (15 days, 25 days, and 35 days) are proposed. By applying the Route Utility Function formulated in Section 3.2,

[26] http://www.51yunli.com/costcounter.aspx.
[27] http://www.ndrc.gov.cn/zwfwzx/zfdj/jggg/201501/t20150130_662884.html.
[28] https://freighthub.com/en/blog/modes-transportation-explained-best/.
[29] http://pernerscontacts.upce.cz/41_2015/Majercak.pdf.

the utilities of the diverse route alternatives for each sub-region are obtained, through which the optimal routes with the highest utilities could be identified. We show the results obtained from the 15-days case in Table 14 (please see Appendix) as an example.

Generally, for each sub-region, the TOR routes generate much lower costs and environmental impacts than the other route alternatives due to the major utilization of ocean vessels. However, ocean shipping is disadvantageous because of the long traveling distance and low speed. Therefore, for each sub-region, the TOR requires the longest delivery time, followed by the CPEC and CIPEC that also consist of long sea shipment. On the other hand, the NELBEC and CMREC routes spend the least time during transportation owing to the relatively shorter distances and higher speed of trains than ocean vessels. Besides, the major application of railway makes the NELBEC and CMREC advantageous in high mode reliability and security, but disadvantageous in high costs. In addition, for the route arcs that both roadway and railway are available (i.e., the domestic delivery from product origins to transfer stations and the movement from Kashgar to Gwadar), it is found that, although roadway could achieve a shorter transit time for the arc, the high level of air pollution and transportation costs, and the low level of mode security and reliability, prevent it to be a good choice compared to railway. Therefore, in our analysis, railway is always selected rather than roadway for the arcs where both modes are available.

Table 8 summarizes the optimal route selections for each sub-region under the three cases in the basic scenario. From the results, several implications could be concluded.

Table 8. The optimal routes for each sub-region in the basic scenario.

Sub-regions	15-days case												25-days case												35-days case											
	TOR		NELBEC		CMREC		CIPEC		CPEC				TOR		NELBEC		CMREC		CIPEC		CPEC				TOR		NELBEC		CMREC		CIPEC		CPEC			
	1	2	1	2	1	2	1	2	1	2	3	4	1	2	1	2	1	2	1	2	1	2	3	4	1	2	1	2	1	2	1	2	1	2	3	4
S1					√																√												√			
S2					√										√												√									
S3			√												√										√											
S4					√								√												√											
S5			√												√										√											
S6			√												√										√											
S7			√												√										√											
S8			√												√										√											
S9					√												√												√							
S10					√										√												√									
S11			√												√												√									
S12					√										√										√											
S13					√										√										√											
S14					√										√												√											

First, it is obvious that the BRI economic corridors are superior to the TOR as 80% of the optimal selections are the BRI routes among the three cases. On average, the BRI routes save 33.61% of delivery time compared with the TOR for all sub-regions. Hence, one could expect that when the time requirement is rigorous, the TOR becomes increasingly undesirable due to the expensive time violation penalty costs. Accordingly, as seen in Table 8, the BRI routes account for 92.86% of the optimal decisions in the 25-days case, and a remarkable of 100% in the 15-days case. Consequently, it is concluded that the BRI economic corridors are especially advantageous over the TOR when tight delivery time requirements are proposed.

Second, in the 35-days case where the time requirement is relatively loose, the advantages of cost efficiency and low carbon emissions of ocean vessels enable the TOR to be the best selection for more than a half of the sub-regions, most of which are located in the southern and eastern coastal regions of China. Therefore, we conclude that the TOR could be an attractive solution for the coastal regions when a loose time requirement is raised. However, one exception is S9 that always prefers the CMREC rather than the TOR even in the 35-days case.

Third, among the BRI economic corridors, the NELBEC and CMREC are proved to be the most preferable trading route alternatives. Overall, these two China-Europe freight trains are the optimal choice for 73.8% of the sub-regions in the three cases. Moreover, it is noted that in the 15-days case, all sub-regions turn to the NELBEC and CMREC trains, which implies that the China-Europe freight trains could provide the most valuable solutions for Chinese export businesses especially when the delivery is required to be completed in short times.

Fourth, in the 25-days and 35-days cases, CPEC-1 shows great potential to support the China-Europe trading logistics for the companies located in S1 that is the closest sub-region to the CPEC. On the contrary, CPEC-2, CPEC-3, and CPEC-4 demonstrate low route utilities due to the application of roadway for the delivery either from product origins to Kashgar or from Kashgar to Gwadar Port. However, the construction projects related to these routes impose significant strategic importance for both the development of Pakistan and the enhancement of the Chinese international logistics network. Therefore, the significance of these routes should not be underestimated.

Last, the CIPEC shows little impact on the China-Europe trading route selections, as none of the sub-regions in all cases select the CIPEC routes. Even for S13, the representing city of which (Kunming) is exactly the originating station of the CIPEC, it prefers CMREC-1 in the 15-days case, NELBEC-1 in the 25-days case, and TOR-1 in the 35-days case, rather than the CIPEC routes. To be specific, for S13, in the 15-days and 25-days cases, the CIPEC routes are inferior than CMREC-1 and NELBEC-1 mainly due to the lengthy delivery time led by the long rail journey from Kunming to Singapore and the following long ocean travel from Singapore to Hamburg. In the 35-days case, the CIPEC routes are less attractive than TOR-1 primarily because of the high costs and carbon emissions led by the long railway transportation from Kunming to Singapore. However, although this corridor may not provide preferable delivery routes for the China-Europe trading market, it helps enhance the diversity of the Chinese international logistics network and the collaboration between China with the ASEAN countries.

4.4 Demonstration: The impact of infrastructure reliability

After demonstrating the heterogeneous impacts of the BRI economic corridors in a basic scenario, we focus on studying the impact of infrastructure reliability on the China-Europe trading route selections in this section. As discussed in Section 1 and Section 2, the transportation infrastructures along the BRI economic corridors and the TOR are threatened by diverse risks and uncertainties. Therefore, it is possible that the reliability of some infrastructures declines to a low level. Accordingly, in this section, we generate new scenarios to study the impact of infrastructure reliability. Specifically, seven scenarios (Scenarios 1 to 7, as shown in Table 9) are constructed. In each new scenario, the reliability level of one infrastructure declines to 0.1, while the others remain unchanged[30]. For example, in Scenario 2, the reliability level of the NELBEC rail line decreases to 0.1, while those for the other infrastructures are still 1. Note that the value of 0.1 is set for the purpose of illustration. Actually, it could be any value less than 1 (e.g., 0.99, 0.5). This is because that a decrease in the infrastructure reliability level would lead the normalized infrastructure reliability for the corresponding route to be 0, while those for other routes to be 1. Besides, in the constructed scenarios, it is seen that a decrease in infrastructure reliability of the original optimal route (selected in the basic scenario) would always lead to a shift of the best selection to the second-optimal route identified in the basic scenario. Therefore, we arbitrarily use the value of 0.1 to demonstrate and highlight the impact of infrastructure reliability on the China-Europe trading route selections.

[30] The reliability levels of the rail line and roadway in China remain unchanged in all scenarios due to two reasons: i) The infrastructures in China are well-developed and secure; ii) our study focus is on investigating the impact of the infrastructure reliability of the BRI corridors and the TOR.

Table 9. The infrastructure reliability levels in Scenario 1 to Scenario 7.

Route	Infrastructure	Reliability	Route	Infrastructure	Reliability
Chinese part	Rail-line	1	CIPEC	Kunming-Singapore rail line	1; 0.1 (Scenario 4)
	Road	1		Ocean line through Malacca to Hamburg	1; 0.1 (Scenario 1)
TOR	Ocean line through Malacca to Hamburg	1; 0.1 (Scenario 1)	CPEC	Kashgar-Gwadar rail line	1; 0.1 (Scenario 5)
NELBEC	NELBEC rail line	1; 0.1 (Scenario 2)		Kashgar-Gwadar road	1; 0.1 (Scenario 6)
CMREC	CMREC rail line	1; 0.1 (Scenario 3)		Ocean line from Gwadar to Hamburg	1; 0.1 (Scenario 7)

The route utilities are updated for each scenario in the 35-days case, and the new optimal trading routes for each sub-region are depicted in Figure 7, where the shadow shapes represent that the optimal choice of the sub-region in the new scenarios differs from that in the basic scenario (35-days case) obtained in Section 4.3. From the results, the following implications could be obtained.

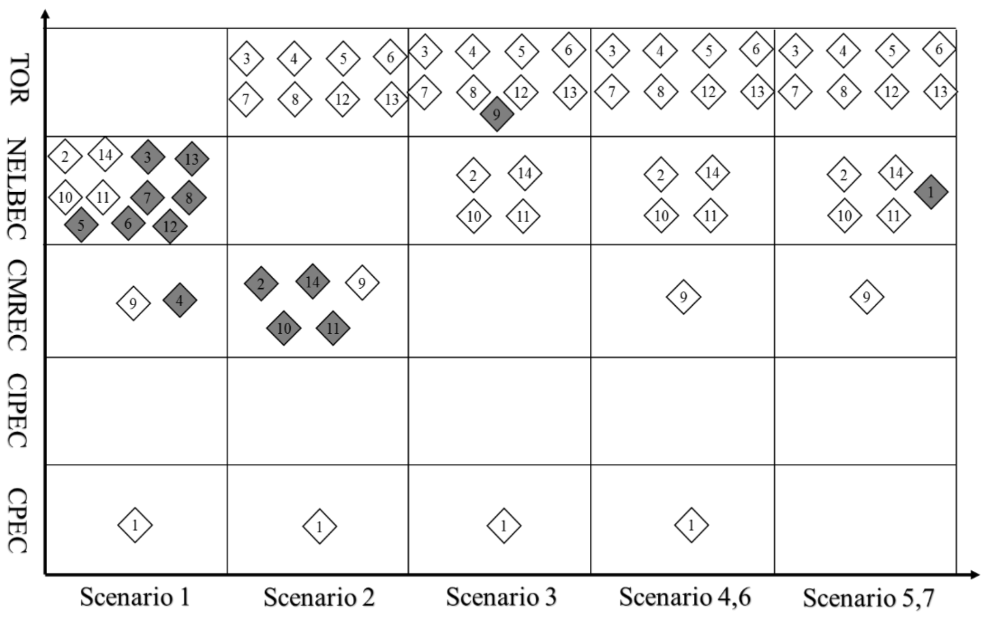


Figure 7. The optimal routes for each sub-region in Scenario 1 to Scenario 7 in the 35-days case.

First, in Scenario 1, the reliability of the ocean line through the Strait of Malacca declines, affecting the TOR and CIPEC that pass through this strait. From Figure 7, we can see that the eight sub-regions selecting the TOR in the basic scenario now turn to the routes of China-Europe freight trains.

Specifically, seven turn to the NELBEC, while one goes to the CMREC, implying that once the TOR becomes unreliable, the NELBEC and CMREC are the best alternatives. Besides, totally 57.14% of the sub-regions are affected to change their optimal decisions due to the infrastructure reliability reduction of the TOR, which is highest among all the 7 scenarios. Therefore, it is concluded that the variation in the TOR infrastructure reliability brings the most significant impact on the trading route decisions for the Chinese export companies.

Second, in Scenario 2, the reliability of the NELBEC rail line drops, leading S2, S10, S11, and S14 to shift from the NELBEC to CMREC. Differently, when the reliability of the CMREC rail line falls in Scenario 3, S9 turns to the TOR instead of the NELBEC. The reason is that S9 is a coastal sub-region with a major sea port (Dalian Port). When the CMREC becomes vulnerable, the merits of low costs and air pollutions of the TOR make it better than the NELBEC for S9 when a loose delivery time requirement is imposed.

Third, in Scenario 4, the reliability decrement of the Kunming-Singapore rail line leads to no route decision adjustments as the CIPEC imposes little impact on the China-Europe trading route selections. Similarly, none of the sub-regions adjust the optimal decisions in Scenario 6 where the reliability of the roadway from Kashgar to Gwadar decreases.

Last, Scenario 5 and Scenario 7 impose the identical impacts on the route decisions of the companies located in S1. Specifically, their optimal route changes from CPEC-1 to the NELBEC-based China-Europe freight trains. The reason behind is that the reliability decline of either the Kashgar-Gwadar rail line or the ocean line from Gwadar to Hamburg could make CPEC-1 unsatisfactory. Therefore, the reliability levels of these two infrastructures should be carefully maintained to preserve the benefits of the CPEC.

In summary, it is shown that the infrastructure reliability imposes significant impact on the optimal decisions for the China-Europe trading route selections. Considering the diverse risks and uncertainties faced by the BRI economic corridors and the TOR, it is hence of great importance to integrate this factor into the decision framework. Besides, it is essential for the government to maintain the reliability level of the economic corridors to maximize the benefits of the BRI.

5. Developmental suggestions

From the perspective of practical operations, this section proposes several managerial suggestions with the objective to help maximize the benefits brought by the BRI.

First, as discussed, the NELBEC-based China-Europe freight trains cross the Chinese border through the Alataw Pass or Horgos Pass in Xinjiang Province. Currently, most of the NELBEC freight trains originate from the central, southern, and eastern regions of China, just passing through Xinjiang without making any contribution to the economic development of this province. However, Xinjiang is a resourceful province that is rich in vegetables, fruits, livestock, and cereal products, which is believed to have a great potential export market in Europe. If the existing NELBEC China-Europe freight trains are used, the exporters in Xinjiang have to waste much time and money transporting their products to the originating cities located in other parts of the country like Zhengzhou. Consequently, the advantages of the NELBEC are strictly limited for Xinjiang Province. Therefore, we propose that it is necessary and beneficial to establish more Xinjiang (Urumqi)-Europe freight trains to improve the international logistics services and stimulate the economic development for this region. From the analysis in Table 10, we could expect a remarkable average reduction of 45.52% in the traveling distance, 56.32% in the freight cost, 53.52% in the carbon emission, and 49.52% in the transit time if the proposed Urumqi-Hamburg freight train (denoted as NELBEC-new) is applied for the exporters located in Urumqi, compared with the existing routes analyzed in Section 4.3 (NELBEC-1 and NELBEC-2). As could be seen, the avoidance of the redundant delivery between Urumqi and Zhengzhou brings huge benefits for both the export companies and the environment. However, although establishing more Xinjiang (Urumqi)-Europe freight trains could bring huge benefits for Xinjiang province, the increasing number of the NELBEC-based trains would impose huge pressure on the capacity of the NELBEC railway line. Therefore, efficient scheduling and operations management are essential for this developmental suggestion.

Table 10. Benefits of the proposed Urumqi-Hamburg freight train for the companies in Xinjiang (S1).

Route	Course	Distance (km)	Cost (USD)	Enviro (g)	Time (h)
NELBEC-new	Urumqi-(*rail*)-Hamburg	7210	2983	4377912	203
NELBEC-1	Urumqi-(*rail*)-Zhengzhou-(*rail*)-Hamburg	13218	5485	8025970	426
NELBEC-2	Urumqi-(*road*)-Zhengzhou-(*rail*)-Hamburg	13250	9045	11397144	379
Reductions achieved by the NELBEC-new					
	NELBEC-1	45.45%	45.62%	45.45%	52.43%
	NELBEC-2	45.58%	67.02%	61.59%	46.61%

Average	45.52%	56.32%	53.52%	49.52%

Second, although the China-Europe freight trains along the NELBEC and CMREC show great benefits in delivery time reduction and high reliability compared to the TOR, the majority of the trains only carry Chinese cargos to Europe without taking European products back to China during the return journey, which leads to the one-way Belt and Road trading dilemma. The major reason is the relatively low demand of Chinese market for European products. To facilitate the normal operations of the China-Europe freight trains, the Chinese government is paying high subsidies to the freight train operators. In order to deal with this problem, several strategies could be adopted. First, the government could collaborate with the European countries to spur the demand for Europe-made products of the Chinese consumers. Actually, this is happening as an increasing number of Chinese customers are pursuing high-quality European products like healthy food and infant formulas. Second, governmental policies could be established to encourage enterprises to utilize these reliable and time-efficient rail lines as the China-Europe trading (both import and export) route. However, the growth in demand for European products may impose negative impacts on the domestic commodities of China, which should be carefully considered by policy makers.

Third, many of the existing China-Europe freight trains are non-stop direct trains from China to the destination markets in Europe. Thus, although these block trains pass through diverse central and western Asian countries like Kazakhstan, Tajikistan, Turkmenistan, and Uzbekistan, the benefits obtained by these countries are mainly the railway toll charges. Therefore, these intercontinental railways have devoted little contribution to the bilateral trading between China with these countries and the economic development of the involved nations. Indeed, the Chinses products are popular in these Asian countries, and their abundant resources are welcomed by China. Accordingly, we propose that setting up stops along the China-Europe rail line should be considered in the development plans in the future. However, due to the distinct customs and trade regulations of the countries along the railway line, smooth and efficient trading is not easy. Therefore, efforts on trade and economic cooperation between China with these countries are crucial for the success of this developmental strategy.

6. Conclusions

The establishment of the Belt and Road Initiative could enhance the international logistics network of

China, thus reducing the dependence of the China-Europe trading industry on the traditional ocean route through the Strait of Malacca. Six economic corridors are proposed to improve the connectivity between China and its neighboring countries through diverse transportation infrastructure construction or upgrading projects. However, whether the proposed corridors have the potential to serve as the China-Europe trading route alternatives is unknown. Besides, the specific impact of the various corridors on the route decision making of the companies located in different regions of China is unclear. Moreover, little research has studied the influence of the uncertainties in transportation infrastructure reliability on the optimal trading route selections.

By reviewing the BRI projects, we identify the four corridors (New Eurasia Land Bridge Economic Corridor, China-Mongolia-Russia Economic Corridor, China-Pakistan Economic Corridor, and China-Indochina Peninsula Economic Corridor) with great potential to serve as the route alternative for the China-Europe trading business. Besides, a Route Utility Function which integrates the factors of cost, transit time, mode reliability, mode security, environmental impact, and infrastructure reliability is constructed to evaluate the diverse route options in the BRI-enhanced logistics network. Through comprehensive analyses based on the delivery case of a general product from China to Hamburg, the significant advantages of the BRI economic corridors over the TOR are demonstrated. Specifically, we find that the BRI routes are especially advantageous when the delivery time requirement is stringent, while the TOR could still be attractive to some coastal regions under a loose delivery time requirement. Besides, the heterogeneous impacts of the diverse economic corridors are illustrated. In short, the New Eurasia Land Bridge Economic Corridor and China-Mongolia-Russia Economic Corridor are found to be the most desirable trading route alternatives for the majority regions of the nation, while the China-Pakistan Economic Corridor could be preferable for the companies located in West China (i.e., Xinjiang). Moreover, seven scenarios are generated to show the significance of integrating the factor of infrastructure reliability into the trading route decision framework and the essence for the government to maintain the reliability level of the proposed economic corridors. Finally, with the aim of helping maximize the benefits of the BRI, we propose three managerial suggestions for the strategic planning of the China-Europe freight trains. First, more Urumqi-Europe freight trains could be established to benefit the Xinjiang export market. Second, strategies such as policy establishment and cost reduction could be utilized to solve the one-way Belt and Road trading dilemma. Third, stops along the rail line could be considered to enhance the bilateral cooperation and trading between China and the involved countries.

Despite the remarkable advantages of the BRI-proposed new trading routes, from the perspective of political issues, we suggest that it is essential for the governments involved in the BRI to work and collaborate closely to support the smooth and efficient operations of the transnational transportation connectivity infrastructures and construction projects by providing a stable and reliable political environment. This is because political reliability is shown to be a prominent prerequisite for the success of the BRI economic corridors, as the benefits brought could be rather limited due to potential breakages caused by political tensions (Yu, 2017; Huang, 2016). Besides, policies that enhance the development and promote the applications of the BRI economic corridors should be established to maintain the sustainability of the initiative.

In summary, this research is believed to bring significant benefits for the company decision makers through the improvements in decision making regarding the optimal selections of the trading route between China and Europe in the increasingly competitive market led by the BRI. For future research directions, as we consider the delivery case of a general product in this work, future extensions could explore the impact of the BRI economic corridors on the transportation of different categories of products with heterogeneous emphases being laid on the diverse route selection factors. Accordingly, different region-division schemes such as industrial clusters and domestic infrastructures based schemes could be useful. Besides, we consider deterministic situations in this work. That is, all parameters remain static for the BRI-enhanced logistics network. However, in reality, situations could change dynamically, leading to the random nature of the crucial factors, which definitely imposes huge impacts on the optimal decision making. Therefore, stochastic routing problem under the BRI should be a desirable and significant future research direction. Furthermore, we propose that sensitivity analysis or simulation are interesting tools to derive more insights regarding the selection of BRI economic corridors by generating various scenarios with different parameter settings (e.g., varying infrastructure reliability levels).

Appendix

Table 11 summarizes the distance information between the determined product origins to the transfer stations of the TOR, NELBEC, CMREC, CPEC, and CIPEC.

Table 11. Distance information from product origins to the determined transfer stations*.

Sub-region	TOR			NELBEC			CMREC			CIPEC			CPEC		
	Transfer port	Distance (km)		Transfer station	Distance (km)		Transfer station	Distance (km)		Transfer station	Distance (km)		Transfer station	Distance (km)	
		Rail	Road		Rail	Road		Rail	Road		Rail	Road		Rail	Road
S1	Tianjin	3280	2953	Zhengzhou	3004	3036	Zhengzhou	3004	3036	Kunming	4225	3763	Kashgar	1475	1464
S2	Guangzhou	4980	3613	Changsha	4273	3213	Changsha	4273	3213	Kunming	4116	2230	Kashgar	6660	3315
S3	Tianjin	772	662	Zhengzhou	1312	872	Yingkou	1191	1103	Kunming	3053	2563	Kashgar	3502	3462
S4	Guangzhou	0	0	Xiamen	778	643	Changsha	707	671	Kunming	1658	1348	Kashgar	5406	5361
S5	Shanghai	315	298	Hefei	156	170	Wuhan	516	540	Kunming	2683	2112	Kashgar	4649	4823
S6	Ningbo	171	202	Hefei	445	431	Wuhan	1113	764	Kunming	2493	2194	Kashgar	5090	5046
S7	Qingdao	381	347	Zhengzhou	668	447	Zhengzhou	668	447	Kunming	2978	2304	Kashgar	4052	4307
S8	Tianjin	429	370	Zhengzhou	408	418	Zhengzhou	408	418	Kunming	2893	2326	Kashgar	3334	4094
S9	Dalian	397	380	Zhengzhou	1416	1360	Shenyang	0	0	Kunming	4035	3236	Kashgar	4854	4655
S10	Tianjin	1472	1209	Zhengzhou	1294	1560	Zhengzhou	1294	1560	Kunming	2191	2308	Kashgar	2818	3349
S11	Tianjin	1393	1153	Zhengzhou	487	482	Zhengzhou	487	482	Kunming	1946	1527	Kashgar	3796	3731
S12	Guangzhou	1697	1383	Changsha	1044	892	Changsha	1044	892	Kunming	1405	838	Kashgar	3700	4182
S13	Guangzhou	1637	1378	Changsha	1587	1311	Changsha	1587	1311	Kunming	0	0	Kashgar	4797	4878
S14	Guangzhou	707	734	Changsha	0	0	Changsha	0	0	Kunming	1587	1310	Kashgar	4699	4715

*The distance information is collected from government websites and maps.

The international freight railways between China and Hamburg are summarized in **Table 12**. To be specific, the first column in the table gives the train number of the railways, while the second column stands for the starting stations of the railways in China. The third and fourth columns show the border pass and approximate transit time, respectively. Besides, the fifth and sixth columns tell whether the train is based on the NELBEC or the CMREC. Finally, the last three columns present the data of distances and average speeds. Averagely, the speeds of the NELBEC-based and CMREC-based freight trains are slightly different (29.92 km/hour and 35.6 km/hour, respectively).

Table 13 illustrates the distances between the Chinese major seaports, Singapore Port, and Gwadar Port, with Hamburg Port. The last column gives the corresponding fees quoted by ocean carriers. Specifically, the quotations for Ningbo Port, Shanghai Port, Tianjin Port, Guangzhou Port, and Qingdao Port to Hamburg Port are obtained from Hapag-Lloyd AG, a multinational German-based transportation company, while those for Dalian Port and Singapore Port are from Seabay International Freight Forwarding Ltd and Evergreen Logistics Corporation, respectively. Additionally, as there is currently no shipping line operating between Gwadar Port and Hamburg Port, an estimated price of 1629 USD obtained from *Freightos* is applied. Actually, the sea freight rates always fluctuate due to diverse reasons such as oil price fluctuation and season changes. Therefore, we apply the average cost of these shipping lines as the ocean transport rate in this work. Accordingly, the average ocean shipping cost per nautical mile for a 40ft container is 0.16 USD.

Table 14 gives the utilities of the route alternatives in the BRI-enhanced logistics network for each sub-region when the delivery is required to be completed within 15 days in the basic scenario. The optimal route for each sub-region is highlighted in bold, italic, and underlined fonts.

Table 12. Major China-Hamburg freight trains*.

Train No.	Starting city	Border pass of China	Approximate transit time (days)	NELBEC	CMREC	Distance (km)	Average speed (km/day)	Average speed (km/hour)
X8001, X8003, X8005, X8069	Zhengzhou	Alataw / Horgos	15	√		10214	680.93	28.37
X8202/3	Zhengzhou	Erenhot	15		√	10300	686.67	28.61
X8406/5	Wuhan	Manchuria	13.5		√	12000	888.89	37.04
X8017/8/7, X8011/2/1, X8035/6/5	Wuhan	Alataw / Horgos	15	√		10324	688.27	28.68
X8066/5	Hefei	Alataw	15	√		11000	733.33	30.56
X8057	Yingkou	Manchuria	13		√	11200	861.54	35.90
X8059/60/59	Shenyang	Manchuria	13		√	11000	846.15	35.26
X8428/7	Changsha	Alataw	15	√		11200	746.67	31.11
X8422/1	Changsha	Erenhot	15		√	11305	753.67	31.40
X8098/7	Xiamen	Alataw	16	√		11866	741.63	30.90
X8031	Harbin	Manchuria	12.5		√	9820	785.60	32.73

* The information summarized in the table is collected from news and government websites.

Table 13. Ocean shipment to Hamburg*.

Seaport	Distance to Hamburg Port (nautical mile)	Distance to Hamburg Port (km)	Normal speed/knots	Estimated transit (hours)	Estimated transit time (days)	Quoted fee (USD) / a 40ft standard container
Ningbo	12225	22641	16	764	32	1850
Shanghai	12277	22737	16	767	32	1700
Tianjin	13023	24119	16	814	34	1850
Guangzhou	11444	21194	16	715	30	1650
Qingdao	12629	23389	16	789	33	1850
Dalian	12846	23791	16	803	33	1890
Singapore	9620	17816	16	601	25	1780
Gwadar	7063	13081	16	441	18	1629

*The distances are obtained from http://ports.com/sea-route/, while the shipping fees are collected from http://www.sofreight.com/ and https://ship.freightos.com/search.

Table 14. The route utilities obtained in the 15-days case under the basic scenario.

Sub-regions	TOR		NELBEC		CMREC		CIPEC		CPEC			
	1	2	1	2	1	2	1	2	1	2	3	4
S1	0.49	-1.01	0.97	-0.67	***1.02***	-0.65	-0.42	-2.12	0.84	-0.68	-0.21	-1.67
S2	0.64	-0.79	0.84	-0.57	***0.90***	-0.51	-0.17	-1.03	0.07	-1.40	-0.82	-2.24
S3	0.64	-0.12	***1.29***	0.48	1.21	0.28	-0.36	-1.44	0.27	-1.01	-1.10	-2.33
S4	1.11		1.02	0.34	***1.22***	0.49	-0.37	-1.05	-0.20	-1.21	-1.49	-2.45
S5	0.66	-0.01	***1.43***	0.74	1.31	0.55	-0.34	-1.18	0.07	-1.05	-1.33	-2.40
S6	0.67	0.00	***1.40***	0.67	1.24	0.51	-0.32	-1.20	0.00	-1.09	-1.36	-2.41
S7	0.64	-0.05	***1.44***	0.70	1.43	0.69	-0.38	-1.28	0.16	-1.01	-1.26	-2.38
S8	0.64	-0.05	***1.46***	0.70	1.45	0.69	-0.31	-1.26	0.30	-0.90	-1.21	-2.35
S9	0.29	-0.26	0.91	0.17	***1.48***		-0.71	-1.61	-0.16	-1.17	-1.40	-2.37
S10	0.64	-0.24	1.33	0.24	***1.36***	0.23	-0.12	-1.29	0.46	-0.86	-1.04	-2.31
S11	0.64	-0.21	***1.50***	0.71	1.49	0.70	-0.06	-0.91	0.31	-0.96	-1.11	-2.32
S12	0.64	-0.21	1.25	0.43	***1.33***	0.49	-0.15	-0.79	0.23	-0.98	-1.26	-2.41
S13	0.64	-0.19	1.22	0.38	***1.30***	0.45	0.62		0.08	-1.06	-1.35	-2.43
S14	0.32	-0.29	1.41		***1.44***		-0.50	-1.12	-0.24	-1.24	-1.48	-2.43

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