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Sustainable Development of the China Railway Express under the Belt and Road Initiative: Focusing on Infrastructure Reliability and Trade Facilitation

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Abstract: The China Railway Express (CR Express) is an important component of the Belt and Road Initiative (BRI). The sustainable development of CR Express provides critical support for regional economic integration and promotes a balanced development of the supply chain. Infrastructure reliability and trade facilitation greatly impact the operation of CR Express and are crucial for improving the competitiveness of transnational trade and cross-border efficiency. Inconsistent transportation infrastructure standards and low-efficient transportation service procedures affect the cross-border movement of cargo among countries. This paper integrates quantified metrics of infrastructure reliability and trade facilitation into a spatial friction model based on the electrical resistance theory, estimating the impact of these factors on the transportation flow of CR Express. Additionally, three scenarios of infrastructure reliability and trade facilitation are established for the four trade routes from Zhengzhou to Hamburg. Numerical experiments show that compared with inland river routes and traditional ocean routes, infrastructure reliability and trade facilitation significantly influence the transport flow of CR Express. These research results can provide a reference for the improvements of CR Express transportation efficiency and the simplification of customs clearance processes, potentially promoting the sustainable development of the CR Express supply chain to some extent.

Keywords: the Belt and Road initiative; infrastructure reliability; trade facilitation; sustainable development

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1. Introduction

Traditionally, the freight mode between China and Europe has mainly relied on shipping for many years. To enhance the development of a trade relationship between China and Europe, the Chinese government proposed the Belt and Road Initiative (BRI) in 2013, which aims to establish a higher-quality transportation infrastructure between China and Europe [1,2]. The China Railway Express (CR Express) is an important component of the BRI. The CR Express showcases its time advantage over traditional shipping methods [3]. Compared with traditional China–Europe liner shipping, the CR Express offers shorter transportation time [4]; compared to air transportation, the CR Express has lower transportation costs, which significantly reduces carbon emissions during the transportation process, decreases energy consumption, and improves the efficiency of the supply chain [2]. Through the CR Express, Chinese goods can be efficiently delivered to the European market, while European products can be also transported to China. This optimizes the allocation of resources, strengthens economic ties between countries along the route, promotes regional economic integration, and fosters the balanced development of the supply chain. These benefits are very conducive to the sustainable development of the supply chain.

However, the CR Express is also faced with problems of lower quality of service, poor operational efficiency, different gauges, diversity of infrastructure standards and so on in the cross-border logistics collaboration between China and Europe. In particular, the punctuality of the CR Express is severely impacted by lengthy delays at cross-border stations [5]. Additionally, due to the impact of the Suez Canal vessel blockage incident, the CR Express has become more important as an alternative to traditional shipping routes [2]. Simultaneously, ocean shipping, passing through the Strait of Malacca and the Indian Ocean, is not always reliable due to heavy traffic flow or pirates [6]. The Chinese government has been focusing on the reliability of trade routes owing to the potential threat resulting from geopolitical uncertainty and transportation security [7].

It is vital to capture the impact of the potential congestion and reliability on rail corridors and ocean shipping. From the perspective of economics, efficient logistic service and reliable infrastructure can not only reduce the cost of trade but also promote trade flows among different countries. The efficiency and reliability of trade routes significantly impact the choice of shippers based on the timely delivery of goods [8]. In this paper, we propose a transportation network flow model that considers the potential impact of cargo flows on rail corridors and ocean shipping based on improvements in hard and soft infrastructures.

Currently, less attention is paid to the impact of qualitative factors on trading route selection such as the service quality of logistics and the reliability of the infrastructure on transportation flow. In practice, shippers choose trading routes not only paying attention to transportation costs but also considering the service efficiency of the transportation mode and the reliability of the infrastructure. It is commonly accepted that the longer the delivery time, the more unreliable the transport option. However, time is strongly associated with the improvement of service and infrastructure [9]. Consequently, in this paper, infrastructure reliability and trade facilitation are chosen as explanatory variables to investigate the impact of changes in transportation costs on the choice of trade routes of shippers, thereby reflecting changes in freight volume on transportation routes.

Infrastructure reliability is difficult to quantify. In order to study its impact on transportation route selection, we have given it a corresponding probability range. The impact of trade facilitation is assessed by the Logistics Performance Index. The Logistics Performance Index is used as a variable to study the impact of trade facilitation. This paper incorporates infrastructure reliability, trade facilitation, and transportation costs into a spatial friction network flow model based on resistance theory, analyzing their influence on the selection of China–Europe trade routes under the BRI.

Our main contributions are summarized as follows:

i. Investigating the influence of qualitative factors such as transport service (“software”) and infrastructure (“hardware”) on transportation cost, and further influence on the selection of shipper transportation routes, thereby reflecting the change of the freight volume of transportation routes
ii. Quantifying infrastructure reliability and trade facilitation to demonstrate the important role of other influencing factors beyond transportation costs in enhancing the competitive advantage in terms of traffic routes
iii. Applying a spatial friction model based on the electrical resistance theory to study the impact of transportation route selection based on the change of transportation cost

The remaining sections are organized as follows. Section 2 reviews the relevant literatures on trading route selection based on infrastructure reliability and trade facilitation. Section 3 introduces a two-step methodology. Section 4 demonstrates case application. Section 5 is the conclusion.

2. Literature Review

2.1. Transportation Infrastructure Improvement

The standard and quality of infrastructure, as well as the underdevelopment of logistics infrastructure and services, are often seen as barriers to the competitiveness of trading routes. Some researchers attempted to investigate the influence of infrastructure reliability on freight transportation. Herrero et al. [10] studied the impact of improving cross-border infrastructure between China and Europe on transportation costs. A bi-level programming model was proposed by Yang et al. [11] to investigate the influence of the improvement of the hub port and the railway system on the shipping network between China and Europe. Reliability, availability, and maintainability analyses were applied by Hidirov and Guler [12] to railway infrastructure management to show the importance of freight transportation. A route utility function was proposed by Wen et al. [7] to evaluate the significant impact of some qualitative factors such as mode reliability, infrastructure reliability and mode security on the selection of trade routes. Transportation infrastructure availability and safety of the transportation process were embedded by Muravev et al. [13] into the multi-criteria decision making model to research the location of logistics centers of the CR Express. A structural general equilibrium model was applied by Soyres et al. [14] to quantify the impact of the improvements in transportation infrastructure, associated with BRI, on trade costs, welfare, and Gross Domestic Product. The congestion caused by the infrastructure facilities was integrated by Li et al. [5] into the multi-modal multi-commodity transportation network model to investigate the effect on the change of freight flows along ocean shipping and rail lines. The above-mentioned references demonstrate the influence of infrastructure improvements on the change of trade routes from different perspectives. In addition, some scholars have studied the impact of technological improvements on reliability. Tan et al. [15] and Hu et al. [16] researched the impact of the improvements of the related technologies in infrastructure on railway transportation performance and metro tunnel water leakage.

2.2. Trade Facilitation Influence

In March 2015, three Chinese ministries jointly issued the "Vision and Action Plan for the Belt and Road Initiative," affirming that trade facilitation is one of the fundamental aspects of the BRI construction and a significant area for international cooperation in trade-related infrastructure [17]. The efficiency of customs clearance procedures has a significant impact on the cost of goods trade. Refs. [18,19] have researched the influence of trade facilitation or trade barriers on the logistics cost. Johns et al. [20] applied international indicators for trade facilitation performance, and they concluded that trade facilitation along the CR Express corridors was weaker than global averages in a global context. The Actor-Network Theory was applied by Wang and Yau [21] as the qualitative analytical framework to study the role of facilitating cross-border transportation along the CR Express corridors. Ramasamy et al. [22] compared the impact of physical infrastructure and border administration on the exports along the CR Express corridors and concluded that improvements in trade facilitation had a significant influence on exports. Wang et al. [23] applied the spatial error model to verify the effect of government corruption on ecological efficiency. The Gaussian Mixture Model was applied by Liang et al. [24] to study the influence of trade facilitation on the trade size of transnational e-commerce from the perspective of the transaction cost theory. Pang [25] researched the positive effect of customs cooperation on trade facilitation of countries among the Belt and Road through the analysis of a series of customs problems. Li and Zeng [26] used the extended gravity model to study the effect of the trade facilitation level of the countries along the BRI corridors on the export trade potential. The gravity model was used for evaluating the effect of cross-border trade facilitation mechanism on Pakistan's export [27].

It can be known that the development of BRI has been studied by many scholars since the release of this initiative in 2013 from the above-mentioned studies. The management and optimization of the logistics networks among BRI economic corridors have been the research hotpot of global logistics [3,28,29]. However, most researchers mainly focused on mode competition in the trading route selection between ocean shipping and the CR Express from the aspect of cost [5,30]. In particular, these studies on trade facilitation primarily considered the cost of infrastructure construction, with little consideration given to qualitative factors such as improvements in infrastructure, customs clearance, and logistics services, and did not account for the integration of hardware and software. Additionally, some researchers pointed out that qualitative factors are also powerful determinants influencing trading route selection because issues of logistic service are of greater importance for shippers to deliver goods on time [20,31–33]. In fact, shippers not only attach importance to high-quality "hardware," such as better infrastructure between countries, but also consider better "software", such as customs clearance, improved logistics services, and the operational efficiency of the entire route.

In this paper, trade facilitation and infrastructure reliability are integrated into the decision framework of transportation route selection to investigate the influence of the changes in transportation costs on the changes in freight volumes among transportation routes.

3. Methodology

In this paper, transportation costs, quantified infrastructure reliability, and trade facilitation are regarded as the total transportation cost to utilize the spatial friction model based on the electrical resistance theory to study the impact of transportation route selection through the change of transportation cost.

As shown in Figure 1, our method is divided into two steps. The first step is to quantify infrastructure reliability and trade facilitation, thereby determining total transport costs. The total transportation cost includes unit transport cost, freight forwarding cost, (un)loading cost, and other factors costs. The quantification of infrastructure facilitation takes into account railway standard, voltage difference, and other factors. Trade facilitation is quantified based on trade policies, customs procedures, and other factors.

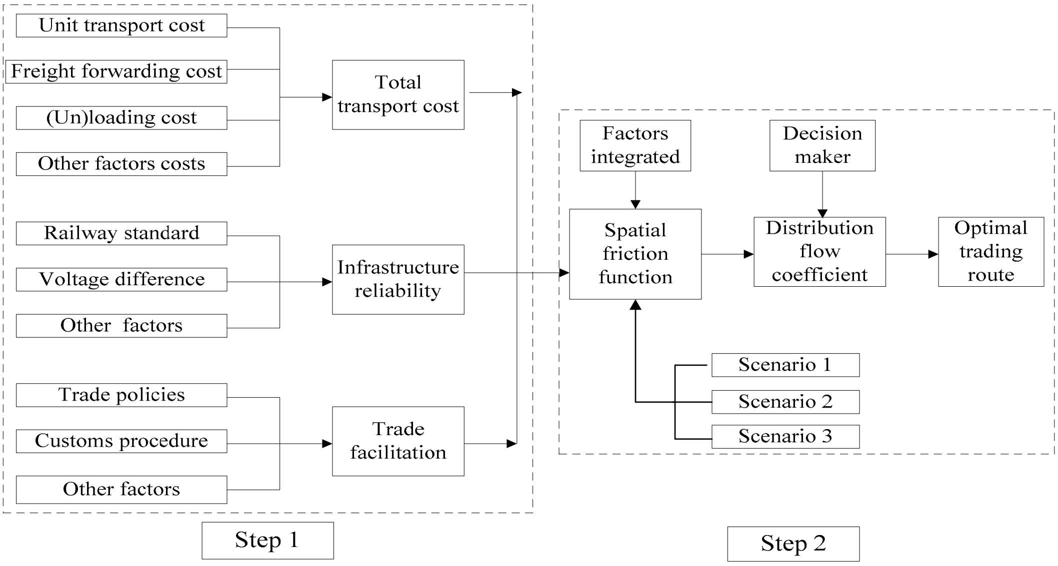

Figure 1. The framework of our method.

In the second step, these factors and the transportation cost are integrated into the spatial friction function through a dynamic process with the scenario analysis method. According to the impact of infrastructure reliability and trade facilitation on carrier behavior, the operation of CR Express is divided into three stages (scenarios), namely the initial operations stage (Scenario 1), the improvement operations stage (Scenario 2), and the future operations stage (Scenario 3). The details are as the follows. The quantified factors from the first step are integrated into the spatial friction function, and the optimal trade routes are determined according to the transportation flow coefficient based on the spatial friction function.

Scenario 1: initial operations stage. This stage is the initial operation stage of CR Express, and infrastructure reliability and trade facilitation are not considered in terms of operation efficiency. Since the first China–Europe freight train departed from Chongqing to Duisburg, Germany, the CR Express has been operating on the Trans-Siberian Land Bridge (SLB) and the New Eurasian Continental Bridge (NECB). The CR express passes through different countries, with the railway gauges in these countries being either standard gauge or wide gauge. The transshipment of these different railway gauges can lead to additional cost burdens. Moreover, some countries along the BRI corridors are relatively backward in infrastructure and transport service [34]. The aforementioned factors may cause the freight rate of the CR Express to be higher than that of traditional sea freight.

Scenario 2: improved operations stage. Poor infrastructure has been regarded as the main cause affecting the effectiveness of this important corridor [35]. Some countries have begun to employ standard gauges on newly built railway projects to better connect the Chinese railway network [36]. On the basis of the initial operation phase, the improvement of the infrastructure along BRI corridors is assumed to be based on the Chinese standard [37]. In the improved operational phase, we consider infrastructure reliability and trade facilitation, although there is still room for improvement in trade facilitation. As indicated by the current operational performance of the CR Express, the total transportation cost has decreased compared to the initial operation phase.

Scenario 3: future operations stage. Based on the improved operations stage, the standardization of the railway infrastructure relies on the improvement of the "hardware" of railway transportation. In the future, higher-level reforms through "software" services such as one-stop customs clearance can promote bilateral and multilateral trade facilitation [38]. In the future operations stage, we assume the establishment of a free trade agreement within the BRI regions to better coordinate the related countries to build up trade facilitation measures.

3.1. Qualitative Factors Quantified and Related Transport Costs (Step 1)

3.1.1. Infrastructure Reliability Quantified

It is difficult to quantify the influence of infrastructure reliability and trade facilitation of transport services. In this paper, infrastructure reliability is quantified with reference to Wen et al. [7] to reflect the influence of infrastructure reliability, as shown in Equation (1). The infrastructure reliability is quantified based on the product of the corresponding probability. The overall infrastructure reliability P_R is the arithmetic product of the infrastructure reliability of each section in route R from origin (o) to destination (d), and the formulation is as follows:

$$P_{IR} = \prod\nolimits_{(i,j)\in R} \sum\nolimits_{f\in F} x_{ij}^{f} IR_{ij}^{f} \tag{1}$$

where F is the set of transportation infrastructures (indexed by f), and IR_{ij}^{f} stands for the probability of applying infrastructure f in a section (i, j) of the route R. Each section $(i, j) \in \mathrm{R}$, x_{ij}^{f} is defined as follows:

$$x_{ij}^{f} = \begin{cases} 1, & f \text{ is applied for delivery from } i \text{ to } j, \\ 0, & \text{otherwise.} \end{cases}$$

3.1.2. Trade Facilitation Quantified

It is well-known that inefficient trade procedures not only increase total trade costs but also affect the choice of shippers. Trade facilitation reforms of international freight transportation are of great importance for streamlining the flow of goods across borders. In this paper, the Logistics Performance Index (LPI) is adopted as an explainable variable to assess trade facilitation. The six LPI components are the efficiency of customs and border management clearance, the quality of trade and transport infrastructure, the ease of arranging competitively priced shipments, the competence and quality of logistics services, the ability to track and trace consignments, and the frequency of on-time deliveries [8]. LPI scores are obtained through a standardized questionnaire ranging from one to five by the World Bank and relevant 652 logistic professionals [8], and then normalized to between [0,1] using the following Equation (2). Finally, the value of trade facilitation is obtained by the product of the normalized value and the assumed external value.

$$\omega = \frac{max(x_i) \ - \ x_i}{max(x_i) - min(x_i)} \tag{2}$$

where ω denotes the normalized LPI scores, and x_i represents the LPI scores before normalization.

3.1.3. Costs Relevant to Goods Transportation in Transport Process

Costs are identified based on transportation mode, unit cost, distance, and other factors in terms of transporting a full 40 foot standard container between China and Europe. In this paper, the freight rate of railways for a 40 foot standard container is obtained from the rate standard regulated by the Chinese government. Herein, r and v stand for rail mode and ocean mode, respectively. The total railway cost TC_{od}^{r} between origin o and destination d is shown in Equation (3).

$$TC_{od}^{r} = FC_r + VC_r \tag{3}$$

where FC_r is the fixed cost of a unit container, and VC_r denotes the variable cost, which equals the unit variable cost (γ_r) multiplying the distance (φ_{od}^{r}) between two nodes, as shown in Equation (4).

$$VC_r = \gamma_r * \varphi_{od}^{r} \tag{4}$$

Similarly, the sea cost—that is, the vessel transportation cost TC_{od}^{v} between origin o and destination d—can be calculated using the following vessel transportation cost function, as shown in Equation (5).

$$TC_{od}^{v} = \alpha_v * \beta_{od}^{v} \tag{5}$$

where α_v is the unit variable cost, and β_{od}^{v} is the distance between two nodes.

Given the diversity of cost, it is assumed that the main costs are applied in this paper for the simplicity of calculation, and then the total transport cost (*TTC*) for a 40 foot container from origin o to destination d can be expressed as follows (6):

$$TTC = TC + HC + FFC \tag{6}$$

where *TC* is the total cost generated by the main mode, i.e., rail (TC_{od}^{r}) or vessel (TC_{od}^{v}), *HC* is the total cost for (un)loading cargoes among nodes, and *FFC* is the cost for freight forwarding.

3.2. Spatial Friction Functions (Step 2)

Inspired by Bollobás [39] and Kundu and Sheu [4], we employ the spatial friction model to analyze the impact of infrastructure reliability and trade facilitation on the choice of transport routes during the three stages of the CR Express. The entire trade route is divided into multiple sections based on the differences in train gauge and transportation modes.

We consider the total cost composed of infrastructure reliability, trade facilitation, and transportation costs as the transportation resistance along the route. By using the spatial friction function, we determine the optimal trade route. Transport cost is related to unit cost, time, and distance. The better the infrastructure reliability, the higher the degree of convenience of transportation services, the shorter the time required, and the lower the total cost. From step 1, the spatial friction function F_K can be expressed as Equation (7):

$$F_K = \sum_{k=K} TTC_{ij} + \rho * (1 - P_{IR}) + \mu * (1 - \omega) \tag{7}$$

where $\sum_{k=K} TTC_{ij}$ is the sum of transportation costs for different arcs from origin o to destination d, K denotes the set of routes, k indicates the route in the transportation network, (i, j) represents the set of arcs in the transportation network and TTC_{ij} is the transportation costs for different arcs (i, j). The symbol μ is an external variable on the improvement of the trade facilitation of transport service, and then $\mu * (1 - \omega)$ is the normalized loss value of the score of LPI of trade facilitation on the trading route (o, d). The symbol ρ is an external variable of the enhancement of infrastructure reliability, and then $\rho * (1 - P_{IR})$ represents the loss value of infrastructure reliability between o and d. The value of F_{od} stands for the transport resistance of the trade route.

The above parameters are applied to quantify the corresponding resisting effects by a function. However, the dimensions of the parameters are different. We use the calibration procedure, which is from Bollobás [39] and Kundu and Sheu [4], to address the problem.

Herein, the different dimension values of the transport flow friction function are normalized by Equation (8),

$$F_K = \begin{bmatrix} F_1 & \dots & F_K \\ \vdots & \ddots & \vdots \\ F_K & \dots & F_K \end{bmatrix} \tag{8}$$

where F_K denote the freight flow function along the transit nodes among the trade routes. Subsequently, the freight flow percent (U) along each transit section is obtained through the inter-nodal freight friction function. After that, the freight flow coefficient is formulated in the form of the network flow of electric current through resisters, following the method of Bollobás [39] and Kundu and Sheu [4].

The freight flow coefficient of a single trade route is shown in Equations (9) and (10):

$$U_1 = \frac{F_2}{F_1 + F_2} U_{ideal} \tag{9}$$

$$U_2 = \frac{F_1}{F_1 + F_2} U_{ideal} \tag{10}$$

where U_{ideal} represents the ideal transportation volume of 100% on transportation route, and U_1 and U_2 denote percentages of the ideal transportation volume responding to the resisting force F_1 and F_2 along each section. Similarly, U_K possesses the same meaning for a network with K parallel routes:

$$U_K = \frac{F_{1-equivalent}}{F_1 - F_{1-equivalent}} U_{ideal} \tag{11}$$

$$F_{1-equivalent} = \frac{F_2 F_3 \cdots F_K}{\sum F_1 F_2 F_3 \cdots F_{K-1}} \tag{12}$$

Hence, the transport flow percent (U_K) of the whole network is expressed with the following matrix:

$$U_K = \begin{bmatrix} U_1 & \dots & U_K \\ \vdots & \ddots & \vdots \\ U_K & \dots & U_{KK} \end{bmatrix} \tag{13}$$

Through the matrix transformation, the optimal trade route can be determined based on the comparison of the maximum transport flow percent values. Subsequently, a case study will be shown based on the BRI in the following section.

4. Case Application and Numerical Illustration

In this section, we utilize the spatial friction model to check the effect of trade facilitation and infrastructure reliability on freight volume changes under the BRI. It is expected that the research results can also provide help for Chinese export enterprises to choose appropriate trade routes.

The case study on the trade route selection is performed based on the assumption of the 40 ft standard container located in China to be exported to Europe in combination with the impact of infrastructure reliability and trade facilitation on transportation volume. Here, it is assumed to be exported from Zhengzhou to Hamburg, which is selected as the destination because Germany is the largest export market for Chinese cargoes in Europe. Trains and vessels are chosen for the process of comparison of trade routes. For the simplicity of calculation, the transportation scale is ignored in this paper.

A comparison of the proposed trade routes is summarized, as shown in Figure 2. First, the container is delivered to Erenhot from Zhengzhou by rail and then continues to be delivered by train via the Eurasian Land Bridge to arrive in Hamburg. The transportation mode of the whole route is rail, which is Route 1. Second, the train departs from Zhengzhou, then leaves China through Alashankou, and continues to go through New Eurasian Land Bridge to Hamburg. This route is operated by railway, which is Route 2. Third, a train is used to carry the container to Kashgar from Zhengzhou, then continues to Gwadar by train, and is finally shipped by vessel through the Suez Canal to Hamburg, which is Route 3. Fourth, the container is transported by rail from Zhengzhou to Shanghai and then shipped from Shanghai through the Suez Canal to Hamburg, which is Route 4. The detailed information map of each route is shown in Figure 2. In this network, Shanghai, Erenhot, Gwadar, and Alashankou are viewed as the nodes for the division of infrastructure reliability and trade facilitation of the container transportation route. Here, Gwadar is assumed as a node for the convenience of the division of infrastructure reliability since the China–Pakistan Economic Corridor (CPEC) is under construction by Chinese railway companies.

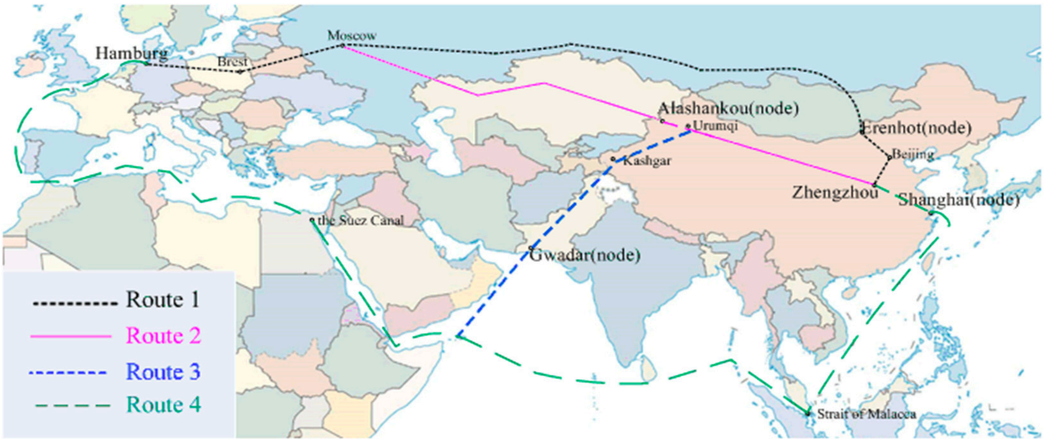

Figure 2. Map of the proposed trade routes.

4.1. Data Collection

The associated data are gathered to better evaluate the influence of infrastructure reliability and trade facilitation on the choice of diverse trade route by using the proposed method.

1. Infrastructure reliability

There is currently no consensus on evaluating the infrastructure reliability index in the previous literatures [40]. The railway infrastructure across Eurasia is characterized by differences in railway systems on gauges, voltages, loading heights, coupling, and safety systems [29]. According to the different rail gauges, each route is divided into different arcs and railway systems, the concrete contents are shown in Table 1. In addition, the reliability of transportation systems is also influenced by heavy traffic flow, earthquakes, pirates, and so forth. The reliability of the infrastructure of the intermodal mode might be lower than that of unimodal transportation [41]. In this paper, the reliability index value of infrastructure is determined following the method by Wen et al. [7]. Infrastructure reliability and trade facilitation are not included in Scenario 1, which is regarded as the reference scenario. According to Wen et al. [7], the infrastructure reliabilities of routes of Scenario 2 and Scenario 3 are the product of their respective given probabilities and assumed external values, with the given probabilities ranging between zero and one.

Table 1. The arcs and railway systems of four transportation routes based on Zhengzhou–Hamburg.

Arc	Route 1	Route 2	Route 3	Route 4
Arc 1	Zhengzhou–Erenhot (SRG)	Zhengzhou–Alashankou (SRG)	Zhengzhou–Kashgar (SRG)	Zhengzhou–Shanghai (SRG)
Arc 2	Erenhot−Brest (BRG)	Alashankou−Brest (BRG)	Kashgar−Gwadar (SRG)	Shanghai–the Suez Canal (V)
Arc 3	Brest–Hamburg (SRG)	Brest–Hamburg (SRG)	Gwadar–Hamburg (V)	the Suez Canal–Hamburg (V)

Notes: SRG denotes standard rail gauge, BRG denotes broad rail gauge, and V denotes vessel.

2. Trade facilitation

In this paper, LPI is adopted as a variable to quantify the influence of trade facilitation on transportation costs. Herein, the score of LPI is obtained through a standardized questionnaire on a scale of one to five by the related logistic professionals at the World Bank. It is difficult on this score to quantify trade facilitation directly. Therefore, the scores of LPI will be normalized by Equation (2), and all normalized values are valued between [0,1]. Relatively speaking, the trade facilitation performance of low-income countries is generally weaker than that of higher-income countries. Hence, the value of the trade facilitation index is chosen based on high-income groups, which is inputted into Scenario 2 and Scenario 3. In addition, the assumed external value of the improvement of trade facilitation, μ, is given in this paper, and then $1-\omega$ is the loss value of return on trade facilitation. Then, the value of trade facilitation is the product of the corresponding normalized value and the assumed external value–that is $\mu * (1-\omega)$ of Equation (7).

3. Distance

The distances of the four different trade routes between source and destination are different in this paper. The distances of Route 1 and Route 2 are divided into three parts owing to the differences in train gauge, as shown in Table 1. The standard rail gauge is used in China, Poland, Germany, and so on, while the broad rail-gauge is applied in Kazakhstan, Belarus, Russia, and so on. Additionally, the construction of the infrastructures of CPEC is still ongoing, and the distance of railway transportation from Kashgar to Gwadar port is obtained from Wen et al. [7]. The other route distances are collected from news websites and government websites. The concrete distances are shown in Table 2.

Table 2. The route distances of four transportation routes based on Zhengzhou–Hamburg.

Index	Route 1	Route 2	Route 3	Route 4
Total distance, km	10,454	10,245	20,026	23,735
Chinese standard gauge distance, km	1400	3606	3945	998
Foreign broad gauge distance, km	7954	5539	-	-
Foreign standard gauge distance, km	1100	1100	3000	-
Seaborne distance, nm	-	-	7063	12277
Period, days	15	15	21	32

Notes: a dash indicates that it is empty item; nm—nautical miles; km–kilometer; FEU–Forty Foot Equivalent Unit.

4. Transport cost

The freight costs for the related train routes and seaborne container shipping lines are calculated and shown in Table 3, and the data in the table are from Jiang et al. [42], Xinhua Silk Road, Sofreight, and other websites. In this section, the freight rate of the train transportation part of Route 4 is obtained from the rate standard regulated by the Chinese government, where the fixed cost FC_r, in Equation (3) equals 97 USD per container and the unit variable cost γ_r, in Equation (4) is 0.4 USD/km. However, the freight rates in Europe are different from the freight rates in China owing to cost structure reasons. It is evident that the unit costs for standard gauge rails are distinct from that of broad gauge rails, as a result of the reasons previously mentioned. Accordingly, there are three different unit prices on railway transportation. Then, the total cost is the product of unit cost and distance. Additionally, it is well known that the infrastructure of the China–Pakistan corridor is being built and managed by Chinese companies. The estimated costs of the relative items are obtained from Chinese railway transportation routes and ports, as shown in Table 3.

Table 3. Transport costs of four transportation routes based on Zhengzhou–Hamburg.

Index	Route 1	Route 2	Route 3	Route 4
Chinese unit cost, USD/FEU·km (standard gauge)	0.6	0.6	0.6	0.4
Foreign unit cost, USD/FEU·km (broad gauge)	0.441	0.694	-	-
Foreign unit cost, USD/FEU·km (standard gauge)	0.864	0.864	0.6	-
Foreign unit cost, USD/FEU·nm (seaborne container)	-	-	0.16	0.16
(un)Loading unit cost, USD/FEU	1000	1000	1165	1165
Forwarding cost, USD/FEU	1500	1500	1629	1700
Total freight costs, USD/FEU	7798	9458	8091	5229
External variable μ(USD)	60,000.00	60,000.00	60,000.00	60,000.00
External variable ρ(USD)	40,000.00	40,000.00	40,000.00	40,000.00

Notes: a dash indicates that it is empty item; nm—nautical miles; km–kilometer; FEU–Forty Foot Equivalent Unit.

The ocean shipping cost is the product of unit cost per nautical mile and the distance between two ports. The estimated price for a 40 ft container of seaborne shipping is 0.16 USD per nautical mile, and the quoted price for a 40 ft container on the China–Pakistan Economic Corridor under construction is estimated as 1629 USD per standard container, which can be referred to Ref. [7]. Transport unit prices of Scenario 1 are considered as a reference scenario, which is different because of the different railway gauges and countries. Based on Scenario 1, the transport unit prices of Scenario 2 will be given to the middle one shown in Table 3. The transport unit prices of Scenario 3 will be given to the lowest one shown in Table 3 based on Scenario 2.

4.2. Analysis and Discussion

We first compare and analyze the four routes based on the transport flow friction percent, and then conduct a sensitivity analysis on the infrastructure reliability and trade facilitation.

4.2.1. Comparison and Analysis of Four Routes Based on Transport Flow Friction Percentages

Figure 3 displays the transportation volume percent of different routes. It can be seen that Route 4 has a related better transportation flow percent than the other three routes in terms of the comparison of cost excluding reliability and trade facilitation, which indicates that the traditional ocean shipping line has the bigger competitive advantage in China–Europe trade route selection owing to the lowest transportation costs. On the other hand, Route 2 has the lowest transportation flow coefficients compared with other routes. Although Route 2 has a shorter transport time shown in Table 2, it still has higher transport costs perhaps because this railway route passes through more countries than other routes, which results in more transshipment in the process of transportation. It shows that the more countries a route passes through, the more inspections are required, which consequently takes more time and results in higher transport costs. Route 1 has a similar situation to Route 2 in Scenario 1, but most of the distance of Route 1 is in the territory of

Russia. In addition, the unit price of the broad gauge of this route is lower than that of other land routes, and the lower total transportation cost is also reasonable.

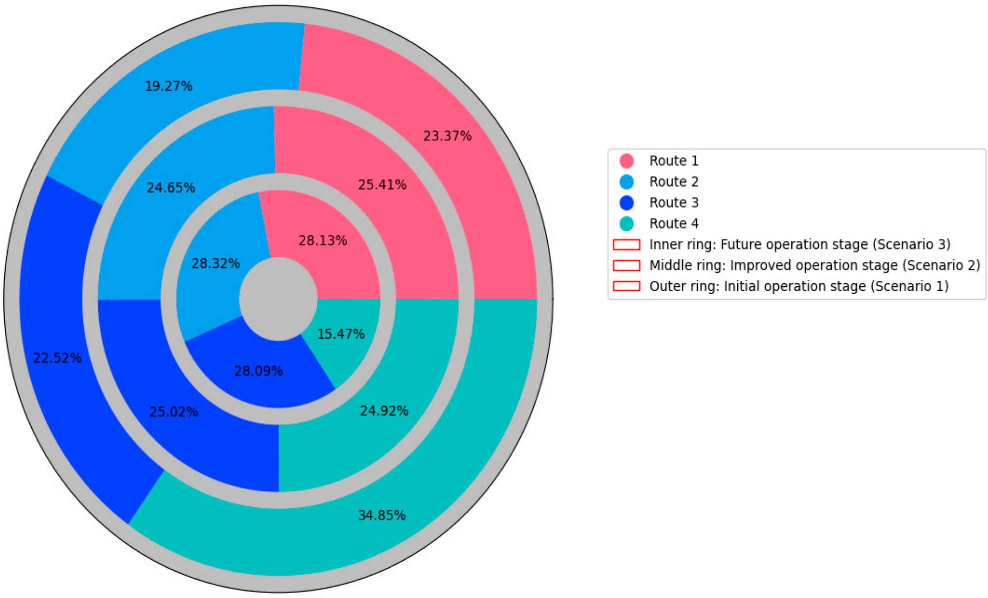

Figure 3. Proportional distribution of freight volumes of transportation routes.

The transportation flow percentages changed when infrastructure reliability and trade facilitation were incorporated into the proposed model in Scenario 2. The transportation flow coefficients for Route 1, Route 2, and Route 3 were increased by enhancing infrastructure reliability and improving trade facilitation from Figure 3. Route 3 shows an increase, although it is the combination of railway transport and ocean shipping. Meanwhile, Route 3 has a relatively shorter distance than Route 4. Correspondingly, the transportation flow coefficient of Route 4 declined due to the influence of the lower reliability and lower level of trade facilitation.

Figure 4 illustrates larger changes in the transportation flow percentages when more reliable infrastructure and more perfect trade facilitation are introduced in assumed Scenario 3. It can be observed in Figure 4 that Route 4 in Scenario 3 exhibits a greater reduction than in Scenario 1, with a negative 125 percent decline in the transportation flow percent. On the contrary, Route 1, Route 2, and Route 3 experience a relatively larger increase in the transportation flow percent. In particular, Route 2 shows a 32 percent increase in the transportation flow percent when compared with Scenario 1. Similarly, Route 1 and Route 3 exhibit a 17 percent and a 20 percent increase, respectively. This can be explained by the influence of infrastructure reliability and trade facilitation on transportation volume.

The changes of the freight volumes for Routes 2 and 4 are particularly pronounced. On the one hand, this is because Route 2 passes through many countries. When their infrastructure is standardized and trade facilitation measure is unified, the transport competitiveness of these countries is enhanced. On the other hand, the reliability of the ocean shipping itself is relatively lower due to the threat of piracy and unreliable infrastructure, which could lead to higher costs. Correspondingly, Route 4 not only passes through the Strait of Malacca but also transits the Gulf of Aden. On the contrary, Routes 1 and Routes 2 pass through landlocked countries with relatively stable geopolitics. These countries could reduce transportation time and costs by improving trade facilitation and enhancing infrastructure reliability. As a result, the lower the costs, the more shippers are likely to be attracted, leading to an increase in transportation volume. In addition, the transport flow percent for Route 3 increased, while it decreased for Route 4. The reason for this is perhaps that Route 3 can be influenced by the political stability of Pakistan as well as improvements in infrastructure reliability and trade facilitation. Conversely, although Route 4 has the lowest transport unit price compared to other routes, its service quality and infrastructure are subpar. As a result, shippers may be attracted to alternative transport routes.

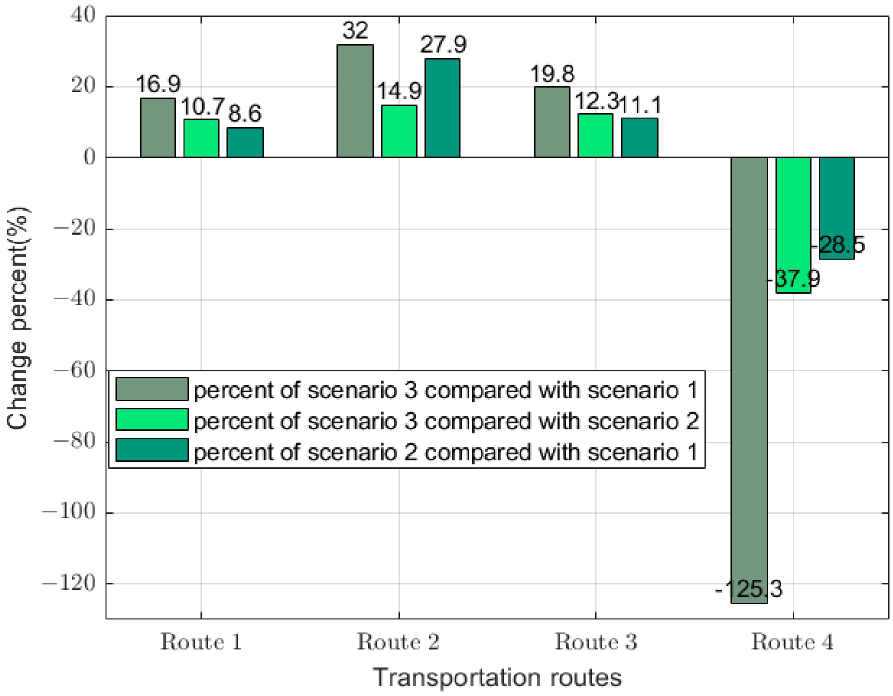

Figure 4. The change percent of the comparison of four routes in different scenarios.

To sum up, infrastructure reliability and trade facilitation have an impact on the transportation flow of the China–Europe trade route. Consequently, the selection of trade routes by Chinese export companies may also be influenced. Accordingly, it is necessary for the government to coordinate with countries along the CR Express to unify the different standards of infrastructure, thereby improving trade facilitation. Simultaneously, providers of transport services should also enhance their service levels to maximize the benefits for Chinese export companies. Additionally, it can be concluded that the competitiveness of a single mode is relatively better than that of an intermodal mode.

4.2.2. Sensitivity Analysis

This section will assess the impact of infrastructure reliability and trade facilitation on traffic flow by adjusting the parameters of trade facilitation and infrastructure reliability. The analysis will focus on the changes in transportation flow friction coefficients when the infrastructure reliability value or trade facilitation value is altered, mainly including the following: (1) the changes in transportation flow friction coefficients for each route when the trade facilitation value is altered, with the impact of infrastructure excluded; (2) the changes in transportation flow friction percent for each route when the infrastructure reliability value is altered, with the impact of trade facilitation excluded; (3) the changes in transportation flow friction percent for each route when both the infrastructure reliability value and trade facilitation value are altered simultaneously.

Table 4 and Figure 5 displays the changes in the friction percent of each route as the trade facilitation value gradually increases from zero to one, with the infrastructure reliability value set to one to eliminate the impact of infrastructure. As the trade facilitation value increases, Route 2 is most notably influenced by trade facilitation. Particularly, when both the trade facilitation value and the infrastructure reliability value are set to one, Route 2 can significantly attract more transportation flow, whereas the transportation flow on the other three routes decreases. Route 2 has a single transportation mode, is the shortest in distance among the four transport routes, and has the highest transportation cost, making it more susceptible to the effects of trade facilitation. This indicates that in situations where the level of trade facilitation is high, Route 2 is the optimal trade route.

Table 4. Proportional change of freight volume when changing trade facilitation.

Degree of Trade Facilitation (Infrastructure Reliability Is 1)	Route 1	Route 2	Route 3	Route 4
0	0.2489	0.2631	0.2406	0.2474
0.2	0.2487	0.2658	0.2387	0.2468
0.4	0.2482	0.2700	0.2359	0.2459
0.6	0.2473	0.2772	0.2312	0.2443
0.8	0.2450	0.2926	0.2217	0.2406
1	0.2337	0.3485	0.1927	0.2252

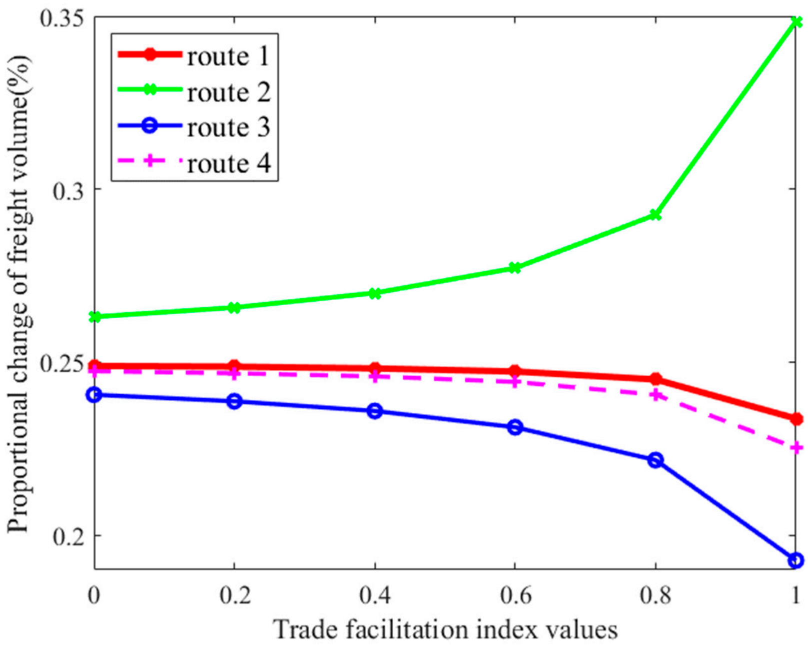

Figure 5. The proportional change of transportation volume when trade facilitation index values are changed.

Similarly, when the trade facilitation value set to one to eliminate the impact of trade facilitation, the infrastructure reliability value changed, as shown in Table 5 and Figure 6. As the infrastructure reliability value increases, Route 2 remains the most significantly affected. When both the trade facilitation value and the infrastructure reliability value are set to one, the transportation flow friction coefficient of Route 2 is still the highest, while the transportation flow on the other three routes decreases. This indicates that in situations where the level of infrastructure reliability is high, Route 2 remains the optimal trade route.

Table 5. Proportional change of freight volume when changing infrastructure reliability.

Degree of Infrastructure Reliability (Trade Facilitation Is 1)	Route 1	Route 2	Route 3	Route 4
0	0.2493	0.2591	0.2433	0.2482
0.2	0.2491	0.2611	0.2419	0.2478
0.4	0.2488	0.2643	0.2397	0.2472
0.6	0.2482	0.2700	0.2359	0.2459
0.8	0.2465	0.2832	0.2274	0.2429
1	0.2337	0.3485	0.1927	0.2252

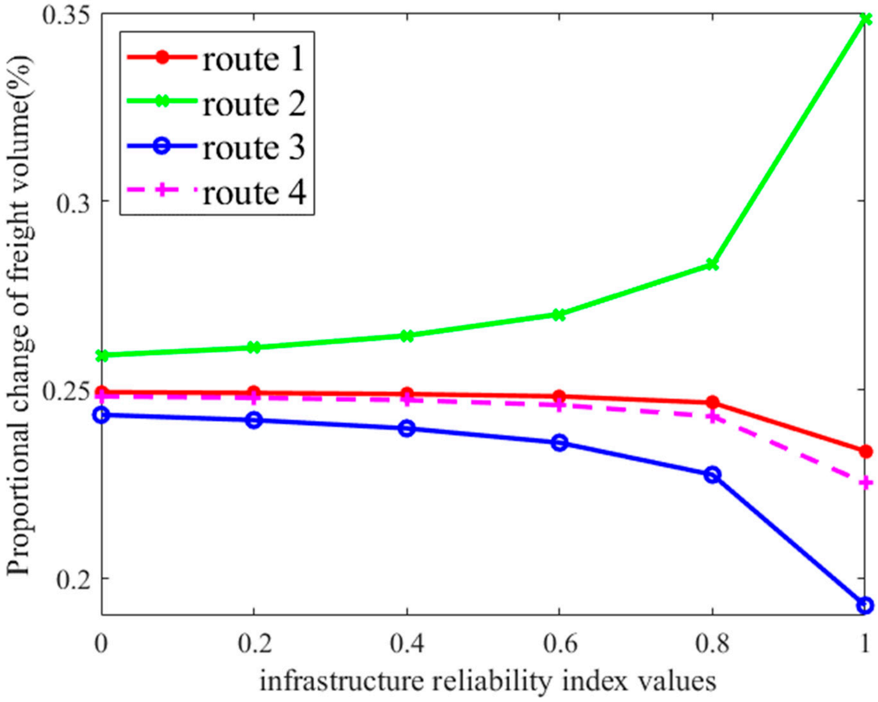

Figure 6. The proportional change of transportation volume when infrastructure reliability index values are changed.

When both trade facilitation and infrastructure reliability index values are changed simultaneously, as shown in Figure 7, there is no significant change in the ranking of the proportion of freight volume for the four routes. This suggests that infrastructure reliability and trade facilitation have an impact on freight volume through changing transportation costs. From the analysis of Figure 7, Route 2 is still the optimal trade route among the four routes.

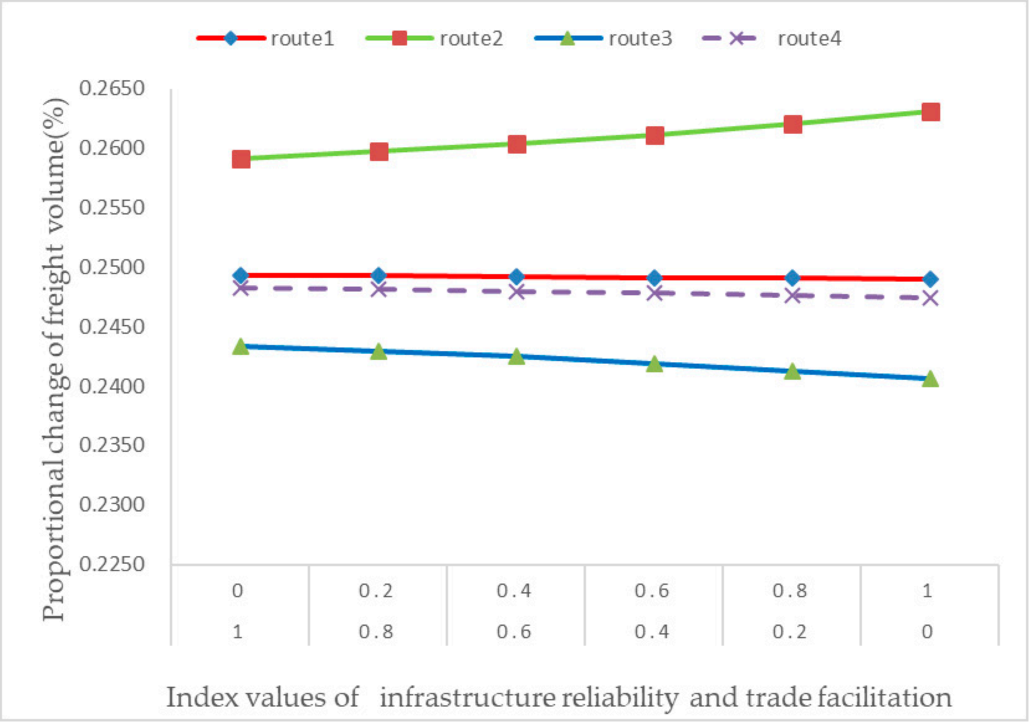

Figure 7. Proportional change of freight volume when changing trade facilitation and infrastructure reliability simultaneously.

The analysis above shows that infrastructure reliability and trade facilitation have a significant impact on the freight volume of trade routes. It is hoped that this study can provide some reference for the management of transportation modes and the construction of infrastructure.

5. Conclusions

In this paper, we analyze the impact of infrastructure reliability and trade facilitation on the freight volumes based on the transportation route selection. By integrating infrastructure reliability and trade facilitation into the transportation friction function using a spatial friction model, this paper estimates their influence on changes of transportation flow. The case study of transportation based on four trade routes from Zhengzhou to Hamburg illustrates the impact of increased infrastructure reliability and trade facilitation on the transportation flow between the CR Express and traditional maritime shipping. In particular, in terms of transportation costs, the New Eurasian Land Bridge is significantly affected by infrastructure reliability and trade facilitation. However, once infrastructure is standardized and trade facilitation measures are implemented, which greatly reduce transportation costs, the competitiveness of this route becomes apparent. Moreover, compared to other routes, this route is relatively shorter in distance.

In conclusion, the higher the reliability, convenience, and safety, the shorter the transportation time, and the lower the transportation cost of the CR Expresses, the more positive the impact on the route selection of shippers. To encourage more shippers to use CR Expresses, on one hand, efforts can be made to actively coordinate with other countries to implement trade policy reforms, reduce trade policy barriers, and improve the management of the CR Express corridor. At the same time, the adoption of unified standards for infrastructure and trade procedures can achieve cross-regional integration. This will allow the transportation supply chain to unlock the potential of the corridor, reduce transportation costs, and increase cargo volumes. CR Expresses provides a reliable mode of transportation that reduces the impact of unpredictable factors such as weather and piracy on the supply chain, enhancing its stability and resilience. Furthermore, with the improvement of infrastructure reliability and trade facilitation for CR Expresses, related technological and management innovations, such as cold chain transportation, information management, and intelligent logistics, can further promote the sustainable development of the supply chain. Additionally, future research can explore more detailed qualitative factors such as carbon emissions, government policies, customs clearance, geographical position, environment, etc., to provide better support for building an efficient, stable, and sustainable supply chain system.

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