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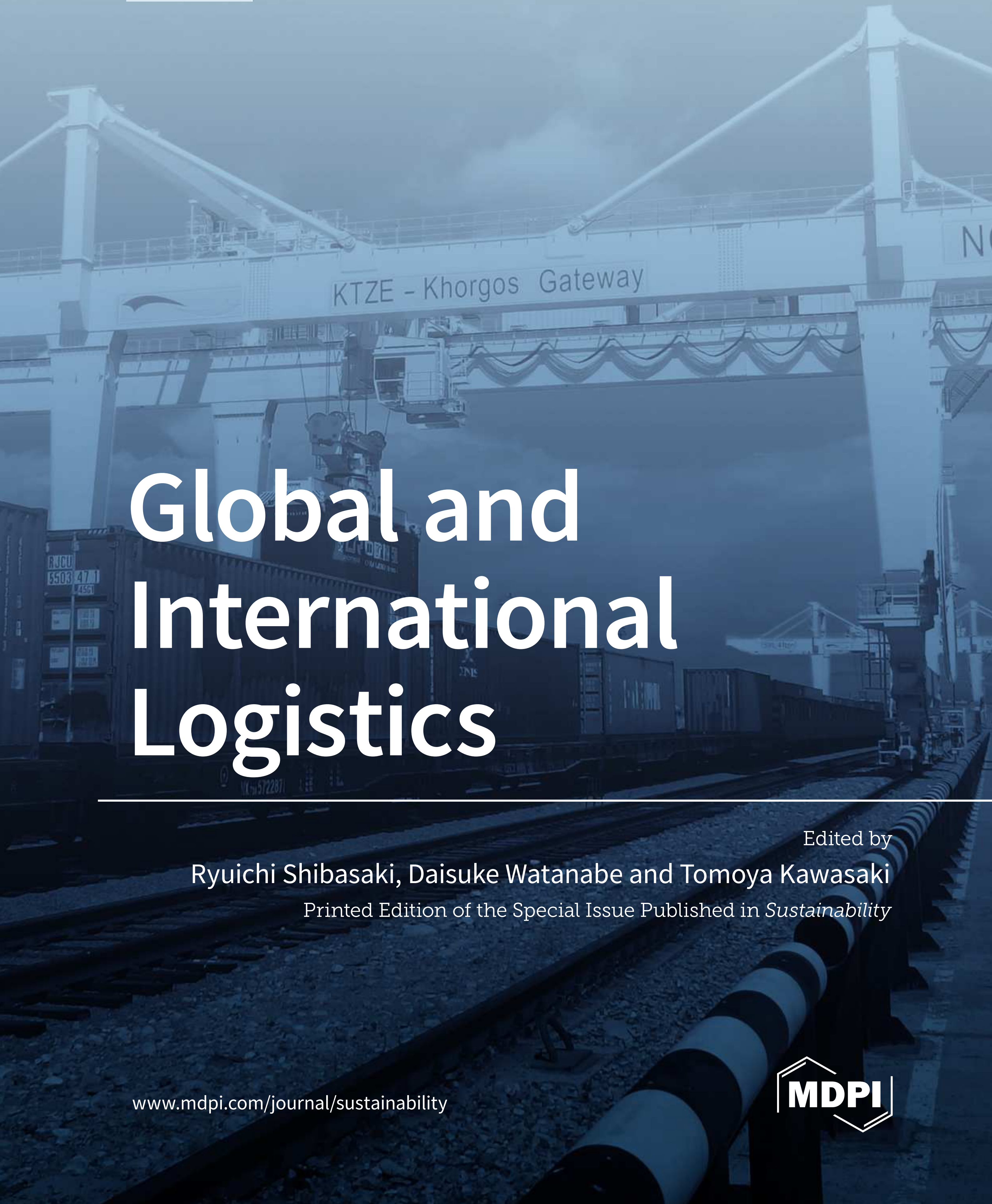

Global and International Logistics

Edited by

Ryuichi Shibasaki, Daisuke Watanabe and Tomoya Kawasaki

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Global and International Logistics

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About the Editors

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Dr. Ryuichi Shibasaki is an Associate Professor at the Resilience Engineering Research Center and Department of Technology Management for Innovation (TMI), Graduate School of Engineering, the University of Tokyo. His research focus is primarily on global intermodal freight flow modeling, port logistics, and maritime big data analysis. Dr. Shibasaki's research has received three awards for "Best Application in Practices" from the Eastern Asia Society of Transport Studies (EASTS) in 2009, 2011, and 2015, and two from the International Association of Maritime Economists (IAME) in 2014 and 2020. He currently serves as an associate editor of Maritime Policy & Management and Asian Transport Studies. Additionally, he is one of representative organizers of International Conference on Transportation and Logistics (TLOG Network).

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Editorial

Global and International Logistics

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In the present world, with the recent advances in the globalization of trade and economic activity, research on the logistics issue should be approached from more global or international viewpoints, to achieve sustainable economic development. Global issues in the logistics field include not only international cooperation and cross-border issues, but also intermodal transport, global shipping network analysis, supply chain integration and coordination, intelligent transport system and information technologies, green and reverse logistics, impacts of China's Belt and Road Initiative (BRI), and others. Furthermore, since the current advancement of information technologies enables us to use some kinds of big data in the global logistics field, new ideas on big data analysis in this field is also very important topics [1]. This special issue (SI) is comprised of 10 thoroughly refereed contributions that shed light on a wide array of research activities within three themes: international trade, maritime shipping, and intermodal transport.

In the topics of international trade, we attempt to synthesize the relationship between international trade and several economic activities that involve regional economic development, cross-border e-commerce trade, and international reverse logistics. Transport infrastructure and logistics are increasingly becoming important factors affecting international trade. In particular, China is developing the international logistics corridor along the BRI. Ma et al. (Contribution 1) discuss the impact of logistics development level on bilateral trade from 31 of China's provinces to 65 countries along the BRI by using the improved gravity model with data for the period 2008–2018. From these research results, strengthening domestic and international logistics infrastructure does not only contribute to the sustainable development of future trade in China, but also helps to realize the coordinated development among regions in China. Since logistics networks along BRI routes face several challenges that hinder efficient operations, logistics practitioners must align their networks with future developments. Nitsche (Contribution 2) discusses current barriers to the BRI from a logistics and supply chain management perspective, proposes strategies for dealing with them, and outlines and assesses conceivable BRI development scenarios to create awareness for possible international logistics network developments.

E-commerce trade that is developing rapidly all over the world brings a market for the development of international logistics and plays a role in improving the quality of service, improving the effectiveness of the supply chain, enhancing the efficiency of business operations, and increasing the volume of international trade. He et al. (Contribution 3) explore the dynamic interaction between international logistics and cross-border e-commerce trade using the panel data in Organization for Economic Co-operation and Development (OECD) countries for the period 2000–2018. They reveal that each OECD country's government should take up corresponding policies to ensure the sustainable development of both international logistics and cross-border e-commerce trade. In terms of global waste trade as reverse logistics, Tran et al. (Contribution 4) discuss the effect of

China's restrictive programs on the international trade of waste products. These restrictions divert the flow of waste mostly to the low- and middle-income countries of the East Asian and Pacific regions along with Europe and Central Asia, and shipping companies face with a lack of products on backhaul routes and thus force to change their longstanding practices.

On the second topic, maritime shipping, we attempt to synthesize the efficiency of shipping with foldable containers as new technology, the port development in global shipping network, and the impact and effectiveness of greenhouse gas (GHG) emissions in the shipping and shipbuilding market. In recent years, rapid economic growth and globalization have led to a substantial increase in container cargo shipping demand and growing trade imbalances between imports and exports among different regions, resulting in an imbalance between the inbound and outbound flows of full containers. Liang et al. (Contribution 5) consider the empty container repositioning problem of shipping companies that use standard and 3-in-1 foldable containers with more advanced designs. The introduction of foldable containers not only effectively reduces the management costs of empty containers, but also makes costs more stable and predictable.

Global manufacturing activities have a strong relationship with regional port development, and a well-developed port has sufficient capacity and strong access from/to the hinterland. Riaventin et al. (Contribution 6) discuss the problem of improving the capacity and connectivity of ports in the hub and feeder port network by allocating the available budget for investment in Indonesia. Under a circumstance that several new ports are to be improved to ensure smooth interisland transport flows of goods, the effects of the investment on economic consequences and increased network connectivity are assessed.

GHG emissions from the global shipping sector have been increasing due to global economic growth. The International Maritime Organization has set a goal of halving GHG emissions from the global shipping sector by 2050 as compared with 2008 levels, and has responded by introducing several international regulations to reduce the GHG emissions of maritime shipping. Wada et al. (Contribution 7) develop a model to consider GHG emission scenarios for the maritime shipping sector using system dynamics incorporating a shipping and shipbuilding market model. They evaluate the effects of current and future measures for GHG emission reduction, including ship speed reduction, transition to liquefied natural gas (LNG) fuel, promotion of energy efficiency design index regulation, and introduction of zero-emission ships. Kim et al. (Contribution 8) discuss the emission inventory around the world and bunker consumption from a LNG fleet using position data calculated from an automatic identification system (AIS) database. Comparisons regarding the LNG trade amount and bunker consumption of a LNG fleet, as well as the total CO_2 inventory and CO_2 emissions from a LNG fleet in the vicinity of the coasts of relevant countries are made.

In the final topic, intermodal transport, we attempt to synthesize the modal choice factors and the optimal policies in long-distance inter-regional cross-border transport. Land transport is a vital alternative to international maritime shipping in inter-regional transport and several cross-border land corridor projects have been implemented worldwide. Hanaoka et al. (Contribution 9) discuss the factors that can help select between these two modes in long-distance inter-regional cross-border transport. They identify eight significant variables: distance, export of manufacturing commodity, landlocked country/area, neighboring country/area, country risk, infrastructure level, port-access time, and maritime transport frequency. Yamaguchi et al. (Contribution 10) focus on container transport in Myanmar with the global logistics intermodal network simulation model including both maritime shipping and land transport in the land-based Southeast Asia region. Based on the simulation results, the policies that reduce cross-border barriers and improve service levels in Dawei port would result in using Myanmar's ports for Thai cargo.

This SI is related to the 8th International Conference on Transportation & Logistics (T-LOG 2020) which was held online on 6–7 September 2020 hosted by Universitas Internasional Semen Indonesia (https://tlog2020.uisi.ac.id/, accessed on 6 May 2021). Through years of effort organizing the conference series every two years, since being initiated in

2004 by the National University of Singapore, The University of Tokyo, and Tsinghua University, T-LOG has been extended to an extensive network consisting of 30 member institutes from 12 countries. Under the conference theme "Logistics Connectivity in East Asia: Practices & Challenges", which aims to promote interaction between practitioners and academics, through presentation of papers, discussions and exchange of knowledge, ideas, and experience, we have explored various theories and methods concerning logistics connectivity in East Asia, including creation and innovation in infrastructures design, multi-modal transport synchronization, transport technology, and information technology and management. We have also discussed approaches to collect, process, manage, and use various kinds of information efficiently and effectively, so that logistics and transport competitiveness and value in East Asia that face global challenges in transport and logistics issues can be improved. The next T-LOG will be held in Incheon, South Korea in 2022, and we hope to provide regular opportunities for researchers as well as practitioners in the field of logistics to present their work.

List of Contributions in This Special Issue

1. Ma, W.; Cao, X.; Li, J. Impact of Logistics Development Level on International Trade in China: A Provincial Analysis. *Sustainability* **2021**, *13*, 2107, 10.3390/su13042107
2. Nitsche, B. Decrypting the Belt and Road Initiative: Barriers and Development Paths for Global Logistics Networks. *Sustainability* **2020**, *12*, 9110, doi:10.3390/su12219110
3. He, Y.; Wu, R; Choi, Y-J. International Logistics and Cross-Border E-Commerce Trade: Who Matters Whom? *Sustainability* **2021**, *13*, 1745, doi:10.3390/su13041745
4. Tran, T.; Goto, H.; Matsuda, T. The Impact of China's Tightening Environmental Regulations on International Waste Trade and Logistics. *Sustainability* **2021**, *13*, 987, doi:10.3390/su13020987
5. Liang, Z.; Shibasaki, R.; Hoshino, Y. Do Foldable Containers Enhance Efficient Empty Container Repositioning under Demand Fluctuation?—Case of the Pacific Region. *Sustainability* **2021**, *13*, 4730, doi:10.3390/su13094730
6. Riaventin, V, N.; Cahyo, S, D.; Singgih, I, K. A Model for Developing Existing Ports Considering Economic Impact and Network Connectivity. *Sustainability* **2021**, *13*, 3705, doi:10.3390/su13073705
7. Wada, Y.; Yamamura, T.; Hamada, K.; Wanaka, S. Evaluation of GHG Emission Measures Based on Shipping and Shipbuilding Market Forecasting. *Sustainability* **2021**, *13*, 2760, doi:10.3390/su13052760
8. Kim, H.; Watanabe, D.; Toriumi, S.; Hirata, E. Spatial Analysis of an Emission Inventory from Liquefied Natural Gas Fleet Based on Automatic Identification System Database. *Sustainability* **2021**, *13*, 1250, doi:10.3390/su13031250
9. Hanaoka, S.; Matsuda, T.; Saito, W.; Kawasaki, T.; Hiraide, T. Identifying Factors for Selecting Land over Maritime in Inter-Regional Cross-Border Transport. *Sustainability* **2021**, *13*, 1471, doi:10.3390/su13031471
10. Yamaguchi, T.; Shibasaki, R.; Samizo, H.; Ushirooka, H. Impact on Myanmar's Logistics Flow of the East–West and Southern Corridor Development of the Greater Mekong Subregion—A Global Logistics Intermodal Network Simulation. *Sustainability* **2021**, *13*, 668, doi:10.3390/su13020668

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Reference

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Article

Impact of Logistics Development Level on International Trade in China: A Provincial Analysis

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Abstract: Transport infrastructure and logistics are gradually becoming important factors affecting global trade. At the same time, with the international logistics corridor along the Belt and Road Initiative (BRI) going deep into construction, China is emerging as a unique case to study how logistics affects international trade. Therefore, based on the evaluation index system of logistics development level of China's provinces by using the entropy method, this paper systematically analyzed the impact of logistics development level on bilateral trade from 31 China's provinces to 65 countries along the BRI by using the improved gravity model with data for the period 2008–2018. Empirical results show: (1) Logistics development level had significantly promoted international trade development. (2) Compared with partner countries, China's provincial logistics development level presented a greater impact on bilateral trade. (3) Influence of logistics development level was manifested in different periods, different international and regions, especially, logistics development level coefficient of the western region was negative, while that in eastern region was positive. In view of the above research results, we argue that strengthening domestic and international logistics construction is not only conductive to the sustainable development of China's future trade, but also help to realize the coordinated development between China's eastern, central and western regions.

Keywords: logistics development level; international trade; gravity model; China; the Belt and Road Initiative

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1. Introduction

With the rapid advancement of economic globalization and trade liberalization, tariffs and non-tariff barriers have been significantly reduced, while transport and logistics are gradually becoming important factors affecting global trade. "Sound development of logistics is a prerequisite for promoting a country's competitiveness", according to *Connecting to Compete: Trade Logistics in the Global Economy* issued by the World Bank in 2018. In 2013, China's President Xi Jinping put forward major initiatives to jointly build the Silk Road Economic Belt and the 21St Century Maritime Silk Road, which has attracted great attention from the international community [1]. The proposals are officially termed the Belt and Road Initiative (BRI). Since the launch of the BRI, the Chinese government has been paying special attention to the construction and investment of logistics infrastructures and introduces a series of plans such as *Medium- and Long-Term Plan for the Development of the Logistics Industry (2014–2020)*, *China-Europe Railway Express Construction Development Plan (2016–2020)*, *National Logistics Hub Layout and Construction Plan*, and *Overall Plan for the Country's New Western Land-sea Corridor*. By carrying out the abovementioned plans, the government aims to strengthen the construction of domestic logistics hub and network, strives to build a large logistics corridor of land, sea, and air connecting China to foreign countries to enhance logistics support for the implementation of BRI [2].

As an important part of BRI's cross-border logistics network, China-Europe railway express (CER-express) is a new type of international trade transportation mode between China and Eurasian continents [3]. By the end of 2019, the total number of operations on the CER-express had exceeded 21,161 round trips, reaching 57 cities in 18 European countries [4], and the role of logistics channel is gradually obvious. The implementation of CER-express has two advantages: (1) balance time and transport costs. On the one hand, CER-express is more time-sensitive and stable which transport time is half that of sea transport [5]. On the other hand, compared with air transport, CER-express has the characteristics of low transport costs and large volume. Therefore, CER-express is more suitable for transporting processed products and end consumer goods that have certain requirements on timeless, and have a certain scale and higher value; (2) balance regional sustainable development. With the vigorous development of CER-express, it is expected to break the logistics pattern of a single ocean-oriented direction. Furthermore, it provides a stable international logistics channel guarantee for inland enterprises in China's central and western regions and Central Asia to go out along the BRI, so that the inland areas have the basic conditions for opening up and trade development [6,7]. However, some authors pointed out that the shortcomings of CER-express, such as gauge inconsistency, unreasonable layout, high return empty box rate, overreliance on government subsidies [8,9], so what is the level of logistics development in China's provinces? Whether the improvement of logistics development level has promoted the growth of trade between China and countries along the BRI? If so, whether there are regional heterogeneity effects? Through the exploration of these issues, it is of great theoretical and practical significance to promote the construction of the logistics network of the BRI and expand the opening of inland areas to the outside world.

In view of the above, taking 65 countries along the BRI as research subjects, this paper firstly built an index system of the provincial logistics development level of China, then discussed the spatio-temporal evolution pattern of the trade between Chinese provinces and partner countries along the BRI, and eventually analyzed the impact of logistics development level on bilateral trade by using the improved gravity model from 2008 to 2018, in order to provide decision-making reference for promoting the coordinated development of China's three major regions.

The remainder of this paper is organized as follows: Section 2 provides a review of previous studies. Section 3 presents the methodological approaches and data utilized in this paper. Spatio-temporal pattern of trade between China and countries along the BRI is shown in Section 4. Section 5 analyzes impact of logistics development level on bilateral trade. Discussions and conclusions are drawn in Sections 6 and 7, respectively.

2. Literature Review

Under the background of economic globalization and market internationalization, domestic and international logistics plays an important role in improving the international trade environment and providing various conveniences for international trade. With the further expansion of global trade, logistics development level has a key factor affecting and restricting international trade. In this regard, a large number of studies have been carried out the impact of logistics on international trade.

Due to the lack of a widely accepted definition of logistics both at national and regional levels, previous studies only considered the impact of a certain aspect of logistics on international trade [10]. Limao and Venables [11], Martinez-Zarzoso et al. [12], Baier and Bergstrand [13] found that transport costs had a significant negative impact on international trade. Hummels [14], Nordas [15], Djankov et al. [16] found that trade time also had a remarkable negative impact on international trade, especially on the export of time-sensitive products such as agricultural products. In addition, most scholars have carried out a large number of empirical studies about the impact of logistics infrastructure on international trade. Longo and Sekkat [17] believed that weak highway infrastructure was one of the three major obstacles to the development of international trade in Africa. Egger and Larch [18] studied the impact of transport infrastructure on bilateral trade among 180 countries in the world and found that transport infrastructure had a notable positive impact on bilateral trade. Furthermore, compared with the highway network, the railway network was 50% higher in promoting international trade flow. By using microscopic data of exports from other ports in the world to the United States, Clark et al. [19] analyzed the relationship between port efficiency, shipping costs, and bilateral trade. Based on the survey data of 20 regions in Italy and 24 countries in Europe, Alderighi and Gaggero [20] analyzed the relationship between air transport services and international trade during 1998–2010 and found that direct flights can reduce "spatial and temporal distance" between trading partners, having a positive impact on exports.

Since the Logistics Performance Index (LPI) published by World Bank in 2007, most scholars have analyzed the effect of LPI on international trade from a broader perspective. Behar and Manner [21] held that LPI could significantly reduce the distance trade effect, and the exports of landlocked countries depended on the LPI of their neighbors. Puertas et al. [22] studied the influence of LPI on bilateral trade among EU countries, finding that the influence coefficients of the LPI of exporting countries were greater than that of importing countries. They also made a decomposition analysis of the six indicators of LPI, finding that goods traceability was the most influential among all the indicators. According to the research performed conducted by Celebi [23], the influence of LPI on international trade existed evident differences among countries with different levels of economic development, and the influence degree of LPI was larger in low-income countries. In recent years, with the proposal of the BRI, most scholars have focused on the influence of LPI on trade between China and countries along the BRI. Wang and Gong [24] analyzed the impact of LPI of Silk Road Economic Belt on China's export of machinery and electronic products. Feng and Liu [25] found that LPI of countries along the BRI could significantly promote the export of China's machinery and transportation equipment. Zhao et al. [26] discussed on the LPI of countries along Silk Road Economic Belt and its impact on international trade of Xinjiang. Wang et al. [1] found that LPI had a more positive effect on China's exports after the BRI than before it.

Through the review of existing literature, studies on the impact of logistics on international trade can be divided into two directions: the first one is focusing on the impact of a specific logistics factor on trade (such as trade time, transport costs, and logistics infrastructure); the second one is through attempting to make a comprehensive evaluation of national logistics elements (mostly using LPI) to analyze the development of logistics and its influence on trade. Given the progress of current research, this paper may enrich and extend the existing studies in the following aspects: (1) the existing researches mostly adopt LPI as a logistics factor and focus on the international and national macro-scales to analyze the effect of logistics on trade from a comprehensive perspective, while the provincial and city medium-scale studies are relatively limited. However, with the carrying out of the BRI construction, the logistics conditions of China's central and western provinces have witnessed an improvement, so it is more practical to reveal the trade effect of China's logistics from a provincial perspective. (2) the development level of logistics is mainly determined through the logistics performance evaluation index system (involving efficiency of customs clearance, quality of logistics infrastructure, the convenience of international transportation, quality of logistics service, traceability of goods, and timeliness of goods transportation) released by World Bank. The index system is more frequently used at the national level, and cannot achieve effective application at the provincial scale due to the shortage of data. This paper, based on the existing literature, constructed a preliminary evaluation system of the provincial logistics development level and measures the level. (3) in the aspect of impact research, there are few literatures to compare the heterogeneity of the impact of logistics development level on bilateral trade from different spatial and temporal perspectives.

3. Construction of Index System, Methodology and Data

3.1. Construction of Index System

Based on the existing literature [27–29] and following the principles of scientific research, feasible method, systematical assessment, and comparable indicator, this paper divided the provincial logistics evaluation system into three subsystems (Table 1): regional economic support, logistics infrastructure, and logistics operation and development. The regional economic support system provides driven force for the development of regional logistics and generates the demand for the transportation of commodities and cargo through the developing economy. The logistics infrastructure system is the foundation of the formation and development of a regional logistics system, which realizes the cross-region and cross-nation flow of commodities and goods by hardware and software infrastructure. The logistics operation and development system not only demonstrate the size of regional logistics which involves the size of employment, investment, freight, output value, and others but also reflects the ability of regional logistics development to a certain extent.

Table 1. Comprehensive evaluation index system of logistics development level.

System	Subsystem	Index	Index Interpretation	Weight
Comprehensive evaluation index system of logistics development level	Regional economic support	Economic development	GDP per capita	0.0754
		Industrial structure	Value added by the secondary and tertiary industries/GDP	0.0154
		Investment level	Total investment in fixed assets/GDP	0.0435
		Consumption level	Total retail sales of consumer goods/GDP	0.0386
		Openness	Total import and export/GDP	0.1989
	Logistics infrastructure	Transport infrastructure	Mileage of highway, railway and waterway /Land area	0.0768
		Postal infrastructure	Postal outlets/Population	0.1147
		Internet penetration	Number of internet users/Population	0.0437
		Telephone penetration	Mobile phone ownership/Population	0.0457
	Logistics operation and development	Logistics freight scale	Freight volume of highway, railway, waterway and aviation/land area	0.1889
		Logistics output scale	Value added by transportation, storage and post/GDP	0.0481
		Logistics employment scale	Employment in transportation, storage and post/Total employment	0.0415
		Logistics investment scale	Investment in transportation, storage and post/ Total investment in fixed assets	0.0687

Based on the above-mentioned index system, we adopted the entropy evaluation method to determine the weight of all indexes from each index layer. Firstly, using the extremum method to standardize the 13 indicators in Table 1, and converting original data into dimensionless scores (x_{ij}) between 0 and 1. Secondly, we calculated the information entropy and information utility value of all the indexes:

$$e_j = -k \sum_{i=1}^{m} x_{ij} \ln(x_{ij}) \quad (1)$$

where e_j is the information entropy of the j index; x_{ij} is the standardization value of the j index of the i province; m is the number of province, which is 31; k is the constant term ($k = 1/\ln m$). The information utility value of the j index is d_j ($d_j = 1 - e_j$).

Lastly, we calculated the weight and comprehensive evaluation value of the index. The calculation formula of the weight of the j index is $w_j = d_j / \sum_{j=1}^{n} d_j$; n is the number of the index, which is 13; And the calculation formula of the comprehensive evaluation value of the i province is $z_i = \sum_{j=1}^{n} w_j x_{ij}$.

Table 2 reflects the evolution trend of the logistics development level of China. From 2008 to 2018, the overall logistics development level of China showed a steady upward trend, with the logistics development index rising from 0.189 to 0.277, the logistics development level increasing by 47.07%. Meanwhile, coefficient of variation (CV) of China's logistics development level decreased from 0.579 to 0.320, indicating that the inter-provincial differences in the logistics development level are narrowing and tending to be balanced. During the ten years, with the 4 trillion stimulus plan put forward in 2008 and the BRI launched in 2013, transport infrastructure investment in the western and central regions kept growing rapidly and continuously. The logistics development level of the central and western regions increased by 66.31% and 77.16% respectively. However, the overall logistics development level of China remained an "east-center-west" gradient-descent pattern.

Table 2. Evolution trend of the logistics development of China.

Province	Area	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Beijing	Eastern	0.454	0.402	0.442	0.456	0.457	0.453	0.446	0.412	0.408	0.410	0.437
Tianjin	Eastern	0.329	0.341	0.348	0.341	0.361	0.359	0.369	0.367	0.368	0.374	0.377
Hebei	Eastern	0.154	0.170	0.189	0.187	0.195	0.209	0.219	0.225	0.231	0.232	0.244
Shanxi	Central	0.165	0.186	0.191	0.191	0.201	0.209	0.221	0.242	0.248	0.249	0.253
Inner	Western	0.132	0.150	0.160	0.159	0.171	0.189	0.197	0.193	0.209	0.219	0.217
Liaoning	Eastern	0.200	0.198	0.213	0.216	0.228	0.244	0.254	0.257	0.270	0.279	0.279
Jilin	Central	0.134	0.141	0.151	0.147	0.157	0.162	0.171	0.189	0.197	0.211	0.215
Heilongjiang	Central	0.129	0.139	0.147	0.143	0.144	0.154	0.166	0.176	0.188	0.200	0.209
Shanghai	Eastern	0.618	0.547	0.603	0.613	0.586	0.573	0.582	0.615	0.608	0.694	0.628
Jiangsu	Eastern	0.267	0.257	0.286	0.292	0.297	0.291	0.303	0.302	0.306	0.324	0.332
Zhejiang	Eastern	0.239	0.240	0.260	0.267	0.276	0.284	0.298	0.319	0.323	0.383	0.390
Anhui	Central	0.158	0.155	0.166	0.170	0.188	0.221	0.236	0.241	0.252	0.270	0.274
Fujian	Eastern	0.209	0.210	0.228	0.231	0.242	0.259	0.264	0.282	0.286	0.301	0.308
Jiangxi	Central	0.131	0.139	0.148	0.143	0.152	0.170	0.180	0.187	0.201	0.217	0.216
Shandong	Eastern	0.202	0.208	0.228	0.235	0.246	0.243	0.250	0.257	0.270	0.299	0.312
Henan	Central	0.139	0.143	0.154	0.163	0.180	0.188	0.200	0.212	0.228	0.237	0.255
Hubei	Central	0.162	0.170	0.188	0.171	0.181	0.200	0.214	0.234	0.250	0.267	0.277
Hunan	Central	0.139	0.158	0.160	0.158	0.164	0.177	0.185	0.195	0.203	0.216	0.227
Guangdong	Eastern	0.319	0.303	0.327	0.324	0.337	0.362	0.356	0.363	0.356	0.368	0.373
Guangxi	Western	0.121	0.134	0.144	0.144	0.154	0.162	0.174	0.188	0.198	0.207	0.222
Hainan	Eastern	0.152	0.165	0.169	0.170	0.179	0.196	0.215	0.232	0.235	0.239	0.254
Chongqing	Western	0.194	0.205	0.218	0.226	0.235	0.263	0.285	0.287	0.294	0.312	0.326
Sichuan	Western	0.114	0.131	0.136	0.139	0.151	0.164	0.188	0.195	0.212	0.223	0.235
Guizhou	Western	0.143	0.158	0.168	0.170	0.172	0.190	0.199	0.212	0.218	0.229	0.242
Yunnan	Western	0.100	0.107	0.128	0.118	0.116	0.133	0.148	0.156	0.172	0.195	0.206
Tibet	Western	0.134	0.124	0.149	0.152	0.159	0.160	0.166	0.203	0.226	0.227	0.236
Shaanxi	Western	0.134	0.146	0.152	0.153	0.156	0.168	0.186	0.204	0.219	0.236	0.245
Gansu	Western	0.106	0.112	0.117	0.122	0.129	0.134	0.153	0.168	0.186	0.189	0.194
Qinghai	Western	0.115	0.119	0.121	0.109	0.126	0.162	0.171	0.183	0.196	0.208	0.214
Ningxia	Western	0.127	0.140	0.152	0.153	0.165	0.178	0.197	0.202	0.214	0.210	0.209
Xinjiang	Western	0.128	0.121	0.121	0.121	0.133	0.154	0.164	0.177	0.174	0.195	0.197
average		0.189	0.191	0.205	0.206	0.214	0.226	0.237	0.248	0.256	0.272	0.277
CV		0.579	0.489	0.500	0.513	0.473	0.423	0.391	0.368	0.336	0.360	0.320
Eastern average		0.286	0.277	0.299	0.303	0.309	0.316	0.323	0.330	0.333	0.355	0.358
Central average		0.145	0.154	0.163	0.161	0.171	0.185	0.197	0.210	0.221	0.233	0.241
Western average		0.129	0.137	0.147	0.147	0.156	0.171	0.186	0.197	0.210	0.221	0.229

3.2. Methodology

As an important tool to study spatial interaction, gravity model is widely used in the field of economic research, and its application in investment and trade shows diversified characteristics. Tinbergen [30] firstly applied gravity model to international trade, believing that bilateral trade flows between two countries are proportional to their respective economic strength and inversely proportional to the distance between them. Subsequently, Anderson [31], Bergstrand [32,33] gave the theoretical basis of gravity model. The standard form of the gravity model is as follows:

$$lnX_{ij} = \alpha + \beta_1 lnGDP_i + \beta_2 lnGDP_j + \beta_3 lnD_{ij} + \varepsilon_{ij} \quad (2)$$

where X_{ij} is the total volume of import and export between i province of China and j country along the BRI; GDP_i and GDP_j are the gross domestic product of i province and j country; D_{ij} is the geographical distance between i province and j country. In order to test the impact of logistics development level on trade, logistics development level (LDL) variable is added based on the gravity model, and the model form changes into:

$$lnX_{ij} = \alpha + \beta_1 lnGDP_i + \beta_2 lnGDP_j + \beta_3 lnD_{ij} + \beta_4 LDL_i + \beta_5 LDL_j + \varepsilon_{ij} \quad (3)$$

where LDL_i is the logistics development level of i province in China, and LDL_j is the logistics development level of the j country. If β_4 is significantly positive, it means that the improvement of the provincial logistics development level of China can be conducive to promoting its trade growth. Likewise, if β_5 is significantly positive, it indicates that the logistics of trading partners also can promote the trade growth of China to a large extent. ε_{ij} is the random error term.

Based on the formula (3), add two types of pseudo-variables: which country belongs to costal countries ($Coast_j$). And whether the countries willing to reach free trade agreement with China (FTA_{ij}). At the same time, this paper also takes boundary effect variable ($Domestic_i$) into consideration to measure the boundary effect value (the times of Chinese provincial trade and international trade) of China's provinces and countries along the BRI. The specific form of the formula is as follows:

$$lnX_{ij} = \alpha + \beta_1 lnGDP_i + \beta_2 lnGDP_j + \beta_3 lnD_{ij} + \beta_4 LDL_i + \beta_5 LDL_j + \beta_6 Domestic_i + \beta_7 Coast_j + \beta_8 FTA_{ij} + \varepsilon_{ij} \quad (4)$$

where if country i is a costal country, $Coast_j = 1$. If the country i is not a costal country, $Coast_j = 0$. When $FTA_{ij} = 1$, it means that country i reaches free trade agreement with China. But when $FTA_{ij} = 0$, it means that country i fails reach free trade agreement with China. When $i = j$, the gravity model reflects provincial trade. The index value e^{β_6} of the coefficient in front of $Domestic_i$ is used to express boundary effect.

3.3. Data

Based on the availability of data, 31 provincial units in mainland China were selected as research samples, excluding Hong Kong, Macao, and Taiwan. As a global economic cooperation network, the BRI has not yet given a precise spatial scope. In this paper, the scope of the BRI was defined as 65 countries and we divided them into six groups (Table 3, Figure 1), and the time scope was 2008 to 2018.

The data in this paper were from multiple sources. For example, the data of bilateral trade flows between 31 provinces of China and 65 countries along the BRI were from the foreign trade database of the Development Research Center of the State Council Information Network [34]. The provincial trade volume was calculated by subtracting total exports from the share of tradable goods [35,36], and the trade distance was represented by the point-to-point linear distance between provincial capitals and national capitals, which can be obtained through Google Earth. The calculation of provincial trade distance adopted the calculation method of Poncet [37]. The free trade agreement data were from China Free Trade Area Service Network [38]. The country-level logistics data came from the database of World Bank [39] (since 2007, the World Bank has been publishing the logistics performance index of all countries in the world every two years, while the data of the rest of the year were obtained through interpolation). Data of indicators at the provincial level were obtained from *China Statistical Yearbook (2009–2019)* [40], *China Transportation Yearbook (2009–2019)* [41], and statistical yearbooks of all provinces.

Table 3. List of countries along the BRI.

Region	Country
Mongolia-Russia	Russia(*), Mongolia(*);
Southeast Asia	Singapore(√), Malaysia(√), Indonesia(√), Myanmar(√), Thailand(√), Lao PDR(*), Cambodia(√), Vietnam(√), Brunei Darussalam(√), Philippines(√);
South Asia	India(√), Pakistan(√), Bangladesh(√), Afghanistan(*), Sri Lanka(√), Maldives(√), Nepal(*), Bhutan(*);
Central Asia	Kazakhstan(*), Uzbekistan(*), Turkmenistan(*), Tajikistan(*), Kyrgyzstan(*);
West Asia-North Africa	Iran(√), Iraq(√), Turkey(*), Syria(*), Jordan(*), Lebanon(*), Israel(*), Palestine(*), Saudi Arabia(√), Yemen(√), Oman(√), United Arab Emirates(√), Qatar(√), Kuwait(√); Bahrain(√), Greece(√), Cyprus(√), Egypt(√), Azerbaijan(*), Armenia(*), Georgia(*);
Central-Eastern Europe	Poland(*), Lithuania(*), Estonia(*), Latvia(*), Czech(*), Slovakia(*), Hungary(*), Slovenia(*), Croatia(*), Bosnia and Herzegovina(*), Montenegro(*), Serbia(*), Romania(*), Bulgaria(*), North Macedonia(*), Albania(*), Ukraine(*), Belarus(*), Moldova(*);

Note: * indicates that the country belongs to the countries along the "Silk Road Economic Belt" and √ indicates that the country belongs to the countries along the "21st Century Maritime Silk Road".

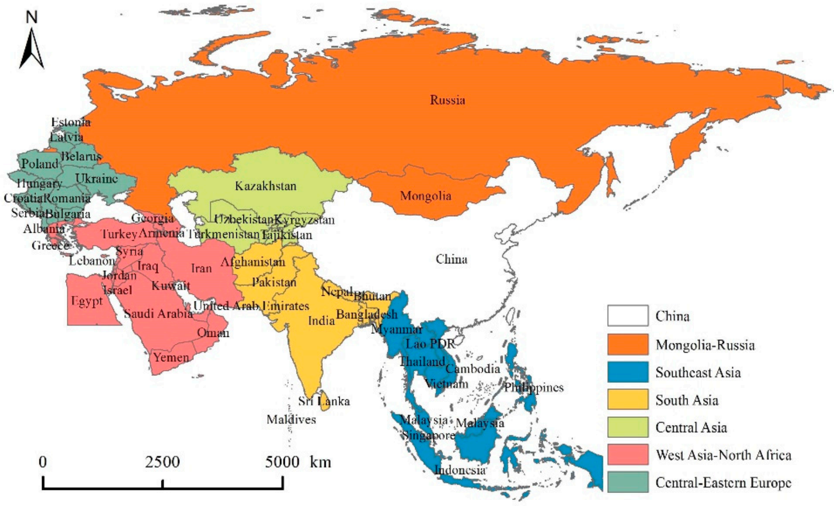


Figure 1. Grouping of countries along the BRI.

4. Spatio-Temporal Patterns of Trade between China and Countries along the BRI

4.1. Temporal Evolution Characteristics

From 2008 to 2018, the trade between China and countries along the BRI showed an overall "W-shaped" fluctuating upward trend ("upward-downward-upward-downward"). At the same time, the proportion of the trade volume between China and countries in the total trade of China demonstrated a similar evolutionary trend (Figure 2). In the first stage (2008–2009), the total trade volume plummeted from $598.41 billion in 2008 to $503.60 billion in 2009, declining 15.84%. The decline was mainly due to the global economic downturn and a slump in the international market caused by the outbreak of the international financial crisis. In the second stage (2009–2014), the total trade volume presented a steady upward trend. On the one hand, China quickly introduced a 4 trillion-yuan investment plan after the financial crisis, effectively promoting the rapid development of transport infrastructure as well as creating favorable conditions for stabilizing domestic economic development for Chinese enterprises to "go out". On the other hand, with the gradual opening of China Railway Express like Chongqing-Sinkiang-Europe International Railway in 2011, and the proposal of the BRI, China has established all-round, cross-field, open and inclusive cooperation platforms as well as increasingly closer economic and trade ties with countries along the BRI. In the third stage (2014–2015), the total trade volume declined for the second time, by 10.58%. The main reasons for the decline are the downturn of the international market, the decline of commodity prices, and the new normal transformation of domestic foreign trade structure; In the fourth stage (2015–2018), the total trade volume increased steadily again, with an increase of 28.78%. In 2018, the total trade volume between China and countries along the BRI accounted for 27.91% of China's total trade volume, indicating that trade links with countries along the BRI have become a new growth point of China's economy.

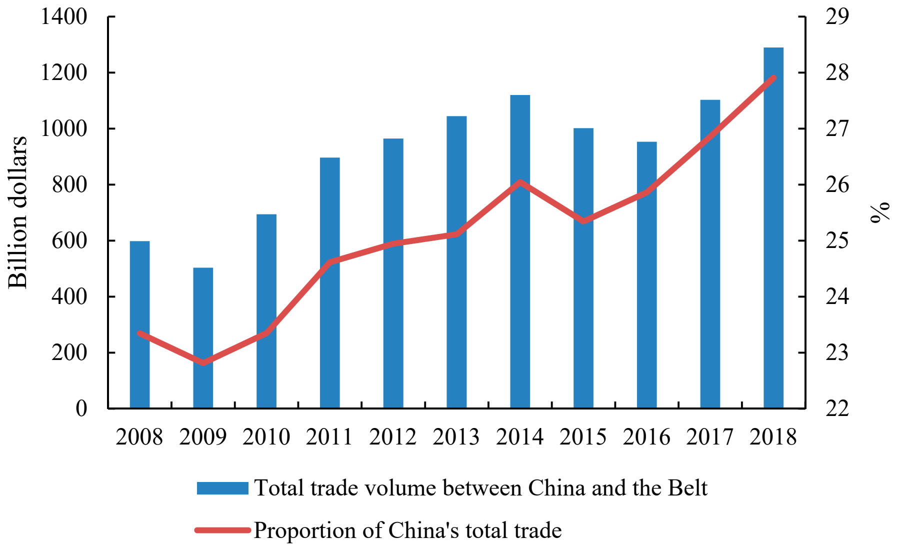


Figure 2. Evolution trend of total trade volume between China with countries along the BRI.

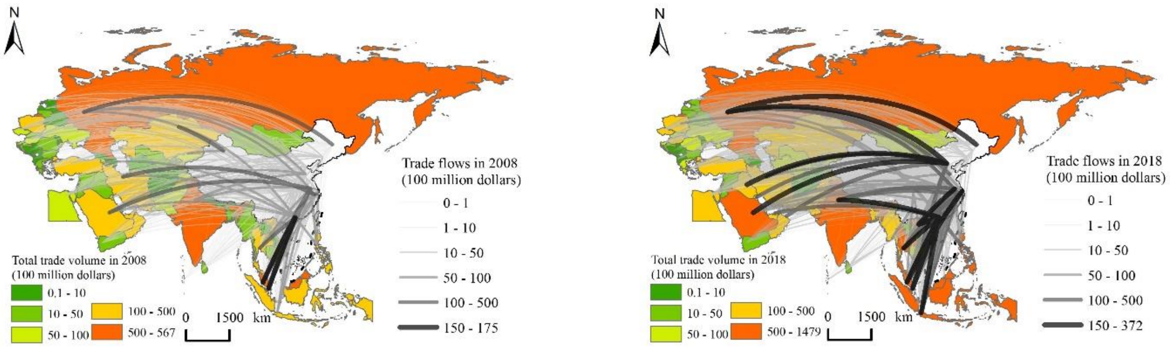
4.2. Spatial Evolution Characteristics

4.2.1. Overall Network Spatial Characteristics

With $100 million, and $1, $5, $10, and $15 billion being the critical values, we conducted quantitative statistics of the trade flows between the provinces of China and countries along the BRI (Table 4, Figure 3). On the whole, from 2000 to 2018, the breadth and intensity of trade links have increased significantly. In 2008, the trade flows of less than $100 million accounted for the majority, arriving at 75.48%. The second was the trade flows between $100 million and $1 billion, reaching 17.82%. While the trade flows over $10 billion occupied less than 0.5%. The high trade flows mainly existed between Guangdong and countries in Southeast Asia. In 2018, the proportion of trade flows less than $100 million presented a significant decline of 10%. While the rest types of the trade flows all showed an upward trend. In this stage, the trade flows were gradually shifting its close links with Southeast Asia to Russia, India, and countries on the Arabian Peninsula.

Table 4. Statistics of trade flows between China's provinces with countries along the BRI from 2008 to 2018.

Type	2008		2018	
	Trade Flows	Proportion	Trade Flows	Proportion
<$100 million	1521	75.48	1322	65.6
$100 million–$1 billion	359	17.82	462	22.93
$1 billion–$5 billion	106	5.26	165	8.19
$5 billion–$10 billion	20	0.99	35	1.74
$10 billion–$15 billion	7	0.35	18	0.89
>$15 billion	2	0.1	13	0.65



(**a**) (**b**)

Figure 3. Trade network between China's provinces with countries along the BRI from 2008 to 2018. (**a**) 2008, (**b**) 2018.

4.2.2. Domestic Spatial Characteristics

In the domestic aspect, the 31 provinces of China were divided into three regions (eastern, central, and western regions) according to the economic and geographical space of China (Table 2). From 2008 to 2018, the trade between the eastern, central, and western regions of China and countries along the BRI showed a "W" type fluctuating upward trend (Table 5). The total trade volume of the eastern region increased from $504.47 billion in 2008 to $1,030.27 billion in 2018, with an average annual growth rate of 7.40%. The total trade volume of the central region increased from $42.18 billion in 2008 to $105.43 billion in 2018, with an average annual growth rate of 9.61%. And the total trade volume of the western region increased from $51.82 billion in 2008 to $154.38 billion in 2018, with an average annual growth rate of 11.53%. The above-mentioned data indicated that the trade link between the eastern region and countries along the BRI was much higher than that of the central and western regions, and the trade link between the western region and the countries was a little higher than that of the central region. Among the development of foreign trade with the countries along the BRI, the inter-provincial differences of China have been narrowing to a certain extent. From 2008 to 2018, the CV values of the central and western regions have been declining, with the falling range being 39.18% and 32.18%. While the CV value of the eastern region enjoyed a lower falling range of 5.27%. It meant that with the rapid development of cross-border logistics like China Railway Express, the trade links between the regions of inland China and countries along the BRI were further strengthened, and provincial foreign trade differences of the central and western regions thus became smaller.

Table 5. Evolution trend of total trade volume between China's three regions with countries along the BRI from 2008 to 2018.

Year	Total Trade Volume ($1 Billion)			CV		
	Eastern	Central	Western	Eastern	Central	Western
2008	504.47	42.12	51.82	0.82	0.66	1.41
2009	432.75	31.29	39.56	0.84	0.63	1.15
2010	594.99	45.09	54.27	0.81	0.56	1.12
2011	760.25	62.67	73.45	0.79	0.64	1.11
2012	801.98	69.79	92.95	0.79	0.63	1.09
2013	863.28	74.62	106.63	0.83	0.55	1.09
2014	911.37	85.29	123.67	0.89	0.54	1.02
2015	828.84	76.27	96.66	0.90	0.36	0.94
2016	797.80	70.50	84.92	0.93	0.36	0.95
2017	902.83	80.08	120.14	0.90	0.38	0.95
2018	1030.27	105.43	154.38	0.78	0.40	0.96

According to the statistics of the total trade volume between the provinces and countries along the BRI, the provinces were divided into high trade zone, relatively high trade zone, medium trade zone, relatively low trade zone, and low trade zone according to the critical value of $ 5, $10, $50 and $100 billion (Figure 4). From 2008 to 2018, the high trade zone, besides Guangdong, was newly added with other cities like Shanghai, Beijing, Jiangsu, and Zhejiang, while the relatively high trade zone included Shandong and Fujian. In the medium trade zone, provinces such as Xinjiang, Heilongjiang, Liaoning, Tianjin, and Hebei remained their positions, and the provinces newly added to the medium trade zone are mostly concentrated in the central and southwest regions. The pattern of relatively low trade zone encountered complete changes which were mainly concentrated in Jilin and Shaanxi. Shanxi, Ningxia, Gansu, Qinghai, Xizang, and Guizhou in the low trade zone remained unchanged all the time. In general, the total trade volume between China and countries along the BRI showed a spatial decreasing trend from the east to the west, with Beijing, Shanghai, Guangdong, and other provinces as the core.

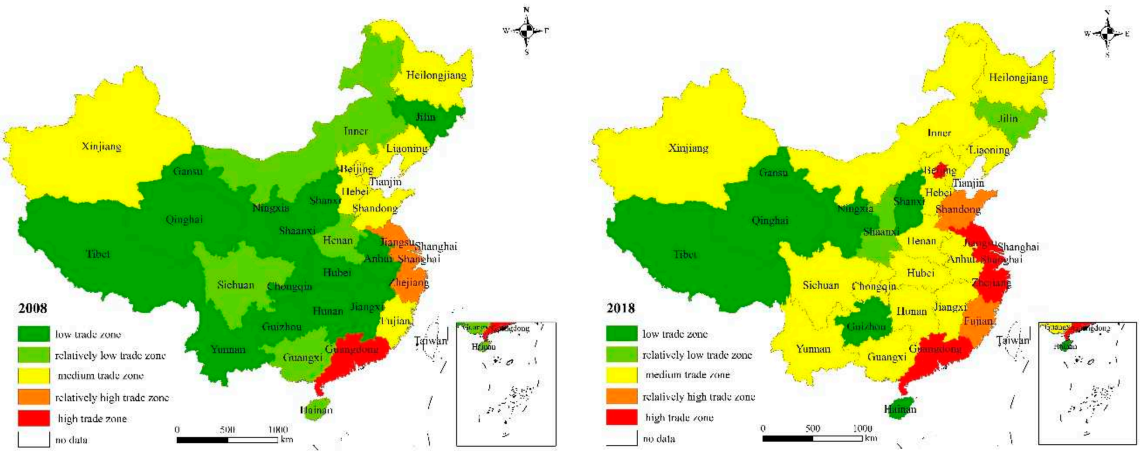


Figure 4. Spatial distribution of total trade volume between China's provinces with countries along the BRI from 2008 to 2018. (**a**) 2008, (**b**) 2018.

4.2.3. International Spatial Characteristics

In the international aspect, according to the geographical distribution of the world, the 65 trade partner countries along the BRI were divided into Mongolia-Russia, Southeast Asia, South Asia, Central Asia, West Asia-North Africa, Central-Eastern Europe (Figure 3). Meanwhile, combining with the key direction of the development of the BRI regions, the above-mentioned six regions were further divided into the "Belt" (Silk Road Economic Belt) regions and the "Road" (21st-Century Maritime Silk Road) regions (Table 3).

From 2008 to 2018, the trade between the regions along the BRI and China showed a certain upward trend (Table 6). From the development of the total trade volume of the six regions of the Belt and Road, the descending order of the six regions was Southeast Asia, West Asia-North Africa, South Asia, Mongolia-Russia, Central-Eastern Europe, and Central Asia. During the study period, Southeast Asia showed an evolutionary trend of "W", increasing from $231.07 billion in 2008 to $587.72 billion in 2018, with an average annual growth rate of 9.79%. The evolutionary trend of West Asia-North Africa was the same as Southeast Asia, but the annual growth rate of the former was 6.17% which was much smaller compared with the latter. The total trade volume of the other four regions was relatively small, and the sum of which only accounted for 28% to 34%. In terms of the average annual growth rate, South Asia held the highest value of 7.83%, followed by Central-Eastern Europe (6.89%) as well as Mongolia-Russia (6.88%). While Central Asia was the lowest (3.07%). From the change of the total trade volume of the five regions, Southeast Asia, as an important part of the BRI, had a strengthened economic and trade link with China, which can be ascribed to two reasons. On the one hand, Southeast Asia and China are geographically adjacent, so the land, sea, and air transport between them is relatively convenient. On the other hand, China and Southeast Asia established their free trade areas (China-ASEAN Free Trade Area, CAFTA) in an early stage. After the completion of the free trade zone in 2010, most products of both sides are free of the tariff, greatly promoting trade liberalization. In addition, China's total trade with West Asia-North Africa and its growth rate were both lower than that with Southeast Asia. And the main reason is that our country is in the rapid development stage of industrialization, and thus is largely dependent on the energy market of West Asia-North Africa. Under the background of the new normal, the structure of the economic industry of China is in urgent need of optimizing and adjusting, making the trade commodity structure, especially the export trade of China to West Asia and North Africa change. Zhang et al. [42] found that the proportion of China's exports to West Asia of products with high technological content such as machinery, electrical equipment was increasing, while the proportion of exports of textiles, furniture, and other products with low technological content was decreasing. Though the total trade volume between South Asia, Central and Eastern Europe, Mongolia-Russia, and China was far lower than that of South Asia and West Asia-North Africa, the growth speed of the former was faster than that of the latter. The main reason is that China promoted the construction of the cross-border logistics network "hardware" and further deepened the development of the "software". For example, in 2011, China launched the second stage negotiation of the China-Pakistan free trade agreement. In 2017, China signed a free trade agreement with the Maldives. In terms of the Central and Eastern European, China established a cooperation mechanism with the Central and Eastern European. And in 2017, China and the Central and Eastern European jointly issued the *Budapest Outline of China-Central and Eastern European Countries Cooperation*. Central Asia does not take any advantage of the total volume and the development speed of trade. But with the continuous improvement of the transportation efficiency and performance of China Railway Express, and the deepening of interconnection construction of infrastructure in Central Asia, the economy and trade of China and Central Asia will be injected into new impetus.

Table 6. Evolution trend of total trade volume between sub-regions along the BRI and China from 2008 to 2018.

Year	Mongolia-Russia	Southeast Asia	South Asia	Central Asia	West Asia-North Africa	Central-Eastern Europe	"Belt" Region	"Road" Region
2008	59.17	231.07	65.47	30.82	163.73	48.15	172.00	426.41
2009	41.10	212.93	56.83	23.74	128.96	40.03	127.96	375.64
2010	58.92	292.79	80.47	30.13	179.08	52.97	173.70	520.65
2011	85.53	362.39	96.99	37.75	249.01	64.69	228.24	668.12
2012	94.01	400.06	92.97	45.95	267.67	64.07	245.64	719.08
2013	95.10	443.12	93.20	50.27	268.38	94.45	290.41	754.11
2014	100.75	480.08	106.03	42.95	319.68	70.84	264.36	855.98
2015	73.19	466.58	111.16	32.60	253.01	65.23	216.60	785.16
2016	73.85	447.65	112.73	30.15	221.88	66.96	214.27	738.95
2017	90.58	518.66	126.93	36.27	249.97	80.64	255.94	847.11
2018	115.07	587.72	139.12	41.70	297.87	93.73	301.42	973.79

From the development of the two major regions of the BRI, it showed the characteristics that the total trade volume of the "Road" region was larger than that of the "Belt" region (Table 6). The total trade volume of the "Road" region showed a "W" type fluctuating upward trend, increasing from $426.38 billion in 2008 to $973.39 billion in 2018, with an average annual growth rate of 8.61%. And the trade of the "Belt" region presented a similar development trend, with a relatively low average annual growth rate of 5.78%. Therefore, the "Road" region is the main trading place of China's foreign trade. The reason why the trade of the "Road" region and the "Belt" region existed huge differences was that the goods transportation way of China and the world is predominated by sea transportation.

According to the *China's Ports-Of-Entry 2019 Yearbook*, the import and export trade of China through water transportation accounted for 61.60% in 2018, while road and railway transportation accounted for 16.0% and 1.10%.

5. Empirical Analysis

5.1. Overall Regression

Investigating the impact of logistics development level on the provincial international trade of China by utilizing Stata.16 and adopting the mixed least square method (OLS) to analyze the panel data from 2008 to 2018. The results of the empirical model are shown in Table 7. Model 1 in Table 7 is the standard trade gravity equation. Model 2 adds logistics development level variables. Model 3 adds boundary effect variables. Model 4 adds variables of logistics development level based on Model 3. In model 5, all variables are incorporated into the equation. Based on Model 5, Model 6 and 7 conducts temporal heterogeneity investigation, respectively representing the period of 2008–2012 (before the proposal of BRI) and 2013–2018 (after the proposal of BRI). In Table 4, the fitting results of all variables are completely consistent with the expected ones, and all the regression coefficients can pass the significance test of 1%. Therefore, it is very suitable to use the gravity model to analyze the provincial international trade of China.

Table 7. Estimation of overall results.

Variable	Standard Equation (Model 1)	Add *LDL* (Model 2)	Add Domestic (Model 3)	Add LDL and Domestic (Model 4)	2000–2018 (Model 5)	2000–2012 (Model 6)	2013–2018 (Model 7)
$lnGDP_i$	0.883 ***	0.707 ***	0.854 ***	0.684 ***	0.679 ***	0.667 ***	0.807 ***
$lnGDP_j$	0.662 ***	0.590 ***	0.637 ***	0.599 ***	0.587 ***	0.554 ***	0.620 ***
lnD_{ij}	−1.254 ***	−1.267 ***	−0.807 ***	−0.843 ***	−0.743 ***	−0.785 ***	−0.777 ***
LDL_i		4.053 ***		4.002 ***	3.987 ***	4.210 ***	4.606 ***
LDL_j		1.546 ***		0.831 ***	0.619 ***	0.714 ***	0.971 ***
$Domestic_i$			4.172 ***	3.942 ***	4.441 ***	4.180 ***	4.293 ***
$Coast_j$					0.099 ***	0.078 ***	0.086 ***
FTA_{ij}					0.242 ***	0.114 ***	0.282 ***
Cons	−0.595 ***	−0.294 ***	−4.167***	−3.590 ***	−4.374 ***	−3.498 ***	−5.832 ***
R^2	0.639	0.680	0.681	0.716	0.717	0.720	0.746

Note: *** indicates the significance at 1% level; Since logistics performance index published by the World Bank is between 1–5, LDL_j is converted to between 0–1 through extreme value standardization to facilitate the comparison with the LDL_i.

Models 1 to 7 show that the bilateral trade between China's provinces and countries along the BRI was positively proportional to the economic scale of the two and inversely proportional to the geographical distance of the two, which was consistent with the theoretical analysis of the trade gravity equation. In Model 2, the provincial logistics development level had a significant positive influence on bilateral trade, with every 1% increase in provincial logistics development leading to a 4.053% rise in bilateral trade. The logistics development level of the partner country also had an obviously positive influence on bilateral trade, but its influence coefficient (1.546) was lower than that of the provincial logistics development level. It means that the improvement of logistics development level played a critical role in promoting the trade between China's provinces and countries along the BRI. And the trade effect of the bilateral logistics had prominent differences, with notable "motherland directivity". Thus, the strengthening of the logistics infrastructure construction and the logistics service level of China is of great importance, which is an example of the saying "It takes a good blacksmith to make steel".

Model 3 showed that there was a significant border effect on the trade between China's provinces and countries along the BRI, with a boundary effect value of 64.845. This value was higher than the estimated result of Liu and Hu [43], but far lower than the estimated result of Liang and Zhang [44] on the border effect of the export trade of China with its neighboring countries. Combined with the research results of Helliwell [45], the border effect between China's provinces and countries along the BRI was close to its counterpart (around 70) between developing countries. This paper certainly differed from previous studies in some aspects such as the use of the data of bilateral trade between China's provinces and countries along the BRI instead of the provincial level data of China's partner countries, which may lead to a certain degree of deviation when estimating border effect. After the introduction of the variable of logistics development level in Model 4, the boundary effect value significantly decreased from 64.845 to 51.522, with a declining range of 20.547%, which fully indicated that the improvement of logistics development level is conducive to reducing the boundary effect and further expanding the geographical range of the provincial trade of China.

From Model 6 and 7, the impact of the logistics development level on the provincial international trade of China contained obvious temporal heterogeneity. Compared with the period of 2008 to 2012, the influence coefficients of the logistics development level of China's provinces and partner countries increased by 9.406% and 35.994% between 2013 and 2018. The data demonstrated that after the proposal of BRI, China has strengthened the construction of domestic regional logistics infrastructure, and established a preliminary logistics network. As a result, the trading time and costs between China and countries along the BRI are further lowered, facilitating the exchange of economic and trade personnel and promoting the circulation of various elements of the trade.

In terms of variables controlling, $Coast_j$ and FTA_{ij} both had significant positive effects on the bilateral trade, with coefficients of 0.099 and 0.242 (Model 5).

5.2. Sub-Regional Regression

5.2.1. Domestic Sub-Regional Regression

Model 8 to 10 in Table 8 represented the empirical results of the eastern, central, and western regions respectively. The coefficients of the provincial logistics development level in the three regions were significantly different. The coefficient of the eastern region was positive and passed the significance test of 1%. The coefficient of the central region was positive as well but did not pass the significance test. While the coefficient of the western region was negative and did not pass the significance test either, indicating that the provincial logistics development level significantly promoted the trade between the eastern region and countries along the BRI. Probably because of the excellent geographical location and the developed transport infrastructure of the eastern region, transport cost can be reduced to a large extent and the logistics trade effect was thus more noticeable. In contrast, the geographic locations of the central and western regions had little advantages, and the poor logistics infrastructure called for further promotion, thus the overall logistics trade effects of the central and western regions cannot play their full roles. The logistics development level of the partner countries had a significant positive influence on the bilateral trade, and the descending order of the influence was the eastern, central, and western regions, showing that the logistics development of the countries along the BRI is conducive to the foreign trade growth of the regions of China. Meanwhile, as the eastern region is endowed with the advantage of the shipping conditions, the transport connection between it and the countries along the BRI is much more convenient.

In terms of controlled variables, there were significant boundary effects between the eastern, central and western regions, and countries along the BRI, with the boundary effect values of 9.708, 114.663, 156.179, indicating that boundary effect between the eastern region and countries along the BRI was rather close to the effect among developed countries, and the boundary effects of the central and western region even exceeded the average level of the effect among developing countries. FTA_{ij} had a significant positive influence on the three regions, while $Coast_j$ merely had an obvious impact on the eastern region.

Table 8. Estimation of domestic division.

Variable	Eastern Region (Model 8)	Central Region (Model 9)	Western Region (Model 10)
$lnGDP_i$	0.874 ***	0.414 ***	0.445 ***
$lnGDP_j$	0.836 ***	0.578 ***	0.384 ***
lnD_{ij}	−0.827 ***	−0.811 ***	−0.859
LDL_i	1.190 ***	0.207	−0.222
LDL_j	1.254 ***	0.641 ***	0.433 ***
$Domestic_i$	2.273 ***	4.742 ***	5.051 ***
$Coast_j$	0.305 ***	0.003	−0.026
FTA_{ij}	0.199 ***	1.179 ***	0.110 ***
Cons	−5.931 ***	−1.089 ***	0.275 ***
R^2	0.802	0.787	0.687

Note: *** indicates the significance at 1% level.

5.2.2. International Sub-Regional Regression

Model 11 to 16 in Table 9 represented the empirical results of Mongolia-Russia, Southeast Asia, South Asia, Central Asia, West Asia-North Africa, and Central-Eastern Europe, while Model 17 and 18 showed the fitting results of the "Belt" region and the "Road" region. From the six regions, the provincial logistics development level had a significant positive impact on Southeast Asia, South Asia, West Asia-North Africa, and Central-Eastern Europe, with fitting coefficients of 4.286, 2.351, 4.068, and 4.073, while had no significant impact on Mongolia-Russia and Central Asia. In terms of the logistics development level of the partner countries, Southeast Asia, South Asia, Central Asia, West Asia-North Africa had a significant positive impact; Mongolia-Russia had no significant impact, and Central-Eastern Europe had a negative impact. From the "Belt" region and the "Road" region, the logistics development level had a significant positive impact on the trade development of the two regions, but the impact on the "Road" region was larger than that on the "Belt" region, which fully demonstrated that the construction of the logistics network of the inland countries along the BRI should be effectively strengthened.

Table 9. Estimation of international division.

Variable	Mongolia-Russia (Model 11)	Southeast Asia (Model 12)	South Asia (Model 13)	Central Asia (Model 14)	West Asia-North African (Model 15)	Central-Eastern Europe (Model 16)	"Belt" Region (Model 17)	"Road" Region (Model 18)
$lnGDP_i$	0.976 ***	0.886 ***	0.530 ***	0.623 ***	0.687 ***	0.472 ***	0.523 ***	0.905 ***
$lnGDP_j$	−0.112	0.650 ***	0.467 ***	0.321 ***	0.583 ***	0.545 ***	0.548 ***	0.667 ***
lnD_{ij}	−0.306 ***	−0.781 ***	−0.269 ***	−1.066 ***	−0.060	0.688 ***	−0.715 ***	−0.542 ***
LDL_i	0.433	4.286 ***	2.351 ***	0.162	4.068 ***	4.073 ***	3.089 ***	5.049 ***
LDL_j	−0.273	1.525 ***	2.161 ***	1.987 ***	0.494 ***	−0.554 ***	0.325 ***	0.736 ***
$Domestic_i$	7.440 ***	3.953 ***	5.995 ***	3.324 ***	6.964 ***	10.127 ***	4.669 ***	5.030 ***
$Coast_j$	3.586 ***	0.163 **	0.316 ***		0.174 ***	0.115 ***	0.147 ***	
FTA_{ij}			0.197 ***		−0.247 *		−0.124 **	0.499 ***
Cons	−5.302	−6.370 ***	−7.046 ***	0.970	−10.581 ***	−15.225 ***	−2.865 ***	−8.701 ***
R^2	0.903	0.857	0.905	0.886	0.772	0.855	0.738	0.778

Note: * indicates the significance at 10% level, ** indicates the significance at 5% level, *** indicates the significance at 1% level.

6. Discussion

6.1. The Government Must Strengthen the Coordinated Development of Logistics among the Provinces of China

The results of the research show that the gap of the logistics development level among provinces of China tends to narrow, but the coefficient of variation always exceeds 0.3. The logistics development level of the eastern region is still far more than that of the central and western regions, and the trade effect of logistics of the central and western region is not been effectively reflected. Therefore, for the eastern region, the adjustment of the internal structure of the logistics should be strengthened, intelligent logistics should be developed to improve the quality of logistics development. In the central and western regions, the construction of logistics infrastructures such as highway, railway, waterway, and aviation should be strengthened; the layout of logistics hubs should be optimized; the comprehensive logistics transportation network should be built to transform the geographical conditions of the central and western regions from "remote edge" to "frontier zone".

6.2. Countries along the BRI Should Strengthen Policy Communication and Coordination

The results show that the trade connection between China and Southeast Asian is the closest, and the trade effect of the logistics in Southeast Asian is much higher than that of other BRI regions, showing that the improvement of "software" conditions such as policy will greatly exert the trade effect of "hardware" logistics. For Central Asia and Mongolia-Russia, on the one hand, it is necessary to establish a sound policy communication mechanism, gradually reduce trade barriers, and promote trade liberalization and development. On the other hand, the backwardness of logistics infrastructure in Central Asia and Mongolia-Russia needs to be improved fundamentally by relying on the financial and technical support of the BRI investment institutions like the Asian Infrastructure Investment Bank (AIIB) and Silk Road Fund.

7. Conclusions

Under the background of the dual-circulation development, strengthening the construction of domestic logistics is not only conducive to realizing the free and orderly flow of domestic economic factors, but also promotes the balancing of the coordinated development of China's three regions. Meanwhile, the strengthening is also beneficial to enhance China's economic and trade ties with the countries along the BRI and to drive the building of a global community with a shared future for mankind. Taking the 65 countries as the research object, this paper firstly built the index system of the provincial logistics development level of China, secondly discussed the spatial-temporal evolution pattern of the trade between China provinces and countries along the BRI, then utilized the improved gravity model system to analyze the impact of the logistics development level on the bilateral trade. The main research conclusions are as follows:

(1) The overall logistics development level of China had a steady upward trend from 2008 to 2018, with an increase of 47.07%. Besides, the logistics development level of the western region was significantly higher than that of the central and eastern regions, with an increase of 77.16%.

(2) The trade between China and countries along the BRI generally showed a "W" type fluctuating upward trend, and the breadth and intensity of trade connections were significantly enhanced. Domestically, the total trade volume between China and countries along the BRI presented the trend of decreasing from the east to the west, with Beijing, Shanghai, Guangdong, and other provinces as the core. Internationally, the descending order of the total trade volume was Southeast Asia, West Asia-North Africa, South Asia, Mongolia-Russia, Central-Eastern Europe, and Central Asia.

(3) The logistics development level significantly promoted the growth of the bilateral trade between China and countries along the BRI. However, compared with partner countries, the provincial logistics development level of China had a greater impact on trade.

(4) The development level of logistics can significantly reduce the border effect, with a declining range of 20.547%.
(5) The influence of logistics development level was different in different periods as well as international and domestic regions. The level was higher after the proposal of the BRI than that before the proposal of the BRI. Besides, the descending order of the level in the three regions was the eastern region, the central region, and the western region. And the descending order of the level in international regions was Southeast Asia, West Asia-North Africa, South Asia, Mongolia-Russia, Central-Eastern Europe, and Central Asia.

In this paper, the evaluation system of the provincial logistics development level is decomposed into three subsystems: regional economic support, logistics infrastructure, and logistics operation development, which is conductive to clarifying the key elements of provincial logistics development and highlighting the role of logistics organization and regional integrated service, and has a certain reference significance for relevant studies. However, the evaluation system of the provincial logistics development level involves many indicators, and there are some difficulties in data collection and unification. Therefore, the evaluation index system needs to be supplemented and improved in future research.

Different from the existing research results on a national scale, the provincial logistics development level has a more obvious impact on bilateral trade, and the effects of logistics trade in eastern, central and western regions shows huge differences. In the follow-up research, we should strengthen the research on the spatial effect of the provincial logistics development level, the interaction between the subsystems and its mechanism to bilateral trade, so as to further summarize the mechanism and law of spatial interaction in international trade research.

Finally, logistics development level is not significant in some models, especially for the eastern and central regions in China. Overall, in international logistics, transport costs is more important than physical distance, especially for inland areas. In this paper, we use the physical distance rather than transport costs which may cause the logistics trade effects are not significant in some inland areas.

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Decrypting the Belt and Road Initiative: Barriers and Development Paths for Global Logistics Networks

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Abstract: The Belt and Road Initiative (BRI) is an ambitious infrastructure and development project promoting sustainable economic growth through facilitating prosperous trade across Eurasia and Africa; however, its potential remains underexploited. Logistics networks along BRI routes face several challenges that hinder efficient operations. In addition, although uncertain of how the initiative will develop, logistics and supply chain management (LSCM) practitioners must align their networks with future developments. This study aims to synthesize current barriers to the BRI from an LSCM perspective; propose strategies for dealing with them; and outline and assess conceivable BRI development scenarios to create awareness for possible international logistics network developments. The study builds on a structured and moderated Nominal Group Technique exercise among 15 LSCM professionals to extract current barriers, mitigation strategies, and potential development scenarios, followed by a survey among 52 LSCM professionals to assess those issues. The study synthesizes and assesses 17 BRI barriers for LSCM practice and proposes 20 strategies for dealing with them, assessed in terms of effectiveness and complexity. Moreover, 14 development scenarios are assessed in terms of their probability of becoming reality and impact on the vulnerability of logistics networks, categorized into four scenario clusters (monitor, prepare, propel, and exploit) for guiding LSCM practice.

Keywords: Belt and Road Initiative; New Silk Road; One Belt One Road; international logistics networks; Nominal Group Technique; scenario analysis

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1. Introduction

The ancient Silk Road was a vast network of land and sea trade routes connecting Europe, Asia, and Africa and facilitating trade and cultural exchanges from the second century BCE to the 18th century [1]. In 2013, mindful of the history of this ancient trade network, the Chinese President, Xi Jinping, introduced a national strategy, then called the New Silk Road and later known as the Belt and Road Initiative (BRI) [2], one of the biggest infrastructure projects in the world, with over US$900 billion of investment in road, rail, gas, oil, and port infrastructure to connect the entire Eurasian world and Africa, covering 64% of the global population and 30% of the world GDP [3,4].

There are different ideas, opinions and discussions on China's motivation behind the BRI. One could argue that it is to sustain China's economic growth by better connecting existing markets and opening up to new markets, which is also reflected by Chinese foreign direct investments in these markets. It could also be argued that the main purpose may be to improve the country's international economic influence, but this is also accompanied by the creation of geopolitical influence that can be used opportunistically by China [5,6]. This could be the case, for example, when capital loans have been granted by China (i.e., through the Asian Infrastructure Investment Bank), for infrastructure development in a certain BRI-related country, but are difficult to repay by the debtor. There are also others that argue that an additional major motivation of China behind the BRI might be getting long-term access to the natural resources of Africa and Central Asia [7,8]. Without delving into these and further potential motivations behind the BRI, it can be concluded that there are multiple, interrelated reasons for its creation.

However, what is certain is that the BRI connects numerous countries on three large continents and thereby provides the potential for increased trade among those regions. Because of the direct linkage to trade facilitation, it is argued that the BRI contributes to the UN Sustainable Development Goals (SDGs), as both are "mutually supportive development agendas" (cf. [9]). The supportive nature of the BRI contributing to the SDGs is mainly stated due to the assumption that the BRI focusses on encouraging more efficient trade, which consequently can lead to the economic growth of the involved parties. Previous research has also indicated that the BRI provides the potential to positively impact the sustainable development of the countries involved through increased trade [10–13]. However, it must be stated that this refers to economic sustainability, which is the main focus of the BRI—ecological and social sustainability perspectives are mostly out of scope when relating the BRI and SDGs, and in-depth analyses on the connection of the initiatives are still missing [14]. These previous studies also confirm that due to the novelty of the BRI and the lack of available data, the assessment is not possible at this stage, since economic development can only be determined from a long-term perspective. Additionally, previous studies indicate that the BRI might positively impact economic growth among the countries involved, but benefits are not shared equally, considering that China seems to profit even more from the cooperation [15]. Nevertheless, the BRI can be a win-win scenario for all countries involved if current challenges are tackled and barriers are removed. Owing to its global importance, the BRI has captured the interest of researchers, thereby leading to a wide range of research on the initiative and its effects at multiple levels [16–21], that often focuses on the macroeconomic assessment of the initiative and the effects related to it. To ensure the long-term success of the BRI and the economic growth of the countries involved, logistics is considered as a "driving force" [22]. This being said, without enabling efficient logistics along the BRI paths the success of the initiative is in jeopardy. Remarkably, given its clear implications for global supply chains [23–25], the BRI has received only limited attention in the logistics and supply chain management (LSCM) literature compared with other domains [26,27]. Although LSCM researchers can support global supply chains by investigating the implications of the BRI, so far, they have largely failed to do so.

BRI is one of the most ambitious logistics and infrastructure initiatives of this century, and its implementation may impact on LSCM practitioners located on BRI routes. Moreover, companies must prepare for an uncertain future, as the initiative is more of a fluid concept than a clearly formulated plan with precisely determined developments, and that provides uncertainties for the countries and companies involved [28–31]. LSCM practitioners are seeking assistance to understand the initiative and its future implications for global supply chains, so that they can tackle the barriers, leverage the full potential of the BRI, and ensure continued, efficient material flows.

To bridge this gap between research and practice, which is frequently discussed in the management literature [32–35], a comprehensive understanding of the barriers that the BRI presents to efficient operations is needed, and the possible future developments of the BRI must be outlined. By shedding light on this area, this study will identify additional BRI-related fields in which research can support practice. This study aims, therefore, to contribute to the following research objectives (RO):

RO1: Outline and assess the current barriers that the BRI presents, from an LSCM perspective, that inhibit efficient operations along BRI paths.
RO2: Provide indications of strategies for dealing with current BRI barriers.
RO3: Propose and assess future development scenarios for the BRI.

To contribute to these ROs, this study follows a two-stage approach. First, a moderated on-site group exercise with 15 professionals with long-standing experience in LSCM is performed to systematically extract current barriers to the BRI and potential strategies for dealing with them, as well as to propose potential development scenarios of the BRI. Second, an additional follow-up survey among 52 LSCM professionals is done to assess the barriers by importance; the strategies by *complexity* and *effectiveness*; and the development scenarios by *probability* and their impact on the *vulnerability* of logistics networks. The group exercise builds on the Nominal Group Technique (NGT), which is a structured moderated group exercise process that separates problem description and problem solution seeking to reduce the biases of traditional group exercise formats [36]. To synthesize the results, the researchers apply the Q-methodology [37], which is a bottom-up approach to condense a variety of factors to overarching meta-factors in a structured way, and which has also been applied in LSCM research [38]. Additionally, different measures to reduce bias throughout the various stages of the research process have been taken. The study, and the results obtained, are limited to European–Chinese logistics networks. Although Africa is playing an essential role in the BRI, the European–Chinese trade relationship remains dominant in this trilateral network. The logistics barriers are very different when African countries are included, and Africa therefore remains beyond the scope of this study. Moreover, the results gained through this analysis represent the regional view of companies mostly operating in networks between Central Europe and China, which is one of the most important trade relationships in the BRI context. Equally important views of Southern European, Central Asian, and other stakeholders have not been included in the analysis.

2. Background of the Belt and Road Initiative

Before China started its economic reform in the 1970s, it was a small agriculture-based economy. In the early decades of this reform, China tried to focus on reforming the domestic market and was not too much involved in international affairs. However, due to an increasing focus on manufacturing labor-intensive goods for the international market, China developed into one of the biggest economies and trade partners in the world [4]. This opening up to international affairs is also evident in the development of China's five-year plans. The BRI, which was initially presented by Xi Jinping in 2013, is a prominent part of China's 13th five-year plan (2016–2020) for economic development. This shows the importance of the initiative for China and is, from China's point of view, a consistent step in opening up to even more international trade and the global interlinking of value chains.

Before outlining the current barriers to BRI, the strategies for dealing with them, and future development paths from an LSCM perspective, the overall BRI network must first be explained. The BRI comprises investments in infrastructure projects seeking to develop the Maritime Silk Road (MSR) and six economic corridors (EC) within the Eurasian region, as outlined by the National Reform and Development Commission of China [39]. These ECs connect different Eurasian countries with one another and also connect them to the MSR. That said, from a logistics perspective, both infrastructure dimensions—ECs and the MSR—must be analyzed together.

The MSR describes a vision of a better-connected maritime transport network in Eurasia, achieved by investing in port infrastructure in China, Southeast Asia, India, the Middle East, and Europe [23]. For European–Chinese logistics networks—the focus of this study—port infrastructure investments in European ports are of clear importance, as they could impact on future maritime transport routes between China and Europe [40]. In this regard, the ports of Piraeus, Greece, and Venice, Italy, form prominent developments that could provide viable future options for trade between China and Europe through the Suez Canal. To provide viable competition to northern European seaports, the BRI plans to connect the Piraeus via a high-speed rail connection to Central European rail tracks already in use for rail transport between Europe and China [41].

In order to outline the current state and potential future developments of rail transportation between China and the rest of the world, the ECs need to be explained. Three of these are relevant to transporting goods via rail between China and Europe. First, the China–Mongolia–Russia EC connects China with the Russian railway system via Mongolia [39]. Using this connection, goods moving between China and Europe can be transported through Moscow (Russia) to Brest (Belarus) and on to Central Europe, e.g., Duisburg, Germany [28,41]. Second, the New Eurasia Land Bridge EC is a direct rail connection between China (Jiangsu Province) and the Port of Rotterdam, The Netherlands, via Dostyk (Kazakhstan), Moscow (Russia), and Brest (Belarus) through to Poland and Duisburg, Germany.

Third, the China–Central Asia–West Asia EC seeks to develop a connection for Central Asian countries such as Kazakhstan, Kyrgyzstan, Tajikistan, Iran, and Turkey. For goods in transit from China to Central Europe, this line provides a third option with a more direct connection to southern Europe via Istanbul (Turkey) and also to Central Europe via Brest (Belarus), utilizing the same rail infrastructure in Eastern Europe as the previously mentioned corridors [28,30,41]. The remaining three ECs—China–Pakistan, Bangladesh–China–India–Myanmar and China–Indochina–Peninsula—predominantly serve to connect the remaining South and South-East Asia region with China and also to connect participating countries to the MSR [23]. However, those ECs are developing in a different way, and the choice of a certain transport route is determined by several characteristics (e.g., transport times and transport modes, among others) and needs case-specific analyses [42].

Although the strategy for the ECs and MSR has been clearly communicated, the projects and investments developing them are diverse and hard to keep track of. A recent investigation showed that the implementation of the BRI is less coordinated than intended and a large proportion of the infrastructure projects are taking place outside the ECs and the MSR [30]. Therefore, the BRI is better understood as a fluid concept with a long-term vision rather than a project with a clear top-down strategy and execution [28,29]. Moreover, for rail transportation, there is no holistic optimization and coordination of transport along the three main rail corridors with the Chinese rail network, thus leading to insufficient cargo handling capacity [43].

Cooperation between Europe and China regarding the BRI and its development is increasing, although there is room for improvement in various areas [44]. The literature mentions several barriers that are currently dampening the sustainable development of the BRI, such as volatile and uncertain legal and administrative environments, border and customs barriers, political risks along BRI routes, and shortage of qualified personnel, but also infrastructure barriers, such as the insufficient transport and processing capacity of the railway infrastructure [45,46]. Companies operating in European–Chinese logistics networks need knowledge of the development of future transportation routes to prepare their businesses and supply chains accordingly. Nevertheless, LSCM literature on the BRI and its barriers is sparse [26,27]. In order to create a more comprehensive picture of recent BRI developments and their implications for future LSCM, this study seeks to outline the current barriers to, strategies for, and development scenarios of the BRI.

3. Research Design

To contribute to the ROs stated above, the study follows a two-stage research process. In the first stage, current BRI barriers are synthesized, strategies dealing with them are derived, and potential development scenarios of the BRI are developed, building on a moderated group exercise with 15 LSCM practitioners performed at the end of September 2019. The group exercise was performed using the NGT, a rigorous group exercise process for systematically extracting practitioners' knowledge that outperforms traditional group exercise techniques such as focus groups [47,48]. The NGT process consists of two stages—*problem description* and *problem solution*—that are performed by the same group of people. Through this moderated process, for both stages, participants are first asked to individually generate ideas according to a certain question. These ideas are subsequently shared within the group applying the round-robin procedure in order to ensure that every participant of the group exercise can contribute equally. The detailed process will be described in the following (Section 3.1). The participating practitioners in the group exercise were specifically invited to discuss the current state of, and development paths for, the BRI. Throughout the group exercise, different measures were taken to reduce bias and encourage every participant to contribute equally. The same group of practitioners was also utilized to develop potential development scenarios of the BRI. In the second stage, identified barriers and strategies as well as development scenarios were assessed according to certain characteristics that will be further described in the later part of this chapter. The assessment was done by 52 LSCM professionals through an online survey. The detailed research procedure is outlined in Figure 1 and explained in detail below.

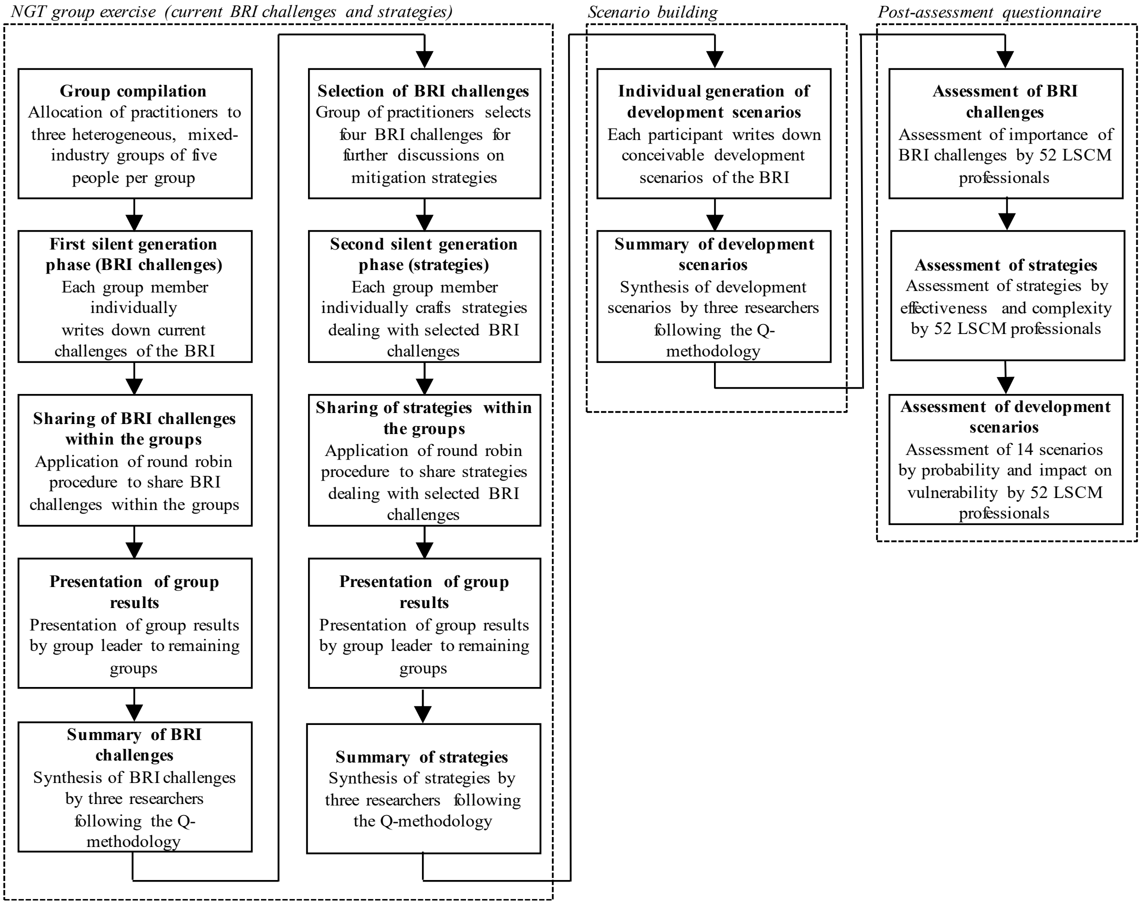


Figure 1. Research procedure.

3.1. First Stage: Group Exercise to Derive BRI Barriers, Strategies, and Development Scenarios

BRI barriers and strategies: In the first part of the group exercise, NGT [36,48] was performed to identify current barriers of the BRI that inhibit efficient operations along the BRI corridors (RO1) as well as to develop strategies for dealing with those barriers (RO2). The NGT clearly separates the *problem description* from the *problem solution* and has been utilized in LSCM research for extracting practitioners' knowledge on complex problems in a structured way [38,49–51]. The separation of the *problem description* and the *problem solution* also seeks to mitigate the shortcomings of other expert group exercises, such as Delphi studies or focus groups [47]. Traditional focus groups can assist in extracting experts' knowledge on a certain topic; however, a problem is that very self-confident group members can dominate the discussion, thus preventing less self-confident members from contributing equally, which can lead to bias. Delphi studies tackle this issue by not allowing face-to-face meetings, thus leading to more equal contributions from all participants [47]. Nevertheless, the absence of face-to-face meetings and discussions prevents any exchange of views or joint idea generation. The NGT seeks to mitigate the shortcomings of both these types of studies by allowing group members to meet, but encouraging all members to contribute equally to the exchange through a structured and moderated process [52,53].

Although NGT guidelines do not prescribe a definite minimum or maximum number of group members, previous LSCM research has found that on-site groups of 8 to 23 participants, separated into sub-groups, are appropriate [38,51]. In assembling the total study group, the researchers intended to bring together a heterogenous group of experienced practitioners from different industries and supply-chain positions to cover different views on the BRI. Most practitioners participating in this study have long-standing practical experience—an average of 15 years of professional experience in LSCM—mostly in leading positions in their respective companies, in which they are responsible for international logistics networks in contact with the BRI. Each participant was dealing with European–Chinese logistics networks on a daily basis and stated that they were familiar with current BRI developments, as the BRI is important for their companies' logistics networks. Table 1 outlines the sample demographics. Most of the participants represent companies with over 2500 employees and annual turnovers of over €500 million. All companies are based in Central Europe (mostly Germany) but operate globally. A discussion on the limitations and implications of the group sample is presented in the final remarks section.

Table 1. Overview of sample demographics for the group exercise.

#	Industry Type	Total Number of Employees	Annual Turnover	Participant Management Level	Years of Professional Experience in LSCM
1	Retailer	More than 10,000	€5–10 bn	Department manager	19
2	Logistics service provider	2500–5000	€250–500 m	Executive assistant	4
3	Logistics service provider	5000–10,000	€1 bn–2.5 bn	Department manager	13
4	Association	Up to 50	Up to €10 m	General manager	6
5	Logistics service provider	1000–2500	€250–500 m	Team member	4
6	Consulting	Up to 50	Up to €10 m	General manager	10
7	Logistics service provider	More than 10,000	Above €10 bn	Department manager	6
8	Logistics service provider	250–500	€500–1000 m	Team leader	10
9	Manufacturing, Machinery/equipment	More than 10,000	€5–10 bn	Team leader	22
10	Logistics service provider	More than 10,000	€2.5–5 bn	Team member	25
11	Logistics service provider	5000–10,000	€5–10 bn	Department manager	10
12	Manufacturing, Electronics	50–250	€10–50 m	Department manager	12
13	Logistics service provider	2500–5000	€1–2.5 bn	General manager	30
14	Manufacturing, Electronics	More than 10,000	Above €10 bn	Department manager	20
15	Logistics service provider	Up to 50	Up to €10 m	General manager	39

For this study, a group of 15 LSCM practitioners was split into three sub-groups of five participants to apply the NGT to identify current BRI barriers as well as strategies for dealing with them. As proposed in the NGT guidelines, an independent researcher moderated each group and was responsible for the compliance with the NGT process and rules.

In the first phase—*problem description*—each group member, during a *silent generation period*, had to individually think for him or herself of current barriers relating to the BRI between Europe and China that inhibit efficient operations, writing each barrier on one card. Afterwards, the group applied a round-robin procedure in which one group member read one barrier out loud and explained it, followed by the next member reading and explaining another. This process went on until all the cards had been read and explained. Throughout this process, discussions on the barriers were forbidden; only questions for understanding the barrier could be asked by the group members, thus enabling all group members to contribute equally [36]. The moderators monitored the compliance with the rules. After collecting and summarizing the proposed barriers, each sub-group presented their results to the others. Subsequently, a group of three researchers (the group moderators) applied the Q-methodology [37] to synthesize all the barriers to provide a common basis for further discussions. To perform the Q-methodology, the researchers followed the following procedure: Building on the set of barriers identified by all three groups and written down on single cards, each researcher individually read each card and placed it on an existing card if there was an overlap, or opened a new category if there was no overlap with already placed cards, until all the cards were allocated. Subsequently, each researcher proposed a synthesized set of barriers. Similarities and differences were discussed among the researchers. Through this comparison and discussion process, a condensed, unified version containing 17 BRI barriers was generated.

To initiate the second phase of the NGT—*problem solution* (which was done using the same group of 15 LSCM practitioners, as proposed by the NGT guidelines)—it was necessary to prioritize barriers that should be discussed further, as, owing to the framing conditions of this group exercise, developing strategies for all 17 BRI barriers was not possible. Therefore, each group member was asked to select four barriers for which he/she would like to develop strategies. This was done because some barriers could have been seen as very important but, from a practitioner's point of view, could not be readily tackled or controlled by strategies that individuals or groups of companies could develop. All individual nominations per barrier were counted, and the four barriers with the most nominations were selected for the second NGT phase.

The second phase—*problem solution*—followed the same procedure as the first phase. For each of the four barriers, during a *silent generation period*, each group member first had to individually think of strategies that could assist in solving or mitigating the corresponding barrier. Subsequently, for each of the four barriers, the strategies developed were shared within the sub-groups and the round-robin procedure applied without discussing them in detail. After collecting and summarizing the strategies within the groups, each group presented their result to the assembly. As in the *problem description* phase, the group of three researchers now synthesized and summarized the strategies developed using the Q-methodology, thus leading to a set of strategies for each of the four barriers chosen by the group.

Scenario building: Owing to the importance of the BRI for European–Chinese logistics networks, an assessment of conceivable future developments of the BRI is important for companies operating in the corresponding rail and maritime corridors. Therefore, the same group of professionals was also utilized to craft potential development scenarios for the BRI. Therefore, each participant, during a third *silent generation period*, was first asked to think of conceivable development scenarios for the BRI between Europe and China and write each of them down on a single card. Practitioners were asked to think open-mindedly into different directions, such as infrastructure development, regulation, political change, future transport routes, pricing developments, and many more. Subsequently, all the scenarios were shared within the group following the round-robin procedure, again preventing any discussion of the scenario. The researchers then collected all the cards/scenarios and performed a third Q-methodology workshop to synthesize the scenarios developed. As a result, the group of researchers proposed a set of 14 scenarios based on the practitioners' input.

3.2. Second Stage: Assessment of BRI Barriers, Strategies, and Development Scenarios

The aim of the second stage was to assess the results of the previous group exercise, utilizing a larger set of practitioners to derive more conclusions for practice, i.e., on which barriers and strategies to focus and how to prepare for particular development scenarios. The assessment was done by a set of 52 LSCM practitioners through an online survey that was sent out to 477 LSCM practitioners. The initial set of 477 LSCM practitioners contacted belongs to a group that participates regularly in workshops, discussions, and other formats on crucial topics in international logistics networks, with a special focus on European–Chinese logistics networks. Therefore, they were assessed as appropriate in terms of content and expertise for participation in this survey. The response rate of 11% can be seen as reasonable owing to ever-declining response rates in LSCM research [54,55]. The questionnaire exercise took place in March 2020. Participants were asked not to include current developments relating to the Coronavirus pandemic in their assessments, as the initial group exercise was conducted in September 2019, when the pandemic was not yet relevant, and the results would otherwise be biased. The sample demographics of the questionnaire participants are outlined in Table 2.

Table 2. Sample demographics of questionnaire participants.

Industry Type	Annual Turnover	Total Number of Employees	Participants' Management Level
Logistics service provider|n = 19	Up to 50|n = 4	Up to 10 m €|n = 4	Team member|n = 6
Retailer|n = 3	50–250|n = 4	10–50 m €|n = 3	Team leader|n = 5
Manufacturing, Consumer goods|n = 2	250–500|n = 4	50–250 m €|n = 5	Department manager|n = 24
Manufacturing, Chemicals & Pharmaceuticals|n = 2	500–1000|n = 5	250–500 m €|n = 6	General manager|n = 15
Manufacturing, Automotive|n = 8	1000–2500|n = 3	500–1000 m €|n = 5	Member of the board|n = 2
Manufacturing, Electronics|n = 5	2500–5000|n = 6	1 bn–2.5 bn €|n = 7	
Manufacturing, Machinery/equipment|n = 8	5000–10,000 n = 3	2.5 bn–5 bn €|n = 2	
Manufacturing, Raw materials/mining|n = 1	More than 10,000|n = 23	5 bn to 10 bn €|n = 6	
Others|n = 4		Above 10 bn €|n = 14	

To complete the survey, the participants were first asked to assess the *importance* of each barrier. The assessment was done on a 7-point Likert scale (1 = low to 7 = high). A barrier that has low *importance* (score = 1) has negligible negative on efficient operations in European–Chinese logistics networks, whereas a very important barrier (score = 7) has a significant negative impact on efficient operations in European–Chinese logistics networks. Afterwards, the strategies developed through the initial group exercise were assessed according to two distinct attributes (*effectiveness* and *complexity*) on a 7-point Likert scale (1 = low to 7 = high). *Effectiveness* describes the impact of a strategy on overcoming the barrier. A strategy perceived as highly effective would have a major impact on the barrier to be overcome. The resources needed to implement this strategy were not considered for this attribute. C*omplexity* describes the amount of resources that would be necessary to implement a certain strategy, with the assumption that a very complex implementation of a strategy will require more resources than an implementation that is not at all complex.

Finally, the survey participants were asked to assess all 14 development scenarios according to two distinct attributes, *probability* and *vulnerability*, on a 7-point Likert scale (1 = low to 7 = high). *Probability* here describes the likelihood of a scenario becoming a reality within the next 5 to 10 years. *Vulnerability* describes the positive, neutral, or negative impact of the scenario on efficient operations along BRI corridors if the scenario becomes a reality. For example, if the vulnerability of a certain scenario is low (score = 1), this means that operations along the BRI would become less vulnerable (e.g., fewer supply chain disruptions) if this scenario were to become a reality. If the vulnerability is rated as high, this means that operations along the BRI would become more vulnerable (e.g., more supply chain disruptions) if this scenario were to become a reality. A neutral score (= 4) implies that the vulnerability of operations would not necessarily change, positively or negatively, in comparison with the status quo, if the scenario described were to become a reality.

4. Results

The goal of this study was to outline the current barriers that companies face when operating along BRI corridors between Europe and China, as well as to provide indications for strategies that can assist in overcoming those barriers. Due to vagueness about how the initiative will develop in the future and the impact of those developments on European–Chinese logistics networks, the study additionally aimed to outline future development scenarios of the BRI, so that practitioners could prepare for them. Therefore, a moderated on-site group exercise building on the NGT was conducted among 15 LSCM practitioners with broad expertise in LSCM in general and the BRI in particular. The exercise identified 17 major barriers that are inhibiting efficient operations along BRI paths and derived 20 strategies for dealing with the four barriers that were selected for further discussions. Moreover, 14 BRI development scenarios were developed through the group exercise. Afterwards, the barriers, strategies and development scenarios from the group exercise were assessed through an online survey among 52 LSCM practitioners.

4.1. Current BRI Barriers

Although the BRI is already providing opportunities for improved logistics between Europe and China, several barriers need to be overcome in order to leverage their full potential. Based on the practitioners' input, 17 major BRI barriers were identified and categorized in six main clusters (see Figure 2). Within the clusters, the barriers outlined are listed in order of decreasing importance, based on the assessment of all barriers through the online survey. The overall assessment of current BRI barriers is outlined in Figure 3.

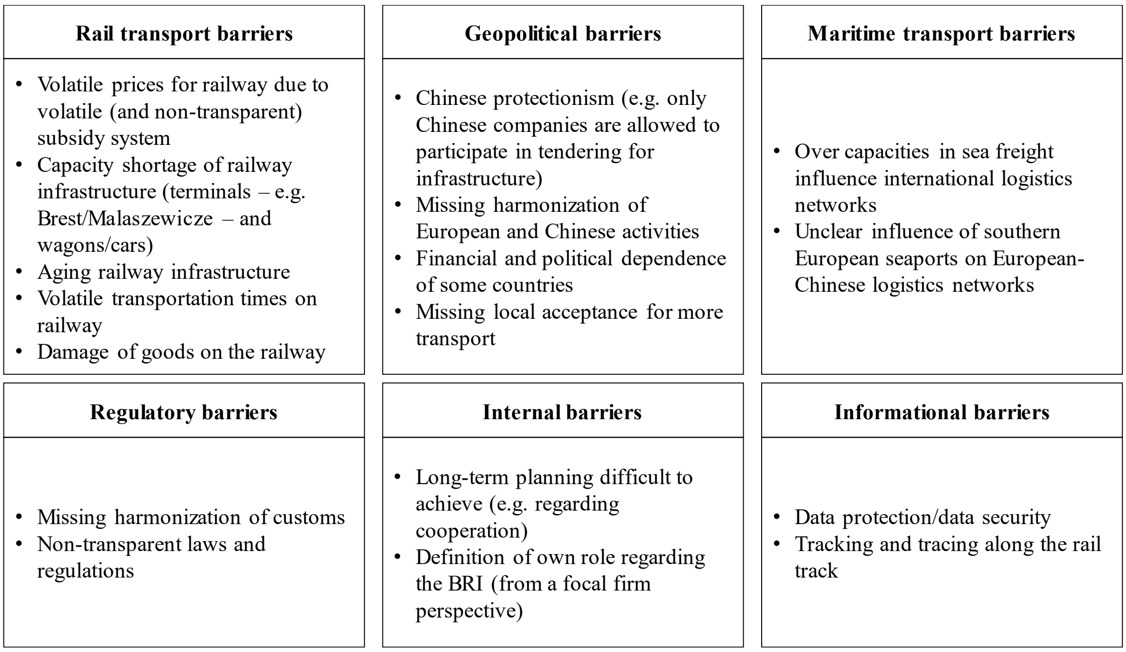


Figure 2. Overview of barriers of the Belt and Road Initiative (BRI).

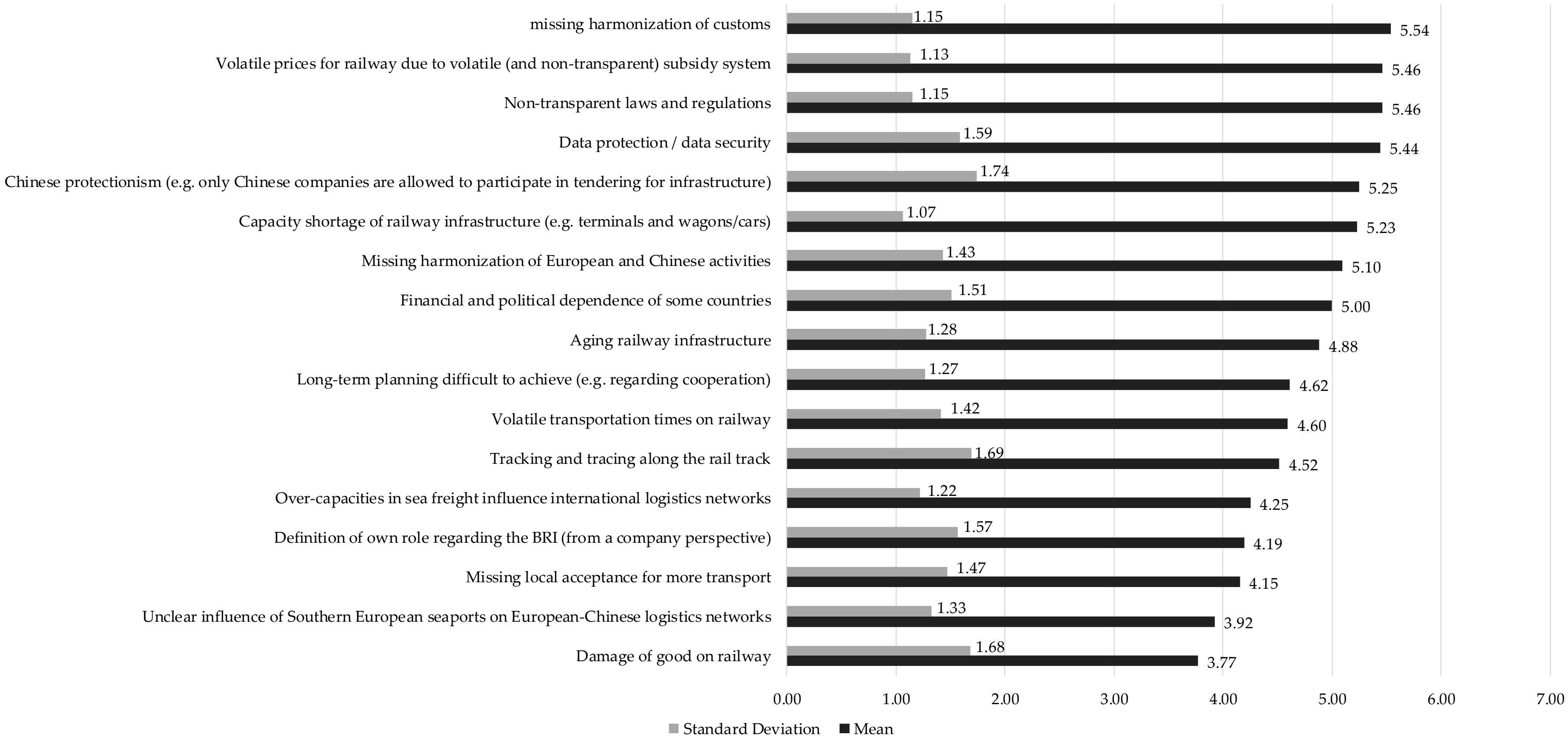


Figure 3. Industry assessment of importance of BRI barriers.

Rail transport barriers: Over the past five years, rail cargo volumes between Europe and China have increased significantly, thus making rail a viable alternative to well-established sea freight, which has longer transportation times but a lower cost, or air freight, which traditionally involves a higher cost [56]. However, the practitioners assessed *volatile prices for railway due to volatile (and non-transparent) subsidy system* as the second most important of the 17 barriers (see Figure 3). According to them, the Chinese government heavily subsidizes rail transportation between China and Europe to increase demand for this transport mode. However, the subsidies are distributed at each quarter to China's domestic railway terminals. This is highly volatile and tends to be unpredictable for practitioners, as transport from a particular Chinese terminal to a European terminal may be low cost in one quarter but disproportionately expensive in the next, thus leading to the re-routing of China's domestic transport flow. This is particularly challenging for logistics service providers and their customers, as one of the participants explained, with everyone's agreement:

> *Our clients are used to having fixed prices for certain transport routes and volumes. In the case of rail transportation between China and Germany we are struggling to provide fixed prices since the subsidies for Chinese rail terminals are changing constantly. Once we establish a profitable and stable connection we have to change the domestic terminal to remain profitable, which leads to problems for our logistics planning on a regular basis. However, without the Chinese subsidies, the demand for rail transportation would be much lower than it is today.*

Potential customers explained that, from their point of view, logistics service providers can provide them with fixed prices but only by pricing in the risk on their side, which makes these prices barely competitive. In addition, *capacity shortage of railway infrastructure (terminals and wagons/cars)* is among the more important BRI barriers. Owing to the different railway gauges in China, Europe, and the former Soviet Union, containers have to be transferred at dedicated terminals. This is currently causing a bottleneck on the border between Poland and Belarus (Malaszewicze/Brest). Although there are, depending on the EC used, different terminals available on the Chinese side, regardless of the EC taken, most rail transport to Europe has to pass through the Malaszewicze/Brest terminal, where containers often have to wait for four days or longer.

The infrastructure is not being expanded as fast as the demand for this mode of transport is increasing, and it is therefore becoming increasingly overloaded. This has led to increasing rail transport times between China and Europe because of high demand that is unaligned with the infrastructure capacity, as one participant underlined:

> *A few years ago, a train between Xi'an and Duisburg took around twelve days on average. Today, in 2019, this connection takes around 16 days, sometimes even more, which is mainly caused by the infrastructure bottleneck that we face at the Malaszewicze/Brest terminal.*

This infrastructure capacity bottleneck is accompanied by a shortage of cars and wagons, also leading to delays of days at terminals before shipments can join a train. Due to the aforementioned infrastructure barriers and other issues, *volatile transportation times on railways* is also among the core current barriers to rail transportation between China and Europe. Customers and their service providers are often uncertain of when goods will arrive. The increase in transport times is manageable, according to the practitioners, but logistics planning is even more difficult when transport times are getting more and more volatile owing to unpredictable waiting times at important transport nodes. In addition, in some regions *aging railway infrastructure* remains a barrier, but it is improving owing to several BRI-related projects. Although *damage of goods on the railway* was named by the group as a potential BRI barrier, it had the lowest importance among the barriers assessed (see Figure 3).

Maritime transport barriers: According to the practitioners, the MSR provides fewer barriers compared with railway transportation. However, one barrier is *overcapacities in sea freight impact international logistics networks*, and practitioners are undecided as to how this will impact the BRI. As prices for sea freight between China and Europe are decreasing, this remains the dominant shipping option. Although, from a lead-time-perspective, rail transportation provides a viable option compared with sea freight, taking the cost perspective into account, rail transportation is struggling to compete. For logistics service providers and their customers, current sea freight prices impact their strategic assessment of BRI railway corridors, and they are undecided as to how new developments will impact future transportation routes. Additionally, the *unclear influence of southern European seaports on European–Chinese logistics networks* remains a barrier for companies operating along the BRI. The importance of this barrier is lower than others, but, with multiple Chinese investments in southern European seaports [40,41], logistics service providers have to investigate how this will impact on future transportation flows before investing accordingly.

Geopolitical barriers: Participants identified several geopolitical barriers throughout the group exercise that impact on the operations of, and strategic planning for, logistics networks. *Chinese protectionism* was rated as the most important barrier within this cluster. Company representatives participating in the group exercise concluded that, typically, only Chinese companies are involved in infrastructure projects along the BRI and foreign companies are prevented from participating in the tendering process. The same holds true for other stakeholders in the network, such as Chinese railway terminals, which are exclusively operated by Chinese companies, with no open tendering. Although this barrier was assessed as very important at the workshop conducted in September 2019, the Chinese president, Xi Jinping, directly addressed this issue in April 2019, when he invited more countries to participate in China's infrastructure projects. The continuing assessment of this barrier as important suggests that Western companies are still undecided as to whether this announcement represents a genuine effort to open up the initiative.

Second, *missing harmonization of European and Chinese activities* leads to a situation in which Western companies fear that the potential of the BRI cannot be leveraged. Participants unanimously agreed that the BRI can be beneficial for all stakeholders, but they fear that Europe is currently not taking an active role in the BRI, missing the opportunity to help create the foundation for future logistics networks. This is underlined by the statement of one participant:

> *Europe and China are the most important trade partners regarding the Belt and Road Initiative but are not working together as closely as necessary. If everything is done correctly, the initiative can be a win-win situation for all countries and stakeholders involved since it facilitates trade and consequently economic development. But currently, it seems to me that Europe does not have a unified voice to talk to China and to set up joint actions*.

Third, participants stated that the risk of *financial and political dependence of some countries* remains a barrier, as China provides many of the countries along the BRI with the cash with which to finance infrastructure and other projects. Companies fear that less stable countries could fall into financial difficulties from which they would struggle to recover, directly impacting international supply chains in those regions. Fourth, most of the supply-chain-related BRI projects involve increased transport, but companies operating on the BRI experience *missing local acceptance for more transport*. This can lead to strikes and protests, giving rise to supply chain disruptions and delayed projects.

Regulatory barriers: *Missing harmonization of customs* was ranked as the most important BRI barrier (see Figure 3). Specifically, participants stated that customs clearance for importing goods from China to Europe is not harmonized and is handled differently in different European countries. This is challenging, as goods and customs declarations are interpreted differently in different European countries. For goods entering China, customs clearance still remains one of the major sources of supply chain disruption. Therefore, the group unanimously agreed that inconsistent customs processes between China and Europe form one of the major barriers preventing the success of the BRI. This is in line with current research in this field that has concluded that trade facilitation can positively impact the success of the BRI [57,58]. Closely connected to this and also among the most important barriers are *non-transparent laws and regulations*. Companies with logistics operations between Europe and China struggle to adapt their operations to constantly changing laws and regulation, mainly induced, from their point of view, by the Chinese side. This includes not only customs regulations, but also safety regulations and rules for transporting goods via rail.

Internal barriers: These include barriers that a focal firm faces when operating on BRI routes between China and Europe. Owing to the volatile nature of the BRI, companies experience the barrier that *long-term planning is difficult to achieve*, especially when it comes to finding long-term partners with which to set up logistics networks. Owing to the circumstances described when discussing rail transportation barriers, with networks regularly changing, logistics service providers expend more effort in constantly adjusting their networks than in establishing long-term cooperation with terminal operators. In addition, *definition of own role regarding the BRI (from a focal firm perspective)* was identified as a BRI barrier, although its importance is relatively low. Logistics service providers stated that they do not yet know what their role in the BRI will be, regarding their active involvement and future possibilities, if China reduces protectionism (e.g., becoming terminal operators or actively investing in infrastructure). This indecisiveness is based on the volatile nature and uncertain future of BRI developments from a focal firm perspective.

Informational barriers: According to the practitioners, *data protection/data security* is among the most important barriers regarding the BRI. Participants fear that the data they have to divulge in order to transport goods across a multitude of countries, especially when considering transporting goods by rail, could be misused. Although they have no concrete evidence that their particular data has been misused in the past, they have trust issues when it comes to data sharing with partners from foreign countries. Researchers in this field have shown that, in the case of China, government support can increase trust in data sharing, but it is also up to the cooperating companies to gain *guanxi* (China's unique form of interpersonal relationships) in order to gain trust and facilitate data sharing [59]. In addition, *tracking and tracing along the rail track* remains an issue. This barrier was placed in this cluster owing to its informational nature, although it also belongs with the rail-transport-related barriers. Company representatives stressed that, for large parts of the rail route, especially entering and leaving Russia, they do not know exactly where their containers are. Without information on location and expected waiting times along the track, forecasting arrival times becomes even more challenging.

4.2. Strategies to Leverage the Potentials of the BRI

Through the NGT among 15 LSC professionals, strategies for four BRI barriers were synthesized. Four BRI barriers—missing harmonization of customs, volatile prices for railway due to volatile (and non-transparent) subsidy system, capacity shortage of railway infrastructure (e.g., terminals and wagons/cars), and tracking and tracing along the rail track—were chosen by the group of 15 LSCM professionals for strategy development (the second phase of NGT, problem solution) and a total set of 20 strategies was proposed. Subsequently, all of the strategies were assessed according to their effectiveness (impact on the barrier being resolved) and complexity (amount of resources necessary to implement the strategy) through a subsequent questionnaire completed by 52 LSCM professionals. The results can be seen in Table 3.

Table 3. Strategies for dealing with BRI barriers.

BRI Barrier	Strategy	Effectiveness	SD Effectiveness	Complexity	SD Complexity
Missing harmonization of customs	Digitalization of customs clearance process	6.19	0.90	5.79	1.23
	Establishment of EU-wide standards for interpretation of goods	5.67	1.17	5.48	1.37
	Creation of political associations to draw attention to the topic by lobbying	4.60	1.40	4.87	1.40
Volatile prices for railway due to volatile (and non-transparent) subsidy system	Block space agreements: customer, service providers and Chinese provinces agree on volumes for a longer period and a fixed price	5.42	1.12	4.83	1.41
	(Cross-industry) cooperation of multiple customers to consolidate volumes for more bargaining power for stable prices	4.58	1.41	4.85	1.34
	Establish cross-industry lobby organization to show China that volatile prices keep customers from using the railway	4.29	1.72	4.48	1.32
	Buy insurance to cover price volatility	4.19	1.51	4.62	1.61
Capacity shortage of railway infrastructure (e.g., terminals and wagons/cars)	Digitalized and standardized documents along the track to avoid waiting trains due to incorrect documents	5.94	1.10	4.96	1.56
	Upgrading of more double track sections to avoid waiting trains	5.58	1.17	5.15	1.34
	Increased transparency on current and expected capacity bottlenecks and planned construction works as well as impact on transit times	5.42	1.23	4.35	1.43
	Having infrastructure expansion financed directly by European companies instead of waiting for government action	5.10	1.30	5.44	1.31
	More optimized, coordinated timetables of trains	5.08	1.43	4.44	1.63
	Additional cross-border terminals around Brest/Malaszewicze	4.94	1.39	4.48	1.20
	Cross-industry cooperation through a neutral, third-party authority that creates synthesized transparency on customer orders and schedules them accordingly	4.94	1.36	4.88	1.37
	Establishment of giga-cargo trains on the main tracks in the former Soviet Union	4.81	1.66	4.75	1.53
	Creation of political associations to draw attention to the topic by lobbying	4.23	1.35	4.63	1.47
Tracking and tracing along the rail track	Logistics service providers put GPS trackers on containers by themselves	5.69	1.20	3.40	1.73
	Implementation of a tracking system, similar to the one for ships, for trains	5.63	1.11	4.29	1.31
	Establishment of data standards to regularly report train/container locations	5.42	1.10	5.10	1.29
	Increase funding for further development and deployment of smart interconnected train infrastructure	5.02	1.22	5.06	1.25

In general, during the practitioner discussions it became obvious that dealing with many of the BRI barriers requires governmental support from either the European or Chinese side, or both. Therefore, companies participating in the group exercise were unable to tackle the barriers alone and often had to react to changes rather than proactively addressing them.

This is especially true for one of the most important BRI barriers that was discussed. Although the group managed to synthesize some strategies to manage issues regarding the missing harmonization of customs, they clearly expressed the need for more government support, as they are directly affected by customs procedures but have little influence on simplifying them. However, for unifying EU-wide standards for customs clearance, government authorities should collaborate to ensure the practicability of the processes and rules developed. In conjunction with this, the digitalization of customs clearance processes on both sides would improve logistics efficiency for trading goods between Europe and China, although the group agreed that this would be highly complex.

For dealing with volatile prices, some logistics service providers outlined that they are working on block space agreements with their customers and the Chinese provinces to agree fixed volumes and prices for longer than the typical quarter. Although this strategy has been very effective, implementing it is complex, and customers must have very high volumes. Practitioners also stressed the importance for cross-industry cooperation of consolidating volumes to increase bargaining power for more stable prices. Other possible, but less effective strategies include insurances to cover price volatility or the formal lobbying of the Chinese government.

To manage the capacity shortage of railway infrastructure, different approaches have been developed that either utilize the existing capacity more efficiently or call for additional infrastructure to relieve current bottlenecks. The utilization of existing capacities, as well as the upgrading of additional capacities, was assessed as being effective but equally complex. To utilize the existing capacity more efficiently, digitalized and standardized documents can assist clearance processes at specific nodes to reduce waiting times. Digitalization could also assist in creating more transparency on expected bottlenecks and construction works, and their impact on expected transit times. Without this transparency, companies are unable to react promptly. Digitalization can also assist in scheduling order fulfillment according to expected bottlenecks and transit times. However, with increasing demand for rail transportation along the BRI, more efficient capacity utilization will not be enough, and either governments or private actors must invest in physical infrastructure. More precisely, more double track sections and additional cross-border terminals must be built to relieve the current bottleneck at Brest/Malaszewicze. Indeed, the call for railway infrastructure expansion is in line with existing studies. Lobyrev et al. [45] also suggest more infrastructure investments at the Poland-Belarus-border, since railway volume is increasing but the terminal cannot cope with the increasing demand. Moreover, they propose additional backup/backbone terminals and other measures to improve railway performance. Zhao et al. also stress that existing railway capacities have to be managed more efficiently and propose cargo consolidation centers before cargo is supplied to the terminals in order to facilitate a more efficient flow of goods to the domestic terminals in China [43].

To manage tracking and tracing along the rail track, most logistics service providers offer a container GPS tracking service, a widely used, relatively simple, and effective strategy. However, data protocols and tracking systems are not standardized, so every logistics service provider has to develop its own solution. Moreover, even if the location of goods is made visible, waiting times at infrastructure nodes and construction works remain unpredictable.

4.3. Future Development Paths of the BRI

Following the procedure outlined in Section 3, 14 BRI development scenarios have been proposed and assessed through the follow-up survey. Table 4 outlines the scenarios developed as well as the overall results of the assessment, sorted by descending probability.

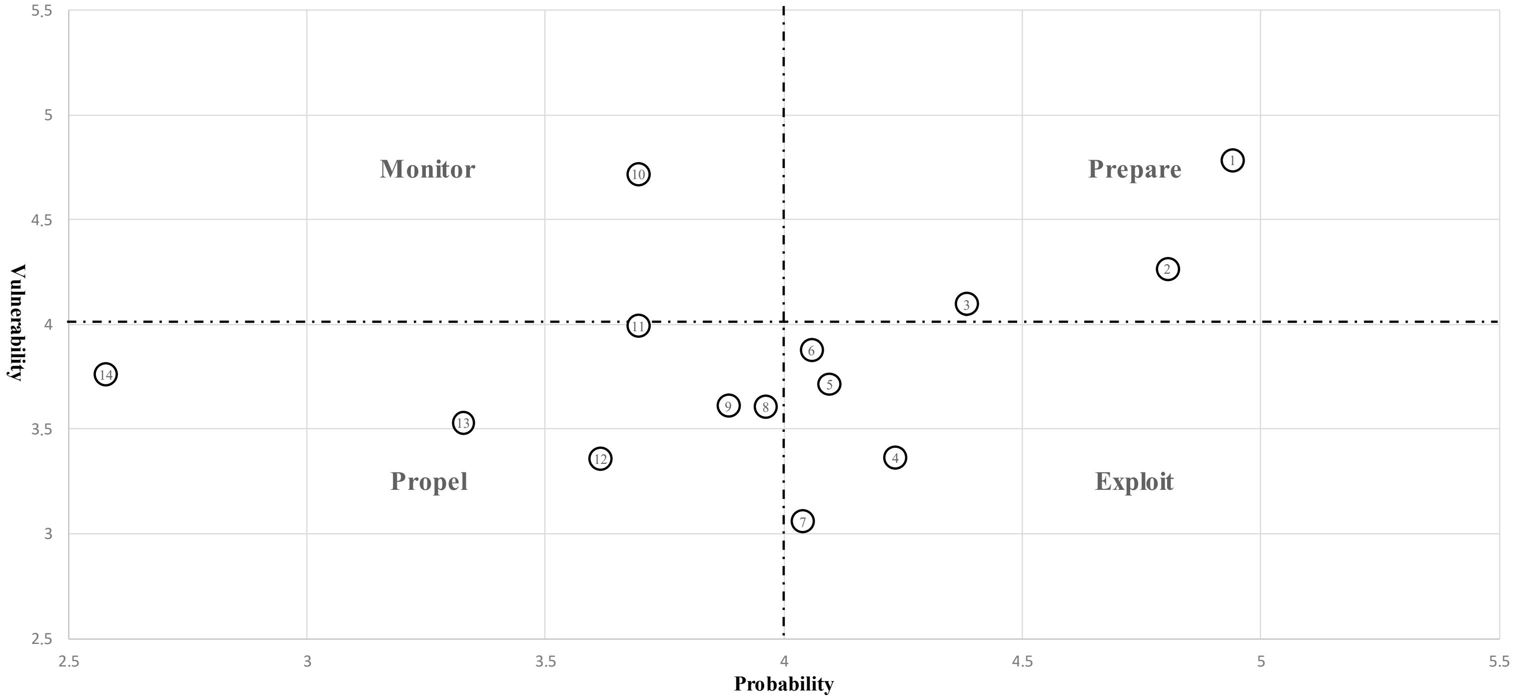
Table 4. Overview of BRI scenario assessment by probability and vulnerability.

#	Scenario	Probability (Mean)	SD Probability	Vulnerability (Mean)	SD Vulnerability
1	China's protectionism increases and Europe's dependence on China increases	4.94	1.13	4.77	1.42
2	Owing to the BRI, industrial production of Eastern Europe moves further east (industrial center of gravity moves east)	4.81	1.18	4.25	1.19
3	Significant sea freight volume from China to Europe will be handled via southern European seaports	4.38	1.39	4.06	1.17
4	Dobrá establishes itself in the long term as a strong intermodal terminal to relieve Brest/Malaszewicze	4.23	1.12	3.37	1.04
5	Transport by rail from China to Europe will become a strong competitor to sea freight	4.10	1.78	3.71	1.63
6	The Northern Sea Route will be established as a viable option for sea freight between China and Europe	4.06	1.46	3.87	1.39
7	Import customs clearance to Europe is carried out according to a uniform standard	4.04	1.47	3.06	1.32
8	China and Europe get closer to each other and develop a common strategy regarding the BRI	3.96	1.56	3.62	1.76
9	IT standards for data exchange among all partners will be established	3.88	1.64	3.62	1.61
10	China reduces subsidies drastically for railway	3.69	1.60	4.71	1.57
11	The United States of America is increasingly isolated from world trade by the BRI	3.69	1.45	3.98	1.25
12	China and Europe reach a free-trade agreement	3.62	1.60	3.37	1.68
13	Europe develops a unified strategy for how to respond to the BRI	3.33	1.55	3.54	1.38
14	New transport technologies, e.g., Hyperloop, UAVs, and AGVs, will disrupt the logistics industry and make the rail connection obsolete	2.58	1.47	3.79	1.64

Figure 4 provides a graphical representation of the BRI scenario portfolio classified into four different BRI scenario clusters (*monitor*, *prepare*, *propel*, *exploit*). Although the lines between those clusters are not as narrow as displayed, the clusters aim to provide guidance to practitioners on how to deal with those scenarios. Scenarios in the *monitor* cluster are less likely to become reality but would increase the vulnerability of European–Chinese logistics networks. Therefore, companies have to observe their development closely to track whether they become more probable. Scenarios in the *prepare* cluster are more likely to become reality in the near future and may lead to increased vulnerability. Therefore, companies need to prepare proactively for them and develop strategies that take these scenarios into account. The *propel* cluster includes scenarios for less vulnerable, though less probable, logistics networks between Europe and China. Scenarios in the *exploit* cluster must be utilized in a beneficial way, since they are more likely to occur and can decrease the vulnerability of European–Chinese logistics networks.

Analyzing Figure 4, it is obvious that most scenarios do not dramatically impact the *vulnerability* of European-Chinese logistics networks. This could indicate that the participants are unsure about the scenarios' impact on vulnerability; however, the *probabilities* of the scenarios are diverse and provide a valuable guide for practice. The practitioners believe that, owing to the BRI, the resulting logistics connection of Eurasian countries and their corresponding economic development and industrial production could move far eastward from Europe. In addition, practitioners from Central Europe expect that China's protectionism will increase and participation in tendering processes will only be possible for Chinese firms, despite China's expressed willingness to open up. Moreover, European companies need to prepare for, or at least analyze the possibility of, a volume shift from northern to southern European seaports. This could lead to a need for service providers to build their competence and capacity in the southern European region. This scenario does not predict how much volume will shift, and it does not necessarily imply that northern European seaports will lose importance. However, it is a scenario that companies operating in European–Chinese logistics networks should consider and prepare for.

Participants identified the current cross-border railway terminal at Malaszewicze/Brest as a major bottleneck for rail transportation and asserted that the development of Dobrá (Slovakia) as an additional terminal could relieve this situation. This scenario is in the *exploit* cluster, as it was assessed as more likely to become reality, and would decrease the vulnerability of current logistics networks. Moreover, LSCM practitioners think that it is more likely that railway transport between Europe and China will become a strong competitor over sea freight in the near future. Nevertheless, this does not necessarily mean that this transportation mode is about to take over the sea freight volume completely. Since the volume currently transported via rail is much lower than the sea freight volume, it is more likely that becoming a competitor in this case means that rail transportation will develop into a reliable second option after sea freight and will be more implemented by practitioners as a result of it. The scenario in which the import customs clearance to Europe is carried out with uniform standards has been assessed as the scenario with the highest positive impact on the vulnerability of European-Chinese logistics networks, meaning that less disruptions would occur if this scenario becomes reality. This is underlined by the previous finding that the BRI challenge of *missing harmonization of customs* has been assessed as the most significant barrier (see Figure 3) in the path to enable more efficient operations along the BRI corridors. The practitioners participating in the assessment are also undecided as to whether China and Europe should get closer to each other and develop a common strategy regarding the BRI, or whether IT standards for data exchange among the involved parties will be established, although both scenarios would slightly decrease the vulnerability. Moreover, it is viewed as more unlikely that the United States will be increasingly isolated from world trade due to better trade connections between Asia, Europe and Africa generated through the BRI. One of the scenarios clearly placed in the *monitor* cluster is that China will drastically reduce subsidies for the rail route within the next five to ten years. BRI has been clearly positioned as one of China's major long-term strategies, so it seems unlikely that support for rail connections will decrease.



1. China's protectionism increases and Europe's dependence on China increases
2. Due to the BRI, industrial production of Eastern Europe moves far more east (industrial center of gravity moves east)
3. Significant sea freight volume from China to Europe will be handled via Southern European seaports
4. Dobrá establishes itself in the long term la strong intermodal terminal to relieve Brest/Malaszewicze
5. Transport by rail from China to Europe will become a strong competitor over sea freight
6. The Northern Sea route will be established as a viable option for sea freight between China and Europe
7. The import customs clearance to Europe is carried out according to a uniform standard
8. China and Europe get closer to each other and develop a common strategy regarding the BRI
9. IT standards for data exchange among all partners will be established
10. China reduces subsidies drastically for railway
11. The United States of America are increasingly isolated from world trade by BRI
12. China and Europa reach a free trade agreement
13. Europe develops a unified strategy how to respond to the BRI
14. New transport technologies e.g. Hyperloop, UAVs, AGVs, will disrupt the logistics industry and make the rail connection obsolete

Figure 4. Graphic representation of the BRI scenario portfolio by probability vs. vulnerability.

Two scenarios are clearly placed in the *propel* cluster, meaning that those scenarios may be unlikely, but their realization should be forced from an LSCM perspective, since their becoming reality would generate more efficient operations with fewer disruptions along the paths between Europe and China. First, a free trade agreement between Europe and China would decrease the vulnerability of networks between those regions and would be beneficial for LSCM. Second, a unified European strategy on how to respond to the BRI has been assessed as beneficial from an LSCM perspective, but is even less likely than the aforementioned scenario of a free trade agreement. Lastly, the scenario that new technologies such as Hyperloops of automatically guided vehicles will make the rail connection obsolete has been assessed as highly unlikely.

5. Implications

By systematically synthesizing LSCM practitioners' knowledge on the BRI through a moderated on-site group exercise among 15 LSCM professionals building on the NGT, followed by a post-assessment through an online questionnaire among 52 LSC practitioners, the study outlined a coherent picture of the current barriers and development paths of the BRI from an LSCM perspective and provided strategies for dealing with important barriers. Specifically, 17 barriers that inhibit efficient operations within European-Chinese logistics networks were identified and their importance assessed. Those barriers are gathered into the clusters *rail transport barriers*, *maritime transport barriers*, *geopolitical barriers*, *regulatory barriers*, *internal barriers*, and *informational barriers*, based on which the group derived 20 strategies for dealing with important barriers, that were subsequently assessed by the group of 52 LSCM professionals according to each strategy's *effectiveness* and *complexity*. Moreover, 14 conceivable development scenarios for the BRI have been proposed through the group exercise and assessed according to their *probability* and impact on the *vulnerability* of European–Chinese logistics networks through the follow-up online questionnaire. This study is therefore the first of its kind seeking to outline current barriers and development paths of the BRI from a LSCM perspective and attempting to close the gap between research and practice in this field, thereby contributing to both sides equally.

For LSCM research, the study provides a holistic overview of current BRI barriers. This will allow researchers to better understand the current problems and needs of practice and align research activities accordingly to contribute to addressing existing problems. Although this study cannot seek to overcome all the barriers identified, it can contribute to the discussion and propose, among other measures, capacity utilization schemes for rail transportation, utilization of artificial intelligence algorithms for arrival forecasting, or assessing optimal network configurations to relieve current infrastructure bottlenecks. Moreover, owing to the vague and unpredictable nature of the BRI and its projects, this study can contribute to a more comprehensive understanding by calling on researchers to conduct more in-depth scenario analysis than has been possible here. This study must be understood as only the starting point.

For practice, the study seeks to provide a more comprehensive understanding of the BRI and its implications from an LSCM perspective. Although leaving their refinement to practice, the strategies suggested for dealing with important BRI barriers suggest valid future directions for dealing with them. However, the group discussions and results also indicate that most of the present BRI barriers that companies operating in European–Chinese logistics networks face can only be overcome with government support, either from the European or the Chinese side. Therefore, this study can assist government actors in better understanding the needs of practice. However, before implementing countermeasures at a government level, further, closer discussions between government stakeholders and companies are necessary.

Moreover, it must be acknowledged that the study is the first of its kind that has sought to contribute to the analysis of the future development of the BRI and its impact on LSCM. By developing 14 conceivable scenarios and assessing them in terms of *probability* and *vulnerability,* the group has provided practitioners with a first indication of possible future developments. Through the classification into *monitor*, *prepare*, *propel*, and *exploit* scenarios, practitioners have been provided with a guide for dealing with these scenarios, although it is acknowledged that their development needs closer investigation.

Furthermore, throughout the group exercise, it became obvious that, for rail transportation in particular, the state of development regarding digital technologies is low, but further digitalization could lead to more efficient operations along the track. To improve this, not only researchers and practitioners, but also governmental institutions, could work together to develop digital tools and solutions, thus improving the efficiency of the rail silk road. However, this must go hand-in-hand with physical infrastructure expansion to leverage the full potential of the BRI with regard to rail transport.

6. Final Remarks

Although this study is the first of its kind that has sought to outline a comprehensive picture of the BRI from an LSCM perspective, by synthesizing the current BRI barriers, providing possible strategies to overcome these barriers, and outlining possible future development scenarios for the BRI, no study is without limitations.

First, the BRI aims to facilitate more efficient trade between Europe, China, and Africa by improving infrastructure at different levels. However, this study focused only on BRI barriers and developments between Europe and China, and excluded Africa from the discussion. However, that continent is fundamental to the overall initiative, and China is investing heavily in improving infrastructure in several African countries. Nevertheless, the European–Chinese trade relationship remains one of the most important in the world and is key to the overall success of the BRI. To derive more focused results, the study limited the group exercise to European–Chinese logistics networks, but investigating the BRI's implications for African countries is still a necessary task for future researchers.

Second, the LSCM professionals participating in the NGT group exercise were all employed in Western European companies, mostly of German origin. Although some of the individual participants were of Chinese origin, no Chinese company took part in the exercise. Thus, it can be concluded that the set of practitioners is likely to have expressed a European point of view on the BRI. Nevertheless, all participants had close connections to Chinese companies and the Chinese market, and their long experience in the field of European–Chinese logistics networks can be considered valuable. Additionally, no participant from a public authority or governmental institution was included in the NGT group exercise, which can account for bias, since their perspective was not considered. However, one participant of the NGT group exercise was from an LSCM association that seeks to bridge the gap between industry and governments. Nevertheless, considering both perspectives in a more even compilation of the group might have been insightful as well.

Third, from a methodological point of view, the limited sample size (15 professionals), though sufficient to synthesize the experts' knowledge through the NGT, a proven method for extracting LSCM practitioners' knowledge in a certain field, nevertheless prevents the study from drawing more fine-grained conclusions. In particular, the assessments of barriers, strategies, and development scenarios through the follow-up survey among 52 LSCM professionals should be understood as a first indication regarding specific developments, rather than an in-depth quantitative study. Nevertheless, the assessments provide a condensed opinion of LSCM professionals with longstanding experience in their field and can therefore be beneficial for other practitioners.

In summary, this study should be understood as a call for further research on the BRI and its implications for LSCM. For all the areas covered by this study, further quantitative research is necessary to provide more precise results. However, the study is the first of its kind to aim specifically at identifying current barriers resulting from the BRI from an LSCM perspective and outlining future development scenarios for an initiative that will be of great importance for companies operating in international logistics networks.

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International Logistics and Cross-Border E-Commerce Trade: Who Matters Whom?

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Abstract: Unlike previous papers on international logistics and cross-border e-commerce trade, this paper sets Organization for Economic Co-operation and Development (OECD) countries as an example to explore the dynamic interaction between international logistics and cross-border e-commerce trade. The panel data for the period 2000–2018 will be employed to perform an empirical analysis via a host of econometric techniques, such as panel unit root tests, panel cointegration tests, panel causality tests and the panel vector error correction model. Incorporating with other control variables, we find that there is a long-term relationship between international logistics and cross-border e-commerce trade. Specifically speaking, in the long-run, international logistics has a positive and significant effect on cross-border e-commerce trade. However, in the short-run, international logistics has a negative and significant effect on cross-border e-commerce trade. Furthermore, the results suggest that deviation from a cointegration system of cross-border e-commerce trade and international logistics will lead to the cross-border e-commerce trade and international logistics changing within the range of approximately 2.2% to 47.2% in the next period. Therefore, referring to these findings, each OECD country's government should take up corresponding policies to ensure the sustainable development of both international logistics and cross-border e-commerce trade.

Keywords: international logistics; cross-border e-commerce trade; panel vector error correction model; sustainable development

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1. Introduction

Cross-border e-commerce trade brings a market for the development of international logistics. Traditional business models are increasingly unable to meet the needs of people. In the new era, consumers will pay more attention to both the quality and variety of goods. In addition, consumers will also focus on the shopping experience. Fortunately, the emergence of cross-border e-commerce trade will greatly enhance the shopping convenience, meet consumer demand, and optimize the consumer shopping experience. Meanwhile, the emergence of cross-border e-commerce trade also plays a role in improving the quality of service, improving the effectiveness of the supply chain, enhancing the efficiency of business operations and increasing the volume of international trade. Therefore, many traditional enterprises have introduced the model of cross-border e-commerce trade. The huge cross-border e-commerce trade market provides market opportunities for the development of international logistics and a necessary link for cross-border e-commerce trade. On the contrary, international logistics is an essential part of building a cross-border e-commerce trade supply chain. The process of cross-border e-commerce trade includes negotiation, contracting, payment, logistics and other aspects. The development of cross-border e-commerce trade also provides market opportunities for the development of enterprises related to these links. In cross-border e-commerce trade, the basis of corporate and consumer contract practice is non-virtual "international logistics". The factors affecting consumer consumption experience also include the efficiency and cost of logistics. Therefore, cross-border e-commerce trade not only provides market opportunities for the development of international logistics, but also challenges its development. As such, international logistics is an indispensable link in the development of cross-border e-commerce trade. Its development level has also become a key factor in the integration of the cross-border e-commerce trade supply chain.

In reality, the sustainable development of both international logistics and cross-border e-commerce trade also faces many challenges. From the theoretical level, the rapid development of cross-border e-commerce trade can increase transaction orders, which can promote the sustainable development of international logistics. However, in the actual operation, the coordination and sustainability of both international logistics and cross-border e-commerce trade are fragile. As we know, the e-commerce platform uses the internet to establish communication links with consumers, which provides consumers with more convenient product purchase channels. Transactions can be achieved only with the help of the network, which is not limited by both space and time. As a platform transportation partner, international logistics needs to do a good job in customs, such as in quality inspection and other work, after receiving the international logistics transportation requirements sent by the platform. As a matter of fact, each link is very complex and takes a lot of time. To solve the time-consuming problem, some cross-border e-commerce trade service providers choose to establish an overseas storage model to offer customers return and exchange services. Due to the large cost of overseas warehousing construction, the demand for product sales data information is high. At present, the international logistics enterprises cannot obtain the product warehouse management data information, which leads to the low accuracy of warehouse design. The layout of storage space cannot meet the actual storage needs, which is not conducive to the improvement of warehouse management level, and international logistics enterprises have always struggled to maintain sustainable development. However, the cross-border e-commerce platform does not know enough about overseas warehousing, and does not understand the importance of international logistics enterprises to their own sustainable development. As a result, the sustainability of bilateral cooperation is weak as a whole.

Furthermore, to improve the service, the cross-border e-commerce enterprises need to cooperate with international logistics enterprises to provide high-quality services for consumers. This operation goal needs to be completed by both parties' synchronous operation. However, in the actual operation process, the cross-border e-commerce enterprises focus on their own work. To let consumers experience high-quality shopping services, they do not consider whether the work of international logistics enterprises is difficult or not. In the international logistics transportation services, the cross-border e-commerce enterprises will set the cooperation requirements of the nearest warehouse delivery, which limits the sustainable operation of international logistics enterprises. Considering the feasibility of international logistics delivery, human resources, transportation costs and other issues, international logistics enterprises are unable to meet the requirements of this international distribution, which results in contradictions in the operation and cooperation between both the parties.

In addition, there are still many problems worth discussing between cross-border e-commerce trade and international logistics. Therefore, a larger number of scholars in this field have made attempts to study this proposition. Ying [1] performed research into logistics mode selection in B2C cross-border e-commerce in China. His findings show that the lagged construction of international logistics systems and the high cost of international logistics have seriously hindered the further development of China's B2C cross-border e-commerce enterprises. With different samples such as India, Alyoubi [2] found that the international logistics problems pose a significant barrier for the sustainable development of e-commerce trade. However, Wang and Lee [3] set China as an example to discuss the effect of international logistics on international trade. They found that this kind of effect is positive. Meanwhile, Cho et al. [4] also found that the international logistics capability is positively correlated with the enterprises' performance in terms of cross-border e-commerce market. To this day, although a great many experts have deeply explored the dynamic relationship between cross-border e-commerce trade and international logistics, they have not reached a consensus. As a matter of fact, due to different perspectives, different samples, different times spans and different research approaches, drawing different conclusions about this proposition can be understood. Said differently, it is highly valuable to exploit the relationship between cross-border e-commerce trade and international logistics. Because of this background, this paper sets Organization for Economic Co-operation and Development (OECD) countries as an example over the period 2000–2018 to explore the dynamic relationship between international logistics and cross-border e-commerce trade. Then, the panel data will be used to carry out an empirical analysis under some econometric approaches, such as the panel unit root test, the panel cointegration test, the panel causality test and the panel vector error correction model. Moreover, there are seven variables used in this paper. They are the cross-border e-commerce export trade, the cross-border e-commerce import trade, the GDP per capita, the population, the relative price, the international logistics, and the one-period lagged outward foreign direct investment. Finally, all these variables and econometric methods will be employed to discuss the dynamic relationship between cross-border e-commerce trade and international logistics.

The contribution of this current paper to the previous empirical literature focusing on the relationship between cross-border e-commerce trade and international logistics is fourfold. First, this paper attempts to fill the gap in the empirical literature with regard to the dynamic relationship between cross-border e-commerce trade and international logistics in the Organization for Economic Co-operation and Development (OECD) countries. The examination with the OECD countries regarded as a case study is particularly interesting, since most of these countries are sufficiently open to each other and fully integrated into one economic market to have a high potential for performing economic activities in both new trade modes and new logistics modes. Meanwhile, most of them have a huge capacity for producing a great quantity of goods and platforms to conduct cross-border e-commerce trade. Moreover, most of them also have extremely advanced international logistics systems to satisfy the needs of cross-border e-commerce trade activities. These fundamentals make our results more reliable and robust. Second, unlike previous research that has used traditional econometric models, such as the vector auto-regression model and the vector error correction model, this paper employs a recent multivariate economic technique which is famous as the panel data vector error correction model. Because the properties of both the time series and the cross-section of the data are taken into consideration, this can help us to more accurately estimate the long-run and short-run relationship between cross-border e-commerce trade and international logistics. Thirdly, a large number of panel unit root tests are used to test the stationarity of variables used in this paper. This can also ensure the accuracy of the empirical results. Finally, the evidence this paper provides can form a foundation for future scholars who are interested in exploring the dynamic relationship between cross-border e-commerce trade and international logistics.

To this end, the rest of this paper will proceed as follows. Chapter two discusses the previous research and develops hypotheses. Chapter three describes the variables and analyzes model specifications. Chapter four presents the results and discussions. Chapter five draws the conclusions, puts forward some corresponding suggestions and presents limitations.

2. Literature Review and Hypothesis Development

Since the data acquisition of cross-border e-commerce trade is limited, the empirical research on this issue is still at an initial stage. Different studies draw different conclusions. In other words, the relationship between international logistics and cross-border e-commerce trade is not fully confirmed.

2.1. Sustainable Development of Cross-Border E-Commerce Trade and Hypothesis

With respect to the factors that can influence the sustainable development of cross-border e-commerce trade, some previous research should be mentioned. Gong et al. [5] found that both sustainable supply chain performance and management can expand the volume of cross-border e-commerce trade. Meanwhile, Zimon et al. [6] also agreed with this results. Moreover, with different samples and approaches, Zimon et al. [7] agreed with this view. However, in this area, more emphasis will be laid on the effect of international logistics on the sustainable development of cross-border e-commerce trade. From the East Asian perspective, Carruthers et al. [8] studied the relationship between trade and logistics. They found that reducing the cost and improving the quality of logistics and transport systems can improve international market access and can directly lead to an increase in the trade. Meanwhile, Hausman et al. [9] performed research on the impact of logistics performance on global bilateral trade. Their findings indicate that the improvement of logistics performance can increase bilateral trade, with a sample of 80 countries from the World Bank Group. Moreover, Anderson and Villa [10] set the North American Free Trade Agreement (NAFTA) region as a sample to discuss the relationship between cross-border transportation and trade across international borders. Using a fixed effect model, they found that cross-border transportation is an important factor that affects the trade across international borders. Furthermore, it is apparent that geographical factors and international logistics are two important determinants of cross-border e-commerce trade competitiveness. Stated differently, the distribution and capability of a country's international logistics facilities play an increasingly important role in the design of a business strategy that is aimed at improving a country's market share in cross-border e-commerce trade. Due to this background, Bensassi et al. [11] tried to use the augmented gravity model of trade, including international logistics as the explanatory variable, with a sample of 19 Spanish regions associated with 64 destinations from 2003 to 2007. They found that international logistics is very important for the analysis of cross-border e-commerce trade flows. They emphasized the importance of logistics measures at the regional level. They found that the quantity, scale and quality of international logistics facilities has a positive impact on cross-border e-commerce export flows. However, Hesse [12] found that there is a negative effect of both logistics and freight transport on e-commerce trade due to inefficient physical distribution in the short-run.

In addition, Hsiao et al. [13] found that good cross-border logistics is a driving factor in promoting cross-border e-commerce trade. However, the weakness and shortage of the international logistics function in inland areas have shaped a bottleneck, which restricts the development of cross-border e-commerce trade. Based on the One Belt and One Road Initiative, the development of cross-border e-commerce demand in inland regions is provoking the demand for inland international logistics network functions. The dry ports have played a vital role in constructing international logistics networks, which has obtained more attention from inland governments. Gani [14] attempted to exploit the function of international logistics performance in cross-border e-commerce trade. He found that the overall international logistics performance has a significantly positive effect on cross-border e-commerce trade statistics in the long run. He also expanded his analysis by investigating whether the particularity of logistics is important to cross-border e-commerce trade. From this expansion analysis, he found that obtaining good international logistics performance in many dimensions has statistical significance and a positive effect on cross-border e-commerce export trade. Said differently, sustainable investment in international logistics infrastructure and services can have a positive effect on cross-border e-commerce trade.

Why does cross-border e-commerce trade flourish in some countries while other countries fail to develop it? This common problem is often mentioned in the literature. Halaszovich and Kinra [15] treated Asian regions as an example to explore the deep mechanism of this issue. Their study provided some theoretical evidence that good international logistics can offset some of the negative effects of distance on cross-border e-commerce trade in the long-run. Moreover, they also found that international logistics in more developed countries can more easily overcome the distance costs to some extent in the short-run. In fact, this conclusion was also found by Refs. [16,17]. Wei and Dong [18] set China as an example to study the same proposition. They found that a satisfactory port international logistics foundation can provide a good condition for cross-border e-commerce trade expansion. The sustainable growth of cross-border e-commerce trade depends on the efficiency of a trade support structure, such as the international logistics service. Although logistics plays an indispensable role in supporting business activities, both the number of practitioners of trade analysis and the focus on trade policy research are generally low. Along with the economic globalization and network generalization, this provides a good opportunity for the development of cross-border e-commerce trade.

To this end, based on the empirical analyses above, the hypothesis can be derived as follows:

Hypothesis 1 (H1): *International logistics is positively related to the sustainable development of cross-border e-commerce trade in the long-run.*

Hypothesis 2 (H2): *International logistics is negatively related to the sustainable development of cross-border e-commerce trade in the short-run.*

2.2. Sustainable Development of International Logistics and Hypothesis

In this section, more attention will be paid to the effect of cross-border e-commerce trade on the sustainable development of international logistics. Delfmann et al. [19] found that e-commerce trade is favored by logistics service providers, which is beneficial for the sustainable development of logistics. This finding is also verified by Ref. [20]. Leinbach [21] set North America as a case to discuss this issue. He found that globalized e-commerce really leads to a sustainable growth of international logistics. Meanwhile, Nguyen and Tongzon [22] regarded Australia and China as a study subject to explore the causal relationship between cross-border e-commerce trade and the development of Australian logistics based on the vector auto-correlation framework. They found that the growth of cross-border e-commerce trade between Australia and China has led to the development of logistics in Australia. Żurek [23] found that due to the sustainable development of e-commerce trade, a new logistics chain management strategy has started to show up, which contains processes of handling both offline and online sales channels. Therefore, the sustainable development of logistics will be changed. Based on this research, Qin et al. [23] also support this idea.

Kadłubek [24] has attempted to study the relationship between e-commerce trade and e-logistics with the case of Poland. In the long-run, e-commerce trade can positively expand the scale of e-logistics. Schöder [25] attempted to find some sustainable development solutions for urban logistics. In the short-run, the increase in freight volume caused by the development of e-commerce brings challenges to urban logistics. However, in the long-run, the improvement and rapid development of e-commerce trade platforms also provides a guarantee for the sustainability of urban logistics. Hong et al. [26] set Korea as an example to study logistics with the Association of Southeast Asian Nations. They found that both the increase in cross-border e-commerce platform and the expansion of e-commerce trade volume bring positive effects for the sustainable development of logistics between both two parties. In countries such as Mongolia and Georgia, Wang et al. [27] found that without long-term economic and social development, national e-commerce trade cannot fully support the sustainable development of logistics performance.

To sum up, based on the empirical analyses above, hypotheses can be derived, as follows:

Hypothesis 3 (H3): *Cross-border e-commerce trade is positively related to the sustainable development of international logistics in the long-run;*

Hypothesis 4 (H4): *Cross-border e-commerce trade is negatively related to the sustainable development of international logistics in the short-run.*

To summarize, these papers analyzed above have debated the relationship between international logistics and cross-border e-commerce trade with different frameworks and different perspectives. In order to make a different contribution from others, this paper sets OECD countries as an example to explore the dynamic relationship between international logistics and cross-border e-commerce trade under a series of econometric approaches, such as the panel unit root test, the panel vector error correction model, and so on. In fact, this paper enriches the existing literature in general, in terms of the findings and research methodology.

3. Theoretical Framework

3.1. Model Specification

To estimate the dynamic relationship between international logistics and cross-border e-commerce trade, we set up four basic models, as the following indicates.

The long-run effect of international logistics on cross-border e-commerce export trade is modeled in Equation (1):

$$\begin{aligned}&\log ecex_{i,t} = c_{1i} + \alpha_1 \log il_{i,t} + \alpha_2 \log dgdp_{i,t} \\ &+\alpha_3 \log pop_{i,t} + \alpha_4 \log rp_{i,t} + \alpha_5 \log ofdi_{i,t-1} + \mu_{1i,t}\end{aligned} \tag{1}$$

The long-run effect of cross-border e-commerce export trade on international logistics is modeled in Equation (2):

$$\begin{aligned}&\log il_{i,t} = c_{2i} + \beta_1 ecex_{i,t} + \beta_2 \log dgdp_{i,t} \\ &+\beta_3 \log pop_{i,t} + \beta_4 \log rp_{i,t} + \beta_5 \log ofdi_{i,t-1} + \mu_{2i,t}\end{aligned} \tag{2}$$

The long-run effect of international logistics on cross-border e-commerce import trade is modeled in Equation (3):

$$\begin{aligned}&\log ecim_{i,t} = c_{3i} + \gamma_1 \log il_{i,t} + \gamma_2 \log dgdp_{i,t} \\ &+\gamma_3 \log pop_{i,t} + \gamma_4 \log rp_{i,t} + \gamma_5 \log ofdi_{i,t-1} + \mu_{3i,t}\end{aligned} \tag{3}$$

The long-run effect of cross-border e-commerce import trade on international logistics is modeled in Equation (4):

$$\begin{aligned}&\log il_{i,t} = c_{4i} + \delta_1 ecim_{i,t} + \delta_2 \log dgdp_{i,t} \\ &+\delta_3 \log pop_{i,t} + \delta_4 \log rp_{i,t} + \delta_5 \log ofdi_{i,t-1} + \mu_{4i,t}\end{aligned} \tag{4}$$

where $\log ecex_{i,t}$ represents the cross-border e-commerce export trade (it is defined as the total volume of cross-border e-commerce export trade); $\log ecim_{i,t}$ represents the cross-border e-commerce import trade (it is defined as the total volume of cross-border e-commerce import trade); $\log il_{i,t}$ represents the international logistics (it is defined as the international freight transport in million tons per kilometer); $\log dgdp_{i,t}$ represents the GDP per capita (at the constant 2000 price); $\log pop_{i,t}$ represents the population; $\log rp_{i,t}$ represents the relative price level; $\log ofdi_{i,t-1}$ represents the one-period lagged outward foreign direct investment. $c_{1i}, c_{2i}, c_{3i}, c_{4i}$ and c_{5i} represent the fixed effects and the heterogeneity among cross-sections; i and t represent the country and year, respectively. Moreover, log represents the logarithmic equation. $\alpha_i, \beta_i, \gamma_i$ and δ_i $(i = 1, 2, 3, 4)$ represent those coefficients of each variable. $u_{1i,t}, u_{2i,t}, u_{3i,t}$ and $u_{4i,t}$ represent independent and identical distributions among countries and years.

The GDP per capita, the population, the relative price, and the one-period lagged outward foreign direct investment are always treated as important factors that affect the cross-border e-commerce trade in previous research. Likewise, these variables are also introduced in this paper. In detail, an increase in the GDP per capita indicates a high disposable income. However, a high disposable income will spur the consumer's purchasing desire, which will affect the cross-border e-commerce trade. The large population size, according to the production function, means more output. However, a large amount of output will stimulate cross-border e-commerce trade. The relative price level is introduced into this paper as a positive difference between two countries' price levels will yield additional benefits in terms of the home country. Of course, because of this advantage, the home country is willing to fulfil the cross-border e-commerce trade. The outward foreign direct investment has a certain impact on the productivity of the host country's domestic enterprises. The competitive effect of foreign capital injection will occupy the market of domestic enterprises. It will also help the host country's enterprises to improve their productivity, through the technology spillover effect of foreign capital enterprises on a host country's enterprises. This comprehensive effect will affect the productivity of enterprises, and thus affect the export trade of the whole country, and its influence depends on the magnitude of the role is played. In addition, in the process of globalization, the growth of foreign trade also affects the investment decisions of foreign investors as regards the host country. As such, in order to avoid the endogenous problems caused by the two-way causality between outward foreign direct investment and export trade, one-period lagged outward foreign direct investment is introduced into this paper. This paper selects the OECD countries as an example to explore the dynamic relationship between international logistics and cross-border e-commerce trade. All these panel data employed in this paper are sourced from the World Bank, the Data Center of Organization for Economic Cooperation and Development, the United Nations Conference on Trade and Development, Statista and iimedia.

As for model (1), model (2), model (3), and model (4), we assume that all variables are generated by the panel unit root process, and the residuals of model (1), model (2), model (3) and model (4) are stationary processes. Stated differently, $u_{1i,t}, u_{2i,t}, u_{3i,t}$ and $u_{4i,t}$ are independently and identically distributed among countries and years. Therefore, it can be concluded that model (1), model (2), model (3), and model (4) are a set of panel cointegration models. As such, the panel vector error correction models (short-run effect) are presented as shown below.

The short-run effect of international logistics on cross-border e-commerce export trade is modeled in Equation (5):

$$\begin{aligned} \Delta \log ecex_{i,t} = \lambda_1 ecm_{i,t-k-1} + \phi_1 \Delta \log il_{i,t-k} + \phi_2 \Delta \log dgdp_{i,t-k} \\ + \phi_3 \Delta \log pop_{i,t-k} + \phi_4 \Delta \log rp_{i,t-k} + \phi_5 \Delta \log ofdi_{i,t-\mathrm{k}-1} + \varepsilon_{1i,t} \end{aligned} \tag{5}$$

The short-run effect of cross-border e-commerce export trade on international logistics is modeled in Equation (6):

$$\begin{aligned} \Delta \log il_{i,t} = \lambda_2 ecm_{i,t-k-1} + \varphi_1 \Delta \log ecex_{i,t-k} + \varphi_2 \Delta \log dgdp_{i,t-k} \\ + \varphi_3 \Delta \log pop_{i,t-k} + \varphi_4 \Delta \log rp_{i,t-k} + \varphi_5 \Delta \log ofdi_{i,t-k-1} + \varepsilon_{2i,t} \end{aligned} \tag{6}$$

The short-run effect of international logistics on cross-border e-commerce import trade is modeled in Equation (7):

$$\begin{aligned} \Delta \log ecim_{i,t} = \lambda_3 ecm_{i,t-k-1} + \eta_1 \Delta \log il_{i,t-k} + \eta_2 \Delta \log dgdp_{i,t-k} \\ + \eta_3 \Delta \log pop_{i,t-k} + \eta_4 \Delta \log rp_{i,t-k} + \eta_5 \Delta \log ofdi_{i,t-k-1} + \varepsilon_{3i,t} \end{aligned} \tag{7}$$

The short-run effect of cross-border e-commerce import trade on international logistics is modeled in Equation (8):

$$\begin{aligned} \Delta \log il_{i,t} = \lambda_4 ecm_{i,t-k-1} + \kappa_1 \Delta \log ecim_{i,t-k} + \kappa_2 \Delta \log dgdp_{i,t-k} \\ + \kappa_3 \Delta \log pop_{i,t-k} + \kappa_4 \Delta \log rp_{i,t-k} + \kappa_5 \Delta \log ofdi_{i,t-k-1} + \varepsilon_{4i,t} \end{aligned} \tag{8}$$

where $ecm_{i,t-k-1}$ represents the residual of panel cointegration models; $\lambda_1, \lambda_2, \lambda_3$ and λ_4 represent the short-term adjustment effects. In other words, these coefficients represent the effects of a long-term relationship among international logistics, cross-border e-commerce export trade, cross-border e-commerce import trade, GDP per capita, population, relative price level, and one-period lagged outward foreign direct investment, on the short-term changes in every variable. Δ represents the first difference operator. $\phi_i, \varphi_i, \eta_i$ and κ_i ($i = 1, 2, 3, 4$) represent the coefficients of each variable. $\varepsilon_{1i,t}, \varepsilon_{2i,t}, \varepsilon_{3i,t}$ and $\varepsilon_{4i,t}$ represent independent and identical distribution among countries and years. Additionally, when λ_1 is less than zero, it means that the long-term relationship suppresses changes in cross-border e-commerce export trade in the short term. From the perspective of the econometric approach, this verifies that model (1) is a panel cointegration model. When λ_2 is less than zero, it means that the long-term relationship suppresses changes in international logistics in the short term. From the perspective of the econometric approach, this proves that model (2) is a panel cointegration model. When λ_3 is less than zero, it means that the long-term relationship suppresses changes in cross-border e-commerce import trade in the short term. From the perspective of the econometric approach, this testifies that model (3) is a panel cointegration model. When λ_4 is less than zero, it means that the long-term relationship suppresses changes in international logistics in the short term. From the perspective of the econometric approach, this indicates that model (4) is a panel cointegration model.

3.2. Panel Unit Root Test

To avoid the occurrence of pseudo-regression and other problems, according to the structural characteristics of the data, the panel unit root test will be used to examine the stationarity of variables before conducting further estimations. Clearly, common unit root test methods have often failed in unit root tests of panel data. The robustness of the results must be guaranteed when the panel vector error correction analyses are carried out. In this paper, the IPS test, Fisher test, PP test, LLC test and other methods are used to test the stationarity of each variable, respectively. The test process will be kept in line with the models below.

Based on the research of Ref. [28], the LLC test model gives

$$\Delta y_{i,t} = \rho_i y_{i,t-1} + \sum_{j=1}^{k} \gamma_{i,j} \Delta y_{i,t-j} + X'_{i,t}\beta_{i,t} + \mu_{i,t} \tag{9}$$

where $X'_{i,t}$ indicates the exogenous variables.

Based on the research of Ref. [29], the IPS test model gives

$$\Gamma_t = \left(\frac{\sqrt{N}[t_{NT}(p) - a_{NT}]}{\sqrt{b_{NT}}}\right) \to N(0,1) \tag{10}$$

where $a_{NT} = (\frac{1}{N})\sum\limits_{i=1}^{N} E[t_{NT}(p,0)]$ and $b_{NT} = (\frac{1}{N})\sum\limits_{i=1}^{N} \mathrm{var}[t_{NT}(p,0)] \cdot t_{NT}$ represents the ADF statistics with the lag p of the N cross-sectional individuals. $E[t_{NT}(p,0)]$ represents the ADF statistic mean with the lag p of N cross-sectional individuals. $\mathrm{var}[t_{NT}(p,0)]$ indicates the ADF statistic variance with the lag p of N cross-sectional individuals.

Based on the research of Ref. [30], the Hadri test model gives

$$LM_1 = \frac{1}{N}\left(\sum_{I=1}^{N} \left(\sum_{T} S_i(t)^2 / T_2\right) / \overline{f}_0\right) \tag{11}$$

$$LM_2 = \frac{1}{N}\left(\sum_{I=1}^{N} \left(\sum_{T} S_i(t)^2 / T^2\right) / f_{i0}\right) \tag{12}$$

where $S_i(t)^2 = \sum\limits_{s=1}^{t} \hat{\varepsilon}_{i,t}$ represents the sum of residuals, and $\overline{f}_0 = \sum\limits_{t=1}^{n} \frac{f_{i0}}{n}$ represents the individual mean.

Based on the research of Refs. [31,32], the Fisher-ADF and Fisher-PP test model gives:

$$\chi^2 = -2\sum_{i=1}^{N} \log(p_i) \tag{13}$$

where p_i indicates the corresponding p-value of the ADF test and PP test, respectively.

3.3. Panel Cointegration Test

Engle and Granger [33] found that the determination of the long-term relationship between variables indicates the adjustment period of the causal relationship between related variables. If the variables have unit roots at levels (namely, they are non-stationary), they need to be taken as the first difference. After the first difference, these variables do not have a unit root (namely, they are stationary). In other words, these variables are cointegrated at $I(1)$. We assume that there is a unidirectional relationship between cross-border e-commerce export trade, cross-border e-commerce, GDP per capita, population, relative price level and one-period lagged outward foreign direct investment. For example, for model (1), international logistics granger causes cross-border e-commerce export trade. For model (2), cross-border e-commerce export trade granger causes international logistics. For model (3), international logistics granger causes cross-border e-commerce import trade. For model (4), cross-border e-commerce import trade granger causes international logistics. In this paper, the combined Johansen–Fisher panel cointegration approach will be employed to determine the long-run equilibrium in international logistics (model (1)) in relation to cross-border e-commerce export trade; cross-border e-commerce export trade (model (2)) in relation to international logistics; international logistics (model (3)) in relation to cross-border e-commerce import trade, and cross-border e-commerce import trade (model (4)) in relation to international logistics. The combined Johansen–Fisher system procedure for the long-term equilibrium of these variables obeys the panel vector auto-regressive system equations. These system equations give

$$\Delta Y_{i,t} = \sum_{i=1}^{k} \Gamma_{i,t} \Delta Y_{i,t-j} + \nu_{i,t} \tag{14}$$

For model (1), $Y_{\alpha i,t} = \begin{bmatrix} \log ecex_{i,t} \\ \log il_{i,t} \\ \log dgdp_{i,t} \\ \log pop_{i,t} \\ \log rp_{i,t} \\ \log ofdi_{i,t} \end{bmatrix}$, $\Gamma_{\alpha i,t} = \begin{bmatrix} \Gamma_{11i,t}, \Gamma_{12i,t}, \Gamma_{13i,t}, \Gamma_{14i,t}, \Gamma_{15i,t}, \Gamma_{16i,t} \\ \Gamma_{21i,t}, \Gamma_{22i,t}, \Gamma_{23i,t}, \Gamma_{24i,t}, \Gamma_{25i,t}, \Gamma_{26i,t} \\ \Gamma_{31i,t}, \Gamma_{32i,t}, \Gamma_{33i,t}, \Gamma_{34i,t}, \Gamma_{35i,t}, \Gamma_{36i,t} \\ \Gamma_{41i,t}, \Gamma_{42i,t}, \Gamma_{43i,t}, \Gamma_{44i,t}, \Gamma_{45i,t}, \Gamma_{46i,t} \\ \Gamma_{51i,t}, \Gamma_{52i,t}, \Gamma_{53i,t}, \Gamma_{54i,t}, \Gamma_{55i,t}, \Gamma_{56i,t} \\ \Gamma_{61i,t}, \Gamma_{62i,t}, \Gamma_{63i,t}, \Gamma_{64i,t}, \Gamma_{65i,t}, \Gamma_{66i,t} \end{bmatrix}$ and $\nu_{\alpha i,t} = \begin{bmatrix} \nu_{1i,t} \\ \nu_{2i,t} \\ \nu_{3i,t} \\ \nu_{4i,t} \\ \nu_{5i,t} \\ \nu_{6i,t} \end{bmatrix}$. For model (2), $Y_{\beta i,t} = \begin{bmatrix} \log il_{i,t} \\ \log ecex_{i,t} \\ \log dgdp_{i,t} \\ \log pop_{i,t} \\ \log rp_{i,t} \\ \log ofdi_{i,t} \end{bmatrix}$, $\Gamma_{\beta i,t} = \begin{bmatrix} \Gamma_{11i,t}, \Gamma_{12i,t}, \Gamma_{13i,t}, \Gamma_{14i,t}, \Gamma_{15i,t}, \Gamma_{16i,t} \\ \Gamma_{21i,t}, \Gamma_{22i,t}, \Gamma_{23i,t}, \Gamma_{24i,t}, \Gamma_{25i,t}, \Gamma_{26i,t} \\ \Gamma_{31i,t}, \Gamma_{32i,t}, \Gamma_{33i,t}, \Gamma_{34i,t}, \Gamma_{35i,t}, \Gamma_{36i,t} \\ \Gamma_{41i,t}, \Gamma_{42i,t}, \Gamma_{43i,t}, \Gamma_{44i,t}, \Gamma_{45i,t}, \Gamma_{46i,t} \\ \Gamma_{51i,t}, \Gamma_{52i,t}, \Gamma_{53i,t}, \Gamma_{54i,t}, \Gamma_{55i,t}, \Gamma_{56i,t} \\ \Gamma_{61i,t}, \Gamma_{62i,t}, \Gamma_{63i,t}, \Gamma_{64i,t}, \Gamma_{65i,t}, \Gamma_{66i,t} \end{bmatrix}$ and $\nu_{\beta i,t} = \begin{bmatrix} \nu_{1i,t} \\ \nu_{2i,t} \\ \nu_{3i,t} \\ \nu_{4i,t} \\ \nu_{5i,t} \\ \nu_{6i,t} \end{bmatrix}$. For model (3),

$$Y_{\gamma i,t} = \begin{bmatrix} \log ecim_{i,t} \\ \log il_{i,t} \\ \log dgdp_{i,t} \\ \log pop_{i,t} \\ \log rp_{i,t} \\ \log ofdi_{i,t} \end{bmatrix}, \quad \Gamma_{\gamma i,t} = \begin{bmatrix} \Gamma_{11i,t}, \Gamma_{12i,t}, \Gamma_{13i,t}, \Gamma_{14i,t}, \Gamma_{15i,t}, \Gamma_{16i,t} \\ \Gamma_{21i,t}, \Gamma_{22i,t}, \Gamma_{23i,t}, \Gamma_{24i,t}, \Gamma_{25i,t}, \Gamma_{26i,t} \\ \Gamma_{31i,t}, \Gamma_{32i,t}, \Gamma_{33i,t}, \Gamma_{34i,t}, \Gamma_{35i,t}, \Gamma_{36i,t} \\ \Gamma_{41i,t}, \Gamma_{42i,t}, \Gamma_{43i,t}, \Gamma_{44i,t}, \Gamma_{45i,t}, \Gamma_{46i,t} \\ \Gamma_{51i,t}, \Gamma_{52i,t}, \Gamma_{53i,t}, \Gamma_{54i,t}, \Gamma_{55i,t}, \Gamma_{56i,t} \\ \Gamma_{61i,t}, \Gamma_{62i,t}, \Gamma_{63i,t}, \Gamma_{64i,t}, \Gamma_{65i,t}, \Gamma_{66i,t} \end{bmatrix}$$ and

$$\nu_{\gamma i,t} = \begin{bmatrix} \nu_{1i,t} \\ \nu_{2i,t} \\ \nu_{3i,t} \\ \nu_{4i,t} \\ \nu_{5i,t} \\ \nu_{6i,t} \end{bmatrix}.$$ For model (4), $$Y_{\delta i,t} = \begin{bmatrix} \log il_{i,t} \\ \log ecim_{i,t} \\ \log dgdp_{i,t} \\ \log pop_{i,t} \\ \log rp_{i,t} \\ \log ofdi_{i,t} \end{bmatrix},$$

$$\Gamma_{\delta i,t} = \begin{bmatrix} \Gamma_{11i,t}, \Gamma_{12i,t}, \Gamma_{13i,t}, \Gamma_{14i,t}, \Gamma_{15i,t}, \Gamma_{16i,t} \\ \Gamma_{21i,t}, \Gamma_{22i,t}, \Gamma_{23i,t}, \Gamma_{24i,t}, \Gamma_{25i,t}, \Gamma_{26i,t} \\ \Gamma_{31i,t}, \Gamma_{32i,t}, \Gamma_{33i,t}, \Gamma_{34i,t}, \Gamma_{35i,t}, \Gamma_{36i,t} \\ \Gamma_{41i,t}, \Gamma_{42i,t}, \Gamma_{43i,t}, \Gamma_{44i,t}, \Gamma_{45i,t}, \Gamma_{46i,t} \\ \Gamma_{51i,t}, \Gamma_{52i,t}, \Gamma_{53i,t}, \Gamma_{54i,t}, \Gamma_{55i,t}, \Gamma_{56i,t} \\ \Gamma_{61i,t}, \Gamma_{62i,t}, \Gamma_{63i,t}, \Gamma_{64i,t}, \Gamma_{65i,t}, \Gamma_{66i,t} \end{bmatrix}$$ and $$\nu_{\delta i,t} = \begin{bmatrix} \nu_{1i,t} \\ \nu_{2i,t} \\ \nu_{3i,t} \\ \nu_{4i,t} \\ \nu_{5i,t} \\ \nu_{6i,t} \end{bmatrix}.$$ For the convenience of writing, we assume that $ofdi_{t-1}$ is equal to $ofdi_t$. The reduced form of these matrices as set out by Enders (2008) gives

$$\log ecex_{i,t} = [\log il_{i,t}, \log dgdp_{i,t}, \log pop_{i,t}, \log rp_{i,t}, \log ofdi_{i,t-1}] \quad (15)$$

$$\log il_{i,t} = [\log ecex_{i,t}, \log dgdp_{i,t}, \log pop_{i,t}, \log rp_{i,t}, \log ofdi_{i,t-1}] \quad (16)$$

$$\log ecim_{i,t} = [\log il_{i,t}, \log dgdp_{i,t}, \log pop_{i,t}, \log rp_{i,t}, \log ofdi_{i,t-1}] \quad (17)$$

$$\log il_{i,t} = [\log ecim_{i,t}, \log dgdp_{i,t}, \log pop_{i,t}, \log rp_{i,t}, \log ofdi_{i,t-1}] \quad (18)$$

3.4. Panel Causality Test

The panel cointegration test only exhibits the long-term relationship among cross-border e-commerce export trade, cross-border e-commerce import trade, GDP per capita, population, relative price level, international logistics, and one-period lagged outward foreign direct investment. However, it has not explained how these variables affect each other. Namely, the direction of causality needs to be identified. For this problem, Dumitrescu and Hurlin [34] developed a panel causality test approach to reveal the direction of causality among these variables used in this paper. It is a dynamic panel test, which is called the pairwise Dumitrescu–Hurlin test. Compared with other approaches, it is more efficient and robust on the basis of estimation. The models of the pairwise Dumitrescu–Hurlin panel causality tests give

$$\begin{aligned} \Delta \log ecex_{i,t} = \theta_{1j} + \varsigma_{11ik} \sum_{k=1}^{p1} \Delta \log il_{i,t-k} + \varsigma_{12ik} \sum_{k=1}^{p2} \Delta \log dgdp_{i,t-k} \\ + \varsigma_{13ik} \sum_{k=1}^{p3} \Delta \log pop_{i,t-k} + \varsigma_{14ik} \sum_{k=1}^{p4} \Delta \log rp_{i,t-k} \\ + \varsigma_{15ik} \sum_{k=1}^{p5} \Delta \log ofdi_{i,t-k-1} + v_{1i,t} \end{aligned} \quad (19)$$

$$\begin{aligned} \Delta \log il_{i,t} = \theta_{2j} + \tau_{11ik} \sum_{k=1}^{p1} \Delta \log ecex_{i,t-k} + \tau_{12ik} \sum_{k=1}^{p2} \Delta \log dgdp_{i,t-k} \\ + \tau_{13ik} \sum_{k=1}^{p3} \Delta \log pop_{i,t-k} + \tau_{14ik} \sum_{k=1}^{p4} \Delta \log rp_{i,t-k} \\ + \tau_{15ik} \sum_{k=1}^{p5} \Delta \log ofdi_{i,t-k-1} + v_{2i,t} \end{aligned} \quad (20)$$

$$
\begin{aligned}
\Delta \log ecim_{i,t} = \theta_{3j} &+ \xi_{11ik} \sum_{k=1}^{p1} \Delta \log il_{i,t-k} + \xi_{12ik} \sum_{k=1}^{p2} \Delta \log dgdp_{i,t-k} \\
&+ \xi_{13ik} \sum_{k=1}^{p3} \Delta \log pop_{i,t-k} + \xi_{14ik} \sum_{k=1}^{p4} \Delta \log rp_{i,t-k} \\
&+ \xi_{15ik} \sum_{k=1}^{p5} \Delta \log ofdi_{i,t-k-1} + v_{3i,t}
\end{aligned} \tag{21}
$$

$$
\begin{aligned}
\Delta \log il_{i,t} = \theta_{4j} &+ \psi_{11ik} \sum_{k=1}^{p1} \Delta \log ecim_{i,t-k} + \psi_{12ik} \sum_{k=1}^{p2} \Delta \log dgdp_{i,t-k} \\
&+ \psi_{13ik} \sum_{k=1}^{p3} \Delta \log pop_{i,t-k} + \psi_{14ik} \sum_{k=1}^{p4} \Delta \log rp_{i,t-k} \\
&+ \psi_{15ik} \sum_{k=1}^{p5} \Delta \log ofdi_{i,t-k-1} + v_{4i,t}
\end{aligned} \tag{22}
$$

where Δ represents the first difference operator. p_1, p_2, p_3, p_4 and p_5 represent the lag length. $v_{1i,t}$, $v_{2i,t}$, $v_{3i,t}$ and $v_{4i,t}$ represent independent and identical distributions. i represents the country. t represents the year.

4. Empirical Analyses

4.1. Summary Statistics

In this paper, seven variables will be used. They include the cross-border e-commerce export trade ($\log ecex_{i,t}$), cross-border e-commerce import trade ($\log ecim_{i,t}$), GDP per capita ($\log pgdp_{i,t}$), population ($\log pop_{i,t}$), relative price level ($\log rp_{i,t}$), international logistics ($\log il_{i,t}$) and one-period lagged outward foreign direct investment ($\log ofdi_{i,t-1}$). Both the summary statistics and the OECD countries list will be shown in Tables 1 and 2.

Table 1. Summary Statistic.

Variable	Observation	Mean	Standard Deviation	Min	Max
$\log ecex_{i,t}$	12,544	0.155	0.096	0.052	0.464
$\log ecim_{i,t}$	12,544	0.098	0.370	0.047	0.342
$\log pgdp_{i,t}$	12,544	2.196	3.172	4.745	14.053
$\log pop_{i,t}$	12,544	0.540	0.702	0.336	1.235
$\log rp_{i,t}$	12,544	2.397	5.001	−10.694	22.266
$\log il_{i,t}$	12,544	4.848	0.749	1.416	5.145
$\log ofdi_{i,t-1}$	12,544	3.876	0.940	0.326	4.512

Table 2. OECD Countries List.

No	Country	No	Country	No	Country	No	Country	No	Country
1	Australia	7	Estonia	13	Ireland	19	New Zealand	25	Sweden
2	Austria	8	Finland	14	Israel	20	The Netherlands	26	Switzerland
3	Belgium	9	France	15	Italy	21	Norway	27	UK
4	Canada	10	Germany	16	Japan	22	Poland	28	USA
5	Chile	11	Greece	17	Korea	23	Portugal	29	Luxembourg
6	Czech	12	Hungary	18	Latvia	24	Slovakia	30	Spain
31	Denmark	32	Iceland						

Table 1 presents the basic description of the variables used in this paper. The data include 12,544 observations for each variable. The mean of cross-border e-commerce export trade is 0.155, with a standard deviation equal to 0.096, a minimum value equal to 0.052 and a maximum value equal to 0.464. The mean of cross-border e-commerce import trade is 0.098 with a standard deviation equal to 0.370, a minimum value equal to 0.047, and a maximum value equal to 0.342. The mean of GDP per capita is 2.196 with a standard deviation equal to 3.172, a minimum value equal to 4.745, and a maximum value equal to 14.053. The mean of the population is 0.540 with a standard deviation equal to 0.702, a minimum value equal to 0.336, and a maximum value equal to 1.235. The mean of the relative price level is 2.397 with a standard deviation equal to 5.001, a minimum value equal to −10.694, and a maximum value equal to 22.266. The mean of international logistics is 4.848 with a standard deviation equal to 0.749, a minimum value equal to 1.416, and a maximum value equal to 5.145. The mean of one-lagged period outward foreign direct investment is 3.876 with a standard deviation equal to 0.940, a minimum value equal to 0.326, and a maximum value equal to 4.512.

Table 2 presents the countries used in this paper. As we know, the Organization for Economic Co-operation and Development includes 38 countries. However, due to data unavailability, only 30 countries have been employed to test the propositions of this paper.

4.2. Panel Unit Root Test

In this paper, five kinds of panel unit root test approaches, including the IPS test, ADF test, PP test, LLC test, and HADRI test, will be employed to perform the panel unit root test, respectively. The results of these panel unit root tests are shown in Table 3.

Table 3. Results of Panel Unit Root Test.

Approach	**Statistics**	**Variable**						
		log$ecex_{i,t}$	**log$ecim_{i,t}$**	**log$dgdp_{i,t}$**	**log$pop_{i,t}$**	**log$rp_{i,t}$**	**log$ofdi_{t-1}$**	**log$il_{i,t}$**
IPS	W-stat	−2.269	−2.719	−5.241	−15.356	−10.007	−4.607	−2.224
	P-vale	0.012	0.003	0.000	0.000	0.000	0.000	0.013
ADF	χ^2	59.927	81.740	190.186	168.503	182.945	126.236	89.284
	P-vale	0.621	0.067	0.000	0.000	0.000	0.000	0.020
PP	χ^2	65.685	77.170	163.278	54.741	298.385	151.444	67.258
	P-vale	0.418	0.125	0.000	0.789	0.000	0.000	0.366
LLC	T-stat	−2.017	−0.907	−10.230	−17.196	−13.766	−8.504	−3.859
	P-vale	0.022	0.182	0.000	0.000	0.000	0.000	0.001
HADRI	Z-stat	7.989	9.506	6.549	9.095	10.199	9.757	7.494
	P-vale	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Approach	Statistics	$\Delta \log ecex_{i,t}$	$\Delta \log ecim_{i,t}$	$\Delta \log dgdp_{i,t}$	$\Delta \log pop_{i,t}$	$\Delta \log rp_{i,t}$	$\Delta \log ofdi_{t-1}$	$\Delta \log il_{i,t}$
IPS	W-stat	−0.431	−0.808	−0.231	−0.861	−0.558	−0.561	−0.334
	P-vale	0.731	0.514	0.844	0.504	0.499	0.501	0.822
ADF	χ^2	228.038	218.479	247.742	300.641	254.665	322.513	176.136
	P-vale	0.000	0.000	0.000	0.000	0.000	0.000	0.000
PP	χ^2	314.154	364.121	488.073	109.429	525.135	481.495	234.103
	P-vale	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LLC	T-stat	−13.716	−15.089	−17.933	−17.725	−17.368	−19.340	−13.041
	P-vale	0.000	0.000	0.000	0.000	0.000	0.000	0.000
HADRI	Z-stat	0.708	0.506	0.819	0.159	0.136	0.329	0.579
	P-vale	0.514	0.709	0.438	0.911	0.925	0.832	0.715

Note: LLC indicates that the null hypothesis means that the unit root exists in the sequence. IPS indicates that the null hypothesis means that the unit root does not exist in the sequence. ADF indicates that the null hypothesis means that the unit root exists in the sequence. PP indicates that the null hypothesis means that the unit root exists in the sequence. HADRI indicates that the null hypothesis means that the unit root does not exist in the sequence. Δ indicates the first difference operator.

Table 3 shows the results of five kinds of unit root tests. As for the results of the IPS panel unit root test, the null hypothesis that the unit root does not exist is rejected. That is to say that all variables are non-stationary. However, taking the first difference, all of them turn stationary. As for the results of the ADF panel unit root test, the null hypothesis that the unit root exists is rejected, except for in the cross-border e-commerce export trade. After taking the first difference, it becomes stationary. As for the results of the PP panel unit root test, the null hypothesis that the unit root exists is rejected except for in the cross-border e-commerce export trade, cross-border e-commerce import trade, population and international logistics. Taking the first difference, all of them turn stationary. As for the LLC panel unit root test, the null hypothesis that the unit root exists is rejected, except for in the cross-border e-commerce import trade. Taking the first difference, it turns stationary. As for the HADRI panel unit test, the null hypothesis that the unit root does not exist is rejected. This means that all variables are non-stationary. Taking the first difference, they turn stationary.

To summarise, the estimated results indicate that most of the variables are not stationary at levels. However, when these variables are taken as the first difference, all of them turn stationary. Therefore, it can be concluded that all the variables used in this paper are stationary after taking the first difference. As such, it is essential to perform a panel cointegration test among cross-border e-commerce export trade, cross-border e-commerce import trade, GDP per capita, population, relative price level, international logistics, and one-period lagged outward foreign direct investment.

4.3. Panel Cointegration Test

Based on the results of panel unit root tests and the model specification of the cointegration tests for long-run equilibrium in Section 3.3, the combined Johansen–Fisher cointegration test will be used to confirm the long-run relationship among these variables. The null hypothesis assumes that there is no cointegration among these variables. The combined Johansen–Fisher cointegration test will obey the vector auto-regressive process for the combination of the panel variables by utilizing the Fisher-Trace and Fisher-Maximum eigenvalue tests. The results will be shown in Tables 4–7.

Table 4. Results of Panel Cointegration Test.

Trace Test				Maximum Eigen Value Test			
H_0	H_1	λ-Trace Statistic	p-Value	H_0	H_1	λ-Max Statistic	p-Value
$t = 0$	$t \geq 1$	273.9	0.000 ***	$t = 0$	$t \geq 1$	273.9	0.000 ***
$t \leq 1$	$t \geq 2$	430.6	0.000 ***	$t \leq 1$	$t \geq 2$	314.8	0.000 ***
$t \leq 2$	$t \geq 3$	849.0	0.000 ***	$t \leq 2$	$t \geq 3$	587.7	0.000 ***
$t \leq 3$	$t \geq 4$	590.8	0.000 ***	$t \leq 3$	$t \geq 4$	590.8	0.000 ***
$t \leq 4$	$t \leq 5$	26.34	1.000	$t \leq 4$	$t \geq 5$	284.2	0.000 ***
$t \leq 5$	$t \geq 6$	42.98	0.988	$t \leq 5$	$t \geq 6$	79.82	0.118

$$\log ecex_{i,t} = 0.025 \log il_{i,t} - 0.047 \log ofdi_{i,t-1} + 0.062 \log pop_{i,t} + 0.052 \log dgdp_{i,t} - 0.057 \log rp_{i,t}$$
........................(6.441).............(−0.967)...................(10.071)..................(4.165).................(−0.085)

Note: *** indicates the rejection of the null hypothesis of no cointegration at least at the 1% level of significance. Probabilities are computed using asymptotic Chi-square distribution. ( ) indicates the t-statistics.

Table 5. Results of Panel Cointegration Test.

Trace Test				Maximum Eigen Value Test			
H_0	H_1	λ-Trace Statistic	p-Value	H_0	H_1	λ-Max Statistic	p-Value
$t = 0$	$t \geq 1$	273.9	0.000* **	$t = 0$	$t \geq 1$	273.9	0.000 ***
$t \leq 1$	$t \geq 2$	430.6	0.000 ***	$t \leq 1$	$t \geq 2$	314.8	0.000 ***
$t \leq 2$	$t \geq 3$	849.0	0.000 ***	$t \leq 2$	$t \geq 3$	587.7	0.000 ***
$t \leq 3$	$t \geq 4$	590.8	0.000 ***	$t \leq 3$	$t \geq 4$	590.8	0.000 ***
$t \leq 4$	$t \geq 5$	35.06	0.999	$t \leq 4$	$t \geq 5$	403.5	0.000 ***
$t \leq 5$	$t \geq 6$	44.36	0.981	$t \leq 5$	$t \geq 6$	62.78	0.590

$$\log il_{i,t} = 2.681 \log ecex_{i,t} + 1.138 \log ofdi_{i,t-1} - 0.457 \log pop_{i,t} + 0.053 \log dgdp_{i,t} + 0.011 \log rp_{i,t}$$
....................(6.441)................(61.521)......................(−6.831)...................(4.030)...................(1.504)

Note: *** indicates the rejection of the null hypothesis of no cointegration at least at the 1% level of significance. Probabilities are computed using asymptotic Chi-square distribution. ( ) indicates the t-statistics.

Table 6. Results of Panel Cointegration Test.

Trace Test				Maximum Eigen Value Test			
H_0	H_1	λ-Trace Statistic	p-Value	H_0	H_1	λ-Max Statistic	p-Value
$t = 0$	$t \geq 1$	271.5	0.000 ***	$t = 0$	$t \geq 1$	271.5	0.000 ***
$t \leq 1$	$t \geq 2$	426.6	0.000 ***	$t \leq 1$	$t \geq 2$	304.8	0.000 ***
$t \leq 2$	$t \geq 3$	941.4	0.000 ***	$t \leq 2$	$t \geq 3$	699.6	0.000 ***
$t \leq 3$	$t \geq 4$	573.8	0.000 ***	$t \leq 3$	$t \geq 4$	573.8	0.000 ***
$t \leq 4$	$t \geq 5$	20.79	0.000 ***	$t \leq 4$	$t \geq 5$	352.4	0.000 ***
$t \geq 5$	$t \geq 6$	45.75	0.973	$t \leq 5$	$t \geq 6$	45.75	0.973

$$\log ecim_{i,t} = 0.017 \log il_{i,t} + 0.013 \log ofdi_{i,t-1} + 0.093 \log pop_{i,t} + 0.015 \log dgdp_{i,t} + 0.019 \log rp_{i,t}$$
........................(11.354)...............(0.664)...................(3.789)....................(0.297)....................(0.702)

Note: *** indicates the rejection of the null hypothesis of no cointegration at least at the 1% level of significance. Probabilities are computed using asymptotic Chi-square distribution. ( ) indicates the t-statistics.

Table 7. Results of Panel Cointegration Test.

Trace Test				Maximum Eigen Value Test			
H_0	H_1	λ-Trace Statistic	p-Value	H_0	H_1	λ-Max Statistic	p-Value
$t = 0$	$t \geq 1$	271.5	0.000 ***	$t = 0$	$t \geq 1$	271.5	0.000 ***
$t \leq 1$	$t \geq 2$	426.6	0.000 ***	$t \leq 1$	$t \geq 2$	304.8	0.000 ***
$t \leq 2$	$t \geq 3$	941.4	0.000 ***	$t \leq 2$	$t \geq 3$	699.6	0.000 ***
$t \leq 3$	$t \geq 4$	539.7	0.000 ***	$t \leq 3$	$t \geq 4$	539.7	0.000 ***
$t \leq 4$	$t \geq 5$	27.73	1.000	$t \leq 4$	$t \geq 5$	267.2	0.000 ***
$t \leq 5$	$t \geq 6$	44.36	0.981	$t \leq 5$	$t \geq 6$	62.78	0.590

$$\log il_{i,t} = 1.036 \log ecex_{i,t} + 0.975 \log ofdi_{i,t-1} - 0.352 \log pop_{i,t} + 0.057 \log dgdp_{i,t} + 0.072 \log rp_{i,t}$$
..................(11.354)..................(39.318)...................(−5.958)...................(4.743).................(1.089)

Note: *** indicates the rejection of the null hypothesis of no cointegration at least at the 1% level of significance. Probabilities are computed using asymptotic Chi-square distribution. ( ) indicates the t-statistics.

Table 4 presents the results of the cointegration test for model (1). Both Trace test and the Maximum eigenvalue test verify that the null hypothesis that no cointegration exists is rejected. Said differently, the cointegration exists for model (1). Meanwhile, the results also indicate that international logistics are positively related to cross-border e-commerce export trade and are significant in the statistics. Specifically, a 1% increase in international logistics leads to a 0.025% increase in cross-border e-commerce export trade. Moreover, this result verifies Hypothesis 1. What's more, this result is also consistent with the findings of Refs. [35,36].

Table 5 presents the results of the cointegration test for model (2). Both the Trace test and the Maximum eigenvalue test verify that the null hypothesis that no cointegration exists is rejected. Said differently, the cointegration exists for model (2). At the same time, the results also indicate that the cross-border e-commerce export trade is positively related to international logistics and is significant in the statistics. In more concrete terms, a 1% increase in cross-border e-commerce export trade results in a 2.681% increase in international logistics. Furthermore, this result also verifies Hypothesis 1. Additionally, this result is in keeping with the results of Refs. [3,37].

Table 6 presents the results of the cointegration test for model (3). Both the Trace test and Maximum eigenvalue test verify that the null hypothesis that no cointegration exists is rejected. Said differently, the cointegration exists for model (3). Meanwhile, the results also indicate that international logistics has a positive effect on cross-border e-commerce import trade and is significant in the statistic. Concretely, a 1% increase in international logistics brings about a 0.017% increase in cross-border e-commerce import trade. In addition, this result also verifies Hypothesis 3. Moreover, this result is in accordance with the ideas of Refs. [38,39].

Table 7 presents the results of the cointegration test for model (4). Both the Trace test and the Maximum eigenvalue test verify that the null hypothesis that no cointegration exists is rejected. Said differently, the cointegration exists for model (4). Meanwhile, the results also indicate that the cross-border e-commerce import trade has a positive effect on international logistics and is significant in the statistic. Said differently, a 1% increase in cross-border e-commerce import trade generates a 1.036% increase in international logistics. In addition, this result also verifies Hypothesis 3. Moreover, this result is identical to the findings of Refs. [40–42].

Based on the results of Tables 4–7, it can be confirmed that the cointegrating vectors of cross-border e-commerce export trade, cross-border e-commerce import trade, GDP per capita, population, relative price, international logistics and one-period lagged outward foreign direct investment exhibit panel cointegration. That is to say, there is long-term equilibrium among these variables in the case of OECD countries.

4.4. Panel Causality Test

Even though the results of combined Johansen–Fisher cointegration tests reveal that a long-term relationship among these variables exists, it cannot be confirmed what the magnitude of the relationship is. A bivariate panel causality test, which is based on the Dumitrescu–Hurlin process, will be used to test the causality relationship among these variables. The results of the panel causality tests are shown in Table 8.

Table 8. Pairwise Dumitrescu–Hurlin Panel Causality Test.

Model	Hull Hypothesis	W-Statistic	Zbar-Statistic	*p*-Value	Conclusion
19	$\log ecex$ does not homogeneously cause $\log il$	9.771	6.768	0.000	Rejected
20	$\log il$ does not homogeneously cause $\log ecex$	5.934	2.268	0.023	Rejected
21	$\log ecim$ does not homogeneously cause $\log il$	6.073	2.431	0.015	Rejected
22	$\log il$ does not homogeneously cause $\log ecim$	7.035	3.559	0.000	Rejected

According to the results of Table 8, it can be seen that the null hypotheses from model (19) to model (22) are rejected at 5% significant levels. Moreover, with a sample of OECD countries, the stronger bidirectional causal relationship between cross-border e-commerce export and international logistics, and the relationship between cross-border e-commerce import and international logistics, can be verified. Stated differently, the feedback causal relationship between cross-border e-commerce export and international logistics, and the relationship between cross-border e-commerce import and international logistics, exist within a sample of OECD countries.

4.5. Panel Vector Error Correction Model

In this paper, the panel vector error correction model was used to explore the short-term relationship among cross-border e-commerce export trade, cross-border e-commerce import trade, GDP per capita, population, relative price level, international logistics, and one-period lagged outward foreign direct investment. The results of panel vector error correction models (PVECM) are shown in Table 9.

Table 9. Results of Panel Vector Error Correction Model (PVECM).

Variable	Model (5)	Model (6)	Model (7)	Model (8)
	$\Delta \log ecex_{i,t}$	$\Delta \log il_{i,t}$	$\Delta \log ecim_{i,t}$	$\Delta \log il_{i,t}$
$\lambda_i - ecm_{i,t-1}$	−0.236*** (−4.255)	−0.022 ** (−2.502)	−0.472 *** (−8.617)	−0.103 * (−1.896)
$\Delta \log il_{i,t}$	−0.065 *** (−4.221)		−0.011 ** (−2.477)	
$\Delta \log ecex_{i,t}$		−0.383 ** (−2.342)		
$\Delta \log ecim_{i,t}$				−0.306 * (−1.734)
$\Delta \log dgdp_{i,t}$	0.052 * (1.806)	−0.032 (−1.476)	0.021 (0.540)	−0.025 (−1.356)
$\Delta \log pop_{i,t}$	0.039 (0.265)	0.039 (0.243)	0.066 (0.013)	0.120 (0.825)
$\Delta \log rp_{i,t}$	0.018 (0.986)	0.080 ** (2.531)	−0.053 (−0.247)	0.015 * (1.873)
$\Delta \log odfi_{i,t-1}$	−0.038 ** (−2.142)	−0.012 (−0.136)	−0.036 ** (−2.447)	0.013 * (1.878)
Category	Cross-border e-commerce export trade and international logistic		Cross-border e-commerce import trade and international logistic	

Note: ( ) indicates the t-statistics. * indicates 10% significance level. ** indicates 5% significance level. *** indicates the 1% significance level.

Table 9 shows the results of the panel vector error correction estimation for model (5), model (6), model (7), and model (8), respectively. For model (5), λ_1 is equal to −0.236 and is significant at the 1% level. Moreover, this result also verifies that the panel cointegration relationship exists. Namely, model (1) holds. This suggests that deviation from the cointegration system of cross-border e-commerce export trade will lead to the cross-border e-commerce export trade changing by approximately 23.6% in the next period. Meanwhile, it can be also found that international logistics has a negative effect on cross-border e-commerce export trade. This result verifies Hypothesis 2. For model (6), λ_2 is equal to −0.022 and significant at the 5% level. This result also implies that the panel cointegration relationship exists. In other words, model (2) holds. This suggests that deviation from the cointegration system of international logistics will lead to the international logistics changing by approximately 2.200% in the next period. At the same time, the cross-border e-commerce export trade has a negative effect on international logistics. This result verifies Hypothesis 4. Compared with the estimating value of λ_1 and λ_2, the ability to return to the long-term equilibrium of deviation from the cointegration system of cross-border e-commerce export trade in the short term is stronger than that for the deviation from the cointegration system of international logistics. For model (7), λ_3 is equal to −0.472 and significant at the 1% level. Moreover, this result also verifies that the panel cointegration relationship exists. Said differently, model (3) holds. This indicates that the deviation from the cointegration system of cross-border e-commerce import trade will lead to the cross-border e-commerce import trade changing approximately 47.2% in the next period. Simultaneously, international logistics has a negative effect on cross-border e-commerce import trade. In fact, Niu [43] agreed with this finding. Moreover, this result verifies Hypothesis 2. For model (8), λ_4 is equal to −0.103 and significant at the 10% level. Furthermore, these results also verify that the panel cointegration relationship exists. Stated differently, model (4) holds. This shows that the deviation from the cointegration system of international logistics will lead to the international logistics changing approximately 10.3% in the next period. Meanwhile, cross-border e-commerce import trade has a negative effect on international logistics. As a matter of fact, this result responds well to the idea of Ref. [44]. Furthermore, this result verifies Hypothesis 4. When taking the estimating value of λ_3 and λ_4 into consideration, the ability to return to the long-term equilibrium of the deviation from the cointegration system of cross-border e-commerce import trade in the short term is stronger than that for the deviation from the cointegration system of international logistics.

In addition, the results of the panel vector error correction model have vital economic and trade policy implications. An increase in the GDP per capita will achieve a breakthrough in the cross-border e-commerce export trade. An increased relative price level will restrain the development of international logistics in terms of cross-border e-commerce import trade. More importantly, the one-period lagged outward foreign direct investment has a crowding-out effect on cross-border e-commerce trade. However, it has a crowding-in effect on international logistics in terms of cross-border e-commerce import trade.

5. Conclusions and Suggestions

Economic globalization provides a new impetus for the development of cross-border e-commerce trade and international logistics. As the history of the development of cross-border e-commerce trade is relatively short, the data collection is very difficult. Due to this limitation, there are few empirical studies on the relationship between cross-border e-commerce trade and international logistics. Even so, the current research reaches no consensus about this proposition. Due to this background, this paper regards OECD countries as a sample to explore the dynamic relationship among cross-border e-commerce export trade, cross-border e-commerce import trade, GDP per capita, population, relative price level, international logistics and one-period lagged outward foreign direct investment. The panel data from 2000 to 2018 will be employed to fulfil an empirical analysis under a series of econometric approaches, such as panel unit root tests, panel cointegration tests, panel causality tests, and the panel vector error correction model. The results of the panel unit root test illustrate that most variables are generated by the panel unit root process. The results of the combined Johansen–Fisher cointegration test indicate that there is a long-run relationship among these variables. The results of the panel causality test confirm the existence of the stronger bidirectional causal relationship between cross-border e-commerce export and international logistics, and the relationship between cross-border e-commerce import and international logistics. Finally, the results of the panel vector error correction model reveal the short-term relationship between these variables.

In the long run, the interaction between international logistics and cross-border e-commerce trade is positive and significant in terms of statistics. In terms of cross-border e-commerce export trade, the population and the GDP per capita have a positive effect on cross-border e-commerce export trade. However, the one-period lagged outward foreign direct investment has a negative effect on cross-border e-commerce export trade. Meanwhile, the one-period lagged outward foreign direct investment and the GDP per capita have a positive effect on international logistics. However, the population has a negative effect on international logistics. In terms of cross-border e-commerce import trade, the population has a positive effect on cross-border e-commerce import trade. The one-period lagged outward foreign direct investment and the GDP per capita have a positive effect on international logistics. However, the population has a negative effect on international logistics.

In the short run, the interaction between international logistics and cross-border e-commerce trade is negative and significant in terms of statistics. In terms of cross-border e-commerce export trade, the GDP per capita has a positive effect on cross-border e-commerce export trade. The one-period lagged outward foreign direct investment has a negative effect on cross-border e-commerce export trade. The relative price has a positive effect on international logistics. In terms of cross-border e-commerce import trade, one-period lagged outward foreign direct investment has a negative effect on cross-border e-commerce import trade. The relative price and one-period lagged outward foreign direct investment have a positive effect on international logistics. Meanwhile, this suggests that deviation from the cointegration system of cross-border e-commerce trade and international logistics will lead the cross-border e-commerce trade and international logistics to change within a range of approximately 2.2% to 47.2% in the next period.

According to the empirical evidence this paper provides, some corresponding suggestions will be put forward. For example, the GDP per capita is an important factor affecting the dynamic relationship between international logistics and cross-border e-commerce trade. Therefore, OECD countries should expand the production to increase the GDP per capita. When taking the long-term dynamic relationship among them, the dynamic relationship between international logistics and cross-border e-commerce trade is positive. Therefore, OECD countries should take up some related policies, such as reductions of the tariff and improvements of the logistics infrastructure, in order to promote the sustainable development of international logistics. Then, an increase in the international logistics can result in an increase in the cross-border e-commerce trade. When taking the short-run dynamic relationship among them, the relative price level also plays a vital role in affecting the short-term dynamic relationship between international logistics and cross-border e-commerce trade. OECD countries should take up some related policies, such as money demand and money supply, to control the price level. The reason is that the appropriate price level can be beneficial for the sustainable development of international logistics and cross-border e-commerce trade.

To this end, there are some limitations in this paper. The heterogeneity among selected OECD countries is ignored. Therefore, one possible extension for future research in this area may be to segment the full sample into some sub-samples to confirm the evolution of the relationship among them. Furthermore, another possible extension of this investigation may include a proxy of international logistics (in this paper, it is defined as the international freight transport in million tons per kilometer). For cross-border e-commerce trade, this paper only employs the total volume of cross-border e-commerce export trade and the total volume of cross-border e-commerce import trade. In future works, if possible, the volume of cross-border e-commerce trade can be subdivided into B2B, B2C, O2O and G2B. This settlement seems to be more interesting in terms of producing good works. Due to data unavailability, the size of the research sample is extremely limited. Therefore, a possible way to ensure the estimated results are reliable and robust is to expand the size of the research sample and to lengthen the time span.

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The Impact of China's Tightening Environmental Regulations on International Waste Trade and Logistics

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Abstract: In recent years, China's influence as the dominant importer of waste products has reshaped global waste trade through restrictive programs such as Operation Green Fence in 2013 and National Sword in 2017. These restrictions have greatly affected not only China's import of waste products but also the international trade and global logistics of these products. China's import restrictions in 2017 decreased the country's import of waste plastic by 92% and used paper by 56%. It also increased the unit value of these two categories of waste by 27% and 13%, respectively, showing an improvement in the quality of imported waste. Most of these impacts originate from intensive margins. The restrictions diverted the flow of waste mostly to the low- and middle-income countries of the East Asian and Pacific regions along with Europe and Central Asia, as their imports increased by 161% and 266% for waste plastic and 101% and 77% for used paper, respectively. Compared with Operation Green Fence, the impact of the 2017 National Sword has been much higher, with shipping companies faced with a lack of products on backhaul routes and forced to change their longstanding practices.

Keywords: waste plastic; used paper; import ban; import license; international waste trade

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1. Introduction

The global trade of waste and scrap has increased rapidly since the 1990s, and most of it flows into developing countries [1]. The argument for "buying" waste is that it is relatively cheaper than primary material and easier to access in a situation of limited resources and technological ability [2,3]. The argument for "selling" waste is to skirt stringent regulations on waste disposal by exporting it to countries with lax environmental regulations, the so-called waste haven hypothesis proposed by Baggs [4] and Kellenberg [5]. This should not be confused with the pollution haven hypothesis [6], which emphasizes the relocation of pollution-intensive manufacturing sectors to countries with less stringent environmental policies. China as well as other developing countries fit right into this narrative. China is the world's largest importer of solid waste, accounting for around 40% of the world's imports of plastic waste and used paper in 2018 [7]. The logistics industry also benefits from the global waste trade by using (backhaul) empty containers to carry low-value products including waste plastic, and uses paper on their return haul, earning additional revenue [8].

While China utilizes waste as a relatively cheap input for production to meet domestic and export demand, it simultaneously suffers from poor management of waste and rampant waste smuggling [9]. Jambeck et al. [10] estimate that China produces 8.82 million metric tons of waste plastic per year, and 76% of the waste is mismanaged. Illegal imports of hazardous waste also contribute to waste mismanagement in China. Consequently, the country started regulating solid waste imports with policies such as Operation Green Fence (OGF) of 2013 and the recent National Sword of 2017 that banned the import of several types of solid waste.

OGF was an enforcement campaign that ran from February 2013 to November 2013 with the objectives of stopping the illegal hazardous-waste trade and increasing the quality of imported waste via stricter inspections. During this period, "nearly every container" arriving in China was inspected [11]. Shipments with higher contamination than the permissible 1.5% of their weight were rejected [9]. However, as we will show later, the impact of OGF was short-lived.

National Sword was launched in February 2017 to stop "foreign garbage" from flooding the country [12]. As part of this program, every container of waste plastic and paper entering the country was checked from March 2017 to November 2017. China notified the World Trade Organization (WTO) in July 2017 about the ban on the import of 24 kinds of solid waste by the end of 2017. This included plastic waste (all four kinds of class HS3915) and unsorted used paper (HS470790) [12]. It was planned that other solid waste that can be replaced by local resources would have been gradually phased out by the end of 2019. The limit for contaminated waste is 0.5%, which is much lower than that of OGF. As these measures were abruptly introduced, they disrupted the recycling industry and global waste trade.

Blue Sky 2018 ran from March 2018 to December 2018 as a continuation of the National Sword policy, to monitor the import ban and prevent waste smuggling. These policies show that China's government is strongly committed to reducing waste inflows into the country. In April 2020, China approved a revision to its solid waste management policies, aiming at "gradually realizing zero imports of solid waste" [13].

While international trade in non-hazardous waste follows the rules governing goods trade (such as the WTO), hazardous waste is governed by the Basel Convention. According to the convention, countries may ban hazardous waste imports and exporters must honor the ban. In 2019, the convention was amended to include plastic waste in a legally binding framework, which clarified the conditions for plastic waste to be hazardous and banned from imports. The amendment takes effect from 1 January 2021 [14]. China's justification for the ban was written in its notification to the WTO as: "we found that substantial amounts of dirty wastes or even hazardous wastes are mixed in the solid waste that can be used as raw materials. This polluted China's environment seriously" [12]. Plastic waste from living sources and unsorted wastepaper were therefore banned, despite other member countries expressing concern over the ban.

In this paper, we revisit the impacts of China's import restriction with a focus on plastic waste and used paper. There are two main reasons for focusing on these two types of waste. First, China's imports of used papers and used plastics cover 50% and 51%, respectively, of the world's total imports in 2016, which are much higher than those of minerals (10%) and textiles (13%), according to the authors' calculation from the United Nation Comtrade database (we follow OECD's definition of waste but only focus on China's list of banned waste. The corresponding HS codes for these wastes are used papers [HS4707], used plastics [HS3915], minerals [HS2619, 2620], textiles [HS5103, 5104, 5502, 5505, and 6310]). Second, these two types of waste have been transported by containers to utilize empty containers being repositioned from main haul routes [8]. According to the authors' calculation based on the IHS Markit database, plastics and papers account for 68% and 24% of China's total seaborne trade (due to product classification of IHS Markit database, we cannot distinguish between virgin materials and recycled materials. However, both are possibly transported in the same manner). For container trade, these two wastes account for 52% and 15%, respectively, much higher than minerals (0.2%) and textiles (4%). More data allow us to better evaluate the impact of National Sword on China's waste imports. We found that while China's import volumes of waste plastic (HS3915) and used paper (HS4707) decreased by 92% and 56%, respectively, their weighted mean unit values of China's imports rose by 34.5% and 13.1%, respectively. We also observe the diversion of waste flow from China to other countries, mostly in East Asia and the Pacific region, Europe, and Central and South Asia (excluding high-income countries). When the two types of waste are compared, the impacts are more significant for waste plastic due to the stricter regulations in China. However, China will likely continue to reduce import license permits on used paper. Thus, a more persistent and greater impact is expected in the future.

The remainder of this paper is organized as follows. In the next section, we review the current literature and present theoretical frameworks. Section 3 describes the data and methodology. Section 4 discusses the impact of regulations on China's waste imports, trade diversion to other regions, and the impact on the shipping industry. Section 5 concludes.

2. Literature Review

There have been several studies on the impact of OGF and National Sword on the international waste trade. Balkevicius, Sanctuary, and Zvirblyte [9] studied the effects of OGF on imports of all forms of waste (metal, plastic, used paper, rubber, and textiles). They showed that trade flows of low-quality waste from developed countries into China decreased and were diverted to other developing countries, regardless of the stringency of the host countries' environmental regulations. Similarly, Sun [15] compared China's imports of waste and non-waste and found a 9.48% decrease in imports of waste material and a 7.8% decrease in the import price after OGF was implemented. Brooks, Wang, and Jambeck [16] used historical data to estimate that 111 million tons of plastic waste would be displaced due to OGF. Wang et al. [17] outlined the impact of the ban on plastic waste imports on other countries' policies. The ban has incentivized waste exporters such as Europe, the USA, and Japan to adopt more restrictions on the use of plastic packaging, utensils, and straws, and to improve the production of alternative materials. Since some trade was hastily shifted to China's neighboring countries, India, Vietnam, Thailand, and others have announced restrictions on solid waste imports as well. Huang et al. [18] used an input-output model to analyze the impacts of the waste plastic ban. Sectors that accounted for substantial portions of China's plastic waste imports, such as construction (30.6%) and electrical and machinery (12.9%), would be affected significantly. Similarly, Canada, Australia, Japan, and South Korea, which export most of their plastic waste to China, would also be impacted. Wang et al. [19] used network analysis tools to portray the development of the global waste plastic trade.

Our study relates to the literature on international trade in recycled materials and waste management. Baggs [4] showed that the amount of waste trade depends on exporters' and importers' income and trade cost, which resembles the literature of goods trade in general [20]. Kellenberg [5] showed that waste trade also depends on the gap between exporters' and importers' incomes, their recycling productivities, and the stringency of environmental regulations. In addition, he showed that countries with higher income per capita often have higher recycling productivities and stricter environmental regulations. More importantly, both these papers show that waste flows from countries with stricter environmental regulations (and higher income per capita) to countries with less stringent regulations (and lower income per capita). In terms of recycling productivity, Berglund and Söderholm [21] investigated the case of recycled papers during the period 1990–1996 and showed that wastepaper recovery rate and utilization rates depend on both economic and political factors and that rich countries often have higher recovery rates. Van Beukering and Bouman [22] also show that developing countries utilize wastepaper more and developed countries recover them more. In the case of plastic waste, mismanagement has become a huge threat to the environment. Jambeck et al. [10] showed that this problem is more serious in countries with larger populations, many of which are developing countries. Therefore, we divide our samples into two groups of high-income and low-income countries and expect that most of the waste flow to China is from high-income countries. We also expect that trade divergence will more likely go to low-income countries.

This paper also relates to the literature on trade policy. Although the targets of OGF are illegal waste, its stricter inspection policy acts as a technical standard to improve import quality. Contrarily, National Sword imposes quotas on sorted used paper and a ban on plastic waste and unsorted wastepaper, which targets import quantity. The impact of quotas resembles that of tariffs, that is, to reduce import quantities and increase domestic prices (and reduce exporter prices when the importer is a large country) [23]. Similarly, technical standards increase costs of production, which shift the supply curve, reduce import quantities, and increase domestic prices [24,25]. Contrarily, in the case of technical standards, the demand side may change due to a shift in consumer preference toward higher-quality products, so that technical standards can increase quantities and prices [26]. However, in the specific case of recyclable waste, it is not the consumers of final goods but the intermediate producers that affect the demand for imported waste. Technical standards also affect the extensive margin and duration of trade [25]. On the exporters' side, it is more likely that developed countries export higher quality (with higher price) products and to more destinations [26]. From these arguments, we expect that both OGF and National Sword reduce the import quantity to China. In terms of price, we can observe a price increase, if an improvement in quality dominates the drop in exporter prices and vice versa.

Our paper also relates to the literature on container shipping under the effect of trade imbalances. Since the late 1990s, there has been an upward trend in trade imbalances in Transpacific and Far East–Europe routes due to the change in the global production network [27,28]. It is important to make a distinction between trade deficit and imbalances, where the first refers to the net value between export and import and the latter refers to the net quantity (often measured in twenty-foot equivalent units [TEUs]) between main haul and backhaul routes. Imbalances incur costs of repositioning ships for shipping companies [28,29]. Rodrigue [29] estimated that the repositioning cost paid by shipping companies amounted to about 16 billion USD or 15% of container management costs. Further, the Boston Consulting Group pointed out that 5–8% of the operating expenses of container carriers are repositioning expenses, and the burden on the shipping industry is 15–20 USD [30]. To offset these costs, shipping companies have filled empty containers on backhaul routes with wastes and cheap materials [8]. A drop in China's import of these wastes will increase the gap between the main haul and backhaul, all else being equal.

Our study contributes to the literature in the following points. First, we are the first to discuss the extensive margin of trade for both plastic waste and used papers in the context of China's import bans. Second, we are the first to discuss the potential effects of these regulations on the shipping industry in the context of trade imbalances. We have three main research questions. First, what is the impact of China's waste import restrictions on China's import quantities and prices? Second, what is the impact on other countries' imports? Third, what is the impact on the shipping industry? The next sections describe the data and methodology to answer these questions.

3. Data and Methodology

We use data from the United Nations Comtrade Database [7], which has international trade statistics of commodities up to the six-digit level of the HS classification. The data report figures for imports, exports, reexports, and reimports in quantity and value. We use this information to calculate the unit value for each triplet exporter-importer-commodity (six-digit level). To focus on the impact of OGF and National Sword, we report data from 2010 to 2019 for all countries and the six-digit level of two classes: HS4707 and HS3915. However, we only review exporters that consistently appear over the entire period. Since both programs lasted a year, we did not include 2013 and 2017 in calculating the difference before and after these programs. We use two years before and after the event instead of one to calculate the quantity change and weighted mean unit value.

There are few countries in the dataset that have a substantial portion of reexports. The most prominent is Hong Kong, where 99% of imported waste is re-exported to China. Some authors add Hong Kong waste imports to China's waste imports [9]. Since we are interested in unit values, doing so would ignore the gap between Hong Kong's import price and its export price for China. Although the trends of these two prices are similar, the difference in size causes inaccuracy in aggregating prices for groups of commodities and groups of countries. Thus, we excluded Hong Kong from our dataset. We calculated another version that included Hong Kong and found that the results showed the same trend but were slightly different in magnitude.

We then aggregate quantity and unit value to a four-digit level and calculate the extensive changes (entry and exit) and intensive changes. We also confirm the intensive changes in quantity and unit value by running the two-sided and one-sided pairwise t-test for two samples of China's imports from all available countries in the sample for two types of waste at the six-digit level. In the interest of brevity, we abstract the test results. In fact, only the change in quantities after National Sword is significantly different at 1%.

To aggregate unit value at region and/or four-digit level products, we use the share in quantity to calculate the weighted mean unit value. The change in weighted mean unit value can be divided into a change in price (given unchanged share) and a change in share (given unchanged price). We also report the margin of change, including exit, entry, and intensive. Exit (or entry) shows an increase (or decrease) in the number of a triplet exporter-importer-commodity (six-digit-level). Specifically, exit (entry) includes exporter-importer-commodity triplets that only exist before (after) the event. The intensive margin shows the change in quantity and price corresponding to a specific triplet exporter-importer-commodity (i.e., the triplet exists in the dataset before and after the event). The change in the unit value after the event is illustrated in the following equation:

$$\frac{P^a - P^b}{P^b} = \overbrace{\frac{\sum_{ik\in\Omega^a\setminus\Omega^b} p^a_{ik}s^a_{ik}}{P^b}}^{Entry} - \overbrace{\frac{\sum_{ik\in\Omega^b\setminus\Omega^a} p^b_{ik}s^b_{ik}}{P^b}}^{Exit} + \overbrace{\underbrace{\frac{\sum_{ik\in\Omega^a\cap\Omega^b}\left(p^a_{ik} - p^b_{ik}\right)s^b_{ik}}{P^b}}_{UV\ Change} + \underbrace{\frac{\sum_{ik\in\Omega^a\cap\Omega^b}(s^a_{ik} - s^b_{ik})p^a_{ik}}{P^b}}_{Share\ Change}}^{Intensive} \quad (1)$$

where P^a and P^b are the weighted unit values of the commodity at the four-digit level after and before the event, respectively; p^a_{ik} and p^b_{ik} are the price of waste import of commodity k at the six-digit level from country i after and before the event. s^a_{ik} and s^b_{ik} are their respective import quantity shares, and Ω^a and Ω^b are the set of exporter-importer-commodity triplets after and before the event, respectively. Details of the calculation are presented in Appendix A.

It is quite straightforward to predict that the import quantity will decrease after the import ban, as explained in the previous section. However, the effect on the unit value is not as clear. Two major forces may affect the change in the unit value. A higher unit value shows a higher quality [9,25]. If the ban succeeds in preventing highly contaminated waste entry, we should expect a higher unit value after the policy. Even for waste without contamination, exporters will invest more in inspecting products before shipping to reduce the risk of rejection [11]. Alternatively, unit value can be interpreted as price, which is regulated by supply and demand forces. Since China is a large participant in the waste product market, its trade policies will affect the world's waste market. A sudden import ban will cause an oversupply of waste in the world market, which would drive prices downward [23,24]. Sun [10] found this while examining the impact of OGF on China's import price for waste.

In the case of used paper, the immediate effects of the ban are on unsorted wastepaper (HS470790). Other products of the same class are subjected to import licenses that are announced yearly. Between 2012 and 2019, these permits dropped by a third. The effect of permits resembles tariffs, which will reduce import volumes and increase import prices [23].

One may speculate that the impact of these regulations after 2017 may be mixed with the impact of the China-US trade conflict in late 2018 and early 2019. China's demand for recyclable materials may decrease due to the slowdown of the economy because of this conflict. However, China's growth in manufacturing investment doubled from 4.8% in 2017 to 9.5% in 2018, while its merchandise exports grew by 9.1% and inward foreign direct investment (FDI) increased by 21% [31]. Therefore, the decrease in China's import of waste plastic and used paper more likely comes from the shock of National Sword in 2017 and its follow-up policies rather than the trade conflict.

4. Results and Discussion

4.1. The Impact of OGF and National Sword on Chinese Waste Imports

Figure 1 shows the overall trend of China's waste imports from 2010 to 2019 in unit value and import share of waste plastic and used paper. From the right panel, for both types of waste, China's import share has a declining trend from 2013 after OGF, but there is a sharper decrease in 2017 after National Sword. Table 1 shows that the import quantity of plastic waste and used paper decreased by 92% and 56%, respectively, after National Sword (2017). These are much steeper declines than the −7% and −9% experienced after OGF in 2013. In the left panel of Figure 1, the unit values of both types of waste decreased after OGF but increased after National Sword. As shown in Table 1, the percentage changes in the unit values of waste plastic and used paper are 27% and 13% (respectively) after National Sword, and −22% and −17% (respectively) after OGF. As argued before, a decrease in unit value indicates that the supply-demand adjustment force dominates the quality adjustment for OGF, which is in contrast with the case of National Sword. Notably, the magnitude of change in both quantity and unit value is much higher for plastic than that of used paper. This is because all types of plastic waste were banned while used paper trade was still allowed under restriction.

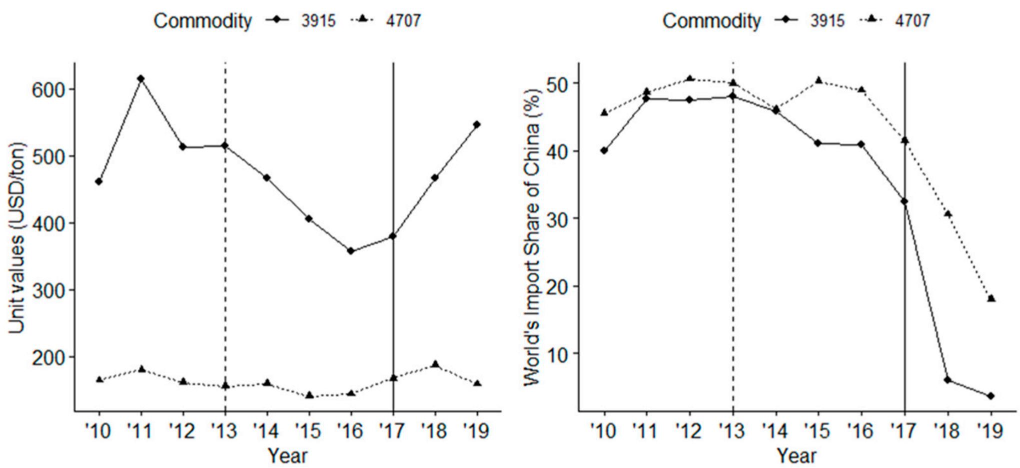

Figure 1. China's import of plastic waste (HS3915) and used paper (HS4707). Source: Authors' calculation based on UN Comtrade [7].

Table 1. Quantity and unit value change after OGF (2013) and National Sword (2017).

Commodity	Margin	National Sword (2017)				Operation Green Fence (2013)			
		Quantity Change (%)	Unit Value Change (%)			Quantity Change (%)	Unit Value Change (%)		
			Total Change	UV Change	Share Change		Total Change	UV Change	Share Change
Waste Plastic (3915)	Total	−92.1	27.4	31.5	−4.1	−7.3	−22.3	−22.0	−0.3
	Entry	0.0	0.6	0.0	0.6	0.1	0.1	0.0	0.1
	Exit	−3.3	−3.8	−3.8	0.0	−0.4	−0.5	−0.5	0.0
	Intensive	−88.8	30.6	35.3	−4.7	−7.0	−21.8	−21.5	−0.3
Used Paper (4707)	Total	−56.0	12.7	34.8	−22.2	−8.6	−17.1	−7.3	−9.8
	Entry	0.2	0.4	0.0	0.4	0.2	0.2	0.0	0.2
	Exit	−0.3	−0.3	−0.3	0.0	−0.2	−0.1	−0.1	0.0
	Intensive	−55.9	12.6	35.1	−22.6	−8.6	−17.2	−7.2	−10.0

Source: Authors' calculation based on UN Comtrade [7].

We also decompose the change in quantity into different margins, as shown in Table 1. In both events, OGF and National Sword, the intensive margin accounts for most of the changes. The only difference is for waste plastic after National Sword, where the exit margin accounts for a 3% decrease in import volume. However, in comparison to the total change, it only accounts for less than 0.05%. This implies that even with the ban in place, most countries maintain some level of exports to China, but with much less volume. Similarly, the changes in unit value come mostly from the intensive margin for both National Sword and OGF. However, the exit margin effect has become relatively larger for waste plastic after National Sword.

Furthermore, we can divide the change in aggregate unit value into pure change in unit value (given import share) and change in share (given unit value). In both events and for both types of waste, the change mostly comes from unit value change, rather than the change in the composition of import products and/or countries. Therefore, we can say that the increase in unit value after National Sword reflects an improvement in the quality of imported waste.

Table 2 shows the quantity and unit value change of the main exporting regions to China. Before 2017, for waste plastic, regions with high export shares were mostly high-income countries, except for low middle-income countries in East Asia and the Pacific region that are close to China. After 2017, all countries experienced a large decrease in import volumes. However, in terms of share, because the high-income countries from Europe, Central Asia, and East Asia and Pacific show a drastic drop, the export share of low- and middle-income countries near China increases. These may also reflect some shipments, which were re-routed from China to other South East Asian nations after the ban.

Table 2. Quantity and unit value change by country group.

Commodity	Country Group	Before 2017			After 2017			Quantity Change (%)	UV Change (%)		
		Quantity (1000 tons)	Share (%)	UV (USD/tons)	Quantity (1000 tons)	Share (%)	UV (USD/tons)		Total Change	Pure UV	Share Change
Waste Plastic (3915)	Europe & Central Asia (HIC)	3,168	32%	333	87	11%	407	−30.7	−15.8	5.3	−21.1
	East Asia & Pacific (HIC)	2,168	22%	371	82	10%	570	−20.8	−5.6	10.1	−15.7
	East Asia & Pacific (LMY)	2,000	20%	477	511	64%	511	−14.8	59.0	10.8	48.1
	North America (HIC)	1,822	18%	358	65	8%	470	−17.5	−4.5	9.3	−13.8
	Latin America & Caribbean (LMY)	415	4%	373	15	2%	512	−4.0	−2.5	−1.5	−1.1
Used Paper (4707)	North America (HIC)	30,011	53%	138	13,704	55%	172	−28.6	14.5	11.1	3.4
	Europe & Central Asia (HIC)	17,360	30%	143	6,201	25%	178	−19.6	−1.6	4.3	−5.9
	East Asia & Pacific (HIC)	8,886	16%	156	4,561	18%	193	−7.6	−1.2	20.0	−21.2
	Latin America & Caribbean (LMY)	671	1%	152	195	1%	215	−0.8	−0.7	−0.6	−0.1
	Middle East & North Africa (HIC)	48	0%	192	155	1%	209	0.2	0.3	−0.0	0.4
	East Asia & Pacific (LMY)	5	0%	151	197	1%	213	0.3	1.0	0.0	1.0

Source: Authors' calculation based on UN Comtrade [7]. HIC and LMY are short for high-income, low-income, and middle-income countries. See Appendix A for further details. Classification by income level follows the World Bank [32].

In terms of unit value change, all regions show an increase in unit value (given the unchanged share). For low- and middle-income countries in East Asia and the Pacific, the total change in unit value was quite high. This was due to a dramatic change in share, even though the unit value change (given unchanged share) is quite like other regions.

For used paper, exporters to China are more concentrated in high-income countries in three regions: North America, Europe, and Central Asia, and East Asia and Pacific. After the ban in 2017, exports from these regions to China dropped drastically in quantity but increased in the unit value. While the share of Europe and Central Asia decreases by five percentage points, the share of North America and East Asia and Pacific increases by two percentage points each. The unit value of Europe and Central Asia increased the least among the three regions. In fact, the import permits of used paper for North America in 2019 cover nearly half of China's total permits, much higher than Japan and Europe. The increase in the unit value can be attributed to an increase in quality. In addition, it is also partly related to a surge in unit value (price) that occurred when buyers were rushing to purchase used papers to utilize the volumes available under their Chinese import permits [33]. As the other regions are low contributors to China's total imports, their contribution to the percentage change in quantity is less than one percent.

4.2. The Trade Diversion Impact of OGF and National Sword

In this section, we examine the change in the total imports of regions other than China. As discussed, China's share of global waste imports declined rapidly after National Sword. The question is, where does that share go? Figure 2 shows the trends in the shares of import volume of different regions as well as the unit value for the two types of waste. The upper panel reveals that the shares of low- and middle-income East Asia and Pacific region, low- and middle-income South Asia, and Europe and Central Asia increased rapidly after 2017. These changes are much more pronounced after National Sword than after OGF, except for South Asia.

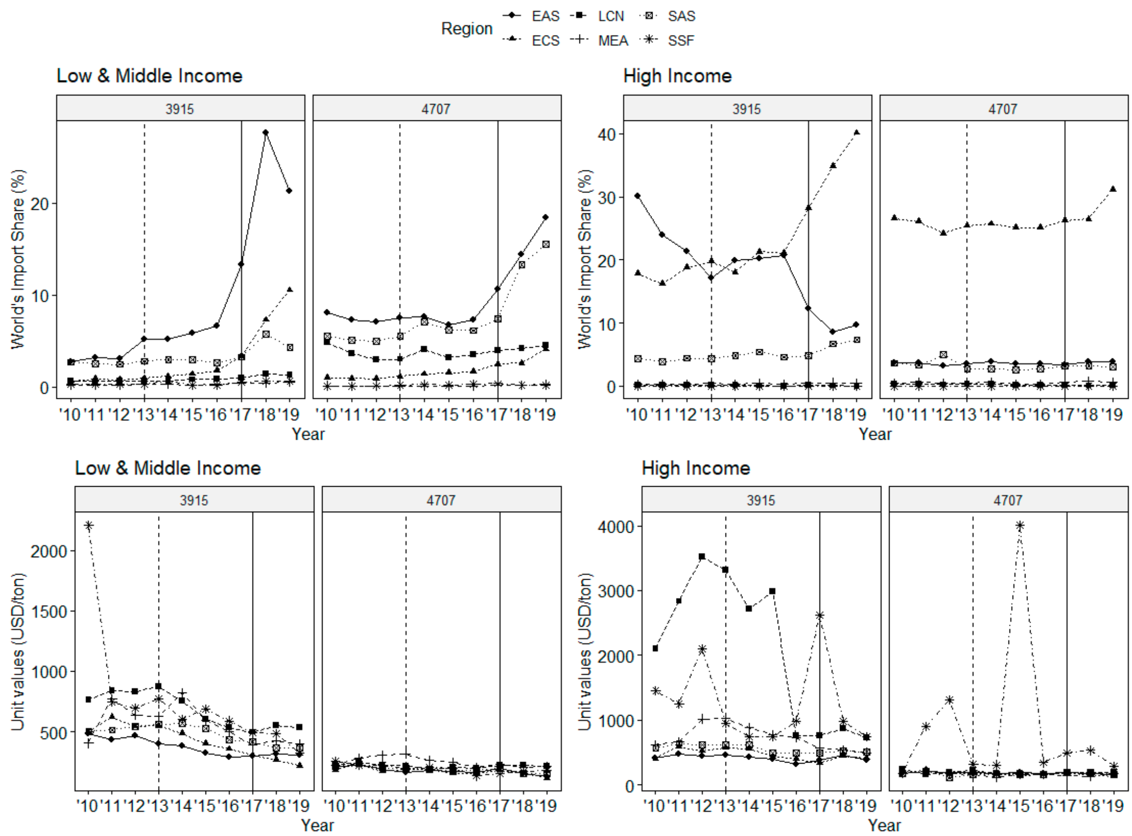

Figure 2. World waste export to regions other than China. Note: EAS: East Asia & Pacific; ECS: Europe & Central Asia; LCN: Latin America & Caribbean; MEA: Middle East & North Africa; SAS: South Asia; SSF: Sub-Saharan Africa. Source: Author's calculation based on UN Comtrade [7].

As shown in Table 3, regions with the highest increase in shares after 2017 are the low- and middle-income East Asian and Pacific regions, and Europe and Central Asia, with changes of 161% and 266% for waste plastic and 101% and 77% for used paper. In addition, South Asia also experienced a significant increase in the import share of used paper after 2017. East Asia and the Pacific region, and South Asia are like China before the ban in terms of less stringent environmental policies and relatively low labor costs. They are also geographically close to China, which makes them an ideal alternative to China for rerouting the waste. However, the total import share of these regions before 2017 was much less than that of China (as in Figure 2). This indicates that they do not have enough recycling capacity to absorb the waste flow diverted from China. Many countries in these regions have an import ban on waste plastic, including India, Thailand, and Vietnam [34].

From Europe and Central Asia, Germany imported 4 million tons of used paper and 523 thousand tons of plastic waste, followed by the Netherlands (3 million tons and 425 thousand tons), Turkey (717 thousand tons and 399 thousand tons), and Poland (406 thousand tons and 207 thousand tons) in 2018. Except for Turkey, these high-income countries are more likely to have better waste management systems and more sophisticated disposal technology. These countries and Japan have passed laws to reduce plastic packaging and develop alternative materials [17]. However, these policies are expected to produce results in the long term rather than in the short term. In fact, many ports were crowded with waste container ships, as they did not meet the criteria of taking permission to unload. Some ships were sent back to the exporting countries despite high fuel and other costs [34].

The lower panel of Figure 2 shows the trend in the unit value for different regions. For waste plastic, both high-income and low-income countries show a declining trend from 2013 (except for the high-income category in 2017). This implies an oversupply in the world waste market due to China's import ban. In terms of magnitude, the unit values of waste, in low- and middle-income and some high-income regions, are not vastly different, except for Latin America and the Caribbean (which include many tax haven countries like the Cayman or the British Virgin Islands with over-reporting of value).

Table 3. Quantity changes in world waste exports to regions other than China.

Commodity	Margin	National Sword (2017)				Operation Green Fence (2013)			
		East Asia & Pacific (LMY)	Europe & Central Asia (LMY)	South Asia (LMY)	Europe & Central Asia (HIC)	East Asia & Pacific (LMY)	Europe & Central Asia (LMY)	South Asia (LMY)	Europe & Central Asia (HIC)
Waste Plastic (3915)	Total	161.4	266.3	20.7	16.5	75.2	57.8	20.5	13.2
	Entry	6.9	30.4	3.0	3.8	5.9	15.5	6.1	2.5
	Exit	−1.0	−1.9	−3.1	−1.1	−4.7	−6.1	−1.9	−2.7
	Intensive	155.5	237.8	20.8	13.8	74.0	48.4	16.2	13.5
Used Paper (4707)	Total	101.4	76.7	104.0	−0.2	−5.6	52.9	23.7	−5.1
	Entry	5.5	8.8	1.1	0.3	1.5	8.9	0.8	0.9
	Exit	−1.4	−1.6	−1.2	−0.4	−2.3	−1.2	−1.1	−0.5
	Intensive	97.3	69.4	104.2	−0.1	−4.8	45.2	24.0	−5.4

Source: Authors' calculation based on UN Comtrade [7].

4.3. Impact on Shipping Logistics

As China participates in the global trade network as the biggest exporter, container services between China and North America, China and Europe, and China and other East Asian countries are the most active. However, trade imbalances between these trading lines have become an issue for the shipping industry [27–29]. In 2019, the container flow from Asia to North America was 17.6 million TEUs, while the opposite flow was only 6.9 million TEUs (authors' calculation from the Port Import/Export Reporting Service data). Similarly, from Asia to Europe, the main haul is 16.7 million TEUs and the backhaul is 8.2 million TEUs (authors' calculation based on Container Trade Statistics [CTS] data). As shown in Table 4, these two routes have the highest imbalances. To cover the cost of the backhaul or return trip, shipping companies utilize empty containers for low-value products, such as waste plastic and used paper [8]. As discussed above, China's import bans significantly reduced the flow of waste products into China, including those from its biggest export destinations, such as North America and Europe. This will result in a lower demand for transporting waste products to China. In comparison to 2017, the backhaul route from North America to the Far East decreased by 6.8% in 2019, while the main haul increased by 0.8%. Backhaul routes from Europe to the Far East increased by 4.2%, which was less than the increase of 5.4% in the main haul. Consequently, imbalances for these two routes increase by 6.4% and 6.5%, respectively. Other backhaul routes from the Far East also experienced a significant increase in imbalances and a decrease in backhaul or an increase in backhaul that is lower than the main haul.

Table 4. Quantity changes in the world waste export to regions other than China.

Routes	Main Haul			Backhaul			Imbalance		
	2017 (mil. TEU)	2019 (mil. TEU)	%Change	2017 (mil. TEU)	2019 (mil. TEU)	%Change	2017 (mil. TEU)	2019 (mil. TEU)	%Change
FE-North America	18.6	18.7	0.8	8.0	7.4	−6.8	10.6	11.3	6.4
FE-Europe	15.8	16.7	5.4	7.8	8.2	4.2	8.0	8.5	6.5
FE-IS and ME	7.5	7.0	−6.4	2.8	2.8	−0.4	4.7	4.2	−10.1
Europe-IS and ME	3.9	4.0	4.3	2.7	2.9	5.2	1.1	1.2	2.3
Europe-North America	4.7	5.1	9.1	2.7	3.0	10.2	1.9	2.1	7.5
North America-South and Central America	2.9	2.9	0.5	2.5	2.5	1.9	0.4	0.4	−7.8
FE-South and Central America	3.6	3.9	6.5	1.8	1.9	8.0	1.8	1.9	5.0
FE-Oceania	2.6	2.6	0.4	1.6	1.6	−1.8	1.0	1.0	3.8
FE-Sub Saharan Africa	2.8	3.2	13.8	1.2	1.3	9.9	1.7	1.9	16.5
Europe-Sub Saharan Africa	2.0	2.2	7.8	0.8	0.8	1.8	1.2	1.3	12.0
Others	7.0	7.5	7.4	4.7	5.1	8.2	2.3	2.4	5.8

Source: Authors' calculation based on CTS. FE is short for the Far East (mostly East Asia and South East Asia). IS and ME are abbreviations for the Indian Sub-Continent and the Middle East and NA for North America. The route name is written in the direction of the main haul.

Another problem that shipping companies face is the uncertainty of China's policy and the risk of being rejected from entering China. In fact, apart from China, other South East Asian countries have also returned tons of waste plastic and wastepaper to the exporting countries. This is the so-called cargo abandonment, which the practitioners often try to avoid [8]. If the cargos were to be abandoned, they would have to pay an extra cost to bring them back and share some of the lost profit from the main haul cargo with the container shipping companies. Furthermore, when port calling is delayed or denied, they may be charged with demurrage cost, fuel cost, and operation cost. Thus, as of 31 August 2020, most of the shipping giants announced the suspension of transportation services for waste plastic and used paper. For example, for the year 2020, COSCO suspended services from 1 September, OOCL suspended services from 16 October, Yang Ming suspended services from 1 September, and HASCO and Wanhai suspended services after October.

Although the import ban affects the supply of waste transportation services to China, it is not likely to affect overall freight because the profit margin from providing backhaul services for low-value products is quite limited, and the revenue is often offset by the fuel cost [8].

The flow of trade and investment for alternative materials will also be affected. In addition, the lack of supply in waste plastic and used paper due to import restrictions will change the form of raw material procurement in China's manufacturing industry. Waste plastic has been used as a material for construction and household goods manufacturing [18]. Recycled paper, among others, has been used to produce packing materials for e-commerce [35]. There has been an increase in the import of plastic raw materials as a substitute for waste plastic in recent years. For example, in the first five months of 2020, the container flow from North America to Asia (mostly China) for polymers of ethylene (HS3901) and polymers of propylene (HS3902) increased by 78% and 81%, respectively, when compared to the previous year. Chinese paper manufacturers have been increasingly moving into the US, Europe, and Southeast Asia because of the shortages in raw materials. This movement has two potential impacts. First, it is good for the environment to establish a system to process recyclable waste in countries where waste is generated. Second, there will be less movement of goods from the United States and Europe. Thus, a ban on importing waste plastics and used paper would lead to a change in logistics in China.

5. Conclusions

In this paper, we reviewed the literature on the impact of China's import ban on waste plastic and used paper. The two direct impacts are the effect on China's import volume and unit value, and the trade diversion to other countries. China's import ban in 2017 has decreased the country's import of waste plastic by 92% and used paper by 56%. It also increased the unit value of the two types of waste by 27% and 13%, indicating an improvement in the quality of imported waste. Most of these impacts come from the intensive margins. We also showed the contribution of different regions to the change in China's imports. In line with the theory of waste trade flow, prior to the bans, high-income countries accounted for a lion's share of China's imports and experienced the highest drop in quantity after the bans. Imports from these countries also increased in the unit value. The flow of waste shifted from China to other countries, depending on the stringency of environmental regulations, types of waste, and geographical factors. The most affected region is the low-income East Asian and Pacific regions, which are close to China and often have lax regulations. These countries, however, have started to impose stricter regulations on their own. Some waste from Europe is flowing into high-income countries, such as Germany and the Netherlands. Even though these countries have strict regulations, they also have good waste management systems, so they can partly absorb diverted waste.

We compared the impact of OGF and National Sword and showed that the magnitude of the latter's impact was much higher and may last longer. China's restriction on waste imports is an ongoing program, and the Chinese government has expressed its commitment toward "Zero Waste" in its recent law revisions. Thus, we expect to see more products added to the ban list, which will have a greater impact on the international waste trade and shipping industry.

We summarize the effects on shipping logistics and suggest that, while the supply of backhaul services might be halted, it is not likely to affect the overall freight market. However, shipping companies may have to find diverse ways to address the backhaul problem. Some practices have been proposed, such as optimizing container logistics by unloading or loading in warehouses or distribution centers in the immediate hinterland of the relevant port [27] or containerizing bulk cargo [8] to improve demand and supply balances. These are ongoing efforts, and their effects would be an interesting subject for future research.

While the impact on trade and container shipping may seem negative in the short term, we expect a positive impact in the long run. Many countries have imposed stricter environmental regulations, and companies have moved toward greener production technology. Consumers have also been increasingly aware of their carbon footprints. Therefore, we expect a change in the global trade network that moves toward cleaner products, thereby creating more trade in the long run.

This study has some limitations. In our study, we have not used empirical methods, such as difference-in-difference or synthetic control methods, due to resource constraints. Thus, our results are mostly descriptive. We hope to resolve this limitation in our future research.

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Appendix A

Table A1. List of countries.

	High Income	Low & Middle Income
East Asia & Pacific	Australia, Brunei Darussalam, French Polynesia, Japan, Korea Rep., New Caledonia, New Zealand, Singapore	Cambodia, Fiji, Indonesia, Lao PDR, Malaysia, Mongolia, Myanmar, Papua New Guinea, Philippines, Solomon Islands, Thailand, Vietnam
Europe & Central Asia	Austria, Belgium, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom	Albania, Belarus, Bulgaria, Russian Federation, Serbia, Turkey, Ukraine
Latin America & Caribbean	Antigua and Barbuda, The Bahamas, Barbados, Chile, Panama, Trinidad and Tobago, Uruguay	Argentina, Belize, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominica, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Paraguay, Peru, St. Lucia, St. Vincent & the Grenadines, Suriname, Venezuela RB
Middle East & North Africa	Bahrain, Israel, Kuwait, Malta, Oman, Qatar, Saudi Arabia, United Arab Emirates	Algeria, Djibouti, Egypt Arab Rep., Iran Islamic Rep., Jordan, Lebanon, Morocco, Syrian Arab Republic, Tunisia, Yemen Rep.
North America	Canada, United States	
Sub-Saharan Africa	Mauritius	Cabo Verde, Cameroon, Congo Rep., Cote d'Ivoire, Ethiopia, Ghana, Kenya, Mali, Mauritania, Mozambique, Namibia, Nigeria, Senegal, Sierra Leone, South Africa, Sudan, Tanzania, Uganda, Zambia, Zimbabwe
South Asia		Afghanistan, Bangladesh, India, Nepal, Pakistan, Sri Lanka

Source: World Bank [32].

Appendix B

This appendix shows the detailed calculation of the entry, exit, and intensive margin for the change in the average unit value. The change in average price is defined as follows:

$$P^a - P^b = \sum_{ik \in \Omega^a} p^a_{ik} s^a_{ik} - \sum_{ik \in \Omega^b} p^b_{ik} s^b_{ik}$$

$$s^t_{ik} = \frac{q^t_{ik}}{\sum_{ik \in \Omega^t} q^t_{ik}} \quad where\ t\ \in \{a, b\}$$

Divide the set of countries and products before and after the event into three categories: entry $(\Omega^a \setminus \Omega^b)$, exit $(\Omega^b \setminus \Omega^a)$ and intensive $(\Omega^a \cap \Omega^b)$, we can rewrite the change as follows:

$$P^a - P^b = \sum_{ik \in \Omega^a \setminus \Omega^b} p^a_{ik} s^a_{ik} + \sum_{ik \in \Omega^a \cap \Omega^b} p^a_{ik} s^a_{ik} - \sum_{ik \in \Omega^b \setminus \Omega^a} p^b_{ik} s^b_{ik} - \sum_{ik \in \Omega^a \cap \Omega^b} p^b_{ik} s^b_{ik}$$

Add and deduct $\sum_{ik\in\Omega^a\cap\Omega^b} p^a_{ik}s^b_{ik}$ to the above equation and rearrange:

$$P^a - P^b = \underbrace{\sum_{ik\in\Omega^a\setminus\Omega^b} p^a_{ik}s^a_{ik}}_{Entry} - \underbrace{\sum_{ik\in\Omega^b\setminus\Omega^a} p^b_{ik}s^b_{ik}}_{Exit} + \underbrace{\sum_{ik\in\Omega^a\cap\Omega^b} p^a_{ik}s^b_{ik} - \sum_{ik\in\Omega^a\cap\Omega^b} p^b_{ik}s^b_{ik} + \sum_{ik\in\Omega^a\cap\Omega^b} p^a_{ik}s^a_{ik} - \sum_{ik\in\Omega^a\cap\Omega^b} p^a_{ik}s^b_{ik}}_{Intensive}$$

$$= \overbrace{\sum_{ik\in\Omega^a\setminus\Omega^b} p^a_{ik}s^a_{ik}} - \overbrace{\sum_{ik\in\Omega^b\setminus\Omega^a} p^b_{ik}s^b_{ik}} + \overbrace{\underbrace{\sum_{ik\in\Omega^a\cap\Omega^b} \left(p^a_{ik} - p^b_{ik}\right)s^b_{ik}}_{UV\ Change} + \underbrace{\sum_{ik\in\Omega^a\cap\Omega^b} (s^a_{ik} - s^b_{ik})p^a_{ik}}_{Share\ Change}}$$

Divide both sides by P^b to get the percentage change.

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Do Foldable Containers Enhance Efficient Empty Container Repositioning under Demand Fluctuation?—Case of the Pacific Region

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Abstract: This study considers the empty container repositioning problem of shipping companies that use standard and 3-in-1 foldable containers with more advanced designs. A mathematical model is developed to compare the total management costs of container repositioning of various patterns in different cargo shipping demand scenarios. Numerous scenario analyses and simulations of empty container repositioning were conducted, focusing on a liner shipping service in the Pacific Islands where empty containers are likely to be present because of the imbalance between inbound and outbound flows of containers, including static analysis and consecutive analysis with demand fluctuation in different approaches. Results show that with the introduction of foldable containers, depending on the growth rate of container cargo shipping demand, the total management costs of empty container repositioning can be reduced. However, introducing a large number of foldable containers may increase the total management costs of container repositioning. Moreover, the cost reduction effect of adding another containership increases in cases where future cargo shipping demand increases substantially. Furthermore, the introduction of foldable containers not only effectively reduces the management costs of empty containers, but also makes costs more stable and predictable.

Keywords: maritime container shipping; empty container repositioning; foldable containers; Pacific Islands; static analysis; consecutive analysis; demand fluctuation

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1. Introduction

In recent years, rapid economic growth and globalization have led to a substantial increase in container cargo shipping demand and growing trade imbalances between imports and exports among different regions, resulting in an imbalance between the inbound and outbound flows of full containers. Therefore, repositioning a large number of empty containers from the surplus to deficit areas is necessary. If the repositioned empty containers cannot temporally meet the required number at the ports in the deficit area, the leased containers would be offset by the shortage. However, the remaining empty containers that cannot be repositioned should be stored in the surplus area. The cost burden of remedying the excess or deficiency of empty containers has become a major pressure on container shipping companies, and it may affect the stable supply of container shipping services; therefore, repositioning empty containers has become an important issue in the management of shipping services [1].

One of the difficulties of repositioning empty containers is that they require the same spaces for transport and storage as full containers. To alleviate this problem, introducing foldable containers is a possible solution. Figure 1 shows the folding process of a foldable container. Less space is required if an empty container is folded, leading to multiple foldable containers being folded into the equivalent dimensions of a standard container. Therefore, containerships and the storage space can be used more efficiently, resulting in reduced transport costs, storage costs, and handling times of containers. In some cases, empty containers that cannot be repositioned may be sold or discarded in the surplus area, and new ones purchased in the deficit area. If foldable containers are introduced, more containers can be reused, reducing resource wastage. Moreover, this contributes to the reduction of road traffic volume, port congestion, and carbon emissions. Therefore, introducing foldable containers can contribute to increasing sustainability.

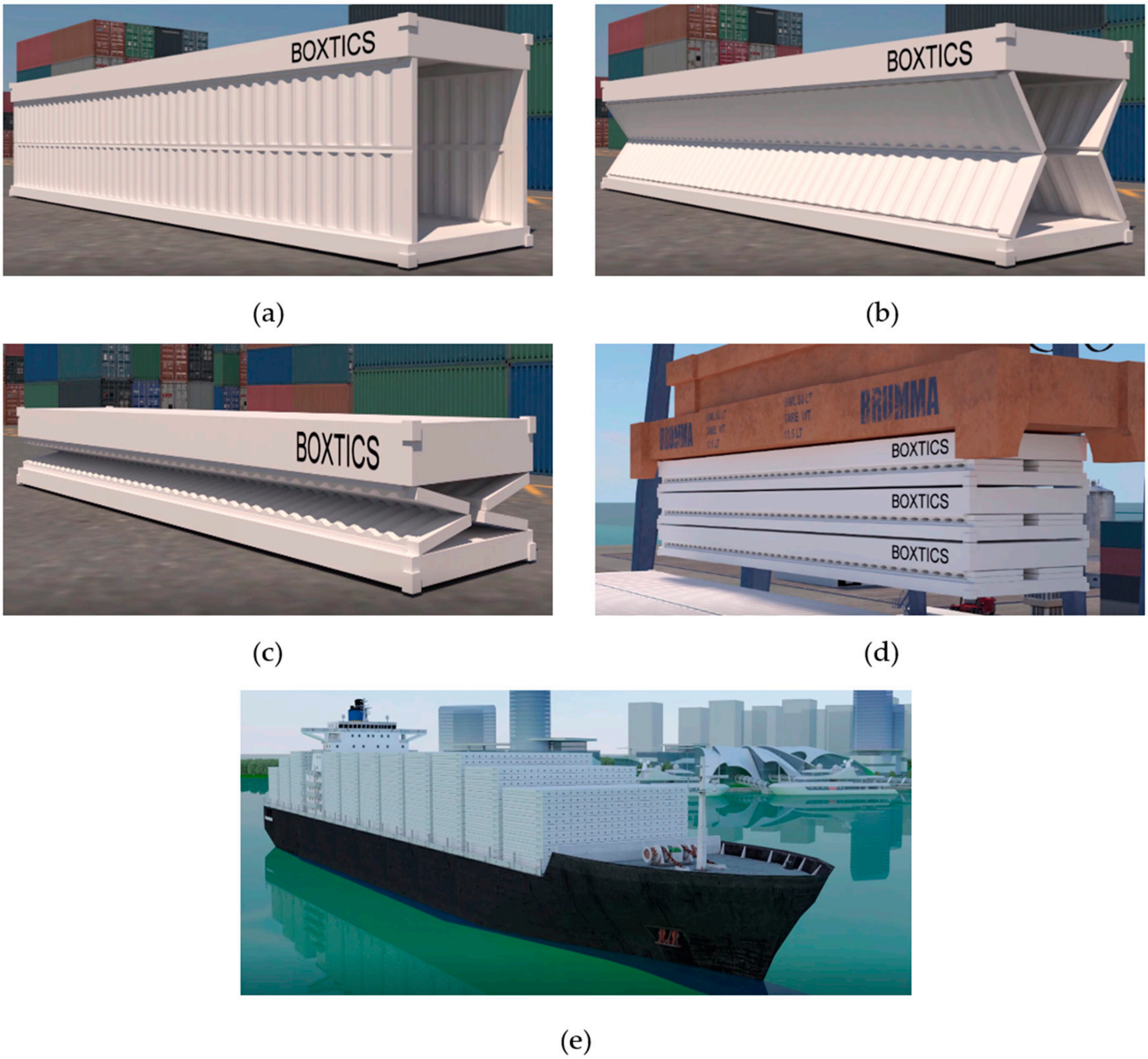

Figure 1. Folding, bundling, and stacking process of the foldable container. (**a**) Original state of the container, (**b**) beginning of folding process, (**c**) end of folding process, (**d**) bundling process, (**e**) stacked on containers ship. Source: Boxtics Inc. [2].

However, foldable containers have not yet been put into practical use, although their concept has already been established, because their merits have not yet been fully revealed. Designs of foldable containers, which affect the additional costs, including the costs of the folding and unfolding processes, manufacturing, maintenance, and repair, are key to their use [3]. A Japanese company has designed a 3-in-1 foldable container that can be folded and unfolded with just one button, which can save the cost and time of folding and unfolding, enabling the containers to be more economical and practical [2].

By comparing the management costs of empty container repositioning between cases where only standard containers are used, and where only the 3-in-1 foldable containers are introduced, this study aims to determine the situations wherein foldable containers can be advantageous in empty container repositioning from an economic perspective. To solve this problem, we formulated an empty container repositioning problem concerning the transport of full containers, focused on a liner shipping service in the Pacific island countries (PICs). This implied that the introduction of foldable containers may reduce the total management cost of container repositioning in some situations by static and consecutive analysis, depending on the current fluctuations and future growth rates of cargo shipping demand. The volume of containerized cargo generated at a port varies according to the shipping market conditions and seasons [4]. Therefore, considering such changeable demands and analyzing various possible scenarios are necessary.

We focused on PICs because empty containers are likely to occur here, since the volume of import of full containers is much greater than that of export containers, as shown in Table 1. Because PICs have few domestic industries aside from agriculture and fishery, they rely heavily on imports to meet the demand for basic goods, which are primarily transported through maritime shipping, including food, fuel, medicine, and productive resources such as commercial machinery and appliances. In contrast, exports from PICs are typically lower in value and consist of a limited range of goods, often resulting in heavy imbalances in trade [5]. Therefore, the imports far outweigh the exports in most PICs. In some cases, this imbalance is extreme, such as in Wallis and Futuna, where the full container rate of imports to exports is approximately 30:1. More typically, the rate is in the range of 2:1 to 20:1. Therefore, the effect of introducing foldable containers to remedy the excess or deficiency of empty containers in PICs is expected.

The Pacific region consists of numerous islands dispersed across the southwest Pacific Ocean that are sometimes called “sea-locked countries” [6]. The region has suffered from high costs of participating in international trade, due to its remoteness from the world’s major markets. The dispersed nature of the region also leads to expensive transport costs, especially when connecting smaller remote islands. Empty containers are not only an issue in terms of transport efficiency, but also seriously undermine the profitability of the liner shipping companies (LSCs) operating in PICs. LSCs often receive subsidies from Pacific island governments to maintain their operations in the region.

The remainder of this paper is organized as follows. Section 2 reviews the relevant literature. Specific factors for repositioning empty containers when considering foldable containers are analyzed in Section 3. Section 4 presents a description and formulation of the problem that needs to be solved. Section 5 introduces some static analyses, considering both cargo shipping demand with smaller increasing rates and higher ones. Consecutive analyses with two different approaches to demand fluctuation are also analyzed in Section 6. Finally, Section 7 concludes this study and discusses future research directions.

Table 1. Annual volumes of export and import full containers at PIC ports (as of 2018). Source: compiled by the authors, based on GTA forecasting.

Port	Export and Import Full Containers (TEU/year)		
	Total	Export	Import
Apra (Guam)	4391	704	3687
Saipan Island (Northern Mariana Islands)	2422	137	2285
Koror (Palau)	3928	281	3647
Pohnpei (Micronesia)	11,491	7243	4248
Majuro (Marshall Islands)	26,246	10,962	15,284
Betio (Kiribati)	11,116	7650	3466
Port Funafuti (Tuvalu)	7873	1404	6469
Nauru (Nauru)	5603	517	5086
Futuna (Wallis & Futuna)	1217	40	1177
Lae (PNG)	111,666	39,382	72,284
Madang (PNG)	8486	3337	5149
Port Moresby (PNG)	48,162	8566	39,596
Rabaul (PNG)	13,520	4783	8737
Honiara (Solomon Islands)	60,411	50,916	9495
Noro (Solomon Islands)	10,069	8486	1583
Port Vila (Vanuatu)	11,239	3802	7437
Santo (Vanuatu)	4879	1167	3712
Lautoka (Fiji)	41,358	21,592	19,766
Suva (Fiji)	13,4178	43,183	90,995
Noumea (New Caledonia)	57,594	22,759	34,835
Apia (Samoa)	14,786	2059	12,727
Pago Pago (American Samoa)	5681	1196	4485
Nukualofa (Tonga)	7851	927	6924
Alofi (Niue)	1033	145	888
Rarotonga (Cook Islands)	4355	553	3802
Papeete (French Polynesia)	30,220	1436	28,784
PIC Ports Total	645,071	248,523	396,548

2. Literature Review

Several studies have explored the potential benefits of foldable containers in container repositioning. Konings [7] analyzed the economic and logistical viability of introducing foldable containers through a cost–benefit analysis, showing that the use of foldable containers could lead to substantial net benefits in the total chain of container transport. However, he also pointed out the additional costs of introducing foldable containers. Shintani et al. [3] modeled the entire empty container flow as an integer programming problem with different strategies in an empty container flow itinerary, and discovered the possibility of saving container fleet management costs by repositioning empty containers through the use of foldable containers. Shintani et al. [8] also proposed an integer programming model to determine which among the three container fleet configurations (i.e., foldable containers only, standard containers only, or a mix of foldable containers and standard containers) would minimize the shipping company's container management costs, and they revealed that a mix of foldable containers and standard containers would provide the best solution. Moon et al. [9] compared the repositioning costs of foldable containers to those of standard containers, using mathematical models with heuristic algorithms to minimize the total relevant cost, including the folding/unfolding, inventory storage, container purchasing, and repositioning costs. Sensitivity analysis revealed that a decrease in the production cost of foldable containers and an increase in transportation costs play a key role in the use of foldable containers. Myung and Moon [10] addressed a multi-port and multi-period container planning problem for shipping companies considering both standard and foldable containers, using a network flow model which optimally allocated both foldable and standard containers to minimize the total purchasing, repositioning, and storage costs. They also pointed out the necessity of determining the rate of foldable containers within a defined period. Bandara et al. [11] demonstrated, through a simulation for the port of Melbourne, that using foldable containers would reduce the total number of containers handled in the port, and then generate numerous benefits, such as reductions in capacity constraints at loading and storage centers, and a reduction in port infrastructure expansion costs. Therefore, foldable containers can contribute to the sustainability of the shipping industry. Moon and Hong [12] developed a mathematical model for repositioning both standard and foldable empty containers, which minimizes the total costs for transportation, inventory holding, handling, folding/unfolding, container leasing, and installing facilities that accommodate foldable containers. Linear programming-based and hybrid genetic algorithms have been used to obtain satisfactory solutions for these problems. Wang et al. [13] addressed the problem of ship-type decisions concerning empty container repositioning and foldable containers, which determines the capacity of ships deployed in a trans-Pacific shipping service route at a tactical level, and empty container repositioning between ports at an operational level. Optimal decisions of ship type can help the effective use of the vessel capacity, and thus promote the sustainability of the shipping industry. Zhang et al. [14] developed a mixed-integer linear programming model to determine the optimal empty container repositioning with foldable containers on the intermodal transportation network related to China's Belt and Road Initiative. Goh [15] investigated foldable containers from the shipper and sustainability perspectives. In particular, the viability of foldable containers as an instrument of carbon offsetting for the shipping industry was explored. Zhang et al. [16] investigated the potential of foldable containers to improve empty container repositioning in river–sea intermodal transport along the Yangtze River in China, taking into consideration bridge height and water depth constraints. Their results showed that introducing foldable containers into empty container repositioning along a river could encourage companies to use vessel space more effectively and decrease the total cost for shipping companies, ensuring their sustainability. Moreover, earlier research [11,15,17,18] demonstrated that foldable containers could help in reducing the carbon footprint of the shipping industry because the number of shipments could be reduced by folding and bundling the empty containers, which is an increasingly important global sustainability issue.

These studies considered certain factors related to foldable containers in empty container repositioning and revealed the economic and environmental benefits of foldable containers. However, none of them considered conducting consecutive analyses to compare the management costs of empty container repositioning when using only standard containers and introducing foldable containers under demand fluctuation. Lee and Moon [19] proposed a robust formulation that requires only limited information about the distribution of demand to replicate real-world situations for the empty container repositioning problem between North America and Asia, considering foldable containers under demand uncertainty. Even in the context of studies on empty container repositioning management without foldable containers being introduced, only a few studies considered the problem under demand fluctuation, as summarized in Kuzmicz and Pesch [20]. Lam et al. [21] demonstrated the application of a dynamic stochastic model for repositioning empty containers. They used the contracting value iteration algorithm to obtain the exact optimal average cost solution. Song and Zhang [22] applied a fluid flow model to determine the optimal empty container repositioning policy in a single-port system, with stochastic demand modeled using a two-state Markov process. They characterized the underlying dynamics and followed the dynamic programming approach to obtain a closed-form solution to the optimal control problem. Song and Dong [23] considered both fleet sizing and empty container repositioning under uncertain demand on a liner shipping system with a trans-Atlantic service. They considered three types of distributions (i.e., exponential, uniform, and normal distributions) for daily demands. Zhang et al. [24] considered repositioning empty containers between multiple ports over multiple periods with stochastic demand and lost sales. Numerical examples were provided to illustrate the solution procedures, based on normal and uniform distributions. Dong and Song [25] considered the joint container fleet sizing and the repositioning problem of empty containers in multi-vessel, multi-port, and multi-voyage shipping systems with dynamic, uncertain, and imbalanced customer demands, and they applied them to a trans-Pacific shipping service and a Europe–Asia shipping service. They also compared the total costs for uniform distributions and normal distributions of customer demands under three policies: non-repositioning, heuristics repositioning, and evolutionary algorithm-based policies. In general, these studies represented the uncertainty of customer demand by probability distributions, including uniform, normal, and exponential distributions, and dynamic programming methodologies were used to obtain optimal cost solutions under different scenarios.

Table 2 summarizes the characteristics of the above studies. As shown in the table, to the best of our knowledge, no studies have considered the impact of introducing foldable containers under demand fluctuation, except for Lee and Moon [19]. However, they did not consider various patterns of demand fluctuation, which are essential to consider in order to reflect the real maritime container shipping market and were considered in certain studies on empty container repositioning without foldable containers being introduced. This study aims to fill this research gap. Moreover, in contrast to Lee and Moon [19], this study considers: (1) the proportion of foldable containers introduced to the container repositioning system, which would significantly affect the total management costs of empty container repositioning; and (2) the cost reduction effect of adding another containership to reposition empty containers, considering the significant increase in future cargo shipping demand. Furthermore, this study focuses on the Pacific region as an application of the empty container repositioning problem, in which a significant imbalance between inbound and outbound flows of containers and the low frequency of liner services have been observed, but no studies on empty container repositioning have been conducted.

Table 2. Summary of relevant studies. Source: compiled by the authors.

Papers	Foldable Container	Demand Uncertainty	Focusing on Specific Region/Shipping Service	Considering Various Patterns of Demand Fluctuation
Research on foldable containers				
Konings [7]	√			
Shintani et al. [8]	√			
Moon et al. [9]	√			
Myung and Moon [10]	√			
Bandara et al. [11]	√		Melbourne port (Australia)	
Moon and Hong [12]	√			
Wang et al. [13]	√		Trans-Pacific shipping service	
Zhang et al. [14]	√			
Goh [15]	√			
Zhang et al. [16]	√		Yangtze River (China)	
Lam and Gu [17]	√			
Hjortnaes et al. [18]	√			
Lee and Moon [19]	√	√	North America–Asia	
Research on empty container repositioning with demand uncertainty				
Lam et al. [21]		√		
Song and Zhang [22]		√		
Song and Dong [23]		√	Trans-Atlantic shipping service	
Zhang et al. [24]		√		
Dong and Song [25]		√	Trans-Pacific and Europe–Asia shipping service	
This study	√	√	PICs	√

3. Factors of Repositioning Empty Containers Considering Foldable Containers

Based on the literature review, five factors that should be considered when analyzing the problem of maritime empty container repositioning with foldable containers are summarized in Figure 2. These comprise waiting time, empty container storage, vessel constraints, empty container flow, and container maintenance and repair.

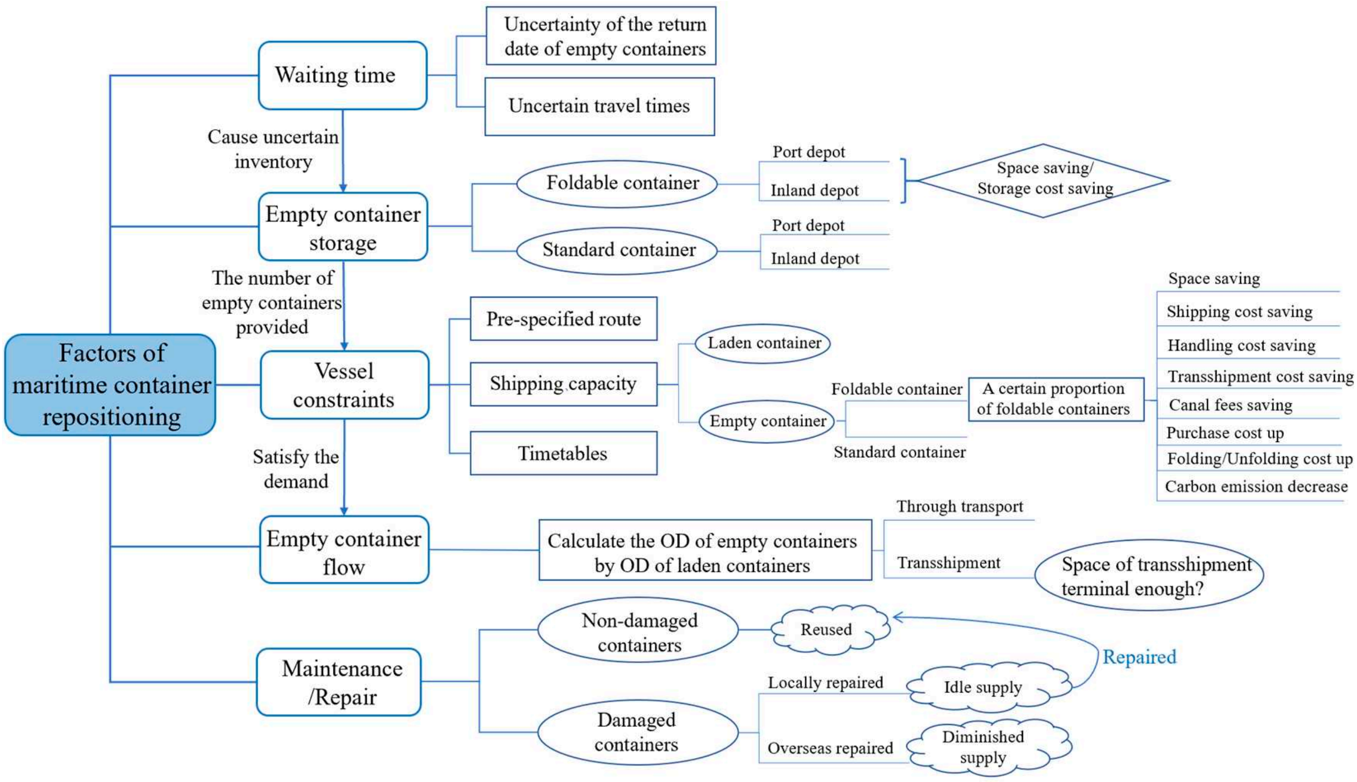

Figure 2. Factors of repositioning empty containers considering foldable containers. Source: compiled by the authors.

Empty containers generated in a particular region are stored in inland depots or returned to the ports, where they wait for a future cargo shipping demand, and a portion of these containers would be relocated to other ports to meet the demand for empty containers in other regions [26]. Compared with standard containers, more foldable containers can be stored in the same space if they are folded and bundled, thereby reducing the storage cost per unit. Uncertainty is a fundamental factor that impacts empty container repositioning, which may be caused by customer demands and container processing activities, such as consolidation, movement, handling, discharge, maintenance, and repair [27]. Owing to the uncertainty of the return date of empty containers and uncertain travel times due to adverse weather, there would be a corresponding uncertainty in the empty container inventory [28]. If a proportion of the empty containers in a certain period cannot be returned to the port in time, it would lead to a reduction of containers that can be repositioned in that period, resulting in unmet demand for the containers at some ports. Therefore, leased containers must be used, which incurs further fees [12]. In addition, uncertainties associated with fuel consumption, variation in vessel speed, fluctuating bunker fuel, and disruption (weather-related adversities or port closure) to container cargo shipping demand may affect the repositioning of empty containers [29,30]. Moreover, empty containers that cannot be repositioned will accumulate in the next period, resulting in a large number of empty containers to be repositioned. Containers must be carried by vessels, and their movements are subject to various constraints, such as the vessels' pre-specified routes, frequency, timetables, and carrying capacities. Empty container repositioning is further constrained by dynamic customer demands and vessels' spare capacities, because the shipping demand of these empty containers is determined to be similar to that of full containers that are prioritized for shipping [25]. Therefore, if the remaining space in the containership cannot afford the repositioning of all empty containers, the remaining empty containers would incur significant storage costs.

Foldable containers would deliver benefits if they can be bundled and transported together. As foldable containers in an empty state can be folded and bundled together to be stored in a specific place and repositioned as a single standard container, they will take up less space. Therefore, introducing foldable containers can reduce the risk of leaving a large number of empty containers that cannot be repositioned owing to demand fluctuations. Moreover, using less storage and shipping space can reduce storage and transport costs per unit. Cost savings can also be realized in transshipment costs if folded containers can be bundled, interlocked, and transshipped in one shipment [7,8]. However, if only repositioning containers is considered by a single liner service, the total maritime transport cost is fixed regardless of whether standard containers or foldable containers are used, and no transshipment costs are incurred. Furthermore, foldable containers can reduce the canal fees, which are determined by the height of the containers stacked on the deck of the ship [14]. However, transporting more containers also implies a higher load draft, which may not satisfy the corresponding limitation for some fairways. Hence, there is a tradeoff between the height above the water and draft when using foldable containers [16]. The impact of foldable containers would also extend to the environment, and studies have suggested that foldable containers could help in reducing the carbon footprint of the shipping industry [11,15,17,18].

However, the disadvantages of foldable containers cannot be ignored. The exploitation/purchase cost is one of the barriers to using foldable containers, and additional costs are incurred when folding, unfolding, and handling foldable containers [20]. Moreover, the exploitation costs will be increased by higher maintenance and repair requirements. As the exploitation/purchase costs for foldable containers are much higher than those for standard containers, a mixed container fleet comprising both container types might be a viable option [7,8]. Such fixed costs in introducing foldable containers make it difficult to adjust the proportion of foldable containers depending on the situation; hence, the number (or rate) of foldable containers must be fixed in advance. Considering the significant increase in future cargo shipping demand, a large number of foldable containers needs to be introduced, which may lead to high costs. In this situation, the management costs of empty container repositioning may become cheaper by introducing another containership to increase service frequency, instead of introducing foldable containers.

In this study, because we aim to analyze the effect of introducing foldable containers for repositioning empty containers from an economic perspective, only four types of management costs are included in the analysis of the total management costs, for comparing with the scenario of using only standard containers; namely, storage costs for the safety stock of empty containers, the additional storage costs of empty containers that cannot be repositioned in time, purchase costs of foldable containers, and the costs of leasing containers to cover the shortage of empty containers at the ports with demand. Note that the voyage cost is not considered in this study, because in the case of repositioning empty containers by a single liner service, the total voyage cost is fixed regardless of whether foldable containers are used or not, and no transshipment costs are incurred. The terminal handling charge is also not included in this study, because we assume that the handling charge of foldable containers is the same as that of standard containers.

4. Problem Description and Formulation

4.1. Framework of the Problem

This study focused on a monthly liner shipping service in the PICs (see Figure 3) and calculated the deficit or surplus of empty containers in ports, including Busan in South Korea, and Rabaul, Lae, and Port Moresby in Papua New Guinea, based on the number of containers loaded and discharged at each port in each period. There is a large demand for empty containers in Busan because it exports a large amount of containerized cargo. On the other hand, although there are containerized cargo export ports in the PICs, in the aggregate, containerized cargo is mainly imported, which implies that there is a surplus of empty containers in these ports. Further, the service frequency is low in these regions because of the low cargo shipping demand, resulting in a longer empty container repositioning period. The introduction of foldable containers can be expected to remedy the excess or deficiency of empty containers, as shipping companies are forced to reposition a large number of empty containers to ports of call to remedy the shortage.

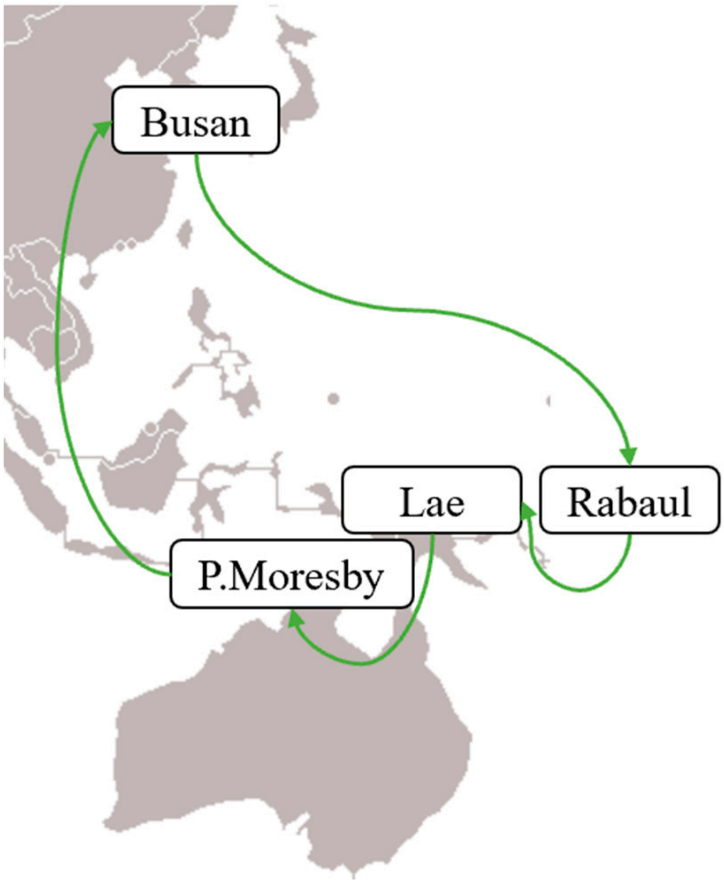

Figure 3. Papua New Guinea/Australia Service provided by Kyowa Shipping. Source: compiled by the authors, based on the Kyowa Shipping Co.

As mentioned in the previous sections, the shipping demand of containerized cargo generated at a port varies according to the shipping market conditions and seasons. Therefore, considering such demand fluctuations and analyzing various possible scenarios, including current and future demands, are necessary. Moreover, if container cargo shipping demand increases in the PICs, the frequency of the liner service will be doubled by introducing another containership, resulting in cheaper management costs for empty container repositioning.

To reflect these characteristics, simulation of the empty container repositioning problem in the PICs would be conducted in two steps ("static analysis" and "consecutive analyses") to compare the total management costs of container repositioning of various patterns in different cargo shipping demand scenarios. In the static analysis, we would focus on one shipping period (i.e., for two months) and assume that container shipping demand is unchanged for each month, which corresponds to the average monthly shipping volume. In the consecutive analysis, a full year of cargo shipping demand is considered. As mentioned above, cargo shipping demand fluctuates depending on the season. Therefore, we assume that cargo shipping demand fluctuates per month, the sum of which is equal to the annual shipping volume. In this study, we assumed two different patterns of demand fluctuation. The first pattern is that the cargo shipping demand of each month fluctuates randomly, and the second is that it fluctuates in a biased manner.

This study compares the management costs of empty containers at different rates of introducing foldable containers. We also compare the cost of introducing another containership to increase service frequency, in cases where future cargo shipping demand would increase substantially. The other fundamental assumptions in the model calculation are as follows:

(1) The shipping volume of the full and empty containers cannot exceed the maximum capacity of the containership.
(2) If there is a shortage of empty containers at the port, leased containers are used for the shortage.
(3) If there are empty containers that cannot be repositioned, the storage fee is charged.
(4) Foldable containers were introduced in advance by a certain proportion.
(5) If foldable containers are introduced, the same number of standard containers is sold.
(6) Unused foldable containers are folded and stored at the port.
(7) The additional containership is used only if there are extra containers that cannot be shipped. Furthermore, even if another containership is introduced to increase service frequency, the annual container cargo shipping demand will not change.
(8) In the PIC maritime container shipping market, the basic transport cycle of containers is two months (a round trip on board of one month, and vanning/devanning and returning to the port of one month).

4.2. Container Flow Estimation

To analyze the empty container flow, the actual shipping volume of full containers for each liner service is necessary, but such data are generally not available for neutral researchers. Therefore, the annual volume of containerized cargo transported between each port for each liner service is calculated using the global maritime container shipping network simulation (GMCSNS) model, as shown in Riku et al. [6].

The GMCSNS model is a model in which the shipping route of each container is determined by the global interregional maritime container cargo shipping demand (OD volume) and maritime network factors, such as service frequency and vessel capacity [31,32]. Congestion would also occur if the capacity of the containership approached the upper limit. In the GMCSNS model, the liner shipping services operated by each container shipping company are treated as a separate network, as shown on the right side of Figure 4. In this study, the number of empty containers that are generated or in demand is assumed to be the difference between the volume of loading and discharging cargo (discharging volume–loading volume) generated at a port in the previous period. In principle, the shipping company meets the demand for empty containers with those that are transported using the extra spaces on board. The outputs of the GMCSNS model are on an annual basis, so in this study, we converted them to a monthly basis. Figure 5 shows an empty container repositioning plan (on average), where the black arrows represent the full container flow, and the blue arrows represent the empty container flow.

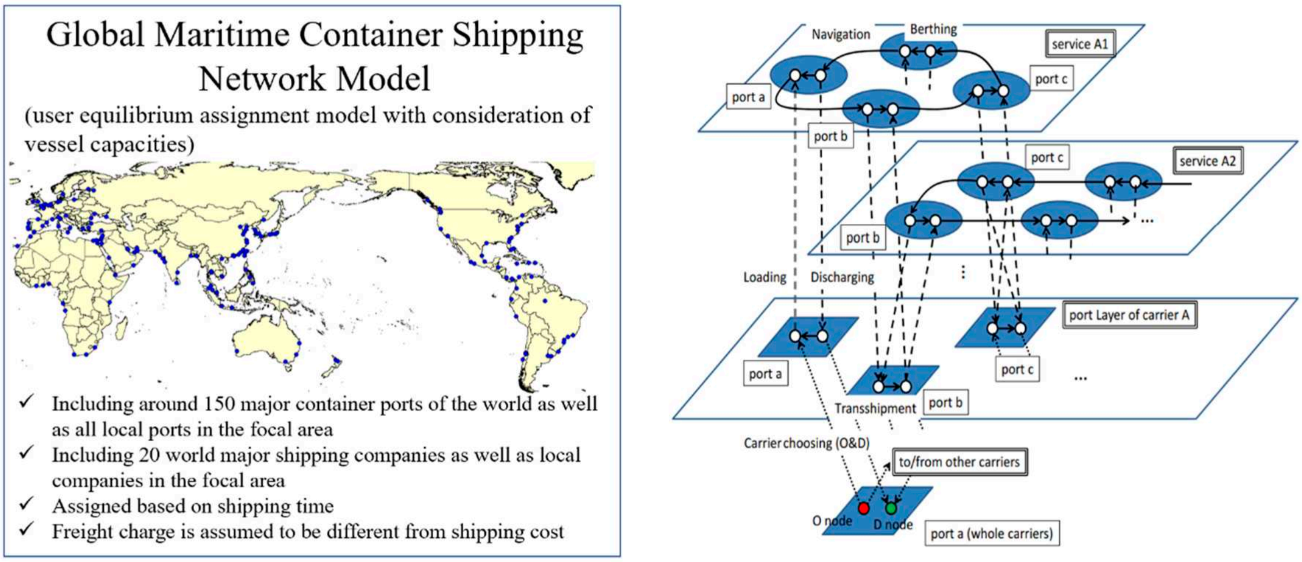

Figure 4. Network structure of the maritime container shipping network model. Source: Shibasaki [31].

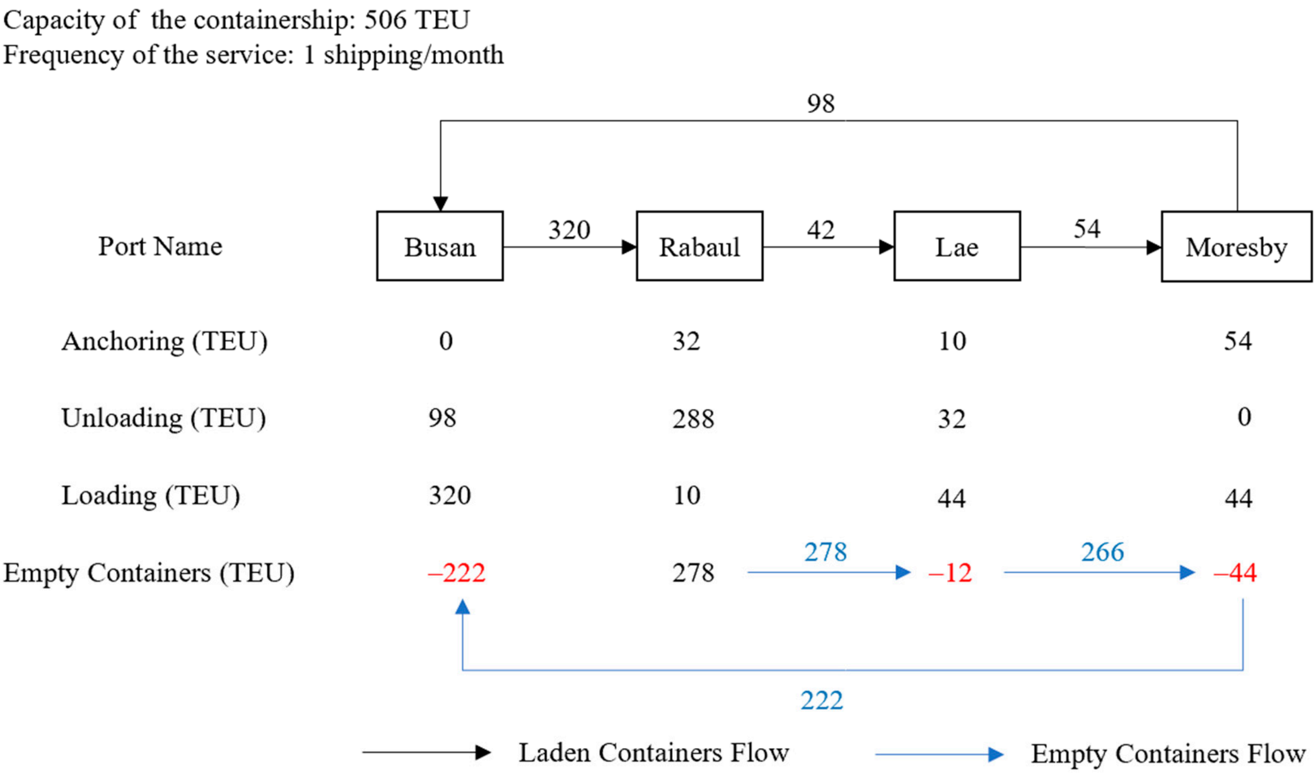

Figure 5. Empty container repositioning plan. Source: compiled by the authors.

4.3. Formulations

4.3.1. Volume of Empty Containers

Repositioning empty containers from the surplus to deficit areas is necessary to ensure the balance between the inbound and outbound flows of full containers. In other words, the shipping demand of empty containers depends on the shipping pattern of full containers [1]. Some empty containers generated two months ago may not have been repositioned in the previous month. Therefore, the empty container repositioning demand of this month is the sum of the empty containers generated in the previous month and the surplus of empty containers in the previous month. The volume of empty containers in this month is expressed by the following equation:

$$R_t = E_{t-1} + \gamma \cdot E_{t-2}, \tag{1}$$

where R_t is the empty container repositioning demand (twenty-foot equivalent unit, or TEU) in period t, E_t is the volume of empty containers (TEU) generated in period t, and γ is the surplus rate of empty containers in the previous period.

As maritime container shipping demand fluctuates with the seasons, the volume of empty containers generated varies accordingly. Therefore, the volume of empty containers is not necessarily the monthly average value in some scenarios. The volume of empty containers generated in the previous period is represented by Equation (2).

$$E_t = \overline{E} \cdot (1 + \alpha_t), \tag{2}$$

where $\overline{E}$ is the average shipping demand of empty containers (TEU), and α_t is the demand change rate in period t.

In principle, the demand for empty container repositioning should be met by the remaining space of the containership, after satisfying the shipping demand for full containers. As described in Section 1, the PICs have few domestic industries aside from agriculture and fishery, and rely heavily on imported goods [5,6]. If their industrial structure and trade construction remain unchanged, the balance of imports and exports would not change even if the total volume of cargo shipping demand changes. Therefore, the volumes of loading and discharging cargo are assumed to change at the same rate in this study, and the variation of full and empty container volumes can be represented by the same value of α_t. Moreover, the number of empty containers that can be repositioned from a port is restricted by the remaining space of the ship after loading full containers at the port [8], which is expressed in Equation (3).

$$S_t = V - \overline{X} \cdot (1 + \alpha_t), \tag{3}$$

where S_t is the remaining space of the ship (TEU) in period t, V is the capacity of the containership (TEU), and $\overline{X}$ is the average shipping demand of full containers (TEU).

In the following formulas, as stated in Section 3, we consider four types of management costs of maritime empty container repositioning.

4.3.2. Standard Containers Only

In the case of using only the standard container, if the empty container repositioning demand is less than the remaining space of the ship, because all the empty containers can be repositioned in the current period, we only consider the storage cost of the standard container. If the empty container repositioning demand is greater than the remaining space of the ship, some empty containers cannot be repositioned in the current period. Because the basic transport cycle of containers is two months, the container inventory at the port should subtract the number of containers that are shipped to other ports in the current period and in the previous period. Therefore, the storage costs and rental fees of those containers that cannot be repositioned should also be considered as follows:

$$C_t = \left[SD - \overline{X} \cdot (1 + \alpha_{t-1} + 1 + \alpha_t)\right] \cdot CS, \; if \; R_t \le S_t, \tag{4}$$

$$C_t = \left[SD - \overline{X} \cdot (1 + \alpha_{t-1} + 1 + \alpha_t)\right] \cdot CS + (R_t - S_t) \cdot (CS + CL), \; if \; R_t > S_t, \tag{5}$$

where C_t is the total management cost (US$), SD is the total number of standard containers (TEU), CS is the container storage cost per TEU (US$/TEU), and CL is the container rental fee per TEU (US$/TEU).

4.3.3. Introducing Foldable Containers

After the introduction of foldable containers, three foldable containers can be folded into the equivalent of a standard container to reposition the empty containers, enabling the space of the containership to be fully used while more empty containers can be repositioned.

If the empty container repositioning demand is greater than the remaining space of the ship, we can use a certain number of foldable containers to satisfy the demand of empty containers to be equal to or less than the remaining space, as expressed in Equation (6).

$$(R_t - F_t) + \frac{F_t}{3} \leq S_t,\ if\ R_t > S_t, \tag{6}$$

where F_t is the demand for foldable containers (TEU) in period t. Therefore, the minimum demand for foldable containers is represented by Equation (7).

$$F_t = \frac{3}{2} \cdot (R_t - S_t). \tag{7}$$

If the empty container repositioning demand is less than the remaining space of the containership, all empty containers can be repositioned without using a foldable container; that is,

$$F_t = 0,\ if\ R_t \leq S_t. \tag{8}$$

If the demand for foldable containers is less than the number of foldable containers that are introduced, all the repositioning demand of empty containers can be met by substituting standard containers with the same quantity of foldable containers. In addition, unused foldable containers can save storage space and contribute to storage cost reduction. In this case, the storage cost of a foldable container is only one-third that of the standard container, because it takes up one-third of the space of the standard container by using the 3-in-1 foldable container.

$$C_t = \beta \cdot SD \cdot CD + CFO + \left((1-\beta) \cdot SD - \overline{X} \cdot (1 + \alpha_{t-1} + 1 + \alpha_t)\right) \cdot CS\ + (\beta \cdot SD - F_t) \cdot \frac{CS}{3},\ if\ F_t \leq \beta \cdot SD, \tag{9}$$

where β is the introduction rate of foldable containers, CD is the purchase cost of foldable containers (US$/TEU), and CFO is the fixed cost (US$) of introducing foldable containers.

However, under the condition that the foldable containers are introduced in advance in a certain proportion, if the demand for foldable containers is greater than the number of foldable containers that are introduced, foldable containers can only alleviate the problem of insufficient capacity to a certain extent, and there would still be empty containers that cannot be repositioned. In this case, the storage fees for the empty containers that cannot be repositioned and the cost of renting leased containers to cover the shortage of empty containers would be incurred, as expressed below:

$$C_t = \beta \cdot SD \cdot CD + CFO + \left((1-\beta) \cdot SD - \overline{X} \cdot (1 + \alpha_{t-1} + 1 + \alpha_t)\right) \cdot CS\ + \left(R_t - \beta \cdot SD \cdot \frac{2}{3} - S_t\right) \cdot (CS + CL),\ if\ F_t > \beta \cdot SD. \tag{10}$$

5. Static Analyses

Initially, we focused on one shipping period (i.e., for two months) and calculated management costs. For the calculation, we assumed that there is a case where half of the empty containers generated in the previous period cannot be returned to the port in time (i.e., $\gamma = 0.5$). Moreover, we assumed the following scenarios: the shipping company possesses 1200 TEU standard containers for this service (i.e., $SD = 1200$); container storage and leasing fees per month per container are 200$US and 300$US, respectively (i.e., $CS = 200$ and $CL = 300$); the purchase cost of a foldable container is 3000$US/TEU with 10 years' lifespan (i.e., $CD = 300$); and the fixed cost for introducing foldable containers is 1,200,000$US with 10 years' lifespan (i.e., $CFO = 120,000$), based on the previous studies [2,7,8,33], with adjustments for considering the maritime shipping and container market in the PICs and the more advanced foldable containers used in this study [2]. Specifically, the container storage fee is assumed to be lower than those in previous studies because the land price is lower in the PICs. Further, the purchase and fixed cost of the foldable containers were assumed to be higher because of their more advanced design as considered in this study.

5.1. Container Cargo Shipping Demand with Smaller Increasing Rate

Figure 6 shows the total management costs of empty container repositioning in the current average cargo shipping demand, as indicated in Figure 5 (i.e., $\alpha_{t-1} = \alpha_t = 0$), as well as those in which the cargo shipping demand is increased to some extent (i.e., $\alpha_{t-1} = \alpha_t = 0.1,\ 0.15,\ 0.2,\ 0.25,\ 0.3,$ and 0.35), with several scenarios on the introduction rate of foldable containers, namely, $\beta = 0$ (scenario S0, standard containers only), $\beta = 0.05$ (S1), $\beta = 0.1$ (S2), and $\beta = 0.15$ (S3). As shown in the figure, the total management cost first decreases as cargo shipping demand increases in each scenario on the introduction rate of foldable containers, because the storage cost decreases as cargo shipping demand increases. However, it gradually increases if cargo shipping demand becomes greater than a certain level, because the rental fee of leased containers significantly increases due to a shortage of available containers.

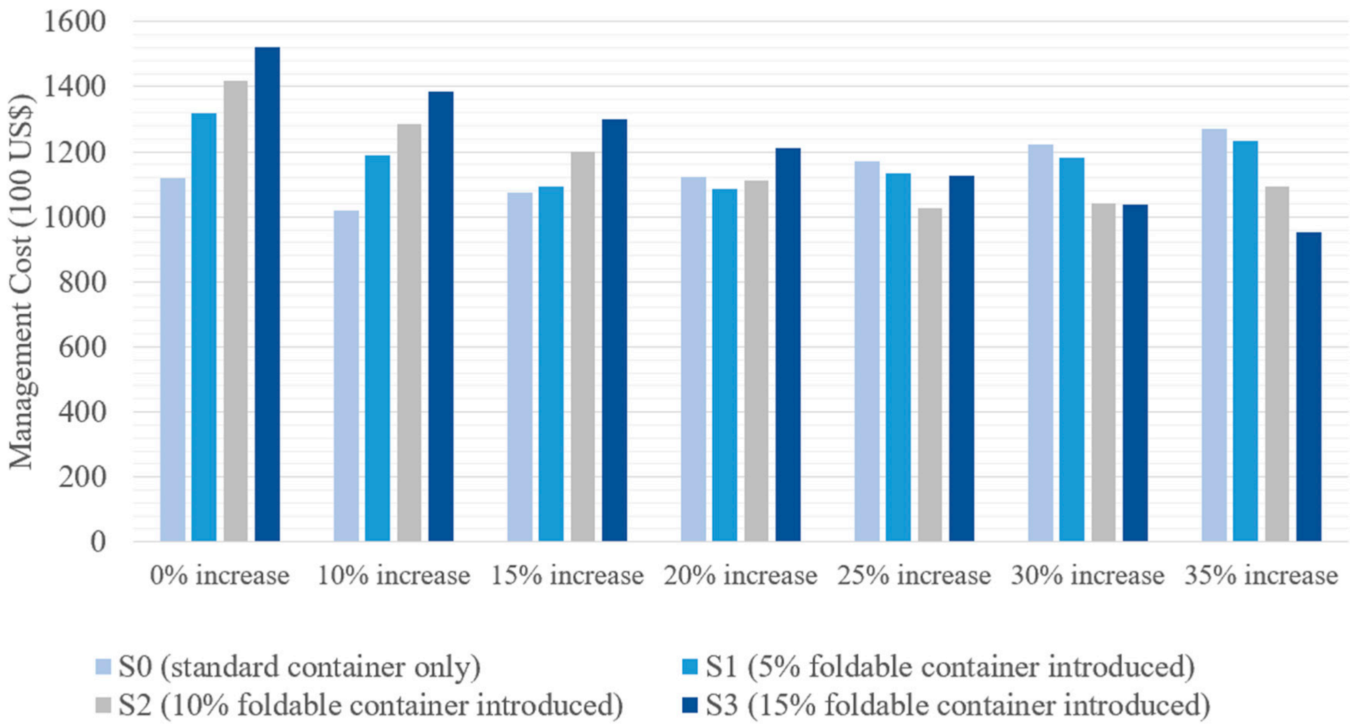

Figure 6. Total management cost of empty container repositioning in the current cargo shipping demand and smaller demand increase scenarios (standard containers only vs. foldable containers introduced). Source: compiled by the authors.

As shown in Figure 6, at the current average cargo shipping demand, or with a slight increase in the cargo shipping volume ($\alpha_{t-1} = \alpha_t = 0,\ 0.1$ and 0.15), the total management costs of empty container repositioning are the cheapest if only standard containers are used (S0). In other words, it is better not to introduce foldable containers because there is enough space on the containership to reposition empty containers, owing to the small shipping volume of full and empty containers. If the cargo shipping demand increases by 20%, by introducing 5% of foldable containers (S1), management costs would be minimized. Moreover, the introduction of 10% of foldable containers (S2) could reduce the management costs compared to using standard containers only. However, it is more expensive than S1. This implies that foldable containers may be effective in reducing the cost of managing empty containers. Meanwhile, with the introduction of 15% of foldable containers (S3), the total management cost is higher than that of S0 (using only standard containers), which implies that introducing too many foldable containers would increase management costs. If cargo shipping demand increases by 25%, S2 has the greatest effect on cost reduction. If it increases by 30% or more, S3 would be more economically effective.

Furthermore, because the effect of introducing foldable containers in reducing management costs is greatly influenced by the related costs of foldable containers, if the related costs of foldable containers exceed a certain range—the threshold—any empty container management costs after introducing any proportions of foldable containers would not be lower than that in S0 (using only standard containers). By calculating the thresholds on purchase cost CD and the fixed cost CFO of foldable containers under different cargo shipping demands, it is found that the threshold increases as cargo shipping demand increases, as shown in Figure 7. If the purchase and fixed costs exceed the threshold of the "35% increase of demand" area, foldable containers would lose their advantage, regardless of the cargo shipping demand and proportion of foldable containers. Note that if the increasing rate of cargo shipping demand is 0%, 10%, and 15%, introducing foldable containers in any proportions would be more expensive than S0 under the minimum condition on these costs (i.e., $CD = 300$ and $CFO = 120,000$), as shown in Figure 6.

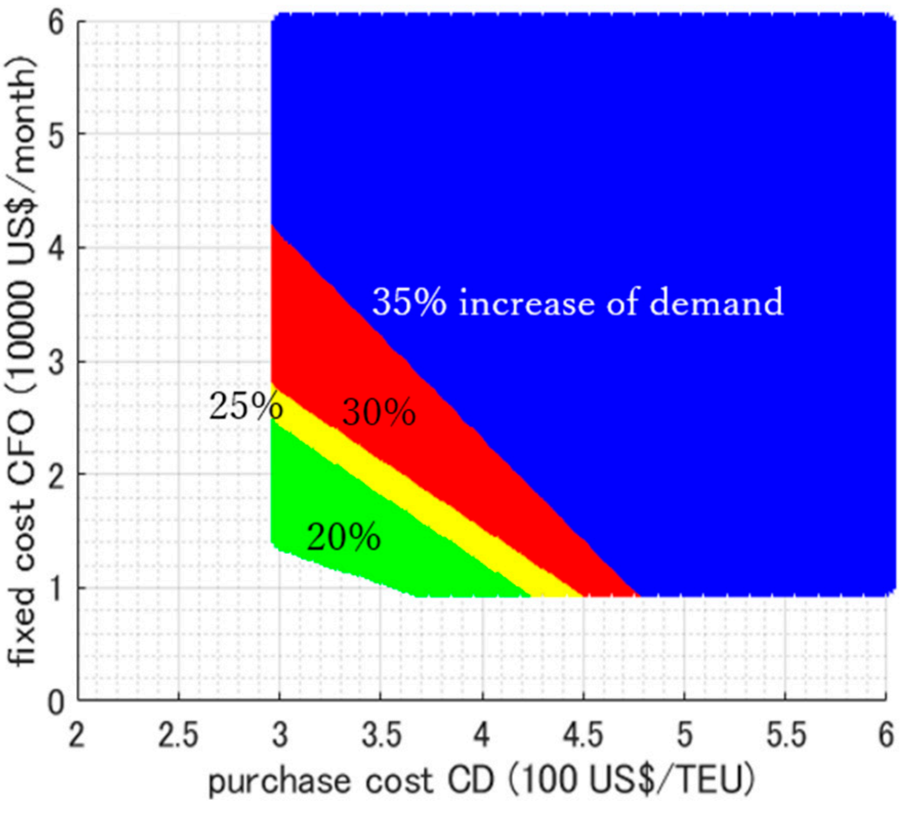

Figure 7. Thresholds of purchase and fixed costs of foldable containers by cargo shipping demand (with smaller increasing rate) at which foldable containers lose their advantage against the scenario of only standard containers. Source: compiled by the authors.

5.2. Container Cargo Shipping Demand with Higher Increasing Rate

In future scenarios, we assumed that the total number of standard containers possessed by a shipping company is 1500 TEU (i.e., $SD = 1500$), to meet the future cargo shipping demand when $\alpha_{t-1} = \alpha_t = 0.45$, 0.5, 0.55, and 0.6. Considering the increase in future cargo shipping demand in PICs, the management costs of empty container repositioning may become cheaper by introducing another containership. In this case, additional maritime shipping costs should be considered as well as the total management costs of empty container repositioning, as incorporated in the previous section. In this study, we calculated the maritime container shipping cost, which consists of the fuel cost, capital cost, and operation cost, based on the formulations in the GM-CSNS model [31,32]. Figure 8 illustrates the total management costs of empty container repositioning for each scenario on the introduction rate of foldable containers, i.e., $\beta = 0$ (S0), $\beta = 0.15$(S3), $\beta = 0.2$(S4), $\beta = 0.25$(S5), and $\beta = 0.3$(S6), as well as the scenario with introducing another containership without any foldable containers (S7). The figure also indicates that introducing foldable containers and another containership can significantly reduce costs, compared to S0 (using only standard containers). More specifically, if the cargo shipping demand increases by 45–55%, it is more economical to introduce 20% of foldable containers (S4), whereas, if the cargo shipping demand increases by 60%, S7 (adding another containership) would be the optimal option. We also calculated the thresholds at which introducing foldable containers (fld) would be more expensive than S0 and S7, as shown in Figure 9. The figure indicates that the thresholds are lower when compete with S7 than S0, regardless of the increasing rate of cargo shipping demand. In other words, the "fld > S0" area is completely encompassed by the "fld > S7" area. If the purchase and fixed costs of foldable containers exceed the threshold of the "fld > S7" area, foldable containers would lose their advantage in competition with introducing another containership, whichever the increasing rate is between 45% and 60% of cargo shipping demand and proportion scenarios of foldable containers. Further, it is found that the threshold of "fld > S7" decreases as cargo shipping demand increases, whereas that of "fld > S0" increases. Note that if the increasing rate of cargo shipping demand is 60%, introducing foldable containers in any proportions would be more expensive than S7 under the minimum condition on these costs (i.e., $CD = 300$ and $CFO = 120,000$), as shown in Figure 8.

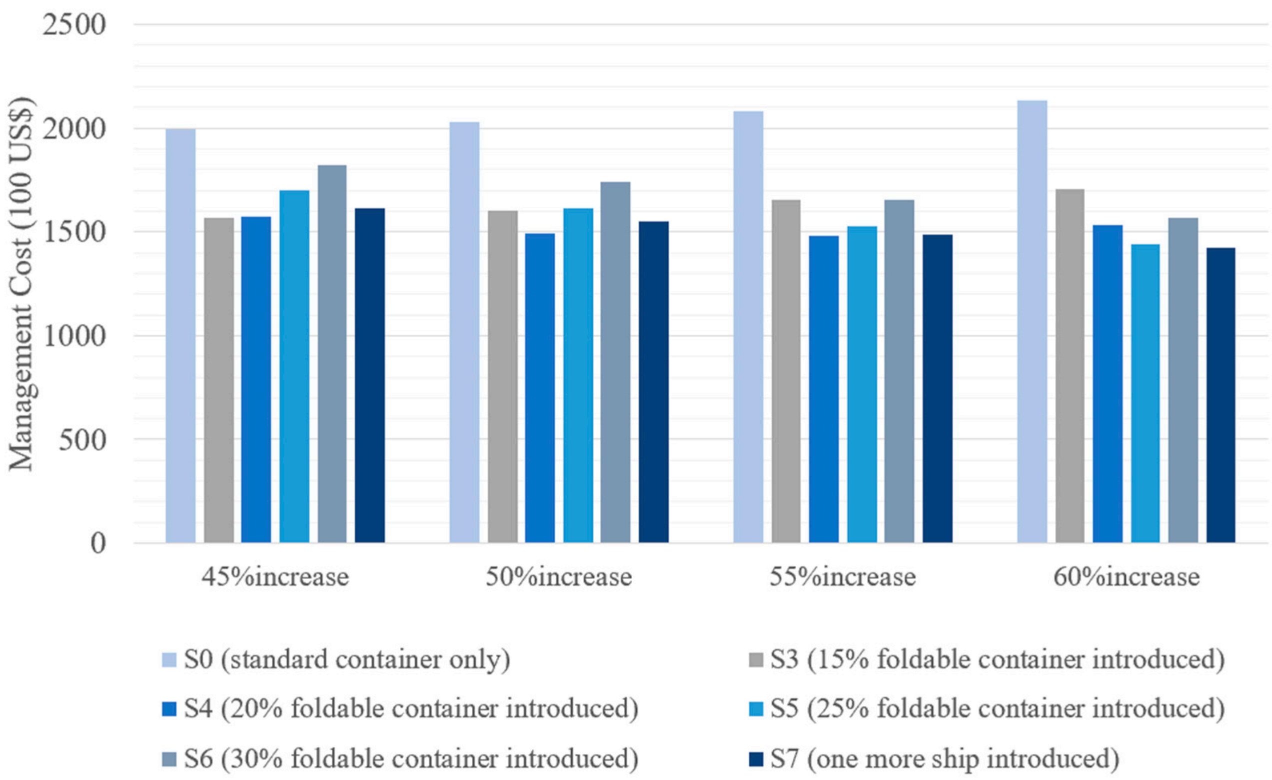

Figure 8. Total management cost of empty container repositioning in the future cargo shipping demand scenarios (standard containers only vs. foldable containers introduced vs. one more ship). Source: compiled by the authors.

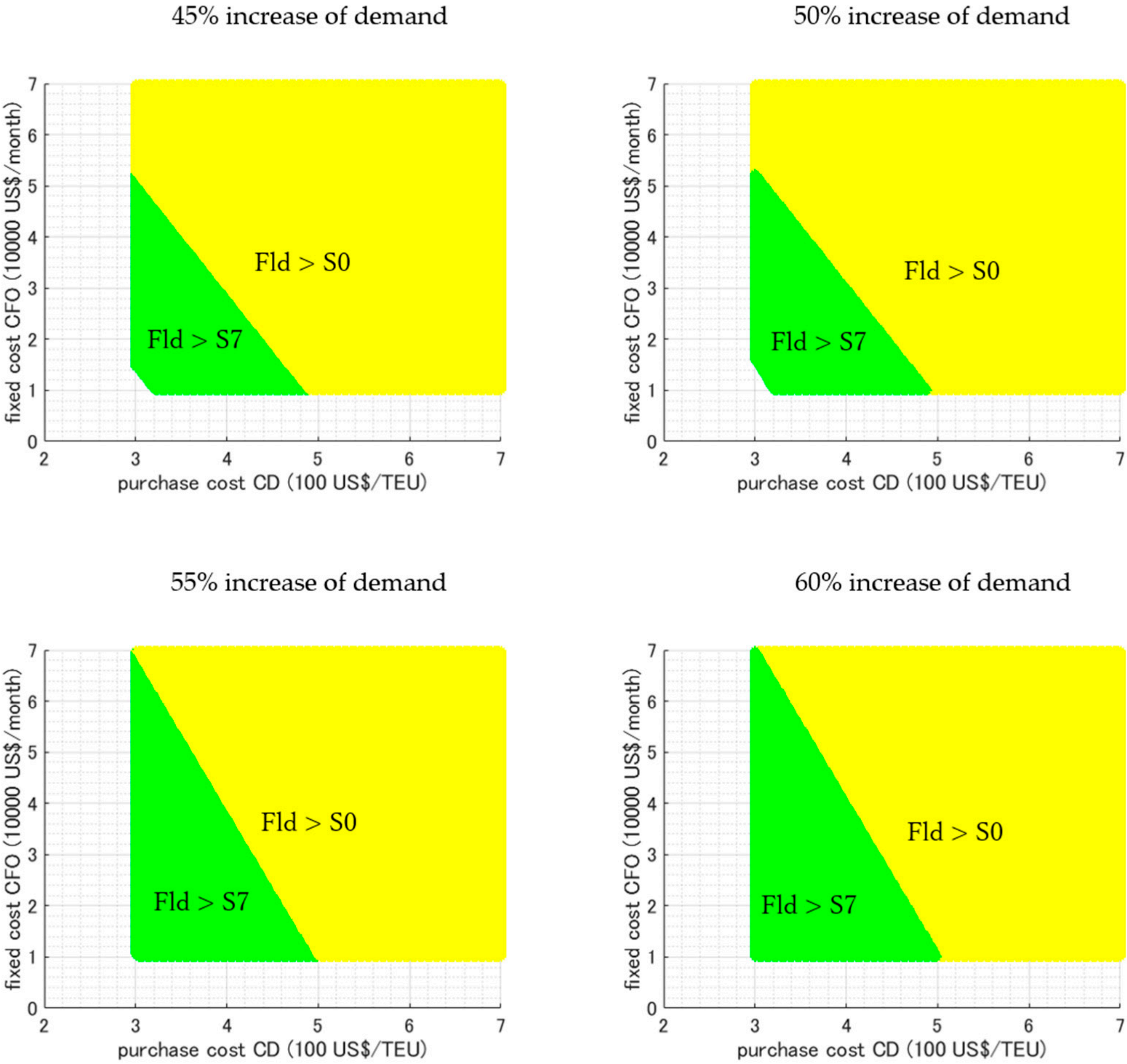

Figure 9. Thresholds of purchase and fixed costs of foldable containers by cargo shipping demand (with higher increasing rate) at which foldable containers lose their advantage against the only standard containers and one more ship introduced scenarios. Source: Compiled by the authors.

6. Consecutive Analyses with Demand Fluctuation

As described in Section 4, cargo shipping demand fluctuates seasonally. In this section, we assume that cargo shipping demand fluctuates from month to month, the sum of which is equal to the annual shipping volume given. In the following consecutive analyses, we assumed two different approaches to generating scenarios on demand fluctuation. The cargo shipping demand of each month (1) fluctuates randomly and (2) fluctuates biasedly. The second approach (biased demand) is necessary to consider because the actual cargo shipping demand is seasonally biased [4], and we assume in this study that the cargo shipping demand of each month in the first half-year is lower than average demand and that of each month in the second half of the year is higher than the average demand. Unlike in Section 5, here, all the empty containers generated in the previous period can be returned to the port in time (i.e., $\gamma = 0$). However, in case that cargo shipping demand is consecutively high for several months, some empty containers may have accumulated for a long period of time.

We randomly generated 1000 different one-year consecutive scenarios on monthly cargo shipping demand, depending on each given future cargo shipping demand (i.e., $\overline{\alpha_t} = 0.2,\ 0.3,\ 0.4,$ and 0.5. $\overline{\alpha_t}$ is the annual average cargo shipping demand growth rate), and then the management costs of empty container repositioning for each scenario were calculated. We set the ranges of consecutive shipping demand for each approach (random and biased demand) by annual average demand growth rate and randomly generated monthly demand with the same probability within the range. Table 3 summarizes the ranges on the cargo shipping demand from Busan to Rabaul for each approach, by annual average demand growth rate (note that the demands in other maritime shipping links are set proportionally to them). Figures 10 and 11 also show examples of generated consecutive shipping demand from Busan to Rabaul for both approaches. As shown in Table 3, we set the maximum value to be slightly less than the vessel capacity (506 TEU), and the minimum value to ensure that the sum of cargo shipping demand throughout a given year is equal to the annual shipping volume, considering demand growth. In the case of biased demand, we assumed that the cargo shipping demand is lower in the first half-year and higher in the second half-year. Unlike the static analysis in the previous section, which is assumed to occur from the beginning of the calculation, the delayed return of empty containers is assumed to occur in this section only if the demand for empty container repositioning becomes more than the vessel capacity in the consecutive calculations. This is the reason the introduction of an additional ship was not efficient in any scenario in this section (therefore, they were not included in the following analyses).

The management costs of empty container repositioning were calculated for each scenario, and the cases were compared to use only standard containers and to introduce foldable containers. As shown in Figure 12, the probability that the management cost of introducing foldable containers is lower than that when using only standard containers increases (S0) as the cargo shipping demand increases in both random and biased demand patterns. Moreover, in the case that the demand fluctuation is biased, it is more likely that introducing foldable containers has a greater effect on cost reduction than in the case of random demand, if they are compared using the same annual average growth rate of cargo shipping demand. This is because the continuous high cargo shipping demand in the second half of the year would lead to the accumulation of large numbers of empty containers, resulting in a significant increase in management costs. Therefore, the use of foldable containers can alleviate the accumulation of empty containers, and then enhance the more efficient use of containers and the sustainability of the shipping industry. In addition, the results shown in the figure imply that there may be an optimal introduction rate of foldable containers, because the probability that the cost of introducing 20% foldable containers (S4) at its lowest is higher than that of introducing 30% foldable containers (S6).

Table 3. Ranges set for random and biased container shipping demand by annual average demand growth rate, in case of the demand from Busan to Rabaul. Source: compiled by the authors.

Annual Average Container Shipping Demand Growth Rate $\overline{\alpha_t}$	Random Demand Scenario (TEU/Month)		Biased Demand Scenario (TEU/Month)			
			First Half Year		Second Half Year	
	Min	Max	Min	Max	Min	Max
0.2	180	480	180	330	330	480
0.3	200	480	200	340	340	480
0.4	230	490	230	360	360	490
0.5	250	490	250	370	370	490

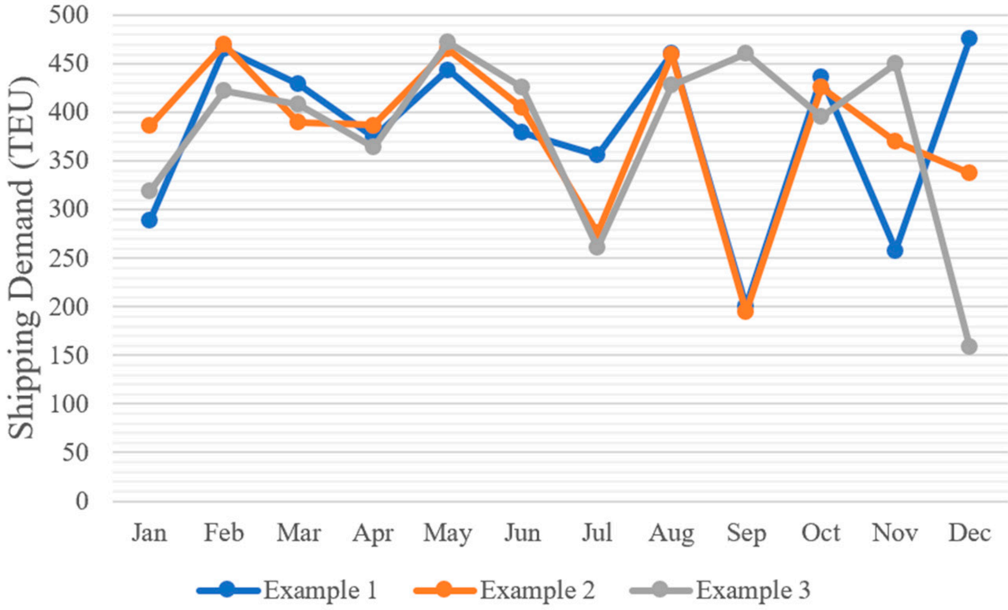

Figure 10. Examples of consecutive cargo shipping demand from Busan to Rabaul in the random fluctuation approach ($\overline{\alpha_t} = 0.2$). Source: compiled by the authors.

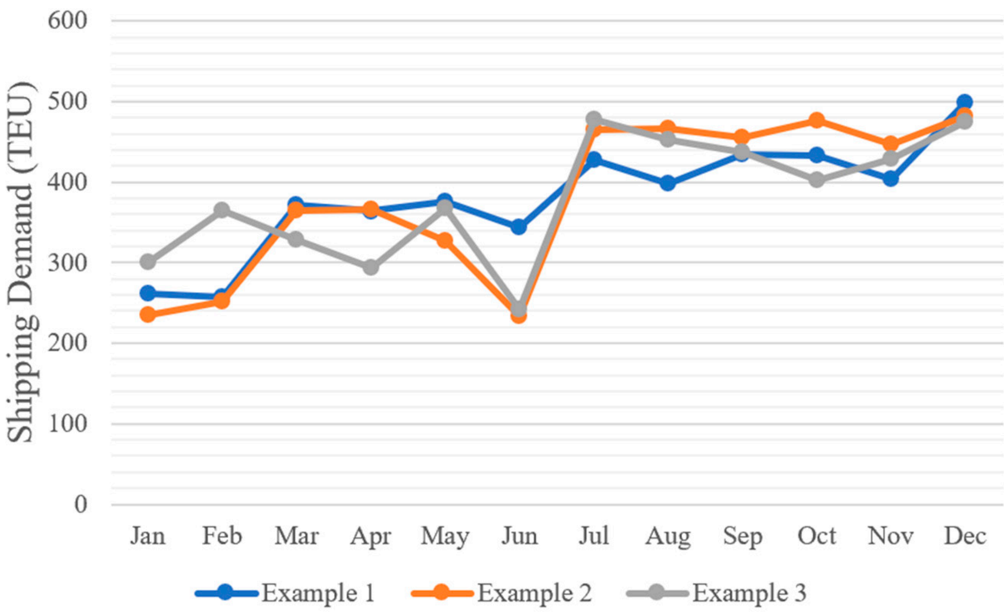

Figure 11. Examples of consecutive cargo shipping demand from Busan to Rabaul in the biased fluctuation approach ($\overline{\alpha_t} = 0.2$). Source: compiled by the authors.

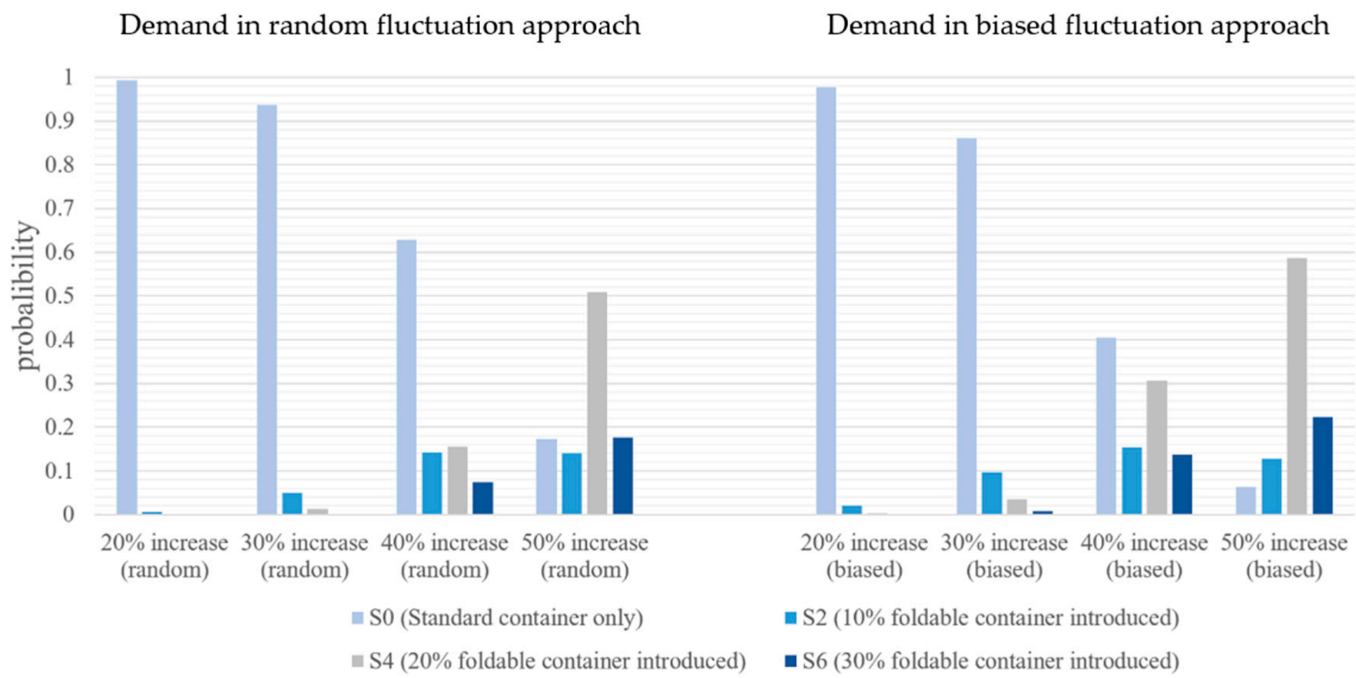

Figure 12. Probabilities that the cost in each scenario is the lowest. Source: compiled by the authors.

Figure 13 describes the frequency distribution of the total management costs when using standard containers only (S0) and introducing 20% foldable containers (S4) in the 1000 scenarios, with 30% and 50% cargo shipping demand growth rates for random and biased demand patterns, respectively. The first finding is that, if fluctuations in cargo shipping demand are biased, empty container management costs are more widely distributed and have a higher probability of incurring higher costs than those in random demand fluctuations. The second is that the greater the growth in cargo shipping demand, the wider the distribution of empty container management costs. In other words, as cargo shipping demand increases, it becomes more difficult to control costs. The third is that, if cargo shipping demand increases by 50%, the average, median, and mode of the distribution of total management costs are lower after introducing foldable containers, which implies that the introduction of foldable containers has a significant effect on cost reduction. The final, but most important, finding is that the frequency distribution of management costs in different time series of cargo shipping demand becomes much more concentrated by introducing foldable containers. This is because the introduction of foldable containers effectively mitigates the fluctuations in the number of empty containers that cannot be repositioned, owing to the fluctuations in cargo shipping demand. The fluctuation in storage costs and leasing fees of empty containers is reduced, which would influence the dispersion of management costs. This implies that the introduction of foldable containers also enables costs to be more stable and predictable, as well as to preserve the long-term sustainability of the shipping industry; therefore, it is more effective if the cargo shipping demand increases.

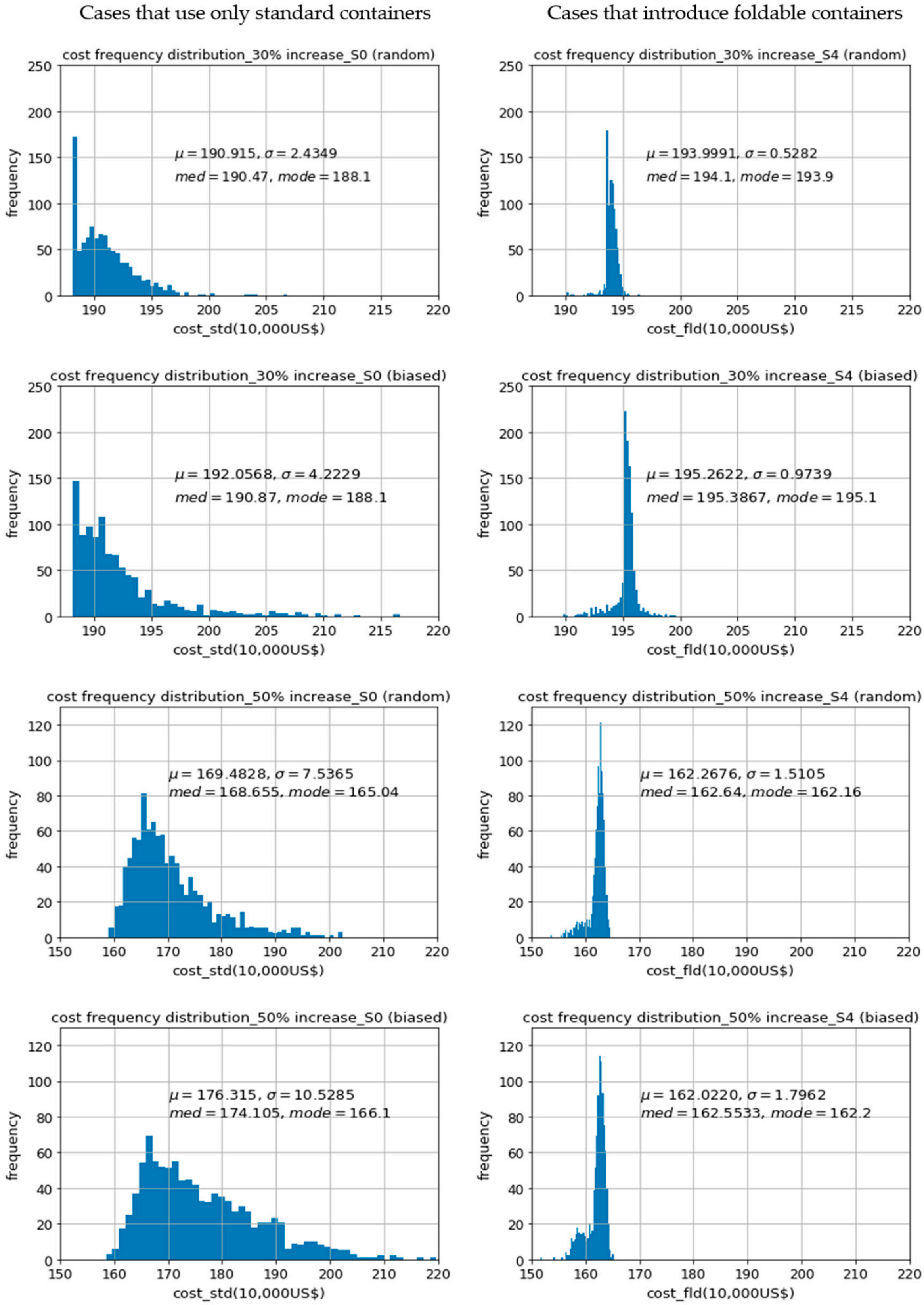

Figure 13. Frequency distribution of the total management costs of empty container repositioning for different scenarios (μ = mean value, σ = mean deviation, med = median). Source: compiled by the authors.

7. Conclusions

In recent years, rapid economic growth and globalization have increased the trade imbalance between Asia and the Pacific region, which has led to a serious problem of repositioning empty containers. One of the measures to alleviate this problem is the introduction of foldable containers, which have not yet been put to practical use. Therefore, to analyze whether foldable containers can be advantageous in empty container repositioning from an economic perspective, we compared the management costs of empty container repositioning when using only standard containers and introducing foldable containers. Specifically, we formulated the problem of empty container repositioning between East Asia and Oceania, based on the flow of full containers, and then we expressed the total management costs of container repositioning considering the introduction of foldable containers by using a mathematical model. We showed under what circumstances and to what extent foldable containers can contribute to the reduction of container management costs through scenario analyses, including static analysis and consecutive analysis with changeable cargo shipping demand. Furthermore, the cost reduction effect of adding another containership was considered if the future cargo shipping demand will increase substantially.

Based on the results of scenario analyses and simulations conducted, the following conclusions can be drawn. Firstly, with the introduction of foldable containers, the total management costs of container repositioning can be reduced depending on the growth rate of container cargo shipping demand. However, introducing too many foldable containers may increase the total management cost of container repositioning, because the related costs of foldable containers are relatively high. Therefore, the proportion of foldable containers is an important issue, and the related costs of foldable containers play a key role in the use of them. Secondly, if the container cargo shipping demand is extremely high, the surplus empty containers can be repositioned by an additional containership, which is more effective in reducing container management costs than introducing foldable containers. Thirdly, if fluctuations in cargo shipping demand are biased, empty container management costs are more widely distributed and have a higher probability of incurring higher costs than those in random demand fluctuations. However, with the introduction of foldable containers, it is more likely that the effect on cost reduction in the case of biased demand is greater than when the demand fluctuation is random. Finally, the distribution of empty container management costs would become much more concentrated after introducing foldable containers. This implies that the introduction of foldable containers not only effectively reduces the management costs of empty containers, but also makes costs more stable and predictable. In general, the results of this research provide useful managerial insights to the shipping company that the introduction rate of foldable containers significantly affects the cost reduction effect, and the shipping company should introduce an appropriate rate of foldable containers considering the cargo shipping demand and demand fluctuation pattern, which would promote the more efficient use of containers, and ensure the profits of the shipping company and the sustainability of the shipping industry. On the other hand, introducing foldable containers is not the only possible solution to the accumulation of empty containers; the management costs of empty container repositioning may become cheaper by introducing another containership to increase service frequency, in the case that future cargo shipping demand is expected to significantly increase. Therefore, the results of this study can support a shipping company's decision on whether to introduce a foldable container or an additional containership, and what proportion of foldable containers to introduce, considering cargo shipping demand.

Although Moon et al. [9] pointed out that foldable containers were not widely used because of higher production and folding/unfolding costs, the 3-in-1 foldable containers with more advanced designs as adopted in this study could save the folding/unfolding costs, making them more advantageous. Moreover, similarly with this study, Lee and Moon [19] validated the advantage of using foldable containers in several consecutive demand scenarios; however, the effect on the cost-saving of introducing foldable containers was not significantly different between demand scenarios. In contrast, this study showed that introducing foldable containers has a greater effect on cost reduction in the case of biased demand rather than random demand. Meanwhile, they found an advantage in foldable containers even when the cargo shipping demand was relatively low, because there was not enough space on the containership to reposition empty containers in their case if compared to our simulation that focused on the PICs.

In summary, this study provided evidence for the economic feasibility of foldable containers for empty container repositioning. However, when an additional containership was introduced, we did not consider the changes in shipping demand for full containers caused by the doubling of service frequency. This is an important issue that should be addressed in future research. Moreover, regarding the fluctuation of cargo shipping demand, for simplicity, uniform distribution was considered when generating cargo shipping demand in this study. A more stochastic approach with various distributions will be discussed in future research. Furthermore, we focused only on one liner shipping service in the Pacific region. It would be interesting to extend the scope of this type of simulation and analysis to the global shipping network. In future research, we will analyze the empty container flow and make an efficient empty container repositioning plan considering multiple liner shipping services, based on the GMCSNS model [6,31]. By doing so, we could compare and analyze the cost reduction of empty container repositioning after introducing foldable containers, when considering multiple services.

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Conflicts of Interest: The authors declare no conflict of interest.

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A Model for Developing Existing Ports Considering Economic Impact and Network Connectivity

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Abstract: This study discusses the problem of determining which container port should be developed within an existing network and when this should be carried out. A case study of Indonesia's port network is presented, where several new ports are to be improved to ensure smooth interisland transportation flows of goods. The effects of the investment on economic consequences and increased network connectivity are assessed. When improving the ports, we consider that the available budget limits the investment. The network connectivity is evaluated by considering the number of reachable ports from the developed ports or transportation time required from other ports within the same port cluster. Based on our knowledge, our study is the first one that discusses the investment problem in multiple container ports under single management, as well as its effects regarding the increase in container flows. The problem is introduced and three mathematical models are proposed and used to solve a real problem. The results show that different models have different improved aspects of container transportation flows—e.g., a balanced improvement of the whole port network (Model 2) and appropriate investment priority for port clusters (Model 3).

Keywords: container port; connectivity; investment; port cluster

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1. Introduction

Global economic activity involves manufacturing processes that are performed in many countries as well as shipping to other consumer countries. A smooth goods transportation between countries must be supported through a good transportation connection within each country. In other words, global manufacturing activities have a strong relationship with regional port development [1]. Such good transportation connections must be ensured in land, water, and air transportation networks. In our study, we focus on developing the connectivity of the water transportation network. Such connectivity highly depends on the container ports with good infrastructure, routine vessel sailing schedule, and sufficient supply of goods. Characteristics of well-developed ports are sufficiently installed port capacity, good information systems [2], and strong access from/to the hinterland [3]. The port capacity development itself includes the appropriate port draft setting to match the visiting vessels' requirements, suitable hub and feeder port network design, and advanced equipment operations. We focus on improving the capacity and connectivity of ports in the hub and feeder port network by allocating the available budget for investment.

Logistics planning and control issues in container ports were classified into three levels [4]: terminal design, operations planning, and real-time control, with details as follows:

1. Terminal design:
    - multimodal interfaces;
    - terminal layout;

- equipment selection;
- berthing capacity;
- IT systems and control software.

2. Operations planning:
   - storage and stacking policies in container yard;
   - quay crane assignment and split;
   - berth allocation;
   - stowage planning.
3. Real-time control:
   - landside transport;
   - quayside transport;
   - slot management in storage yard;
   - crane scheduling and operation sequencing for yard cranes and quay cranes.

Our investment problem is classified at the terminal design level. In a similar terminal management issue classification proposed in [5], our problem is classified into the terminal layout problem at the strategic and tactical levels. Decisions made at this strategic level determine the overall system's capacity when solving operation planning and real-time control issues—e.g., the amount of investment in logistics infrastructure sets the upper bound for the possible flows within the network [6]. Dealing with the port investment problem at the terminal design level is related to increasing the terminal's throughput, which depends on the relationships between ports. This differs from the operations planning and real-time control levels that exclusively attempt to directly increase the productivity of a single port, given the installed capacity at the terminal design level. Although development funds at container terminals can be invested in berths (seaside), container yards, and yard cranes (landside) [7], we focus on the investment in the seaside for the reasons stated above.

Our study has received investment for the purpose of increasing the processing capacity of the terminal's seaside, which mainly depends on the designed and operational capacities of the berths [8–10] and the number of installed quay cranes. Many attempts have been made to ensure the quay cranes operate with high utilization through efficient quay crane assignment, quay crane scheduling, and double cycling operation to increase the terminal's capability of handling more containers from/to the vessels [11]. The terminal's productivity improvement from the increase in the length of the berth and the number of installed quay cranes might be limited by the noncrossing constraints between quay cranes [12] and the capacity of other related equipment in the terminal's landside—e.g., yard crane and internal trucks [13,14]. Nevertheless, berths and quay cranes are considered the most significant resources for the terminal's throughput [15,16].

Some studies that discussed the initial design of the whole or partial hub and spoke port network are [17–20], most of which address the port location problem. Unlike these studies, we found out how to improve the existing hub and spoke port networks by allocating the investment budget, which was not considered in most studies listed above. Some other papers deal with more issues at the tactical or operational level—e.g., demand estimation at origin and destination nodes [21], fleet size [22,23], ship routing [24–26], ship schedule generation [27], container transportation decisions [25], and empty container repositioning [28]. Our study differs from these studies by considering investment decisions at the strategic level.

Investment decisions for the development of existing ports are often considered complicated to make. These decisions require a holistic perspective, considering the port connectivity network and productivity improvement strategies for the ports [29]. Moreover, budget limitation and the effect of the time value of money are important to consider in allocating investments, which is accomplished gradually on a yearly basis.

Many previous studies used a mathematical modeling approach to find the best investment decisions. In general, the investment modeling approaches can be divided into two types: (1) studies that maximize the effects of the investments while considering the limited budget [30–32] and (2) studies that minimize the total investment costs, while ensuring a certain service level of the improved system [33,34]. Our study uses the earlier investment modeling approach and introduces a novel way to evaluate the investment effects in subsequent years after the investment period for the container port development case.

In this port development case, there has been much research investigating port investment models. Many of them emphasized the importance of competition between ports when making investment decisions. In this situation, the best investment decision was made while considering the trade-off of the developments of the ports. To obtain the best strategy for all ports, game theory [35] or methods pursuing equilibrium conditions [36–38] were proposed. In contrast, we discuss a case that emphasizes mutual improvements in all of the related ports when investing in any port. Our proposed methods are more suitable in a case in which the government manages the whole container port network, which allows maximum utilization of the investments to improve the performance of the whole network [39,40]. When the competition between ports is relaxed, there is a better possibility to improve and reduce the cost of the network [41].

After reviewing the studies above, the authors found out that there is still limited research considering port system connectivity and capacity, time value of money, budget allocation, and limitation for a multiyear port investment decision. Thus, we formulated our study's research question as follows: How do we determine the amount of investment in each container port each year considering a limited budget to maximize the effects of the investments when the network is under single management? The effects of the investments are measured based on the amount of the investment multiplied by the years of how long the investments are active until the end of the planning horizon. This amount- and time-based evaluation has been considered in previous studies when calculating (1) the worth (money value) of the investments [42] or (2) the profit obtained from the investments [43] by incorporating them in the objective function of their proposed models. The related research hypothesis for our study is: investment decisions for multiple ports to improve the whole network's productivity are dependent on the relationships between the ports—i.e., the number of connecting links between ports and distances between ports in each same cluster.

The closest studies with ours (that discussed the investment problem in container ports) are [44,45]. Allahviranloo and Afandizadeh [44] discussed a multiyear investment problem for a single port. In their study, they minimized the required total investment to improve the draft for the ships at the port. Allahviranloo and Afandizadeh [44] and Balliauw et al. [45] considered the investment effect of the investment on a single port; meanwhile, we discuss investment decisions on multiple ports while considering the existing connection between the ports. This research direction was supported by Chen and Yang [46], who expressed the necessity of more studies to consider the simultaneous improvement of the port network instead of individual ports. Based on the authors' knowledge, our study is the first that discusses investment decisions on multiple ports under single management while considering relationships between the ports that are related to the container flows. Our proposed models can be a basis for further observation of port development strategies with detailed port characteristics related to the increase in container flows. The models ensure the development of a single container port and consider its effect on adjacent ports to maximize the whole system's performance.

2. Mathematical Formulations

Our study deals with an investment problem with the following inputs, outputs, and objective:

1. Input:
    - A network of container ports with port nodes and connecting edges are provided.
    - The available investment budget for each port cluster and all ports each year is provided.

- The total planned investment for each port (of all years) is provided.
- The time required for vessel travel between each pair of connected ports is provided.

2. Output (decisions):
   - The amount of investment in each port at each period is determined.
3. Objective:
   - The total effects of the investments in all ports during all years must be maximized.

Three mathematical models are developed to determine how much money must be invested for each container port every year. We assumed that the ports' current capacities are sufficient for stable container flow management before any investment. Thus, we also assumed that the amount of investment placed from the starting year considered in this study is equivalent to increasing the ports' capacities. We also discuss how to improve those capacities at the ports appropriately while observing the effects on the connected ports or ports located close within the same clusters. Characteristics of each model are listed and compared in Figure 1. Main changes in Models 2 and 3, compared with Model 1, are marked.

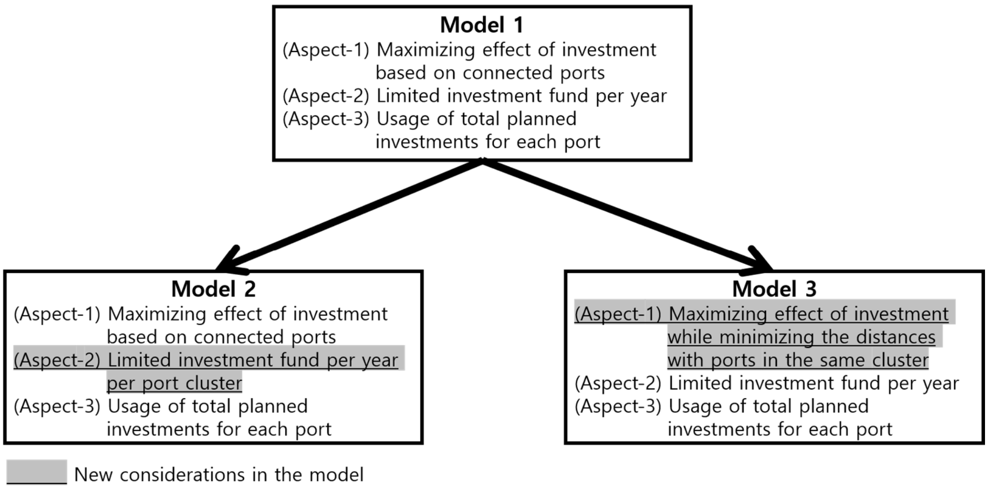

Figure 1. Characteristics of proposed mathematical models.

The sets, parameters, and decision variables are as follows.

Sets:

G set of container port clusters, $g = 1, 2, 3, 4$;
P set of container ports, $P = P_1 \cup P_2 \cup P_3 \cup P_4$;
P_g set of container ports in area g, $i \in P_g$;
$P(i)$ area where container port i is located, $i \in P(i)$;
T set of years, $t \in T$, $m = |T|$.

Parameters:

a_{ij} 1, if there is a direct link between container port i and container port j; 0, otherwise;
b_t available budget for improving container ports at year t;
b_{gt} available budget for improving container ports in cluster g at year t;
d_{ij} required travel time between container port i and container port j;
e_i total investment amount planned for container port i;
m number of investment years;
r devaluation of currency.

Decision variables:

x_{it} number of investments made for developing container port i at year t.

Models 1, 2, and 3 are presented as follows:

Model 1:

$$\text{Max} \sum_{i\in P}\sum_{j\in P}\sum_{t\in T}\frac{(m-t)x_{it}a_{ij}}{(1+r)^t} \tag{1}$$

subject to

$$\sum_{i\in P} x_{it} \le b_t \quad \forall t \in T \tag{2}$$

$$\sum_{t\in T} x_{it} = e_i \quad \forall i \in P \tag{3}$$

$$x_{it} \ge 0 \quad \forall i \in P,\ t \in T \tag{4}$$

Assuming that the investment amount has a linear relationship with the flow improvement between the developed container port and its connected container ports, objective Equation (1) maximizes the investment amount and years during which the investment has some effect. We increase the effects of the investment in terms of amount and time while considering the number of connected ports in the network. The connectivity index was developed based on [47]. The affected years were considered because earlier investment in the port capacity allows a bigger increase in the operational capacity of the system [45]. To convert the future investment amount to the present value, we used the following formula:

$$P = \frac{F}{(1+r)^t} \tag{5}$$

with P as the present value and F as the future value, as considered in [44].

The constraints in Equation (2) limits the total investment amount per year t with the available budget. The constraints in Equation (3) ensures that the total investment amount for each container port i is the same as the planned amount. The constraints in Equation (4) are non-negativity constraints.

Model 2:

Objective function (1)

subject to

$$\sum_{i\in P_g} x_{it} \le b_{gt} \quad \forall g \in G,\ t \in T \tag{6}$$

Constraints (3)–(4)

Unlike Model 1, Model 2 considers the constraints of Equation (6) that limit the total investment amount per year t with the available budget for developing container ports in each cluster g.

Model 3:

$$\text{Max} \sum_{i\in P}\sum_{t\in T}\frac{(m-t)x_{it}}{(1/(|P(i)|-1))\sum_{j\in P(i)} d_{ij}(1+r)^t} \tag{7}$$

subject to

Constraints (2)–(4)

With the same assumption about the linear relationship of the flow improvement, Model 3 considers a different objective (Equation (7)) that maximizes the effect of investment amount and the affected years while minimizing the required travel times between the improved container port and other ports in the same cluster. Such average travel time is stated in [48]. This model aims to improve ports that are closer to all other ports with more investment as soon as possible. Even though there are no links between the ports, such improvement effects can be considered through indirect connections from other ports (or by directly establishing such new connections in the future).

3. Data

Our study's data are taken from a real case of Indonesia's port network development plan [49]. Our study only considers 24 strategic container ports that are the main ports in Indonesia's sea toll network. Other than these strategic ports, there are more than 80 commercial ports and 1400 noncommercial ones. The total allocated investment budget for the strategic ports is more than the one for the other ports; thus, we focus our study on the strategic ports. The network with connections between the container ports (Figure 2) is considered as input data.

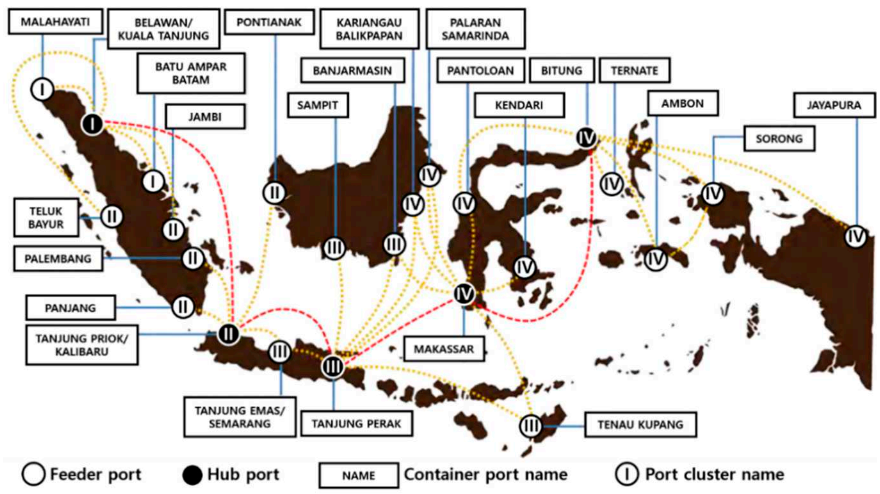

Figure 2. Container port network in Indonesia.

The input data are also container ports and available budget data (Appendix A Table A1; taken from [49]) and travel time data between ports (Table A2; calculated from [50]). The detailed investment plan for Sampit port (No. 14 in Table A1) is not stated in [49], but the total investment is given; thus, we assumed that the investment is divided evenly for all years. When calculating the travel time data in Table A2, we set the vessel speed to 14 knots to match some initial data provided in [49].

Table A1 shows the investment plan for each port every year. The port listed in the table involves hub and feeder ports that are illustrated in Figure 2. The hub port name is written in italics and underlined, while the feeder port is written in regular letters (without italics and underlines). Using the data, we calculated the total available budget for investment every year. In Models 1 and 3, we considered the total investment for the whole year, but in Model 2, we considered the budget limit for each cluster every year. Our study aims to find the best investment plan that can increase the investment effects on the ports, assessed from the number of connections or required travel times between ports.

4. Results

We solved our proposed models using the CPLEX 12.9 commercial solver that has been used in many previous studies [51–53], including the ones that provided solutions for real company problems. Our codes are written in Python language with Python 3.7 version in the Microsoft Visual Studio Community Edition 2019 platform. All experiments were conducted on an Intel® Core™ i5-6600 CPU at 3.30 GHz with 16 GB RAM. The value of r was set to 8.6% based on Indonesia's real interest rate in 2019 [54]. The solutions of Models 1–3 are presented in Tables 1, A3 and A4, respectively. The total money invested each year is listed at the bottom of Tables 1, A3 and A4.

Table 1. Investment decision as the result of Model 1 (in trillion rupiahs).

No.	Container Port	Cluster	Year 1	Year 2	Year 3	Year 4	Year 5
1	*Belawan/Kuala Tanjung*	I	0	10,585	13,815	0	0
2	Malahayati	I	0	0	1352	0	212
3	Batam (Batu Ampar)	I	0	0	594	606	0
4	*Tanjung Priok/Kalibaru*	II	2564	3544	0	0	0
5	Pontianak/Kijing (Kalbar)	II	0	0	0	2909	0
6	Palembang/Tanjung Carat (Sumsel)	II	0	0	0	6581	0
7	Jambi/Muara Sabak	II	0	0	0	0	300
8	Teluk Bayur	II	0	0	0	0	161
9	Panjang (Lampung)	II	0	0	0	0	122
10	*Tanjung Perak*	III	8563	0	0	0	0
11	Tanjung Emas	III	0	0	1170	0	0
12	Banjarmasin	III	0	0	625	0	0
13	Tenau Kupang	III	0	0	78	0	0
14	Sampit	III	0	0	0	0	100
15	Samarinda dan TPK Palaran	IV	0	0	497	0	0
16	Balikpapan dan TP Kariangau	IV	0	0	460	0	0
17	*Bitung (TPB)*	IV	0	114	0	0	0
18	Pantoloan	IV	0	0	349	0	0
19	Kendari (Kendari New Port)	IV	0	0	0	689	0
20	*Makassar*	IV	345	0	0	0	0
21	Ternate	IV	0	0	0	141	0
22	Ambon	IV	0	0	344	0	0
23	Sorong	IV	0	0	799	0	0
24	Jayapura	IV	0	0	0	0	453
	Total Cluster I		0	10,585	15,761	606	212
	Total Cluster II		2564	3544	0	9490	583
	Total Cluster III		8563	0	1873	0	100
	Total Cluster IV		345	1141	2449	830	453

Note: *<name>* Hub port; <name> Feeder port.

As the results, the objective values for Models 1, 2, and 3 are 714,071, 668,197, and 5761 (in trillion rupiahs), respectively. All models obtained the optimal solutions for the considered port network size within a computational time of less than one second. This short computation time proves that port development problems with real cases can be solved by mathematical modeling with optimal solutions (e.g., there is no need to develop algorithms or simulations). For further analysis, we present Tables 2, 3 and A5. The detailed calculations for obtaining the objective values in Models 1 and 2 are presented in Table 2 (an example of Model 1′s result is used). The amount of money invested in a container port at any period (Table 1) affects the container flow at the next year (Table 2), and the effect of the investments is accumulated for the subsequent years while considering the devaluation of the currency. The accumulated investment is multiplied by the total number of connected ports with the developed port, as listed in the last column of Table A5.

Some comparisons between Models 1, 2, and 3 are listed as follows:

- Model 1 has more investment effects than Model 2 because the investment budget is not limited to any cluster every year. Model 1 is appropriate for maximizing the container flow within a short term.
- When we want to ensure more balanced improvements between port clusters (as shown in the "Total Cluster" rows at the end of Table A2) and better long-term improvement within the whole port network, Model 2's solution is better. Having a balanced improvement within port clusters allows better flows of goods between all regions in Indonesia, especially when there is an imbalanced amount of resource types produced in each area.

- Objective values of Models 1 and 3 are not comparable because different parameters are calculated, but some comparable values are provided in Figure 3 (which will be explained later at the end of Section 4).

Table A5 shows the average travel time required from each container port to all other ports in the same cluster, and the average travel time between all ports in each cluster is summarized at the bottom part of Table A5. In Model 3, we maximized the investment for ports with potential lower container transportation costs within each cluster. Such a transportation strategy focuses more on increasing the transportation effectiveness between the hub ports and the feeder ports. Given the current routes (Figure 2), some connections between ports in each cluster do not exist, but the links can be added after calculating the impact of the changes when implementing Model 3′s solution.

Using each cluster's average travel time information leads us to the following port cluster development priority: Clusters III, I, II, then IV. This development priority follows the development strategy presented by objective Equation (7), which invests first in container ports that are located closer to each other within their cluster. The priority is based on a sequence of the average time travels to other ports within each cluster (in ascending order) in the bottom part of Table A5. In Model 3′s solution, the budget is allocated first to the prioritized clusters until their required investment amount is satisfied. The results confirmed that our research hypothesis was correct. The investment decisions for multiple ports were highly dependent on the connectivity of the ports and distances between ports in each port cluster.

Table 2. Estimated investment effect on container flow between ports based on Model 1′s result (in trillion rupiahs).

No.	Container Port	Cluster	Year 1	Year 2	Year 3	Year 4	Year 5
1	*Belawan/Kuala Tanjung*	I	0	0	44,875	95,251	87,708
2	Malahayati	I	0	0	0	1056	972
3	Batam (Batu Ampar)	I	0	0	0	464	863
4	*Tanjung Priok/Kalibaru*	II	0	14,166	31,074	28,613	26,347
5	Pontianak/Kijing (Kalbar)	II	0	0	0	0	2091
6	Palembang/Tanjung Carat (Sumsel)	II	0	0	0	0	4731
7	Jambi/Muara Sabak	II	0	0	0	0	0
8	Teluk Bayur	II	0	0	0	0	0
9	Panjang (Lampung)	II	0	0	0	0	0
10	*Tanjung Perak*	III	0	63,079	58,084	53,484	49,249
11	Tanjung Emas	III	0	0	0	1827	1682
12	Banjarmasin	III	0	0	0	976	899
13	Tenau Kupang	III	0	0	0	122	112
14	Sampit	III	0	0	0	0	0
15	Samarinda dan TPK Palaran	IV	0	0	0	776	715
16	Balikpapan dan TP Kariangau	IV	0	0	0	718	661
17	*Bitung (TPB)*	IV	0	0	5805	5345	4922
18	Pantoloan	IV	0	0	0	545	502
19	Kendari (Kendari New Port)	IV	0	0	0	0	495
20	*Makassar*	IV	0	2541	2340	2155	1984
21	Ternate	IV	0	0	0	0	101
22	Ambon	IV	0	0	0	537	495
23	Sorong	IV	0	0	0	1248	1149
24	Jayapura	IV	0	0	0	0	0

Note: <*name*> Hub port; <name> Feeder port.

Table 3. Sensitivity analysis result.

Change	Cluster	Model 1					Model 2					Model 3				
		Yr1	Yr2	Yr3	Yr4	Yr5	Yr1	Yr2	Yr3	Yr4	Yr5	Yr1	Yr2	Yr3	Yr4	Yr5
0.7	I	0.0	0.0	0.0	**1.4**	**−0.7**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	**−0.1**	**0.8**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	IV	0.0	0.0	**0.2**	**−0.1**	**−0.7**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.8	I	0.0	0.0	0.0	**0.9**	**−0.8**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	IV	0.0	0.0	**0.1**	**−0.6**	**0.4**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.9	I	0.0	0.0	0.0	**0.2**	**2.6**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	0.0	**−0.2**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	IV	0.0	0.0	**0.2**	**−0.2**	**−0.9**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	I	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	IV	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1	I	0.0	0.0	**−0.1**	**1.8**	**−1.1**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	**−0.1**	**1.0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	IV	0.0	0.0	**0.2**	**−0.2**	**−0.8**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2	I	0.0	0.0	0.0	**1.3**	**−1.2**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	IV	0.0	0.0	**0.2**	**−1.0**	**0.6**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.3	I	0.0	0.0	**−0.1**	**1.3**	**3.8**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	**−0.1**	**−0.4**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	III	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	IV	0.0	0.0	**0.3**	**−0.2**	**−1.3**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(no shading) deviation is very close to 0
(light grey) 0 < ∣deviation∣ ≤ 0.5
(dark grey) 0.5 < ∣deviation∣ ≤ 1
(black) 1 < ∣deviation∣ ≤ 4

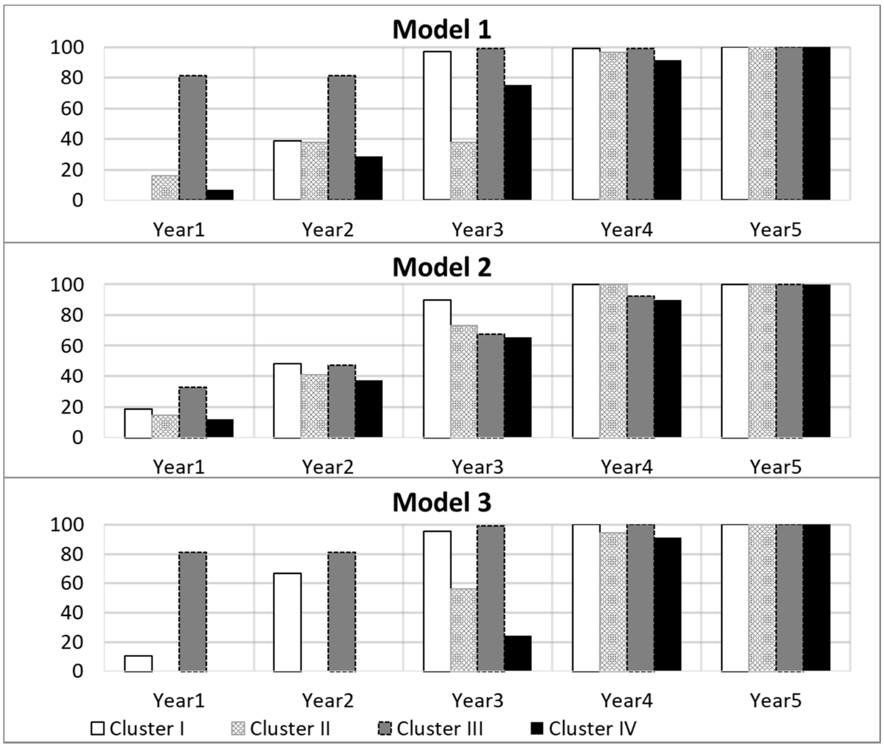

Figure 3. Accumulated investments for port clusters (in percentage).

5. Analysis

We propose basic models that can be used to assess the port development decisions and their effects on the increase in container flows. However, some other aspects should be considered for ensuring a more accurate performance estimation and evaluation, as stated below.

Our study assumes that the ports' initial capacities are sufficient for smooth container flows between ports and port clusters. However, it is necessary to assess the exact capacities by observing the installed facilities, especially the quay cranes and berths that define the container transfer rate from a container port to the other ports. Considering such equipment's limited capacity in the ports is important to ensure the ports' accurate transfer rates. Thus, this existing equipment capacity information should be considered in future research. Additionally, having an accurate quay crane transfer rate can be combined with a detailed simulation that considers the container transportation behavior from/to the hinterland side [55].

The actual container flows between ports should be limited by the number of existing vessels (fleet size) and their installed routes [56]. Consideration of such information allows us to identify the bottleneck part in the container port network performance improvement analysis, which could be the improved port capacity or the vessel fleet's existence. Up to now, there were only a few studies related to bottleneck assessment in maritime networks [57]. Given the information, decisions on improving the vessel fleet size and updating vessel routes can also be evaluated.

We assume that any amount of investment can directly affect the increase in container flows starting from the next year (or increase such potential for container flow growth). In a more realistic setting, we might consider the learning rate required to implement the investment, which depends on its amount. The learning curve was extensively studied in the field of manufacturing system operation management. It refers to the increase in workers' performance after working for certain periods when a new production system is introduced—e.g., new process development [58] and production capacity expansion [59]. In our case, different port clusters might be managed under different management; thus, different areas might have various port development speeds—e.g., in the high-populated region compared with the less developed area.

We tested our models' robustness by modifying the available budget for each container port and year in Table A1, with the values starting from 70%, increasing by 10% up to 130%. In the ideal situation, we expect that the change in the invested amount is as close as possible to the amount of change in the available budget. We observed some more change from that threshold, as shown in Table 3—i.e., −0.1% value in the second row—which means that the total invested amount in port cluster II at Year 4 is 0.6%; thus, the change is −0.1% (calculated from 0.6–0.7%). We categorized the changes into four types of ranges with a maximum value of 3.8%. It can be concluded that the obtained optimal solution is robust when observed from the viewpoint of improvement levels in each port cluster.

Using the proposed models, we can deal with investment plan changes after a certain number of years by solving the models several times using the rolling planning horizon approach. Solving the model several times is no problem because the solutions can be obtained within a short computational time.

Our current study focused on solving the investment problem for multiple ports considering the relationships between the ports. We modeled the effects of the investment amount at the seaside operation on the terminal's throughput. The effect was generally observed by considering that the amount of the investment affects the throughput linearly. For future studies, it is necessary to assess (1) the detailed allocation of the investment to the measurable specific facilities at the seaside, e.g., length of berths and number of quay cranes, and (2) the investment or its effects at the landside of the terminal—e.g., yard capacity, yard cranes, connectivity with the hinterland, etc.

6. Managerial Insights

Mathematical models have been proven to provide good assistance to decision makers in making investment decisions. The reason for this is that quantitative information allows better information sharing and higher success rates than qualitative information [60]. Successful applications of the mathematical modeling approach for investment decisions in real companies (e.g., General Electric, Cities Service Company, and Grantham, May, Van Otterloo and Company LLC (GMO)) are presented in [51,61–63]. The applied models and produced the best combination of investment strategies that satisfy the objectives and constraints set in Cities Service Company [62]. Various cases were generated by modifying the objectives and constraints, allowing the company to consider some alternative investment decisions. The management accepted the models' solutions, and the company became more reactive in terms of anticipating external events. As the users became more familiar with the models, they requested more improvements through the addition of new features in the models. Such success in utilizing the results of investment models above can also be applied to the container port network development case. This mathematical modeling can be used to formalize the knowledge of the decision makers, help to assess whether certain knowledge eventually has a great impact on the expected system's performance, and assess the extent to how much the decision benefits the decision makers. In our case, the proposed models can be used for confirming the importance of port connectivity in the port investment problem [64].

The selection of the best investment decision enabled an opportunity for more detailed analysis by using simulation models or accounting procedures [63]. The models were used for (1) assessments in long-term analysis with estimated values and (2) short-term and detailed decision making [62]. In the example of GMO company, the company gained the following advantages through the investment model implementations: (1) keeping existing businesses, (2) increasing new growth opportunities, (3) improving the company's operation, and (4) being able to track how close their investment decisions are to their target [51].

Our proposed methods are more suitable to optimize investment decisions when the government manages the whole container port network. In this situation, it is possible to allocate the investments to improve the whole network's capacity without dealing with competition between ports. The proposed methods can perform more effectively when applied to port networks with more ports and high connectivity.

7. Conclusions

This study was the first to introduce the problem of making investment decisions on multiple ports under single management while considering relationships between the ports that are related to the container flows. We proposed three mathematical models to determine the appropriate investment amount for container ports within a network. Effects of the investment were observed based on the existing number of connected ports and the travel time between ports in the same cluster. The optimal amount of investment in each container port every year was determined optimally within a very short time. It was shown that the proposed solution method was robust enough to deal with changes in the available investment budget. The produced results could provide useful insights for the managers on how to allocate the investment budget well.

Future research topics should consider a better estimation of the port capacities based on the number of installed quay cranes, port network bottleneck analysis considering existing vessel fleet size and routes, and the increased learning curve in the container flow that applies when the capacities of the ports are increased every year. It is necessary to develop efficient heuristics to solve the problem, considering the potential increase in model complexity through the addition of such new parameters.

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Appendix A. Input Data and Additional Results

In this section, we present the input data for the proposed models and some additional results obtained using the models.

Table A1. Container ports and available budget data (budget in trillion rupiahs).

No.	Container Port	Cluster	Year 1	Year 2	Year 3	Year 4	Year 5	Total
1	*Belawan/Kuala Tanjung*	I	4280	6720	10,700	2700	0	24,400
2	Malahayati	I	549	1015	0	0	0	1564
3	Batam (Batu Ampar)	I	240	360	600	0	0	1200
4	*Tanjung Priok/Kalibaru*	II	1309	2181	2618	0	0	6108
5	Pontianak/Kijing (Kalbar)	II	291	582	727	1309	0	2909
6	Palembang/Tanjung Carat (Sumsel)	II	658	1316	1645	2962	0	6581
7	Jambi/Muara Sabak	II	0	100	100	100	0	300
8	Teluk Bayur	II	44	82	35	0	0	161
9	Panjang (Lampung)	II	24	37	61	0	0	122
10	*Tanjung Perak*	III	3024	1273	1638	2141	487	8563
11	Tanjung Emas	III	320	138	287	234	191	1170
12	Banjarmasin	III	76	108	139	198	104	625
13	Tenau Kupang	III	12	21	33	0	12	78
14	Sampit	III	20	20	20	20	20	100
15	Samarinda dan TPK Palaran	IV	0	99	149	249	0	497
16	Balikpapan dan TP Kariangau	IV	92	138	230	0	0	460
17	*Bitung (TPB)*	IV	150	166	132	249	444	1141
18	Pantoloan	IV	64	31	82	82	90	349
19	Kendari (Kendari New Port)	IV	6	139	206	338	0	689
20	*Makassar*	IV	132	131	36	46	0	345
21	Ternate	IV	8	21	68	44	0	141
22	Ambon	IV	135	53	112	44	0	344
23	Sorong	IV	13	439	171	176	0	799
24	Jayapura	IV	25	100	294	34	0	453
	Total Cluster I		5069	8095	11,300	2700	0	27,164
	Total Cluster II		2326	4298	5186	4371	0	16,181
	Total Cluster III		3452	1560	2117	2593	814	10,536
	Total Cluster IV		625	1317	1480	1262	534	5218
	Total Cluster I-IV		11,472	15,270	20,083	10,926	1348	59,099

Note: <*name*> Hub port; <name> Feeder port.

Table A2. Travel time data between ports (in minutes).

No.	Container Port	1	2	3	4	5	...	22	23	24
1	*Belawan/Kuala Tanjung*		17	25	58	46	...	138	151	195
2	Malahayati			52	74	64	...	155	168	213
3	Batam (Batu Ampar)				33	21	...	113	126	170
4	*Tanjung Priok/Kalibaru*					31	...	93	107	151
5	Pontianak/Kijing (Kalbar)						...	98	112	154
6	Palembang/Tanjung Carat (Sumsel)						...	103	116	161
7	Jambi/Muara Sabak						...	112	125	169
8	Teluk Bayur						...	131	145	189
9	Panjang (Lampung)						...	123	108	171
10	*Tanjung Perak*						...	69	82	127
11	Tanjung Emas						...	79	92	137
12	Banjarmasin						...	65	78	122
13	Tenau Kupang						...	31	46	90
14	Sampit						...	71	84	129
15	Samarinda dan TPK Palaran						...	62	66	108
16	Balikpapan dan TP Kariangau						...	61	68	108
17	*Bitung (TPB)*						...	26	28	110
18	Pantoloan						...	57	59	100
19	Kendari (Kendari New Port)						...	25	55	82
20	*Makassar*						...	41	55	82
21	Ternate						...	21	20	63
22	Ambon						...		19	40
23	Sorong						...			45
24	Jayapura						...			

Note: *<name>* Hub port; <name> Feeder port. Only the upper triangle is used to represent the travel times (symmetric travel times between any pair of container ports are considered).

Table A3. Investment decision as the result of Model 2 (in trillion rupiahs).

No.	Container Port	Cluster	Year 1	Year 2	Year 3	Year 4	Year 5
1	*Belawan/Kuala Tanjung*	I	5069	8095	11,236	0	0
2	Malahayati	I	0	0	0	1564	0
3	Batam (Batu Ampar)	I	0	0	64	1136	0
4	*Tanjung Priok/Kalibaru*	II	2326	3782	0	0	0
5	Pontianak/Kijing (Kalbar)	II	0	0	0	2909	0
6	Palembang/Tanjung Carat (Sumsel)	II	0	0	5186	1395	0
7	Jambi/Muara Sabak	II	0	300	0	0	0
8	Teluk Bayur	II	0	94	0	67	0
9	Panjang (Lampung)	II	0	122	0	0	0
10	*Tanjung Perak*	III	3452	1560	2117	1434	0
11	Tanjung Emas	III	0	0	0	456	714
12	Banjarmasin	III	0	0	0	625	0
13	Tenau Kupang	III	0	0	0	78	0
14	Sampit	III	0	0	0	0	100
15	Samarinda dan TPK Palaran	IV	0	0	0	497	0
16	Balikpapan dan TP Kariangau	IV	0	107	337	16	0
17	*Bitung (TPB)*	IV	280	861	0	0	0
18	Pantoloan	IV	0	349	0	0	0
19	Kendari (Kendari New Port)	IV	0	0	0	296	393
20	*Makassar*	IV	345	0	0	0	0
21	Ternate	IV	0	0	0	0	141
22	Ambon	IV	0	0	344	0	0
23	Sorong	IV	0	0	799	0	0
24	Jayapura	IV	0	0	0	453	0
	Total Cluster I		5069	8095	11,300	2700	0
	Total Cluster II		2326	4298	5186	4371	0
	Total Cluster III		3452	1560	2117	2593	814
	Total Cluster IV		625	1317	1480	1262	534

Note: *<name>* Hub port; <name> Feeder port.

Table A4. Investment decision as the result of Model 3 (in trillion rupiahs).

No.	Container Port	Cluster	Year 1	Year 2	Year 3	Year 4	Year 5
1	*Belawan/Kuala Tanjung*	I	2909	15,270	6221	0	0
2	Malahayati	I	0	0	1564	0	0
3	Batam (Batu Ampar)	I	0	0	0	1200	0
4	*Tanjung Priok/Kalibaru*	II	0	0	6108	0	0
5	Pontianak/Kijing (Kalbar)	II	0	0	2891	18	0
6	Palembang/Tanjung Carat (Sumsel)	II	0	0	0	5986	595
7	Jambi/Muara Sabak	II	0	0	0	0	300
8	Teluk Bayur	II	0	0	0	161	0
9	Panjang (Lampung)	II	0	0	122	0	0
10	*Tanjung Perak*	III	8563	0	0	0	0
11	Tanjung Emas	III	0	0	1170	0	0
12	Banjarmasin	III	0	0	625	0	0
13	Tenau Kupang	III	0	0	0	78	0
14	Sampit	III	0	0	100	0	0
15	Samarinda dan TPK Palaran	IV	0	0	0	497	0
16	Balikpapan dan TP Kariangau	IV	0	0	0	460	0
17	*Bitung (TPB)*	IV	0	0	1141	0	0
18	Pantoloan	IV	0	0	0	349	0
19	Kendari (Kendari New Port)	IV	0	0	0	689	0
20	*Makassar*	IV	0	0	0	345	0
21	Ternate	IV	0	0	141	0	0
22	Ambon	IV	0	0	0	344	0
23	Sorong	IV	0	0	0	799	0
24	Jayapura	IV	0	0	0	0	453
	Total Cluster I		2909	15,270	7785	1200	0
	Total Cluster II		0	0	9121	6165	895
	Total Cluster III		8563	0	1895	78	0
	Total Cluster IV		0	0	1282	3483	453

Note: *<name>* Hub port; <name> Feeder port.

Table A5. Average time travels to other container ports.

No.	Container Port	Cluster	Average Time Travels to Other Ports (in Minutes)	Number of Connected Ports
1	*Belawan/Kuala Tanjung*	I	21.0	5
2	Malahayati	I	34.5	1
3	Batam (Batu Ampar)	I	38.5	1
4	*Tanjung Priok/Kalibaru*	II	25.0	6
5	Pontianak/Kijing (Kalbar)	II	35.4	1
6	Palembang/Tanjung Carat (Sumsel)	II	54.4	1
7	Jambi/Muara Sabak	II	61.4	1
8	Teluk Bayur	II	49.4	1
9	Panjang (Lampung)	II	25.2	1
10	*Tanjung Perak*	III	20.0	8
11	Tanjung Emas	III	34.5	2
12	Banjarmasin	III	28.5	2
13	Tenau Kupang	III	46.3	2
14	Sampit	III	25.3	1
15	Samarinda dan TPK Palaran	IV	39.6	2
16	Balikpapan dan TP Kariangau	IV	44.2	2
17	*Bitung (TPB)*	IV	34.9	6
18	Pantoloan	IV	40.3	2
19	Kendari (Kendari New Port)	IV	38.4	1
20	*Makassar*	IV	35.8	8
21	Ternate	IV	33.1	1
22	Ambon	IV	39.1	2
23	Sorong	IV	46.1	2
24	Jayapura	IV	82.0	1
	Ports in Cluster I		31.3	
	Ports in Cluster II		41.8	
	Ports in Cluster III		30.9	
	Ports in Cluster IV		43.4	

Note: *<name>* Hub port; <name> Feeder port.

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Short Biography of Authors

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Evaluation of GHG Emission Measures Based on Shipping and Shipbuilding Market Forecasting

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Abstract: Greenhouse gas (GHG) emissions from the global shipping sector have been increasing due to global economic growth. The International Maritime Organization (IMO) has set a goal of halving GHG emissions from the global shipping sector by 2050 as compared with 2008 levels, and has responded by introducing several international regulations to reduce the GHG emissions of maritime transportation. The impact of GHG emissions' regulation and measures to curb them have been evaluated in the IMO's GHG studies. However, the long-term influence of these GHG emission measures has not yet been assessed. Additionally, the impact of various GHG reduction measures on the shipping and shipbuilding markets has not been considered; accordingly, there is room for improvement in the estimation of GHG emissions. Therefore, in this study, a model to consider GHG emission scenarios for the maritime transportation sector was developed using system dynamics and was integrated into a shipping and shipbuilding market model. The developed model was validated based on actual results and estimation results taken from a previous study. Subsequently, simulations were conducted, allowing us to evaluate the impact and effectiveness of GHG emission-curbing measures using the proposed model. Concretely, we conducted an evaluation of the effects of current and future measures, especially ship speed reduction, transition to liquid natural gas (LNG) fuel, promotion of energy efficiency design index (EEDI) regulation, and introduction of zero-emission ships, for GHG emission reduction. Additionally, we conducted an evaluation of the combination of current and future measures. The results showed that it is difficult to achieve the IMO goals for 2050 by combining only current measures and that the introduction of zero-emission ships is necessary to achieve the goals. Moreover, the limits of ship speed reduction were discussed quantitatively in relation to the maritime market aspect, and it was found that the feasible limit of ship speed reduction from a maritime market perspective was approximately 50%.

Keywords: GHG emission measures; international shipping; system dynamics; scenario planning; deceleration operation; energy efficiency design index; LNG fuel; zero-emission ships

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1. Introduction

1.1. Background and Research Objective

Sea cargo movement continues to rise because of global economic growth. As a result, there has been an increase in the number of ships used in maritime transportation, which has led to corresponding growth in greenhouse gas (GHG) emissions. The International Maritime Organization (IMO) has estimated GHG emissions by the maritime transportation sector in recent years [1] and has established regulations for GHG emissions based on that estimation.

To project GHG emissions by the maritime transportation sector in the future, it is imperative to forecast fleet volumes. For this purpose, accurate demand forecasting for shipping and shipbuilding is important. However, as the shipping and shipbuilding market is a complex integrated system, the development of an accurate demand forecasting model is not easy. For example, sea cargo movement is, fundamentally, complexly influenced by the world economy. Orders for newly built ships are also influenced by various factors, such as the price of the ship, the order books of shipyards, and the demolition of older ships. In addition, when shipyards receive orders from shipping companies, the order books and the ship price change concurrently. Fleet volumes fluctuate with the number of ships under construction and with ship demolition.

Thus, demand forecasting for shipping and shipbuilding is essential to estimate future GHG emissions. However, the complex and dynamic relationship between shipping and shipbuilding markets was not considered in the IMO's GHG study. Therefore, there is room for improvement in the estimation of GHG emissions. Additionally, research evaluating the long-term impact of GHG emission measures is insufficient.

With these points in mind, this study develops a model to evaluate GHG emission measures for the maritime transportation sector using system dynamics. Using the proposed model, simulations were conducted, based on which we evaluated the impact and effectiveness of current and future measures for GHG emission reduction. Then, we built a theoretical framework to develop a model that comprehensively evaluates the impact of GHG emission measures in the maritime market.

1.2. Related Literature

Some studies have already been conducted to evaluate the social and economic impacts of GHG emission regulations. Komiyama et al. [2] predicted changes in long-term energy demand and power supply composition under the constraint of carbon dioxide (CO_2) emission in Japan. Holz et al. [3] predicted changes in global CO_2 emissions and surface temperatures using system dynamics models and analyzed carbon dioxide removal deployment scenarios.

Similarly, to support decision-making to solve the complex problem of GHG emissions in the maritime transportation sector, some studies have forecasted GHG emissions and discussed effective measures to curb emissions in the maritime logistics field. In the third IMO GHG study [1], current CO_2 emissions were estimated using automatic identification system (AIS) data, while future CO_2 emissions were forecasted using the representative concentration pathway and shared socioeconomic pathway scenarios. In addition to these scenarios, a fuel mix scenario in which liquid natural gas (LNG) is introduced with the main fuel as well as a fuel efficiency improvement scenario were inputted to forecast CO_2 emissions. In the fourth IMO GHG study [4], CO_2 emissions estimations and future CO_2 emissions were updated; additionally, estimation of carbon intensity and an analysis of the relations between CO_2 reduction costs and CO_2 abatement potential for each GHG reduction technology were conducted. Similarly, Faber et al. [5] estimated current CO_2 emissions and considered the impact of an emissions trading scheme on the maritime transportation sector. Lindstad et al. [6] estimated and compared the well-to-wake GHG emissions of LNG fuel and traditional fuels (i.e., marine gasoil (MGO) and heavy fuel oil (HFO)). The results indicated that increased use of LNG engines would increase GHG emissions compared with conventional fuels (MGO, HFO, and Scrubber, as well as very low sulfur fuel oil) by increasing methane emissions. Rehmatulla et al. [7] quantified the implementation of over 30 energy-efficient and CO_2 emission technologies in the shipping sector using a cross-sectional survey. These studies focused on the estimation and forecasting of GHG emissions and carbon intensity, as well as the evaluation of GHG emission measures. However, deployment scenarios for GHG emission reduction technologies were not provided, and comprehensive scenarios to achieve IMO goals (i.e., how GHG reduction measures should be combined and when the measures would start to apply) have not yet been presented.

As can be gleaned by the points highlighted above, estimates of GHG emissions in the shipping industry and the efficiency evaluation of GHG emission reduction technologies have been conducted in previous studies [1,4–7]. However, these previous studies [1,4–7] do not provide a quantitative assessment of the impact of GHG emission measures on the shipping and shipbuilding markets, nor do they fully discuss scenarios for introducing various GHG emission measures. In recent years, there has been a deceleration in ship operations because of a slump in maritime market conditions and soaring fuel costs [8]. Smith [9] analyzed the impact of ship speed reduction operations on GHG reductions and ship owner's profits and found that, ceteris paribus, operations to maximize a ship owner's profits negate the benefit of emissions reductions achieved through technology. However, it is difficult to grasp the time-series changes in the shipping and shipbuilding markets through ship speed reduction, because various factors in the shipping and shipbuilding markets and their causal relationships were not considered. From the above, it appears that deceleration is also effective in reducing GHG emissions; however, the impact of deceleration on the shipping and shipbuilding market has not been fully considered.

On the other hand, in order to support decision making in the maritime industry, various studies on analyzing and modeling of maritime markets have been conducted. Nielsen [10] analyzed the maritime market using a causal loop diagram and developed a forecasting model for the shipbuilding market. Sakalayen et al. [11] formulated ship quantity order fluctuations using Newton's law of gravitation and developed a prediction model for order quantity by applying the multivariate autoregressive integrated moving average model. Gourdon [12] analyzed the price and cost determinants of new ships and discussed the impact of intervention by government agencies in the shipbuilding market. Shin and Lim [13] developed an empirical model of national competition in the shipbuilding industry using a Cournot oligopoly model based on the real behavior of shipbuilding companies. Taylor [14], the Japan Maritime Research Institute SD Study Group [15], and Engelen et al. [16] developed forecasting models for the shipping and shipbuilding market using system dynamics. Similarly, in a previous study by the present authors [17], we developed a model to forecast the main elements of the shipbuilding market, such as the amount of sea cargo movement, order of ships, construction, and scrapping, using system dynamics. Using this model, we forecast fleet volume, which is the key element in GHG emission estimation, by setting parameters such as GDP and cargo transportation distance. Although analysis and modeling in the maritime market have been carried out in these studies [10–17], a model that considers both the maritime market and GHG emissions has not yet been developed.

Against these backgrounds, in this study, a GHG emission prediction model is developed and integrated into a model that forecasts the demand for shipbuilding in a previous study [17]. Based on the aforementioned considerations, the characteristics of this study can be summarized as follows:

- The long-term impact of current GHG reduction measures, such as the deceleration of operations of ships, transition to LNG fuel, and promotion of the energy efficiency design index (EEDI), is evaluated.
- GHG emission reduction countermeasures based on the introduction of zero-emission ships, which are being considered for introduction in the future, are considered.
- The GHG emission reduction effect by current measures and future measures alone is clarified using the proposed model. Additionally, the impact and effectiveness of combining current measures and future measures are evaluated using the proposed model.
- The limitations of operating speed deceleration measures on shipping and the shipbuilding market are evaluated quantitatively using the proposed model.

2. Basic Concept

2.1. Overview of System Dynamics

System dynamics (SD), which was developed at the Massachusetts Institute of Technology in 1956, is a well-known numerical simulation technique used to analyze complex and dynamic systems [18]. The fundamental concept of system dynamics is modeling causal relations by mathematically considering time delays between the elements of the system and conducting a simulation using the developed model. Using this technique, we can analyze complex systems based on logical reasoning, which helps ascertain the characteristics and dynamic behaviors of the systems. In recent years, SD has been progressing, mainly owing to the work of Sterman [19] and colleagues; Sterman et al. [20] developed a policy decision-making model for global GHG emission reductions.

This study uses SD to develop a model that considers the relationship between the shipping and shipbuilding markets and GHG emissions in the shipping sector. On this basis, deployment scenarios for GHG reduction measures are examined.

2.2. Basic Configuration of the SD Model

The target ship type in this study is the bulk carrier. The target cargo commodities include iron ore, coal, and grain. The basic concept of demand forecasting as employed in this study is shown in Figure 1. This figure was described based on the concept of stock and flow diagram [19] in SD. "Flow" shows the inflow and outflow of substances (i.e., ships and GHG in this figure) into the element. "Information Flow" shows the causal relationship between elements and shows that an element affects direction of the arrow in relation to another element. "Information Flow Considering Time Delay" indicates that an element affects the element in the direction of the arrow with a time delay. As shown in the figure, the SD model in this study consists of the following six sub-models:

1. Cargo transportation prediction model: This model forecasts the total volume of sea cargo movement based on world gross domestic product (GDP) and cargo transportation distance.
2. Order prediction model: This model forecasts the number of orders based on sea cargo movement, fleet volume, backlog of shipyard, and ship price. It considers the change in the number of newly built ships due to ship operating speed reduction.
3. Construction model: Ship construction period is influenced by construction capacity and shipyard order book. The model estimates the total number of ships constructed.
4. Ship price prediction model: This model forecasts the price of a newly built ship based on the backlog of shipyards.
5. Scrap model: This model predicts the number of scrapped ships each month based on the ship's age and shipping market condition. It considers the change in the amount of scrapped ships due to ship operating speed reduction.
6. GHG emissions prediction model: This model forecasts GHG emissions based on the number of ships and fuel consumption. It considers differences in engine performance by ship's age and size. Fuel consumption of auxiliary engine and boiler and differences in fuel type are also considered.

The relationships between sub-models are as follows:

- The total volume of sea cargo movement is calculated by inputting world GDP and cargo transportation distance using (1) the cargo transportation prediction model.
- The ship running distance, which is a measure of transportation efficiency of shipping, is calculated based on sea cargo movement and fleet volume. After that, ship orders and scrapped ships are calculated using (2) the order prediction model and (5) the scrap model.
- The number of orders is determined, the orders for new ships are added to the order books in shipyards, and the amount of ship construction and ship price are calculated considering shipyard condition using (3) the construction model and (4) the ship price prediction model.
- In (6) the GHG emissions prediction model, the fuel consumption for each ship is estimated considering operating speed, ship performance, ship composition, and technological developments for GHG reduction. GHG emissions are calculated based on fuel consumption and fleet volume. Moreover, the operating speed influences the transport efficiency of each ship, and hence also the ship running distance. Shipping and shipbuilding market conditions are changed by this influence.
- Fleet volume and ship composition are updated based on the amounts of ship construction and scrap.

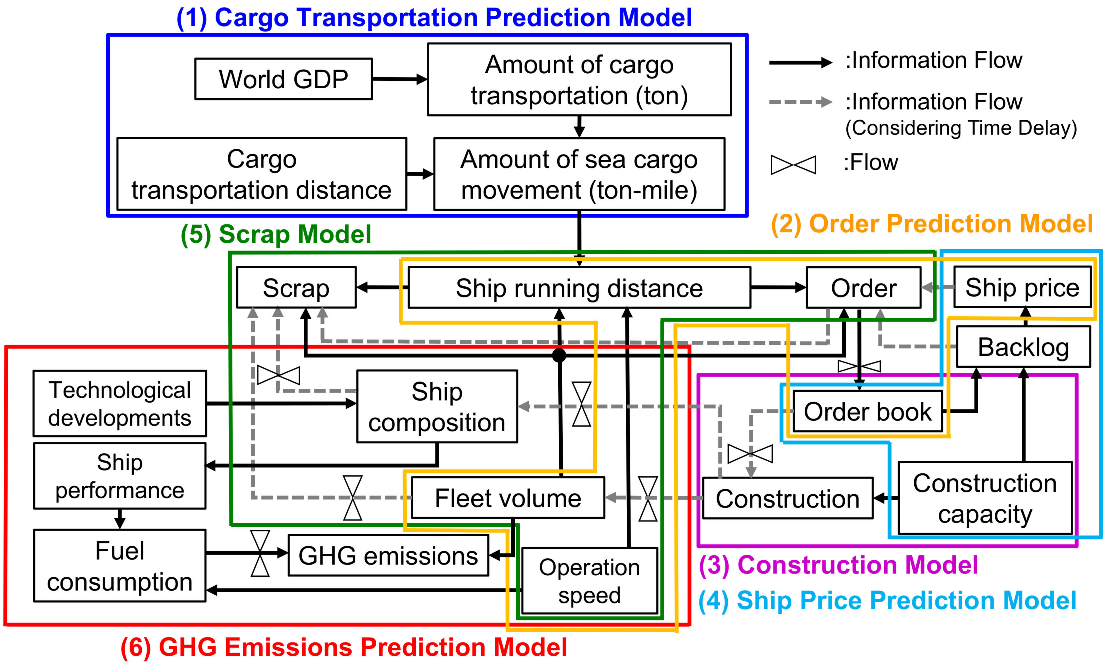

Figure 1. Evaluation model for greenhouse gas (GHG) reduction measures. GDP, gross domestic product.

In summary, this SD model considers the mutual relationships between each of three facets: ship operation, shipping, and shipbuilding markets. Sub-models (1)–(4) were used in previous studies (Wada et al. [17,21]), while (5) the scrap model was improved by introducing the scrap rate to update the ship composition in this study. Additionally, (6) the GHG emissions prediction model is also newly developed.

3. GHG Emissions Prediction Model

3.1. Overview of GHG Emissions Prediction Model

GHG emissions consist of gases such as CO_2, methane (CH_4), and nitrous oxide (N_2O), of which CO_2 accounts for a large proportion. The IMO GHG studies ([1,4]) focused on the estimation of CO_2 emissions; we do the same, to allow for a comparison. Additionally, we focused on CO_2 emission from shipping based on IMO's initial GHG emission reduction strategy [22]. CO_2 emissions from ship construction are not considered in this study.

The volume of CO_2 emissions was determined by fleet volume and fuel consumption. Fleet volume is closely related to the development of shipping and shipbuilding markets, while various factors, such as the fuel efficiency of ships, ship operation, and fuel type, are related to fuel consumption. Therefore, it is important to define and model the relationship among these elements in CO_2 emission estimation using the SD model. Based on the above, in estimating CO_2 emissions, the following points were considered:

- Ship speed deceleration affects shipping and shipbuilding markets. Ship operating speed deceleration influences on shipping and shipbuilding markets and GHG emissions reduction is considered in this study.
- The fuel efficiency performance of ships differs depending on the year of their construction, due to technological developments and regulation changes. The time-series change in fuel efficiency performance of ships is considered in this study.

The models, excluding the GHG emissions prediction model highlighted in Figure 1, were developed in previous studies [17,21]. By integrating the GHG emissions prediction model into the previous study's model and modification of the scrap model, it is possible to evaluate the impact of GHG reduction measures and predict future CO_2 emissions, which is the purpose of this study. Additionally, the impact and effectiveness of operating speed deceleration measures on shipping and shipbuilding markets were evaluated quantitatively using the proposed model.

3.2. Data Utilized in GHG Emissions Prediction Model Development

The data utilized for GHG emissions prediction model development are shown in Table 1. The details of each data type are explained below. The ship specification values are shown in Table 2. These values are used as representative ship types for each size. The definition of each ship size is set as follows: Capesize: 100,000 deadweight tonnage (DWT) and over; Panamax: 65,000–99,999 DWT; Handymax: 40,000–64,999 DWT; and Handysize: 10,000–39,999 DWT. This definition of ship classification follows that of Clarksons [23]:

(1) Ship composition: Ship composition shows the fleet volume for ships at all ages. The ship composition of Capesize, Panamax, Handymax, and Handysize from 2013 to 2018 was obtained from Sea-web ships [24]. It should be noted that Sea-web ships is a ships database provided by IHS Markit.
(2) Ship performance: Ship performance varies depending on the size of the ship. The performance items in this study are shown below.
  (i) Main engine power: The main engine power is the value of the main engine mounted on the ship.
  (ii) Service speed: The service speed is the average ship speed by a ship under loading condition and in calm weather.
  (iii) Specific fuel consumption *(SFC):* SFC indicates fuel consumption per hour of engine output. It depends on the ship's size and age. The values for HFO ships are sets based on the second IMO GHG study [25] and are summarized in Table 3.
  (iv) Fuel consumption of auxiliary equipment and boilers: Fuel consumption of auxiliary equipment and boilers also impacts GHG emission. Fuel consumption by these ship elements is considered. The values are set based on the fourth IMO GHG study [4].
(3) Average voyage time: Average voyage time is determined by converting the annual average voyage days into monthly average hours.
(4) Average DWT: When calculating CO_2 emissions, average DWT is required as a representative value for each ship size, as the unit of fleet volume is converted from the DWT to the number of ships. Average DWT was determined using the actual number of ships and the total DWT of the fleet volume.
(5) Calibration factor, CO_2 emission correction coefficient: CO_2 emissions estimation results for each ship size have been reported in previous studies [4]. The calibration factor was introduced to reproduce the reported CO_2 emissions, because ship size classification and the representative value for each ship size are different between this study and previous studies. This calibration factor was determined using the estimated CO_2 values and actual ship composition data. Additionally, it is also necessary to consider ships whose size is below Handysize (less than 10,000 DWT) when calculating the CO_2 emissions of a bulk carrier. Therefore, we introduced the CO_2 emission correction coefficient to consider the CO_2 emissions of smaller ships. The CO_2 emission correction coefficient has an average value of 1.02, calculated from the actual value for ships smaller than and over 10,000 DWT.
(6) Scrap ship list: The scrap rate for each size is defined to update the ship composition, which is used when calculating CO_2 emissions. The scrap ship list was used to define the scrap rate.

Table 1. Data utilized to define greenhouse gas (GHG) emissions prediction model development. IMO, International Maritime Organization; DWT, deadweight tonnage.

Data Name	Source	Unit	Usage Period
Ship composition	Sea-web ships [24]	DWT	2013–2018
Main engine power	Sea-web ships [24]	kW	2013–2018
Service speed	Sea-web ships [24]	knot	2013–2018
Specific fuel consumption (SFC)	Fourth IMO GHG Study [4]	g/kWh	-
Fuel consumption	Fourth IMO GHG Study [4]	g	2013–2018
Average voyage time	Fourth IMO GHG Study [4]	h	2013–2018
Average DWT	Sea-web ships [24]	DWT	2013–2018
Calibration factor	Fourth IMO GHG Study [4]	-	2013–2018
CO_2 emission correction coefficient	Fourth IMO GHG Study [4]	-	2013–2018
Scrap ship list	Sea-web ships [24]	DWT	Until 2018

Table 2. Ship specifications utilized in this study.

Data Name	Unit	Capesize	Panamax	Handymax	Handysize
Main engine power	kW	17,641	10,248	8,680	6,290
Service speed	knots	14.5	14.4	14.4	13.9
Fuel consumption of auxiliary	ton/month	58.3	58.3	37.2	27.6
Fuel consumption of boiler	ton/month	22.1	26.4	18.2	11.0
Average voyage time	h/month	491	417	374	355
Average DWT	DWT	189,919	79,839	54,322	29,348
Calibration factor	-	1.10	1.02	1.05	0.88
CO_2 emissions correction coefficient	-	1.02			

Table 3. Values of specific fuel consumption (SFC) for heavy fuel oil (HFO) ships (in g/kWh).

Engine Age	>15,000 kW	15,000–5000 kW	<5000 kW
Before 1983	205	215	225
1984–2000	185	195	205
After 2001	175	185	195

3.3. Model Development for GHG Emissions Prediction Model

CO_2 emissions were calculated using Equations (1) and (2).

(1) Calculate main engine output by ship size using Equation (1). The difference in engine output depending on the ship's size is considered; in addition, we consider the effect of deceleration operating on the ratio of service speed to operating speed. Instantaneous main engine power (*Pme*) changes depending on the cube of the ratio of operating speed (*Vt*) to service speed (*Vref*).

(2) Calculate monthly CO_2 emissions using equation (2). First, fuel consumption is calculated by multiplying the main engine output calculated by *SFC*, which represents fuel consumption per hour of engine output, and voyage time. As shown in Table 3, *SFC* is determined by the size and age of the ships. In addition, fuel consumption of auxiliary equipment and boiler for each ship size is considered constant, as noted. For CO_2 emissions below Handysize (0–9999 DWT), the effect is considered by multiplying the total value of CO_2 emissions for each size by the correction coefficient γ. It should be noted that the percentage of total CO_2 emissions taken up by auxiliary equipment and boiler is approximately 10.8% in the case that operating speed is 85.0% of service speed.

$$Pme_t^i = Pref^i \times \left(\frac{Vt_t^i}{Vref^i}\right)^3 \times \alpha^i, \quad (1)$$

$$CO_{2t} = \sum_i \sum_a \sum_\varepsilon \left\{ \left(Pme_t^i \times SFC_{a,\varepsilon,t}^i \times time^i + Ax^i + Bo^i \right) \times Cf_\varepsilon \times N_{a,\varepsilon,t}^i \right\} \times \gamma, \quad (2)$$

where *Pme* is instantaneous main engine power (kW), *Pref* is main engine power (kW), *Vref* is service speed (knots), *Vt* is operating speed (knots), α is the calibration factor, CO_2 is CO_2 emission (g), *SFC* is fuel consumption per kWh (gfuel/kWh), *Cf* is carbon content in fuel (gCO_2/gfuel), time is average voyage time (hours), *N* is the number of ships (number), *Ax* is auxiliary equipment fuel consumption (g), *Bo* is boiler fuel consumption (g), γ is the CO_2 emission correction coefficient, *i* is ship size (1: Capesize, 2: Panamax, 3: Handymax, 4: Handysize), *a* is the age of ships, ε is the fuel type (1: HFO, 2: LNG fuel, 3: zero-emission fuels), and *t* is simulation time (months).

3.4. Correction of Order Prediction Model

In general, transport efficiency decreases as the ships slow down. By this logic, the required fleet quantity per unit of cargo increases and, subsequently, the order quantity of ships increases. This study calculates ship running distance, which indicates transport efficiency using the sea cargo movement and fleet volume, and then uses this to calculate the order and the scrap quantity. The ship running distance is calculated using Equation (3).

$$E_t = \frac{VCtm_t}{V_t}, \quad (3)$$

where *E* is ship running distance (miles), *VCtm* is the sea cargo movement (tons × miles), *V* is the total fleet volume (DWT), and *t* is simulation time (months).

Figure 2 shows the relationship between ship running distance and orders. The features are briefly described below.

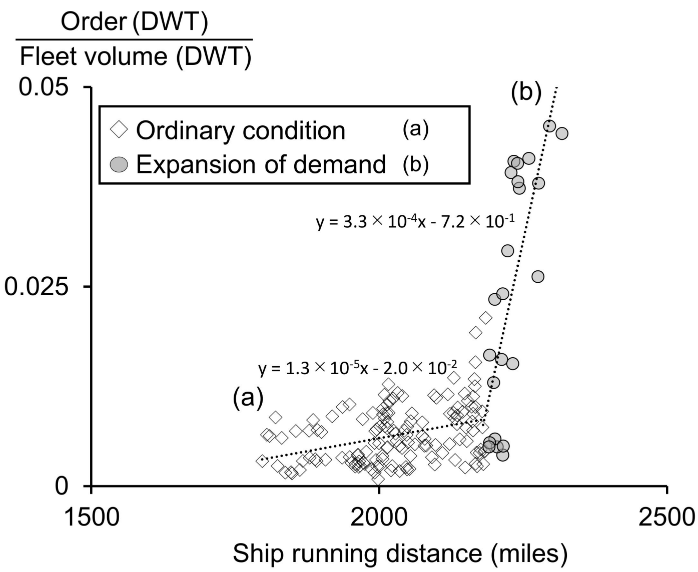

Figure 2. The order prediction model.

- In an ordinary situation, orders will gradually increase as the ship running distance increases (Figure 2(a).
- In a condition where the ship running distance is large, when the ship running distance reaches a certain level, the operation of the ship reaches its limit, and orders increase rapidly (Figure 2(b)).

The influence of operating speed reduction on the order prediction model is shown in Figure 3. Point A is the situation in Figure 2. In the case of Point B in Figure 3, operating speed was reduced by approximately 20%, and the order function moved in parallel by 20% to shorten the ship running distance. In the case of Point C in Figure 3, operating speed was reduced by approximately 30%, and the order function moved in parallel by 30% to shorten the ship running distance. Thus, the order prediction model moved gradually towards the critical juncture of shortening the ship running distance; as a result, the operation of ships was seen to reach the critical limit easily. The total number of orders, considering the influence of operating speed reduction, is calculated using Equation (4). It should be noted here that the basic concept of correction of orders was shown in a previous study by Wada et al. [17]:

$$O_t = f_1(E_t, S_t) \times V_t, \quad (4)$$

where O is the total number of orders (DWT), f_1 is the order prediction model considering operating speed rate, E is the ship running distance (miles), S is the operating speed rate (-), V is the total fleet volume (DWT), and t is simulation time (months).

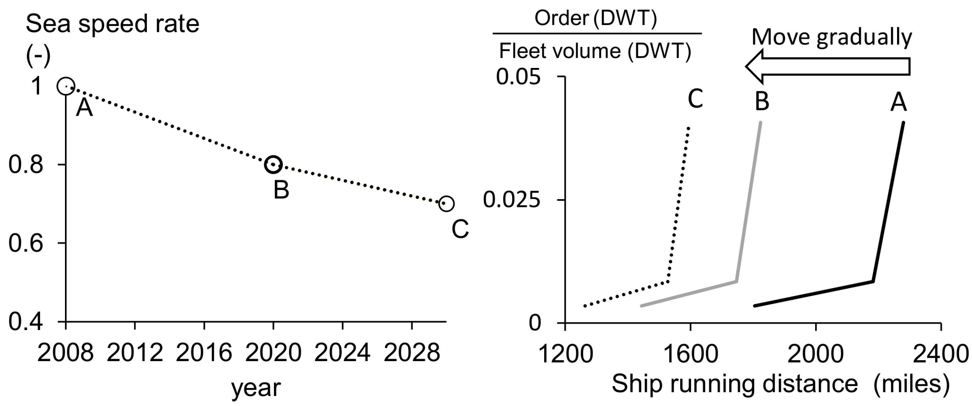

Figure 3. Relation between operating speed reduction scenario and order prediction model.

3.5. Update of Ship Composition

This study suggests that a ship's age composition should reflect changes in ship performance due to the year of construction. The calculation flow is as follows:

(1) Use the scrap model to calculate the amount of scrap. The scrap model was defined for each size (Figure 4). An overview of the scrap model and the model development procedures is given in a previous study (Wada et al. [17]). However, we modified the scrap model by considering the operating speed rate, using the same concept as in Figure 3.

(2) Use the scrap rate according to ship age to calculate the scrap ship by ship age. The scrap rate was defined by normalizing the actual value of demolition (Figure 5). The scrap ship list until 2018 was utilized to define the models. Ship composition was updated by deducting each age of scrap ships. After that, ship composition was updated for 1 month.

(3) Use the construction model to calculate the amount of constructed ships. The amount of constructed ships is added to 0 years of age for each size of ship composition.

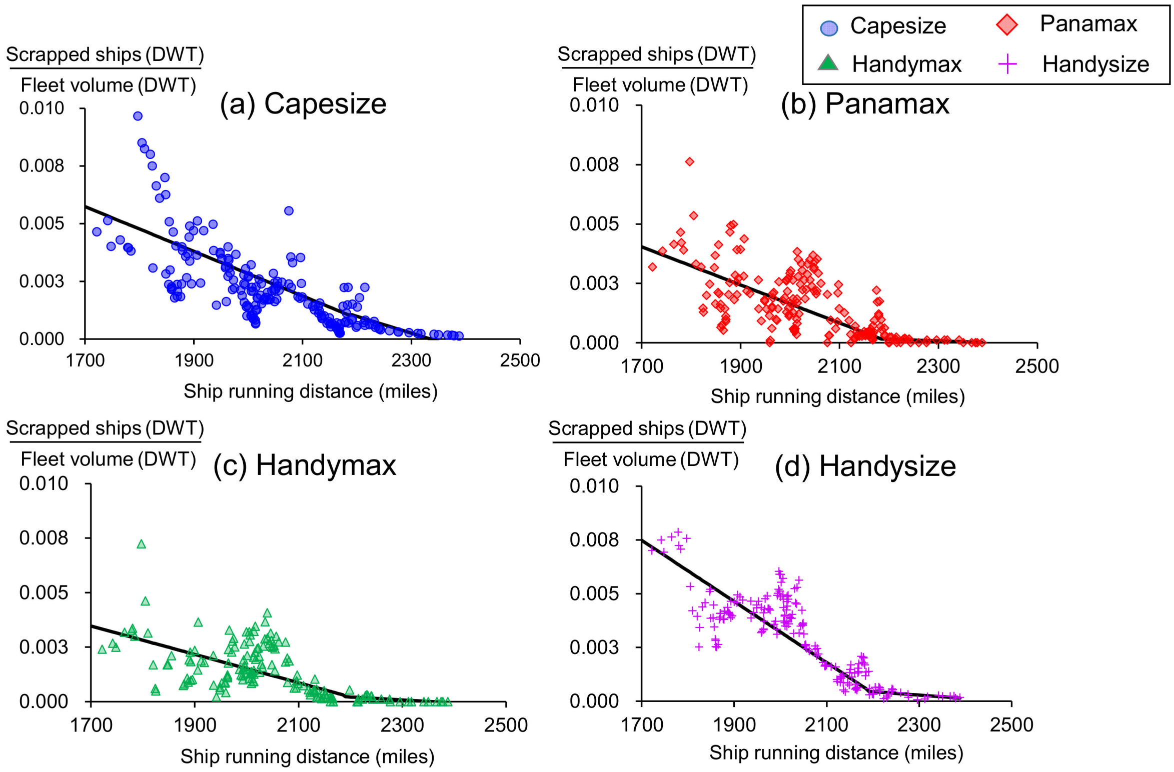

Figure 4. Scrap model for each size of ship. (**a**) Scrap model for Capesize; (**b**) Scrap model for Panamax; (**c**) Scrap model for Handymax; (**d**) Scrap model for Handysize.

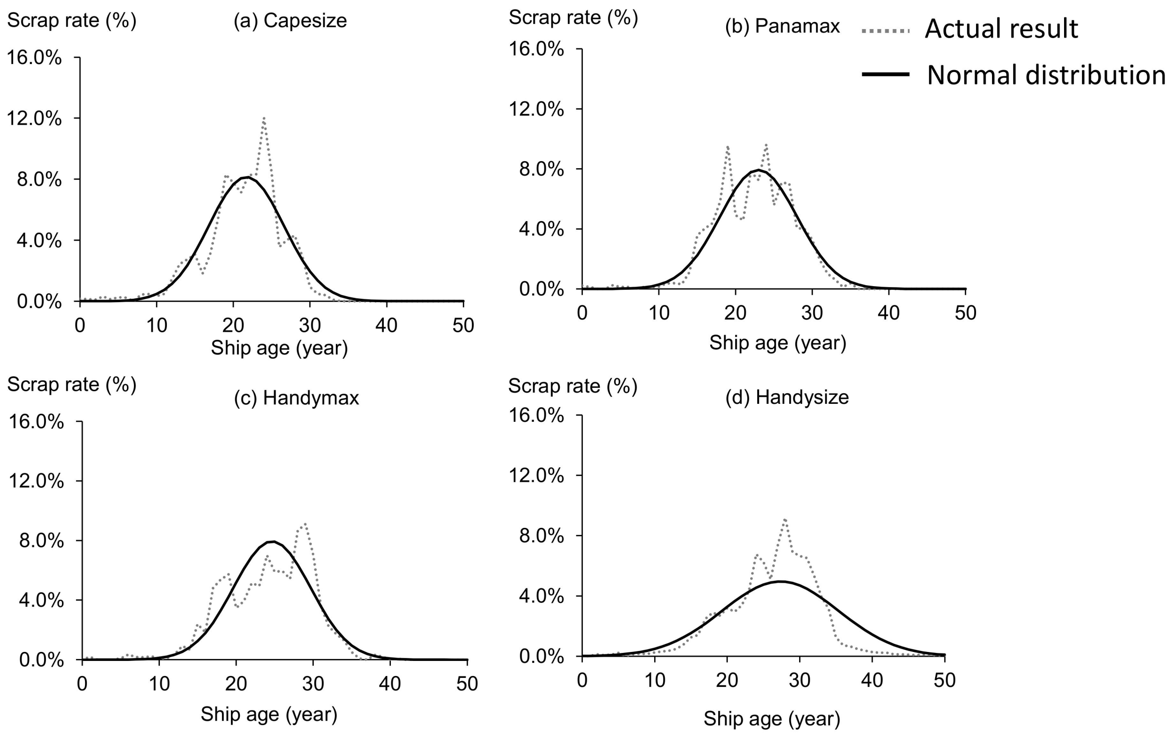

Figure 5. Scrap rate by ship age. (**a**) Scrap rate for Capesize; (**b**) Scrap rate for Panamax; (**c**) Scrap rate for Handymax; (**d**) Scrap rate for Handysize.

The scrap rate represents the probability of demolition for each age of ship based on the actual scrap data. As shown in Figure 5, the average scrap age becomes younger as the ship size increases. The average scrap age is 21.7 years for Capesize, 23.0 years for Panamax, 24.7 years for Handymax, and 27.3 years for Handysize. Using the scrap rate, we considered the actual conditions of scrap considering ship age. The ship composition is calculated using Equations (5)–(8):

$$D_t^i = f_2^i(E_t, S_t) \times V_t^i, \tag{5}$$

$$D_{a,t}^i = f_3^i\left(D_t^i\right), \tag{6}$$

$$Sd_{a,t}^i = Sc_{a,t}^i - D_{a,t}^i, \tag{7}$$

$$Sc_{a,t+1}^i = Sd_{a+1,t}^i + C_{0,t}^i, \tag{8}$$

where D is the amount of scrap (DWT), f_2 is each size of scrap model in Figure 4, E is ship running distance (miles), S is operating speed rate (-), V is fleet volume for each ship size (DWT), f_3 is the each scrap rate in Figure 5, Sd is ship composition deducted each age of scrap ships (DWT), Sc is ship composition (DWT), C is the amount of construction (DWT), a is the age of ships, i is the size of ships, and t is simulation time (months).

4. Model Validation

To confirm the validity of the modeled predictions of CO_2 emissions and ship composition, hindcast simulations were performed for the 2013 to 2018 period. The purpose of this validation is to confirm the validity of the newly developed model (i.e., the GHG emission prediction model and update of ship composition) in this study. The validity of the number of orders, amounts of scrap, and the other elements of sub-models in Figure 1 were confirmed in previous research [17,21]. The initial values are the input scenarios shown below.

- Input scenarios: January 2013 to December 2018
  (1) World GDP: (actual data)
  (2) Cargo transportation distance: (actual data)
  (3) Operating speed (actual data)
- Initial values: January 2013
  (1) Fleet volume: 6.80×10^8 (DWT)
  (2) Order books: 1.40×10^8 (DWT)
  (3) Construction capacity: 9.85×10^6 (DWT)
  (4) Ship amount under construction: 5.10×10^7 (DWT).

The simulation results for CO_2 emissions are shown in Table 4. From these results, CO_2 emissions were estimated within an error margin of ±2.5%. There is no large error, and CO_2 emissions can be predicted well.

Table 4. Simulation results of CO_2 emissions from 2013 to 2018.

Year	2013	2014	2015	2016	2017	2018
Fourth IMO GHG Study ($\times 10^6$ tons)	177.7	177.3	184.2	192.0	198.4	193.4
This Study ($\times 10^6$ tons)	176.6	181.7	182.3	189.0	193.4	196.8
Error (%)	−0.6	+2.5	−1.0	−1.6	−2.5	+1.8

The simulation results for the ship composition are shown in Figure 6. The ship composition in December 2018 can be reproduced from the results. From these results, the validity of the entire model was confirmed.

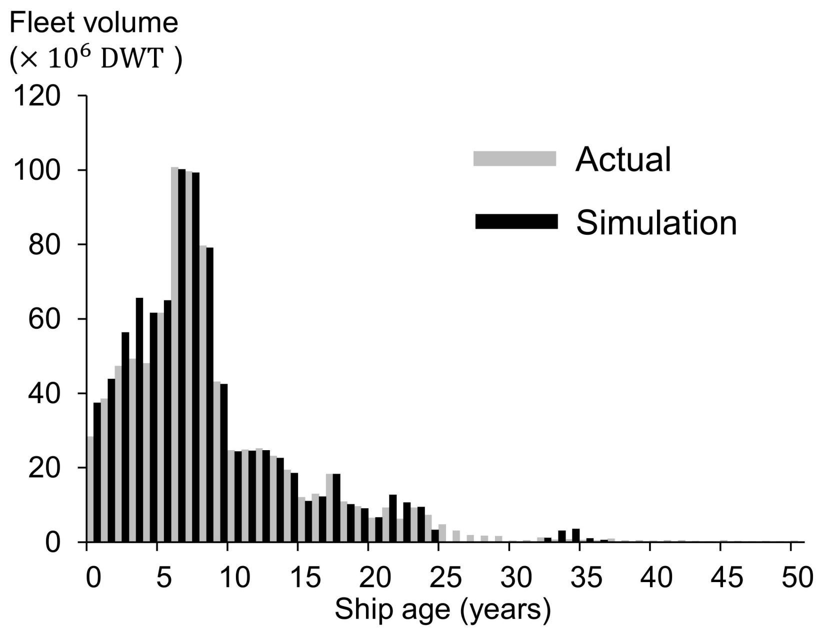

Figure 6. Composition of observed and simulated ship ages in 2018.

In the fourth IMO GHG study [4], detailed ship movement data (i.e., AIS data) and various other data were utilized to estimate recent CO_2 emissions. In this study, we developed a model that obtained results similar to IMO's GHG study without the use of detailed ship movement data. In the proposed model, CO_2 emissions' forecasting can be executed by setting the scenario for GDP and cargo transportation distance only. This is an advantage for forecasting CO_2 emissions under the proposed model.

5. Case Study

In this section, the influences of current and future GHG emission measure deployment scenarios are considered using the proposed model. Concretely, evaluation of current measures for GHG emission reduction, especially deceleration operation, transition to LNG fuel, and technological development to achieve EEDI regulation, is done in Section 5.1. In Section 5.2, we evaluate future measures for GHG emission reduction, especially the introduction of zero-emission ships. In Section 5.3, we evaluate the combination of current and future measures in GHG emission reduction. In Section 5.4, we consider the limitation of deceleration operation and the effectiveness of combining shipping and shipbuilding market models and GHG emission prediction models. In Section 5.5, we discuss the simulation results from Sections 5.1–5.4.

5.1. Impact Assessment of Current Measures

5.1.1. Overview of Current Measures

The current measures are explained in this section.

(1) Deceleration operation: This measure can suppress GHG emissions by reducing the main engine's output to save fuel during voyages. The average operating speed for ships has reduced since 2008.
(2) Transition to LNG fuel: LNG, which has the effect of reducing fuel consumption and the carbon content rate, is drawing attention as an alternative to heavy fuel oil (HFO). The carbon content rate (Cf in Equation (2)) is 3.114 (gCO_2/gfuel) in HFO and 2.750 (gCO_2/gfuel) in LNG. SFC in Equation (2) is 156 g/kWh in LNG. In HFO, SFC in Equation (2) is utilized in Table 3. These values are from the fourth IMO GHG study [4]. Carbon content rate (Cf) and SFC were lower in LNG fuel than in HFO fuel.
(3) Technological development to achieve EEDI regulation: EEDI is the amount of CO_2 emissions when carrying 1 ton of cargo for 1 mile. By restricting this value, the fuel

efficiency of ships is promoted and CO_2 emissions are reduced. As the percentage of ships in the fleet volume that has passed regulation value increases with each passing year, it is necessary to take a long-term perspective on impact assessment of the EEDI regulation. In this study, we assumed that the EEDI regulation will be achieved by technology development, such as reduction of hull resistance and improvement of propeller efficiency in HFO ships.

5.1.2. Scenario Settings

To evaluate current GHG reduction measures, simulations for 2013–2050 were conducted. The market conditions in 2013 were used as initial values, and the following scenarios for current measures were inputted:

(1) World GDP: Actual values for 2013–2019 were used and 3.5% GDP growth from 2020 was assumed. This assumption was based on the average GDP growth rate from 1980 to 2019, obtained from the International Monetary Fund [26].

(2) Cargo transportation distance: Actual values for 2013–2019 were used, and after 2020, the values were assumed to be constant.

(3) Operating speed reduction: It is still unclear how much ships will slow down in the future shipping industry. In this study, the actual value was used for 2013–2019, and after 2020, it was assumed that the speed is linearly reduced until 2050, reaching the intensity of deceleration that achieves 40% deceleration in 2050. The influence of operating speed reduction on GHG emissions and the implication for the maritime market industry are discussed in Section 5.4.

(4) Transition to LNG fuel: The balance of construction for HFO- versus LNG-fueled ships is shown in Table 5. We assumed that the ratio of LNG-fueled ships to total construction is set at 50% in 2020–2029, 60% in 2030–2039, and 70% in 2040–2050. In actuality, the order books of LNG-fueled ships among all type of ships for 2020 were approximately 12.2% based on the Clarkson database [23], and HFO ships are still the main ordered ships. This scenario is different from actual trends.

(5) Technological development to achieve EEDI regulation: We impose a 10% reduction of CO_2 emission efficiency in ships built after 2015, a 20% reduction in ships built after 2020, and 30% reduction in ships built after 2025 as compared with the 2013 EEDI regulation level. This scenario was based on the IMO resolution [27]. Table 6 shows the impact of SFC on EEDI efficiency improvement. The effects of EEDI efficiency improvement on SFC parameters of the main engine are estimated in the third IMO GHG study [1], and we used this table in this study.

Table 5. Percentage of construction volume of liquid natural gas (LNG)-fueled ships.

Year	–2019	2020–2029	2030–2039	2040–2050
		Fleet scenario: LNG		
HFO (%)	100	50	40	30
LNG (%)	0	50	60	70

Table 6. Scenarios for energy efficiency design index (EEDI) efficiency improvement.

Year	EEDI Regulation	Reduction Relative to Baseline, Taking SFC into Account
After 2013	0%	−7.5%
After 2015	10%	2.5%
After 2020	20%	12.5%
After 2025	30%	22.5%

To evaluate these GHG reduction effects, the following evaluation criteria were established:

- Business as usual (BAU) lines: The base year for CO_2 emissions is set as 2008 based on the initial IMO strategy for reduction of GHG emissions from ships [22]. The BAU lines indicate that some GHG reduction measures have not been applied since 2008. The BAU lines are calculated using the model proposed in this study.
- Mid-term goal: In the initial strategy for reducing GHG emissions [22], the goal of halving GHG emissions by 2050 was decided based on 2008. Based on this strategy, a mid-term goal of 50% reduction of CO_2 emissions of bulk carriers by 2050 as compared with 2008 was set. CO_2 emissions of bulk carriers in 2008 were 194.0×10^6 tons based on the third IMO GHG study [1]. Therefore, the mid-term goal is set at 97.0×10^6 tons in this study. It should be noted that CO_2 emissions of bulk carriers were 193.4×10^6 tons in 2018. Comparing the CO_2 emissions in 2018 and 2008, no significant change was found.

These evaluation criteria are original to this study and differ from the existing IMO criteria. For example, the BAU lines of total CO_2 emissions considering several types of ships (for example, bulk carriers, tankers, container ships, general cargo ships, and LNG ships, among others) were shown in the fourth IMO GHG study [4]. However, the BAU lines in the IMO's study were considered as the influence of GHG emission measures, and the evaluation of the CO_2 reduction effect of each measure is difficult using the IMO's BAU lines. Therefore, the BAU lines in this study were simulated using the proposed model and utilized as a baseline to evaluate the reduction in CO_2 emissions quantitatively by several emission measures. The BAU lines simulated using the proposed model are different from those in the IMO's study.

5.1.3. Simulation Results for Current Measures

In this simulation, we analyzed the CO_2 emission reduction effect of the current measures alone. The simulation results of CO_2 emissions considering operating speed reduction, the transition to LNG fuel, and technological development to achieve EEDI regulation are shown in Figure 7. In the case of the BAU scenario, CO_2 emissions will increase approximately 3.3 times by 2050 with respect to 2008 CO_2 emissions. This is because the influence of HFO ships increases with an increase in sea cargo movement. In the case of operating speed reduction, CO_2 emissions decrease by 56.1% with respect to BAU lines by 2050. In the case of EEDI, CO_2 emissions decrease by 24.3% with respect to BAU lines by 2050. In the case of transition to LNG fuel, CO_2 emissions decrease by 14.6% with respect to BAU lines by 2050. As a result, operating speed reduction more effectively reduces emissions compared with EEDI efficiency improvement and the transition to LNG fuel. However, it is difficult to achieve the mid-term goals of 50% decrease with respect to 2008 CO_2 emissions using a single measure alone; instead, it is necessary to combine measures. Based on these results, we considered deceleration of operating speed, transition to LNG fuel, and technological development to achieve EEDI regulation.

5.2. Impact Assessment of Future Measures

5.2.1. Scenario Settings

To examine measures to reduce GHG emissions that achieve the mid-term goal, one new measure, the introduction of zero-emission ships, was introduced and evaluated for after 2030. The initial values are the same as those in Section 5.1.2. The additional measures incorporated are as follows:

- Introduction of zero-emission ships: Zero-emission ships use hydrogen (H_2) fuel, ammonia (NH_3) fuel, or other alternatives. By using these fuels, GHG emissions from shipping become zero and significant reductions of GHG emissions are realized compared with current measures.

Two types of scenarios to introduce zero-emission ships (low case and high case) are constructed and assumed to change the fleet composition if implemented. The scenarios are listed in Table 7. We assume that only HFO fuel ships are constructed until 2019. After 2020, the construction of LNG-fueled ships begins. After 2030, the construction of zero-emission ships begins. Each number shows the ratio of fuel ship types to be built. This percentage applies to the ships that are constructed, and the ships are added to the fleet composition. The scenarios of GDP and cargo transportation distance scenarios follow in Section 5.1.2.

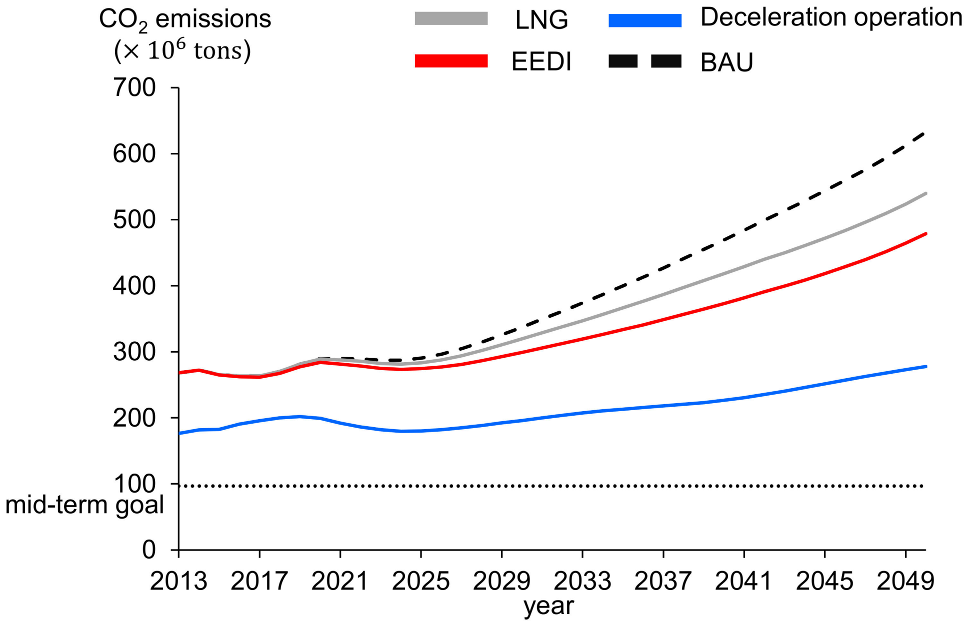

Figure 7. Simulation results of CO_2 emissions considering current measures. LNG, liquid natural gas; EEDI, energy efficiency design index; BAU, business as usual.

Table 7. Percentage of construction volume of alternative fuels. HFO, heavy fuel oil; LNG, liquid natural gas.

Year	–2019	2020–2029	2030–2039	2040–2050
Fleet Scenario: Low				
HFO (%)	100	20	10	0
LNG (%)	0	80	60	30
Zero-Emission Fuel (%)	0	0	30	70
Fleet Scenario: High				
HFO (%)	100	20	0	0
LNG (%)	0	80	40	10
Zero-Emission Fuel (%)	0	0	60	90

5.2.2. Evaluation Results with Future Measures

In this simulation, we analyzed the CO_2 emission reduction effect of the introduction of zero-emission ships alone. The simulation results of CO_2 emissions considering introduction of zero-emission ships are shown in Figure 8. The reduction effect of the introduction of zero-emissions ships is considerably larger than that of other measures; CO_2 emissions decrease by 57.9% in the low scenario with respect to BAU lines by 2050 and by 75.4% in the high scenario with respect to BAU lines by 2050, because the ratio of zero-emission ships to fleet volume directly contributes to the reduction of CO_2 emissions. If all ships are replaced by zero-emission ships, CO_2 emissions will be fully eliminated; however, replacing all ships would be difficult given the immature state of zero-emission technology, and thus introduction of zero-emission ships fluctuates greatly depending on the (projected) status of technology development.

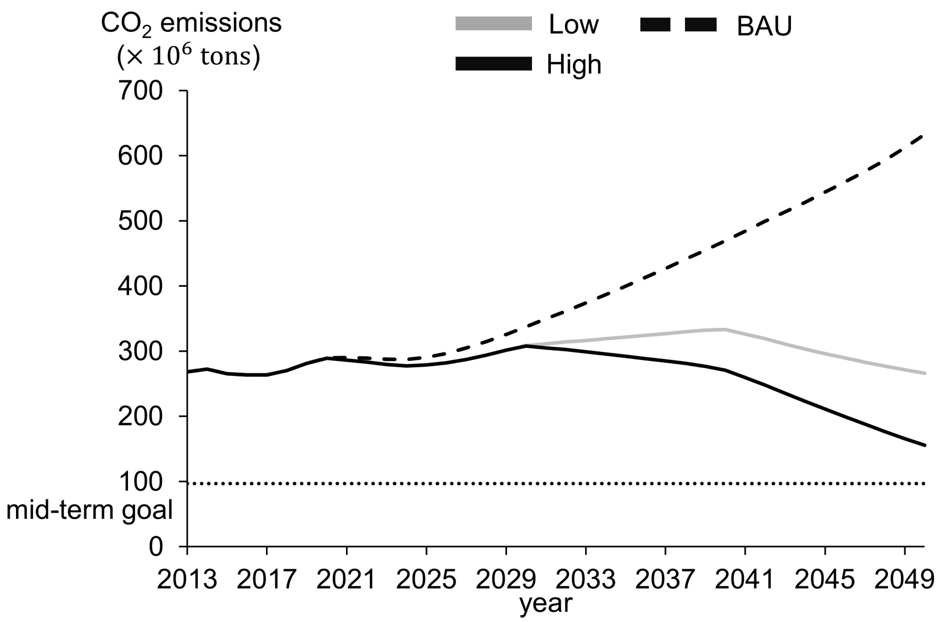

Figure 8. Simulation results of CO_2 emissions considering the introduction of zero-emission ships.

5.3. Impact Assessment of Combination of Current and Future Measures

5.3.1. Scenario Settings

The simulation combines current measures (operating speed reduction, technological development to achieve EEDI regulation, and transition to LNG fuel) and future measures (introduction of zero-emission ships). The purpose of this simulation is to quantitatively grasp the CO_2 reduction effect when current and future measures are combined. In addition, we consider the scenarios to satisfy the mid-term goal for 2050. The following assumptions were used in this simulation.

- Technological development to achieve EEDI regulation is applied to HFO and LNG-fueled ships.
- Reduction in operating speed applies to HFO and LNG-fueled ships; zero-emission ships are not the target of operating speed reduction, which thus does not occur for them. This is because zero-emission ships are more efficient with regards to CO_2 emissions compared with HFO and LNG-fueled ships. Additionally, LNG-fueled ships are more efficient in terms of CO_2 emissions than HFO fuel ships. Therefore, the speed of LNG-fueled ships is 10% faster than that of HFO ships. This assumption is based on the concepts of energy efficiency existing ship index (EEXI) regulation [28].

In this simulation, we consider the four types of cases shown in Table 8. The scenario of GDP and cargo transportation distance is the scenario in Section 5.1.2. The operating speed reduction was set to reach 40% deceleration in 2050 based on HFO fuel ships. In the low and high scenarios, the deceleration rate is set to 17% and is constant after 2020.

Table 8. The scenario for simulation of combination of current and future measures. EEDI, energy efficiency design index.

Scenario Name	Fleet Scenario	Operating Speed Deceleration Scenario	Technological Development to Achieve EEDI Regulation	LNG Fuel	Zero-Emission Ships
Current	LNG (Table 5)	40% deceleration in 2050 (Linearly reduce)	○	○	N/A
Low	Low (Table 7)	Constant	○	○	○
High	High (Table 7)	Constant	○	○	○
Low + Slow	Low (Table 7)	40% deceleration in 2050 (Linearly reduce)	○	○	○

○: Applicable, N/A: Not applicable.

5.3.2. Evaluation Results for Combination of Current and Future Measures

The simulation results of CO_2 emissions for the combination of current and future measures are shown in Figure 9. In the current scenario, CO_2 emissions in 2050 are 207.3×10^6 tons. On the other hand, in the case where only the 40% operating speed reduction measure is applied, the CO_2 emission amount becomes 277.6×10^6 tons as of 2050. Compared with these results, CO_2 emissions are thus reduced by 70.3×10^6 tons by EEDI efficiency improvement and transition to LNG fuel. However, it is difficult to achieve mid-term goals by 2050. From these results, it is found that the introduction of zero-emission ships is necessary to achieve mid-term goals.

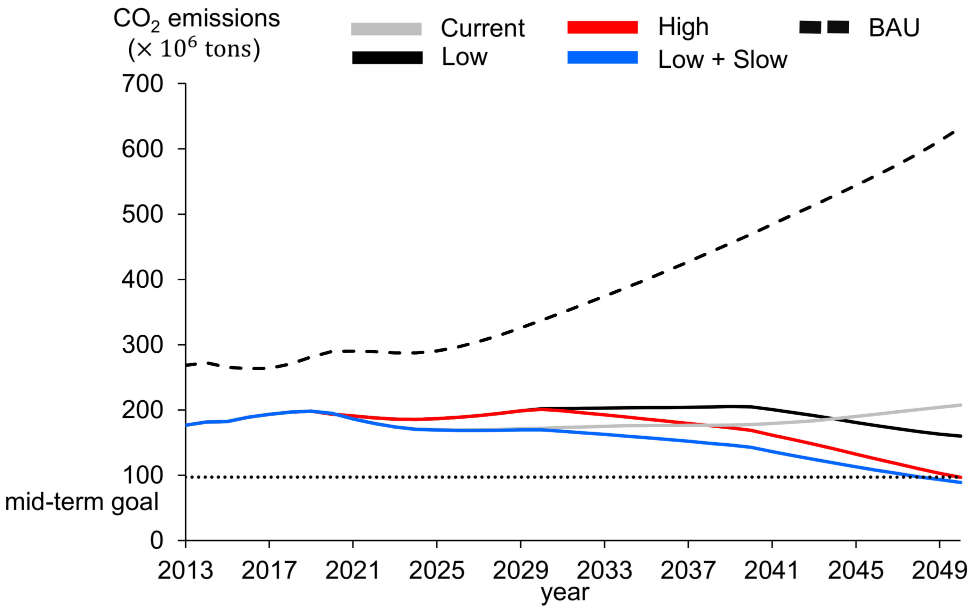

Figure 9. Simulation results of CO_2 emissions for the combination of current and future measures.

In the case of low scenarios, if zero-emission measures are promoted after 2030 in addition to the current measures, it is difficult to achieve the mid-term goal by 2050; conversely, in high scenarios, the 2050 goal can be achieved. Similarly, in the low + slow scenarios, it is possible to achieve mid-term goals. Therefore, it is necessary to consider the transition to LNG fuel, introduction of zero emissions ships, deceleration operation, and technological development to achieve EEDI regulation from a long-term perspective.

The simulation scenario is set such that LNG fuel will be introduced from 2020, and a zero-emission ship is introduced from 2030. This scenario is extremely difficult to realize in relation to reality. Based on the above, to promote GHG reduction, it is necessary not only to promote the development of zero-emission ships, but also to implement additional GHG emission schemes such as market-based measures.

From the results, it can be seen that the influence of the combination of all measures on CO_2 emissions was considered.

5.4. Limitation of Operating Speed Reduction

It is clear that the ship operating speed reduction is effective in CO_2 emissions reduction from the results in Section 5.1.3. However, if excessive deceleration operation is performed, the required fleet quantity will increase sharply. In this simulation, the limit of deceleration is considered using the proposed model. The scenario of GDP and cargo transportation distance is the scenario of Section 5.1.2, and the cases of deceleration operation are four cases of 20%, 40%, 50%, and 70%.

The simulation results of CO_2 emissions considering deceleration operation are shown in Figure 10. In the case of 20%, 40%, and 50% deceleration, CO_2 emissions decrease as the ship speed decreases. In the case of a 70% deceleration, CO_2 emissions decrease progress until 2038. However, CO_2 emissions increased from 2039 because of an increase in shipbuilding orders.

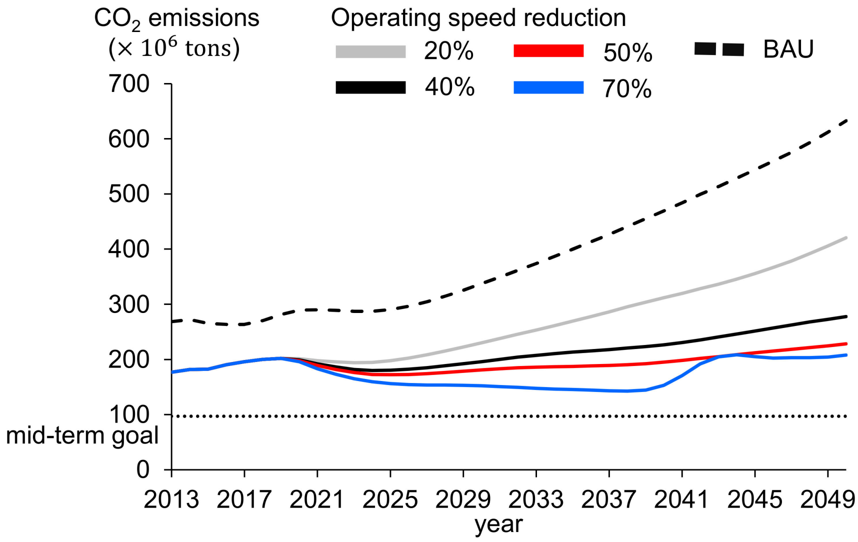

Figure 10. Simulation results of CO_2 emissions considering deceleration operation.

The results under the impact of increases in fleet volume and shipbuilding orders are shown in Figure 11. Both fleet volume and orders increase as the deceleration strength increases. This is the influence of the correction of the order prediction model (Section 3.4). By increasing the operating speed decelerations, it is expected that ship orders will also increase, and the shipbuilding industry can benefit. Especially in the case of a 70% deceleration, orders increase rapidly and fluctuate from 2033, and the fleet volume increases rapidly after 2039. This rapid increase in ship orders is caused by a significant shortage of ship capacity due to rapid deceleration. Although 70% had excessive deceleration, CO_2 emissions increased gradually as the fleet increased. The engine load factor is very small (less than 5%); therefore, CO_2 emissions increase gradually compared with the fleet increase. The fleet volume becomes insufficient, and marine transportation has failed to meet demand because of a significant shortage of fleet volume in 70% deceleration, and 70% deceleration is difficult from a maritime transportation perspective. From these results, it was found that the limitation of deceleration in ship operations was approximately 50%.

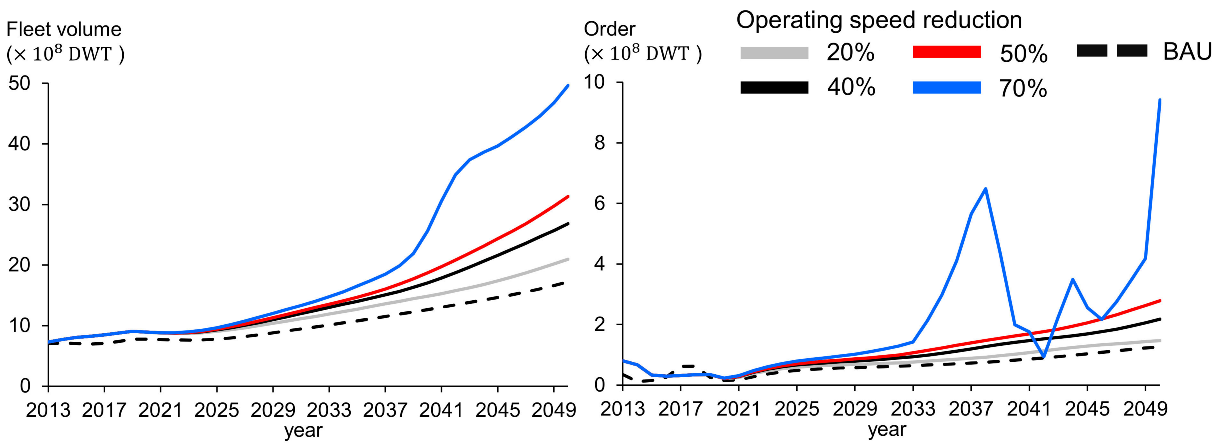

Figure 11. Simulation results for fleet volume and shipbuilding orders.

We also showed that, by combining such a model of GHG emissions with a model of the shipping and shipbuilding market, the effect of reducing GHG emissions can be analyzed based on dynamic changes in the market.

5.5. Discussion

In Section 5.1, we conducted a quantitative evaluation of the current measures for CO_2 emission reduction, especially deceleration operation, transition to LNG fuel, and technological development, to achieve EEDI regulation. The result suggests that the deceleration operation had the highest CO_2 reduction effect, followed by technological development to achieve EEDI regulation and transition to LNG fuel. In particular, the CO_2 emission reduction effect by the deceleration operation considers change in orders and scrap due to the operating speed reduction; few or no evaluations that consider the maritime market aspect have been conducted in previous studies. By modeling the relationship between operation speed and number of orders and between operation speed and amount of scrap, our model enables this consideration.

In Section 5.2, we evaluated the introduction of zero-emission ships for CO_2 emission reduction. The result demonstrates that our model can forecast the impact of the future introduction of zero-emission ships, considering the transition from current ships. In the simulation, we assumed two scenarios of the introduction of zero-emission ships and evaluated the amount of CO_2 emission reduction by the introduction. However, American Bureau of Shipping [29] has reported that zero-emission ships are still at the research stage, and the scenario for their introduction has not become clear yet. The introduction of zero-emission ships greatly depends on the projected status of technology development, thus it is necessary to carefully consider what scenarios should be evaluated.

In Section 5.3, we evaluated the combination of current and future measures for CO_2 emission reduction. In the simulation, EEXI measures for existing ships are also taken into consideration. The result shows that it is difficult to achieve the IMO goals for 2050 by combining only current measures. Additionally, the result shows that the target for 2050 can be achieved in the "high" scenario, which introduces many zero-emission ships, or the "low + slow" scenario, which introduces zero-emission ships and deceleration operation. In the "high" scenario, zero-emission ships account for 60% of ships constructed from 2030; achieving this is considered difficult at the present stage of development of zero-emission ships. The "low + slow" scenario is considered to be more realistic from the perspective of achieving IMO goals for 2050; however, the amount of LNG-fueled ships on order books for all ship types is only approximately 12.2% as of 2020 [23], which is still lower than the assumption of the "low + slow" scenario. Based on these considerations, it is necessary not only to promote the development of zero-emission ships, but also to implement additional GHG emission schemes such as market-based measures.

In the fourth IMO GHG study [4], future CO_2 emissions are predicted. It is reported that CO_2 emissions in 2050 will be approximately 90–130% compared with 2008 owing to deceleration operation, EEDI efficiency improvement, improvement of operation efficiency, and so on. This result can be interpreted to show that additional measures, such as the introduction of zero-emission ships and market-based measures, are required to achieve the 2050 GHG emission target. The "current" scenario in Figure 9 confirms the effectiveness of the current measures and shows that the case where only current measures are combined makes it difficult to achieve the 2050 GHG emission target. The results of the forth IMO study and the simulation results in this study are qualitatively consistent. This paper is novel in that we considered multiple scenarios—"high" and "low + slow"—and the simulation results suggest some example roadmaps for the implementation of the IMO's GHG reduction strategy. Those examples can serve as reference data to discuss the future development of decarbonized shipping, and this is one of the important contributions of this paper.

In Section 5.4, we considered the limitation of deceleration operation and the effectiveness of combining shipping and shipbuilding market models and GHG emission prediction models. In this simulation, we analyzed the limit of deceleration operation from the maritime market perspective and showed that the limit of deceleration operation is approximately 50%. Previous studies cannot consider this limitation because their models do not combine GHG emission prediction and maritime market models. This case suggests the importance of considering the maritime market when evaluating the effect of deceleration, and this consideration is also part of the novelty of our model.

The simulations in Sections 5.1–5.4 demonstrate that our model can analyze dynamics in the maritime market when GHG emission measures are implemented. The results can be used for the establishment of international rules such as IMO rules and for policy making in maritime governance. Specifically, it will be possible to study a scenario with the introduction of zero-emission ships and to analyze market fluctuations due to regulations on existing ships such as EEXI regulation [28].

6. Conclusions

In this study, a model to consider GHG emission scenarios for the maritime transportation sector was developed using SD. Using this model, the influence of several GHG emissions reduction scenarios was examined. Additionally, several simulations were executed using the proposed model, and we evaluated the impacts of several measures on GHG emissions. Then, we built a theoretical framework to develop a model that comprehensively evaluates the impact of GHG reduction measures in the maritime market. The conclusions can be summarized as follows:

- To estimate GHG emissions, a GHG emissions prediction model was developed and the scrap model was improved. Additionally, the GHG emissions prediction model was integrated into shipping and shipbuilding market models, and a model to consider GHG reduction measures was developed.
- To confirm the validity of the evaluation model for GHG reduction measures, simulations from 2013 to 2018 were conducted. The model validity was confirmed quantitatively.
- The GHG emission reduction effect by current measures and future measures alone was evaluated. Additionally, the impact and effectiveness of combining current measures and future measures were evaluated.
- The comprehensive scenarios to achieve IMO GHG emission goals were discussed considering current and future GHG reduction measures. From this simulation result, it was found that, in order to achieve the target of 2050, it is necessary to develop a zero-emission ship in addition to the current measures.
- We focused on the deceleration of operating speed, the influence of which on shipping and shipbuilding markets was evaluated. Concretely, the limitation of deceleration was considered from the maritime market perspective. This simulation result suggests that the limitation of ship operating speed reduction is approximately 50% from the maritime market perspective.

However, on the other hand, the developed model is still insufficient for cost calculation. Concretely, measures to reduce GHG emissions affect ship operating costs and ship prices. However, the influences of ship operating costs and ship prices have not been considered in this study. In future work, we will expand the model to simulate these items, and develop a model to consider optimal scenarios in terms of the balance between maritime market and GHG emissions. Additionally, the proposed model predicts the amount of sea cargo movement using GDP and cargo transportation distance. However, it is difficult to accurately predict these values because of the uncertainties involved. In future work, we are considering how to handle these uncertainties. The sophistication of the shipping and shipbuilding market model is also an issue for future work. In recent years, it has become possible to grasp the ship movement in real time by development of AIS and to obtain detailed cargo flow volume of dry bulk cargo based on ship movement [30]. By using such ship movement data, it is expected that sophisticated cargo transportation volume data will be achievable and the shipping and shipbuilding market model in this study will improve as a predictive tool.

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Data Availability Statement: Some of the data presented in this study are openly available in reference number [1,4,23–27].

Conflicts of Interest: The authors declare no conflict of interest in this paper.

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Spatial Analysis of an Emission Inventory from Liquefied Natural Gas Fleet Based on Automatic Identification System Database

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Abstract: Many states are actively working toward regulating CO_2 emissions from a wide range of industries. However, due to the international characteristic of shipping, the emissions from shipping have not yet been strictly controlled. Using Automatic Identification System (AIS) data acquired through satellites, this study estimates the emission inventory, such as, CO_2, CH_4, CH_4, N_2O, NO_x, CO and non-methane volatile organic compounds (NMVOCs) around the world and bunker consumption from a liquified natural gas (LNG) fleet under the assumption that a LNG fleet uses LNG as fuel. Using position data calculated from an AIS database, we made comparisons regarding the LNG trade amount and bunker consumption of LNG fleet, as well as the total CO_2 inventory and CO_2 emissions from LNG fleet in the vicinity of the coasts of relevant countries. The result provides insights into (1) how the emissions and bunker consumption from LNG fleet is distributed, (2) which countries are taking relatively more advantages of LNG trade, and (3) which countries are suffering possible harmful effects.

Keywords: liquified natural gas (LNG); Automatic Identification System (AIS); spatial analysis; greenhouse gases (GHGs); bunker; emissions

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1. Introduction

Transportation is the second biggest greenhouse gas (GHG) emission sector, following electric power sector, and most of the emissions come from generating energy using fossil fuels to drive trucks, trains, planes, and vessels [1]. Transportation modes, such as trucks, trains, and planes, are relatively well monitored compared to shipping. However, shipping is the least controlled area. The International Maritime Organization (IMO) has been collecting vessel GHG emission data since 2018 and a long-term plan will be established in 2023 after all the data collected has been analyzed. The European Union (EU) is working on controlling emissions from shipping more actively. The EU decided that shipping would be included in the EU Emission Trading system, which is a market-based measurement based on a cap and trade system, if there is no comparable system operating to control GHG emissions until 2021.

This study aims to obtain insight into emissions from liquified natural gas (LNG) carriers and their relation to countries alongside shipping routes. Section 1 reviews the literature and outlines the background and objectives of the study. Section 2 describes the Automatic Identification System (AIS) data collection and data imputation. Section 3 calculates vessel emissions. Section 4 aggregates the bunker consumption at the country level and compares it with its LNG trade volumes. Section 5 validates the correlation of the LNG trade volumes and the estimation of the AIS data on a monthly basis. Section 6 summarizes the study.

1.1. Background of Study

By carrying a huge amount of cargo in one trip, shipping vessels are known as one of the most eco-friendly modes of transport out of the major transportation modes [2]. In particular, by carrying a huge amount of cargo in one voyage, carrying cargo by shipping vessels is a more efficient means of transportation than other modes of transportation in the aspect of CO_2 emissions (tonne-km). Even though the CO_2 emissions from shipping are lower than those caused by other means of carrying cargo in terms of tonne-km, the CO_2 emissions from shipping reached 1056 million tons in 2018, which represents 2.89% of the worldwide CO_2 emissions [3]. The regulations of CO_2 emissions in shipping which are currently being implemented were decided by two main organizations. One of these is the IMO and the other is the EU. They came into effect on 1 March 2018, and the first "calendar year" data collection commenced on 1 January 2019. The data collected includes the IMO number; period of calendar year covered; and technical information such as vessel type, gross tonnage, net tonnage, deadweight tonnage, power output, Energy Efficiency Design Index (EEDI) if applicable, ice class, and fuel oil consumption data [4].

In the EU, the Monitoring, Reporting, Verification (MRV) regulations came into effect on 1 July 2015, and they make it mandatory to report and verify CO_2 emissions for vessels with over 5000 gross tonnage calling at any EU member state and European Free Trade Association (Norway, Iceland) port. Every year, the responsible party; ship owner; or any other organization or person, such as the manager or bareboat charterer, who has responsibility for the ship operation is required to report the CO_2 emissions emitted by the vessel and other required information, including the port of departure and arrival, distance travelled, time spent at sea, amount of cargo carried, and number of passengers [5]. The European Parliament is planning to include shipping in the EU Emission Trading Scheme (ETS), which is basically a cap and trade system, from 2023 if the IMO does not establish a comparable system [6].

1.2. Research Review and Objective

Under IMO regulations, Safety of Life At Sea (SOLAS) Chapter V, it is necessary to carry AIS for vessels which have a gross tonnage of over 300 on international transport. The main purpose of the AIS is to avoid collisions at sea. However, the advent of communication technology has made its areas of application wider. Many studies have been carried out on estimating ship inventories using AIS data. Dong et al. [7] systematically reviewed AIS data application in maritime studies and suggested that environmental evaluation is one of the major AIS application fields. Johansson et al. [8] adopted a database of AIS messages for the full year of 2015 for all vessel types and presented a comprehensive global shipping inventory, which can be applied to obtain annual updates of the global ship emissions. Smith et al. [9] implemented a full-scale ship emission inventory analysis using AIS data. Sérgiomabunda et al. [10] estimated a ship emission inventory near the strait of Gibraltar. Coello et al. [11] estimated an emission inventory for the UK fishing fleet. Winther et al. [12] implemented an emission inventory estimation in the artic though a Satellite Automatic Identification System (S-AIS), and Yao et al. [13] estimated ship emission inventories in the estuary of the Yangtze river. The most recent global-scale ship emission inventory analysis was carried out by the IMO Marine Environment Protection Committee (MEPC) [3].

Two major methods with which to derive ship emissions inventories are top-down (fuel-based) and bottom-up (activity-based) [9]. Smith et al. [9] and the IMO MEPC [3] adopted both methodologies, while Jalkanen and Kukkonen [8]; Sérgiomabunda et al. [10]; Coello et al. [11]; Winther et al. [12]; and Yao et al. [13] adopted the bottom-up methodology. In this study, we adopted the bottom-up methodology to derive fuel consumption.

Power prediction for the ship is one of the most important factors in deriving bunker consumption. Smith et al. [9] and the IMO MEPC [3] used the IHS database; Coello et al. [11] used the statistical fuel consumption; Jalkanen and Kukkonen [8] used the STEAM 3 model; and Winther et al. [12] and Yao et al. [13] adopted the methodology of Kristensen and Lützen [14], which uses the International Towing Tank Conference (ITTC) performance prediction method to obtain the resistance coefficient; and Sérgiomabunda et al. [10] used the ITTC performance prediction method. We adopted the ITTC recommended procedures and guidelines. This allowed us to derive the ship bunker consumption with limited ship specification data. However, the accuracy of the calculation may be improved with comprehensive ship specification data.

The reasons why we chose to analyze the data of LNG carriers are, first, the fact that the demand for gas energy is expected to increase by 1.8% per year from 2015 to 2040. This is much quicker than other conventional modes of energy [15], such as oil (0.6% per year) and coal (0.4% per year). Second, the distribution of the size of LNG carriers is not very wide, which makes it easy to estimate the coefficients related to the calculation of the emissions of LNG carriers. Third, international LNG trade statistics are open to the public, and the import of East Asia countries accounts for more than 60% [16].

The purpose of this study is two-fold. The first is to gain a clear understanding of and insight into the GHGs, such as CO_2, CH_4, N_2O and other relevant substances, such as NO_x, NMVOC, and CO emitted by LNG carriers by visualizing the results of our calculations and the AIS data acquired by satellites. The second is to gain in-depth quantitative insight pertaining to the distribution of the ship emission inventory by applying a geo-spatial analysis. To visualize and compare the calculated AIS-based bunker consumption and other data, such as the trade of LNG and the total CO_2 emissions of each country, data are aggregated through a grid or point and buffer depending on the purpose of each section.

2. Automatic Identification System (AIS)

2.1. Introduction to AIS

As of 31 December 2004, vessels of over 300 gross tonnage engaged in international voyages and cargo vessels of over 500 gross tonnage not engaged in international voyages are obliged to carry Class A AIS. The motivation for adopting the regulation for carrying AIS is preventing collisions at sea by transmitting vessel data, such as time, position, vessel ID, basic vessel dimensions, and draught. Data are transmitted and received at intervals of 2–10 s while underway and 3 min while anchored. However, the advent of a positioning and communication system broadens the fields of use—AIS data can today be used for purposes such as vessel management, power prediction, and tracking trade flow.

2.2. Data Description

The data used in this study were collected by a company named exactEarth. It was founded in 2009 for the purpose of making Satellite AIS data services available to the global maritime market. It currently tracks more than 165,000 vessels through AIS. As exactEarth collects AIS data through satellites, it is possible to obtain AIS data through the ocean regardless of the position of the vessel and regardless of the weather the vessel has faced.

The AIS data used in this study are in the comma-separated values (CSV) format. Every data point is divided by day based on Greenwich Mean Time (GMT). The original data provided by exactEarth include vessel name, callsign, Maritime Mobile Service Identity (MMSI), vessel type, vessel type cargo, vessel class, length, width, flag country, destination, estimated time of arrival (ETA), draught, longitude, latitude, speed over ground (SOG), course over ground (COG), rate of turn (ROT), heading, navigation (nav) status, source, time, vessel type main, and vessel type sub. The message transmitting interval of AIS is 2–10 s while underway and 3 min at anchor. For the details of vessel type, period, the number of vessels, and the total number of data points used in this study, please see Table 1.

Table 1. Outline of data.

Vessel Type	LNG Carrier
Period	From 2016-01-01 UTC to 2016-06-30 UTC
Number of vessels	327
Total number of data points	9,072,300

Table 2 shows a statistical summary of the data reporting interval of the AIS messages used in this study. The mean reporting interval is about 520 s, and 25% and 75% are 6 and 42 s, respectively. Looking into the sampling rate of the AIS data in more detail, we can see that about 31.7% of the data has a reporting interval of less than 10 s, which is the AIS message transmitting interval for an underway vessel. About 90.6% of the messages have a data reporting interval of less than 3 min, which is same as the AIS message transmitting interval for anchored vessels. About 99.3% of the data has reporting intervals of under 2 h, and 0.7% of the data has reporting intervals greater than 2 h, which seems to be a small number. However, considering that the total number of data points is more than 9 million, the small percentages should not be ignored. The data sampling rate needs to be improved in the future to improve the accuracy of all kinds of AIS-based calculations.

Table 2. Distribution of the data interval.

Data Reporting Interval, Hours (A)	Ratio (%) of Data Interval Less than (A)	Number of Data Points with Longer Sampling Rate than (A)
2/3600 (2 s)	7.928	8,353,080
10/3600 (10 s)	31.656	6,200,363
180/3600 (3 min)	90.594	853,331
0.5 (30 min)	95.851	376,392
1	97.501	226,720
2	99.297	63,758
6	99.805	17,707
24	99.963	3387
168	99.992	688

Figure 1 shows the distribution of the data samples acquired. South and west of Africa, south of South America, north-east of Australia, and the Indian Ocean are marked as high-concentration areas. Areas such as the East China Sea, the South China Sea, and the Mediterranean Sea are not marked as areas with heavy traffic. This may be because the AIS data collected through satellites show longer data reporting intervals when the vessels are sailing in high-traffic areas compared with low-traffic areas. Few data are observed deviating from the routes of the vessel and on the land side; this might be due to errors that occurred when collecting the data through satellites. In this study, data with this type of error are filtered using the time, position, and speed recorded in the AIS message.

Table 3 shows a statistical summary of the ship specification. Most of the vessels are sized from 250 to 300 m in length overall (LOA) and 40–50 m in beam. As the cost of transportation occupies 10% to 30% of the LNG value chain [17], efforts to minimize the cost of transportation may have affected the size of the vessel. For 25% and 75%, the vessel size is 283 m and 291 m, respectively. For the beam, 25% and 75% are 44 m and 48 m, respectively.

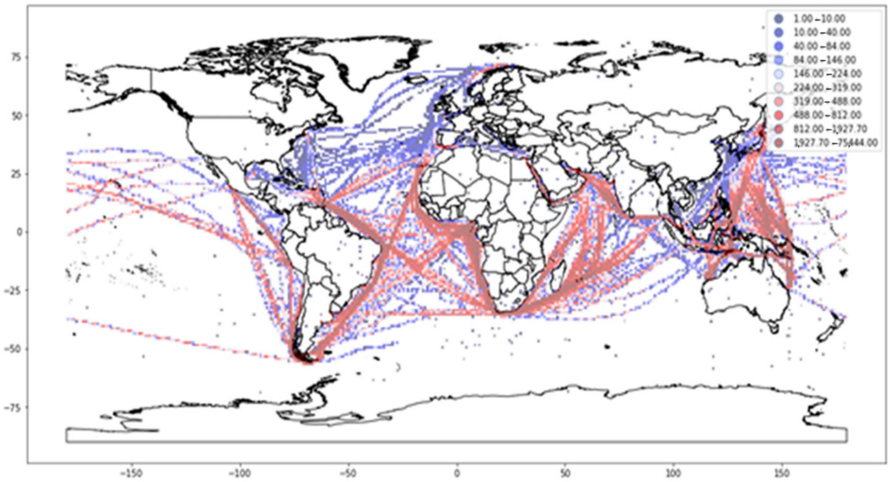

Figure 1. Distribution of the data acquired.

Table 3. Ship specification.

	Mean	std	min	25%	50%	75%	Max
Length over all (Unit: m)	284.5	35.4	69	283	288	291	345
Breadth (Unit: m)	44.8	5.6	11.8	44	44	48	55

2.3. Imputation

AIS data include many types of information. However, human error or error in communication systems causes problems in terms of data reliability. For example, we found data with a missing MMSI number, an exceptionally high vessel speed, or in a position where a vessel physically cannot pass.

In detail, first, we found that the original data include position data, which shows that a vessel is on the land side or has exceptionally deviated from the route. To remove these data, our plan is to remove data which show a speed higher than a certain knot.

Second, to obtain a reasonable value for speed, we considered the effects of following current, prevailing sea conditions, and intended speed of the vessel, and set the maximum value of the vessel speed as 20 knots.

Third, for the MMIS and ship dimensions, we adopted a vessel tracker and marine traffic which are some of the most famous AIS data providers.

The last item to address is error in ship draught. The data on ship draught in AIS solely relies on the on-board deck officer. It is not rare for the duty officer of a ship to forget to change the value of draught. We analyzed the AIS data and found that the average value of maximum draught–(subtract) minimum draught is about 3.4 m, and about 3.1 m for 75% of the vessels. Taking this into consideration, we replaced the missing draught value with "summer draft–(Subtract) 3".

2.4. Origin–Destination Data

As the AIS data included information on the next port of call, it is possible to analyze the origin–destination of the voyages. From the AIS data, origin–destination data are derived. Through the origin–destination trip data and the capacity of the vessel, we calculated the assumed LNG import amount as shown in Table 4. Japan is the biggest LNG import country, followed by unknown (destination country is not identified), Korea, Egypt, Taiwan, China, and India. We will discuss more details of this along with statistical data in Section 3. The reason why "Unknown" ranked second is that, as the destination data in AIS solely rely on the manual input of the onboard officer, errors in data inputting for the destination port can happen. Errors can also happen when data is transferred through a satellite.

Table 4. Top 10 assumed LNG import amounts from the AIS origin–destination (port of departure and arrival) data.

No.	Name of Country	Import Amount (Unit: Million Tons)	Percentage
1	Japan	22.74	28.44%
2	Unknown	22.73	28.42%
3	Korea	6.95	8.69%
4	Egypt	4.1	5.13%
5	Taiwan	3.1	3.88%
6	China	3.02	3.78%
7	India	2.93	3.66%
8	Spain	1.52	1.90%
9	Qatar	1.01	1.26%
10	United Arab Emirates	0.91	1.14%
Others		10.96	13.71%
Total		79.97	100.00%

3. Vessel Emission Calculation

Figure 2 illustrates the data filtering, ship emission calculation, and visualization process of this section. The data for the LNG fleet are filtered from the original AIS data using the ship type recorded in the AIS message. We also remove the messages with the wrong position using the time, position, and speed recorded in the AIS data. Then, using the vessel dimensions, speed, and position data included in the AIS message, we calculate the total resistance when the vessel is sailing at speed V, following the method included in the International Towing Tank Conference (ITTC) recommended procedure [18]. As the vessel performance could vary depending on the condition of the hull, the weather, the current, etc., a margin of error should be considered when calculating the power requirement. From the calculated power, using the specific fuel oil consumption (SFOC) and emission factor, a calculation can be performed to obtain the bunker consumption and emission inventory. Python (version 3.6.6) was adopted as the data manipulation language. We adopted the Python module Pandas (version 0.23.4) to aggregate the calculated emissions and QGIS (version 2.14.21) for visualization.

Several studies have been carried out on the estimation of vessel resistance, which is key to calculating the required power and bunker consumption when the vessel is sailing at specific speed V. In this study, we adopted the method recommended by the ITTC [18] to estimate the total resistance, which is key to derive the power requirement. The detailed parameters used in this study are taken from international organizations and public sources (i.e., Takahashi et al. [19]; Kristensen and Lützen [14]).

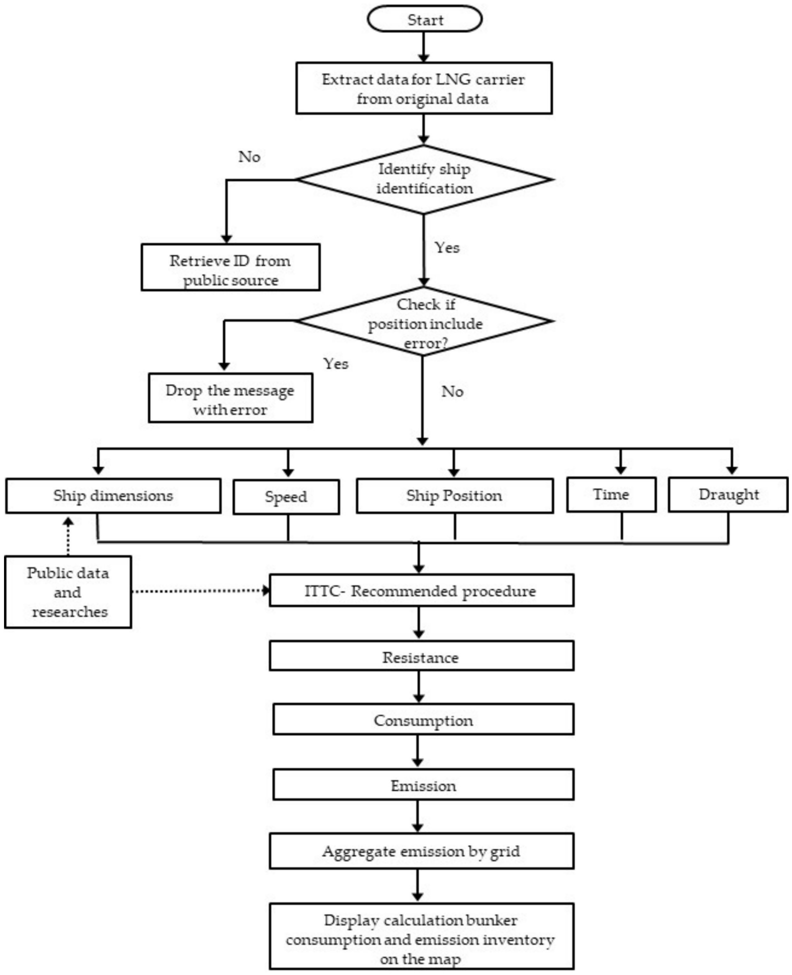

Figure 2. Flowchart of data manipulation in Section 3.

3.1. Total Resistance

When calculating, the total resistance draught, T, and speed, V, which are included in the AIS data, are used as variables. The speed and draught change over time due to external forces and how much cargo and bunker are on board the ship. In order to calculate the power required when the vessel is sailing at speed V, it is necessary to derive the total resistance first. The total resistance can be denoted as [18]

$$R_T = \frac{1}{2} \times C_T \times \rho \times S \times V^2, \quad (1)$$

where R_T is the total resistance, C_T is the total resistance coefficient, ρ is the density of water, S is the wetted surface of the hull, and V is the speed of the vessel. C_T, the total resistance coefficient, can be derived from

$$C_T = C_F \times C_A \times C_{AA} \times C_R, \quad (2)$$

where C_F is the frictional resistance coefficient, C_A is the incremental resistance coefficient, C_{AA} is the air resistance coefficient, C_R is the residual resistance coefficient. The C_F of the hull often causes some 70–90% of the vessel's total resistance for a low-speed vessel (bulk carriers and tankers), and sometimes less than 40% of the vessel's total resistance for a high-speed vessel [20]. C_F can be described as [18]

$$C_F = \frac{0.075}{(log_{10}R_n - 2)^2}, \quad (3)$$

where R_n is the Reynolds number, which is described as

$$R_n = \frac{V * L_{WL}}{\varphi}, \tag{4}$$

where L_{WL} is length of the waterline and φ is the kinematic viscosity of the water. In this study, the value for φ is adopted from the study conducted by Lienhard [21].

C_F, the frictional resistance coefficient, concerns the roughness of the hull surface. As the surface roughness of the model is different from the roughness of the vessel, when calculating the resistance coefficient an incremental resistance coefficient, C_A, is added. The value of C_A can be estimated using the following expression [14]

$$1000 * C_A = Max\left\{-0.1;\ 0.5 \times log(\Delta) - 0.1 \times (log(\Delta))^2\right\}, \tag{5}$$

where Δ is the displacement of the vessel, which can be denoted as

$$\Delta = C_B \times L_{PP} \times\ B \times T, \tag{6}$$

where C_B is the block coefficient of the vessel, L_{PP} is the length between perpendiculars, B is the beam of the vessel, and T is the draught of the vessel.

The value for C_{AA} is derived from the study carried out by Kristensen et al. [14]. The value for C_R is adopted from the study implemented by Kristensen et al. [14]. Finally, the wetted surface, S, for tankers and bulk carriers can be derived by [14]

$$S = 0.99 \times \left(\frac{\Delta}{T} + 1.9 \times\ L_{WL} \times T\right). \tag{7}$$

3.2. Power Prediction

Based on the calculated total resistance of the vessel, the required power when the vessel is sailing at speed V in calm sea conditions can be calculated by considering the components of the propulsion efficiencies. The installed power is the power required to tow a vessel with speed V in a calm sea. The installed power can be derived from [22]

$$P_I = \frac{R_T \times V}{(\eta_D \times \eta_T)} + m, \tag{8}$$

where P_I is the installed power, η_T is the transmission efficiency, η_D is the quasi-propulsive coefficient, and m is the sea margin.

3.3. Bunker Consumption and Emission Pollutants

The bunker consumption can be derived by multiplying P_I by the SFOC in Table A1 [9] in Appendix A. The calculated bunker consumption amount is 3,540,342.2 tons. To calculate how much emission pollutants are released from the LNG fleet, we adopted the emission factors introduced by Smith et al. [9]. The amount of emission pollutants can be derived by multiplying the bunker consumption by the emission factors in Table A2 [9] in Appendix A. The calculated emission inventory is shown in Table 5.

Table 5. Emission inventory of the LNG fleet.

Emission Pollutant	Amount (Metric Tons)
CO_2	9,735,941.05
CH_4	181,265.52
N_2O	389.44
NO_x	27,720.88
CO	27,720.88
NMVOC	10,656.43

To achieve a deeper insight into the distribution of bunker consumption, we plotted the result on a map (Figure 3). Highly concentrated routes are mostly located from the Middle East to the Far East (Arabian Sea–Indian Ocean–Malacca Strait–Singapore Strait–South/East China Sea–West Pacific) and the Middle East to Europe (Arabian Sea–Red Sea–Suez–Mediterranean Sea), and Oceania to the Far East (Indonesian Archipelago–South/East China Sea–West Pacific). As the emission inventory is derived from the product of bunker consumption and the emission factor, the distribution of each air pollutant is the same as in Figure 3.

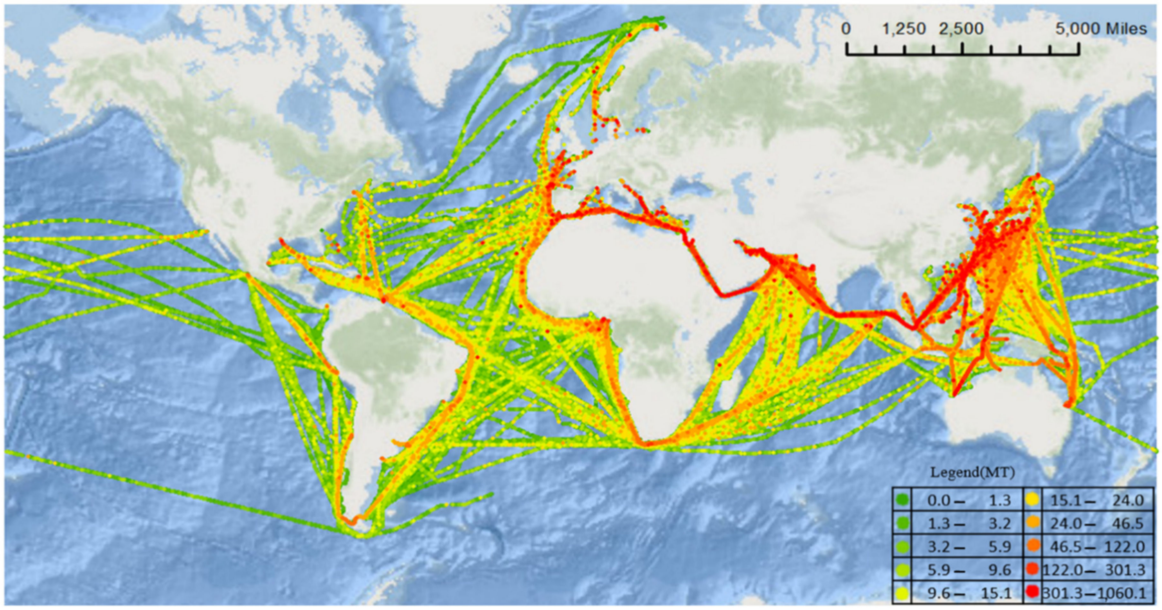

Figure 3. Distribution of bunker consumption by LNG fleet, 1*1 degree.

Compared to Figure 1 (distribution of number of data acquired), Figure 3 shows a high density in the Mediterranean Sea, south of the Bay of Bengal, in the Malacca Strait, in the South China Sea, in the East China Sea, and along the coast of Japan and Korea. This might be the factor supporting the point that a higher number of data points collected does not mean more vessel activity in the area for a specific ship type.

4. Comparison between Bunker Consumption, LNG Trade Amount, and CO_2 Emission from LNG Fleet at the Vicinity of Each Country

The flow of this chapter uses the emission data calculated in Section 3, the position recorded in the AIS message, and the global country boundary data. First, we aggregated the bunker consumption from 0.2 degrees from the coast of each country. Geopandas (version 0.4.0) was used for the tool for buffering and aggregation in this section. Second, from the aggregated data by country, we made a comparison with the international trade data [16] to gain a clearer understanding about which countries are taking advantage of LNG trade and which countries are suffering from the unfavorable effects from the trade of LNG. In addition to this, from the aggregated bunker consumption we calculated the CO_2 emissions and compare them with the entire CO_2 inventory of each country.

4.1. Buffer

To aggregate the bunker consumption in the vicinity of coast of each country, we adopted a buffer. Buffers are areas around the point, line, polygon, or group of it. For example, buffering a point returns a round shape area and buffering a line returns a lane shape area. A buffer could be a great analysis tool. For example, same as what we did in this study, it can create the area from fixed distance (0.2 degree) away from the coast of each country. The reason why we adopted 0.2 degrees in this study is that 0.2 degrees is

12 min which means 12 nautical miles in equator. In UN convention on the law of the sea part 2 "Territorial Sea And Contiguous Zone", Section 2 "Limits Of The Territorial Sea", article 2 states that every state has the right to establish the breadth of its territorial sea up to a limit not exceeding 12 nautical miles, measured from the baselines determined in accordance with this convention. Data for coastline of each country are obtained from the Environmental Systems Research Institute (ESRI). As every calculated bunker consumption has a position, we aggregated the bunker consumption inside of the buffer.

4.2. Result

4.2.1. Comparison Bunker Consumption near the Coastline of Each Country and LNG Trade Amount

The left side of Table 6 illustrates details of how much bunker consumption made inside of buffer created. The counties listed on this table are not only located at the end of the route but also located along the main passage of transportation.

Table 6. Bunker consumption made from 0.2 degrees from each country (top 20) and the sum of LNG export and import for the top 20 countries (million tons per annum) [16].

No.	Country	Bunker Consumption (Metric Tons)	No.	Country	Sum of LNG Export and Import (Million Tons)
1	Malaysia	69,193.20	1	Japan	83.34
2	Indonesia	42,643.16	2	Qatar	77.24
3	Egypt	38,887.04	3	Malaysia	51.07
4	Japan	33,839.04	4	Australia	44.34
5	Yemen	25,016.19	5	Korea	33.71
6	Iran	23,185.27	6	China	26.78
7	Singapore	18,171.99	7	India	19.17
8	Oman	15,807.31	8	Nigeria	18.57
9	Qatar	9291.88	9	Indonesia	16.59
10	Philippines	7625.87	10	Taiwan	15.04
11	Papua New Guinea	6222.00	11	United Arab Emirates	14.09
12	Spain	5561.60	12	Algeria	11.52
13	India	5219.54	13	Russia	10.84
14	Australia	4822.99	14	Trinidad and Tobago	10.57
15	Chile	4065.93	15	Spain	9.88
16	Trinidad and Tobago	3358.28	16	Oman	8.14
17	Korea	3335.94	17	Egypt	7.83
18	Greece	2954.19	18	United States	7.44
19	Djibouti	2542.90	19	United Kingdom	7.37
20	Morocco	2444.64	20	Papua New Guinea	7.36

The right side of Table 6 illustrates the summation of the LNG export and import of each country LNG with the export and import data from the IGU World LNG report 2017 [16]. Few countries listed on left side of Table 6 are not listed in right side of Table 6, and the order of list is quite different. This may give a clearer understanding of which countries are actively involved in LNG trade and which countries may be affected by the emissions of the LNG fleet. Especially, countries such as Sri Lanka and Djibouti are not actively involved in the trade of LNG; however, those countries have a high possibility of being affected by the air pollutants emitted from the LNG fleet.

Figure 4 is the scatter plot of the bunker consumption aggregated inside of the buffer created and the LNG trade amount of each county. It gives a quick insight into which counties are benefiting more from the LNG trade. Many countries are enjoying the advantages of international shipping; however, countries—including Malaysia, Indonesia, Yemen, Oman, Philippines, Sri Lanka, Chile, etc.—who share the coast with a main passage of shipping (e.g., Strait of Malacca, Indonesian Archipelago, Arabian Sea, Mediterranean Sea, Magellan Strait, etc.) may not gain enough benefit from international shipping.

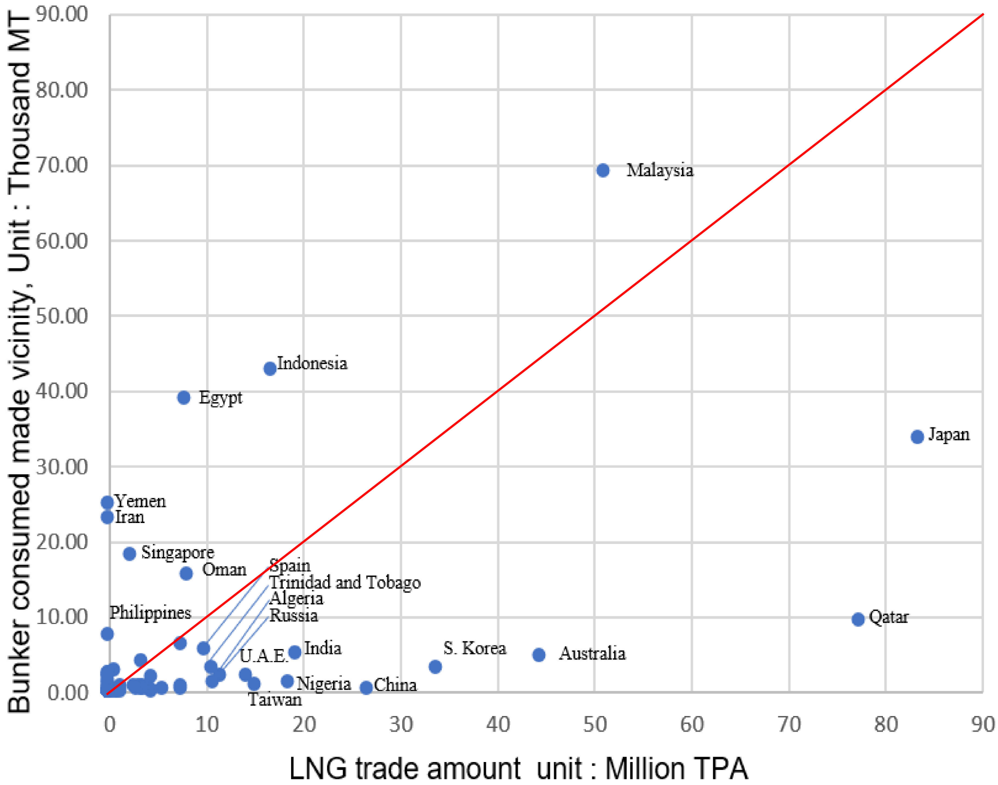

Figure 4. Scatter plot of the LNG trade amount and the sum of emissions made 0.2 degrees away from the coast.

4.2.2. Comparison of the CO_2 Emissions from the LNG Fleet and the CO_2 Inventory of Each Country

We compared the CO_2 emission amount from LNG fleet calculated in this study with CO_2 emission of each country sourced from Emission Database for Global Atmospheric Research [23]. Table 7 shows ratio of CO_2 emission from LNG compared to CO_2 emission of each country. Countries such as Malaysia, Timor-Leste, Yemen, Papua New Guinea, Oman, Egypt, Indonesia, and Sri Lanka are relatively more affected by emission from LNG fleet in country scale. Table 7 outlines detailed value of percentage.

Table 7. Comparison of the calculated CO_2 emissions and entire CO_2 emissions by country (top 20 sorted by CO_2 from LNG fleet ‱).

	Calculated Bunker Consumption (Unit: ton)	Yearly CO_2 Emission of Whole Country (Unit: Kilo-ton)	Half of Yearly CO_2 Emission (*A*) (Unit: ton)	Calculated CO_2 Emission Amount (*B*) (Unit: ton)	CO_2 from LNG Fleet (B/A) (Unit: ‱)
Eritrea	2347	684	342,070	6455	188.70
Timor-Leste	1653	496	247,845	4546	183.42
Djibouti	2543	1509	754,425	6993	92.69
Gibraltar	807	573	286,355	2219	77.49
Puerto Rico	720	713	356,380	1980	55.56
Yemen	25,016	25,648	12,823,995	68,795	53.65
Comoros	105	108	54,210	289	53.31
Papua New Guinea	6222	9087	4,543,495	17,110	37.66
Sao Tome and Principe	27	56	28,090	74	26.34
Saint Helena	6	13.13	6565	16	24.37
Singapore	18,172	48,382	24,190,880	49,973	20.66
Malaysia	69,193	266,252	133,125,770	190,281	14.29
Equatorial Guinea	507	2156	1,078,185	1393	12.92
Anguilla	6	30	15,130	17	11.24
Oman	15,807	87,836	43,917,885	43,470	9.90
Egypt	38,887	219,377	109,688,675	106,939	9.75
Trinidad and Tobago	3358	34,974	17,487,130	9235	5.28
Qatar	9292	98,990	49,495,040	25,553	5.16
Mauritius	283	3192	1,596,155	779	4.88
Indonesia	42,643	530,036	265,017,825	117,269	4.42

5. Validation

To verify that the calculated bunker consumption and air pollutant amount can be explained, first, we re-arranged the daily sum of bunker consumption. From the daily sum of bunker consumption, we made a series of data which is the sum of few days including that day—i.e., data for 4 January in the sum of three days means the sum of bunker consumption from 2 to 4 January. As the period of summation for each data increases, the difference between the mean and the median decreases and the increase in standard deviation is relatively smaller than that of the mean of data. Table 8 shows the detail of the validation. As Japan and Korea were the world's biggest and second-biggest LNG importer [16], we adopted LNG import statics of Japan published by the Japanese Ministry of Economy, Trade, and Industry [24] and data published by the Korea Gas Corporation (KOGAS) was adopted. As the monthly import amount of LNG was not included in the data released by KOGAS, we used the monthly number of voyages for Korea [25]. The Korea Gas Corporation is a state-owned company and accounted for about 90% of the entire LNG import of Korea in 2016 [26,27].

Table 8. Moving average (MA) of consumptions (unit: thousand MT).

	Daily Sum	3-Day MA	7-Day MA	14-Day MA	28-Day MA	56-Day MA	84-Day MA
Mean	19.45	58.60	137.46	275.95	549.98	1092.82	1632.56
STD	12.45	20.61	24.24	26.08	33.96	39.60	42.47
Median	15.37	49.37	143.36	275.35	551.46	1090.39	1633.07

Figure 5 shows the LNG import amount in Japan [24] and the number of voyages of LNG fleet in Korea [25] in 2016. The LNG import in Japan in March recorded the highest import amount, followed by February and January in 2016. The number of voyages of LNG carriers which transported LNG to South Korea in December the recorded highest number of voyages, followed by January and March in 2016. For both the LNG import amount of Japan and the number of voyages of South Korea, January to March are noticeably higher than the values recorded from April to June 2016.

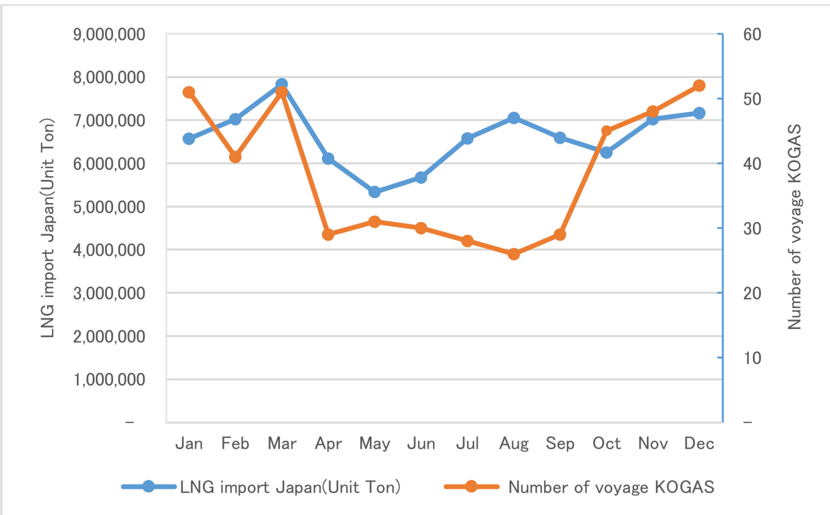

Figure 5. LNG import amount in Japan and e number of voyages of LNG fleet in Korea in 2016.

Looking into detail at the Japanese statistical data of the LNG trade volume and the LNG trade volume assumed from the AIS data, Table 9 shows monthly comparison of the statistical data released by the Ministry of Economy, Trade, and Industry (METI) of Japan and AIS based estimated LNG trade volume of Japan. The ratio estimated from the AIS data is about 59% compared to the data released by METI. Depending on the month, the percentage of estimated trade volume from AIS, compared to the data from METI, varied from 47% to 83%.

Table 9. Monthly comparison of the statistical data and estimated LNG trade volume from AIS, Japan.

Month	Estimated from AIS (*A*) (Unit: MT)	Statistics from METI (*B*) (Unit: MT)	$\frac{A}{B}$
Jan-16	3.07	6.57	0.47
Feb-16	4.48	7.02	0.64
Mar-16	4.06	7.83	0.52
Apr-16	3.84	6.11	0.63
May-16	2.56	5.34	0.48
Jun-16	4.73	5.67	0.83
Sum	22.74	38.54	0.59

In the case of Korea, we calculated the monthly amount of import from the KOGAS data as shown in Table 10. From the total number of voyages (461 voyages) [26,27] and total import amount (31,846,875 tons) [26,27] in 2016, we derived the average amount of LNG carried per voyage (D in Table 10). Then, by the multiple number of voyages (N in of Table 10) with D, the monthly amount imported by KOGAS is calculated. As KOGAS imported about 92.5% [26,27] of the total LNG import amount of Korea, by dividing B (Table 10) by 0.925 we calculated the monthly import amount of Korea (C in Table 10). Depending on the month, 34–58% of the LNG trade volume was covered by the AIS origin–destination data. In both Japan and Korea's case, the % of estimated amount from AIS was the highest in June (Tables 9 and 10).

Table 10. Monthly comparison of the statistical data and estimated LNG trade volume from AIS, Korea.

Month	Estimated from AIS (*A*) (Unit: Million Tons)	Number of Voyages (*N*)	Average Carried Amount per Voyage (*D*) (Unit: ton)	KOGAS (*B* = *N***D*) (Unit: Million Tons)	Extrapolated Import Amount (*C* = *B*/0.925) (Unit: Million Tons)	$\frac{A}{C}$
Jan-16	1.29	51	69,082.16	3.52	3.81	0.34
Feb-16	1.48	41		2.83	3.06	0.48
Mar-16	1.43	51		3.52	3.81	0.38
Apr-16	0.89	29		2.00	2.17	0.41
May-16	0.55	31		2.14	2.32	0.24
Jun-16	1.30	30		2.07	2.24	0.58
Sum	6.94	233	69,082.16	16.08	17.41	0.40

The reasons why the estimated trade volume based on the AIS data is smaller than that of the statistical data might be errors in the destination country, errors in classifying the loading conditions, errors in method used to separate voyages, errors in the loading capacity of the vessel, or incomplete destination databases and tracking.

Figure 6 shows the correlation between the MA of bunker consumption and the LNG import amount of Japan (orange line) [24], and the number of voyages of Korea (blue line) [25]. As the period of summation increases, both correlations show a similar trend. Especially, the correlation coefficient with the 56-day MA, 8 weeks, is higher than 0.8. This may imply that the LNG fleet movement is related to the planned LNG importing amount 1–2 months later.

In conclusion, the bunker consumption of LNG fleet is correlated to the LNG trade volume in the case of Japan and Korea, the top 2 largest LNG importers.

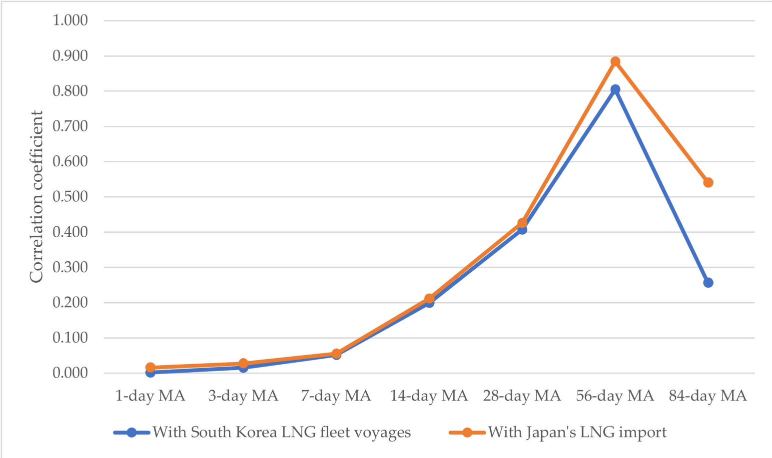

Figure 6. Correlation coefficient between the sum of bunker consumption and LNG import amount and the sum of bunker consumption and the number of voyages.

6. Summary

This paper aims to offer insight into LNG emission inventory and provides empirical evidence for the finding that some countries who do not benefit from LNG trade suffer high emissions near their coasts. The contribution of this paper is four-fold. First, we estimated vessel resistance in accordance with the ITTC recommended procedure and derived the bunker consumption and emission inventory based on AIS data. Second, by plotting it on a map, we obtained a deeper understanding of emissions and bunker consumption. Third, we applied a geospatial analysis to ship emission inventories to figure out how the air pollutant emissions and bunker consumption distributions are clustered. Fourth, by calculating the sum of the bunker consumption, which can be easily converted to emission inventory from the coast of each country, we were able to illustrate how much each country might be affected by emissions from the LNG fleet.

The research result also offers managerial implications. Ships emit along the main LNG shipping routes, such as the Strait of Malacca, the Indonesian Archipelago, the Arabian Sea, the Singapore Strait, the Mediterranean Sea, the Magellan Strait, etc. Many countries, such as Sri Lanka and the Philippines, located in the vicinity of these routes are not actively involved in the trade of LNG or are unable to enjoy much of the prosperity from shipping, but have a high amount of bunker consumption near the coast of their country. By comparing the amount of bunker consumption 0.2 degrees away from the coast of each country with international LNG trade and the amount of CO_2 emitted 0.2 degrees away from the coast of each country, we gained an understanding of which counties are taking relatively more advantage of LNG trade and which countries are suffering relatively more from the probable harmful effects. International society may need to think about how it can compensate these countries for the possible damage from ship-emitted pollutants.

This research could be improved in many ways. First, the accuracy of calculation could be improved by resolving the problem of unstable AIS data intervals. Second, with more detailed data on the fuel efficiency and engine type of LNG carriers, more accurate results could be gained. Third, with a more extensive amount of AIS data points, seasonal and monthly trends could be analyzed. Finally, same approaches could be applied to other types of vessel to gain a more extensive understanding of ship emissions.

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Appendix A

Table A1 shows SFOC by engine age [9] and distribution of engine age of the vessels included in AIS data. SFOC is commonly expressed in g/kW·h. As the vessel engine gets older, an efficiency of the engine goes down and advent of technology make a newer engine more efficient.

Table A1. SFOC [9] and the distribution of the engine age of the vessels included in the AIS data.

Engine Age	MSD (Medium-Speed Diesel (Engine)), Unit: g/kW·h.	Number of Vessels by Engine Age, Unit: Year	Percentage
Before 1983	215	6	1.83%
1984–2000	195	46	14.07%
After 2001	185	275	84.10%

Table A2 shows emission factors for top-down emissions from combustion of fuels. Using emission factors, amount of emitted air pollutant could be derived from bunker consumption amount. It is expressed in kg/kg of fuel.

Table A2. Emission factors of each emission pollutants [9].

Emission Pollutant	Emission Factor (kg/kg of Fuel)
CO_2	2.75000
CH_4	0.05120
N_2O	0.00011
NO_x	0.00783
CO	0.00783
NMVOC	0.00301

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Identifying Factors for Selecting Land over Maritime in Inter-Regional Cross-Border Transport

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Abstract: Several cross-border land corridor projects have been implemented worldwide, because land transport is a vital alternative to international maritime transport in inter-regional transport. Maritime transport generally costs less than land transport, but it is much slower. Nonetheless, land transport can be more appropriate than maritime under certain situations. This study aims to identify factors that can help select between these two modes in long-distance inter-regional cross-border transport; to this end, a Tobit model is employed to estimate the dependent variable, i.e., the land ratio of origin–destination pairs between countries and/or areas. Eight variables are identified as significant: distance, export of manufacturing commodity, landlocked country/area, neighboring country/area, country risk, infrastructure level, port-access time, and maritime transport frequency. We also find that geographical conditions, country relationship, and regulations are barriers for selecting land transport. However, cross-border land corridors contribute to the increase of land ratio.

Keywords: land transport; cross-border land corridor; Tobit model

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1. Introduction

A land corridor is a type of highway or railway infrastructure that links two or more urban areas [1]. They typically comprise one or more routes that connect economic centers within and across countries [2]. Several cross-border corridor projects have been implemented by international agencies with the help of worldwide donors to facilitate trade via land transport. These projects have been initiated not only in developed areas, such as the European Union (EU) and North America, but they have also taken place in relatively underdeveloped areas, such as Africa and Asia [2]. The Chinese government is forging ahead on their Belt and Road Initiative, which will connect Europe to China via cross-border land ("belt") and maritime ("road") corridors [3]. Economic corridors in the Greater Mekong Subregion (GMS) (e.g., North–South, East–West, and Southern Economic Corridors designated as development priorities), as initiated by the Asian Development Bank, were formed to accelerate subregional development [4], and to review their configuration to enhance effectiveness and efficiency for advancing its economic integration [5]. These projects are expected to primarily benefit shippers, freight forwarders, and carriers by reducing transport time and costs along the corridors via infrastructure developments and improvements by institutions which are supported by regulations (e.g., cross-border transport agreements and customs clearances) for seamless transport.

Maritime transport is sometimes considered to be superior to land transport for long-distance inter-regional cross-border trade, because the costs are less, owing to economies of scale that come from loading a large amount of cargo, although it is much slower than land transport. Maritime transport also has an advantage in terms of energy efficiency and greenhouse gas emissions as it is a more environmentally sustainable transport mode than land transport [6,7]. In contrast, land transport has a disadvantage in that crossing borders may spend more time and cost. Furthermore, the capacity per shipment is smaller in land transport than that in maritime transport. Moreover, in developing countries, the value of many trade commodities is not as high as that found in developed countries. Thus, those shippers and forwarders tend to opt for maritime transport instead of land-based transport.

However, in long-distance inter-regional cross-border trade, land and maritime transport may have a competitive relationship, such as the one that led to the Belt and Road Initiative. Land transport has the potential to positively impact economic activities in adjacent areas. Nonetheless, the factors behind choosing land transport have not been clarified at the level of inter-regional cross-border trade even though several studies have done at the intra-regional level. An investigation into the factors that facilitate the selection of cross-border transport via land transport would be useful for donors and agencies, because they need to consider modern and realistic costs vs. benefits regarding transport infrastructure investment (e.g., highway and railway).

This study aims to identify the significant factors that lead to the selection of land corridor transport instead of maritime transport in long distance inter-regional cross-border transport, but not in intra-regional transport. We examine the possible factors by developing a model that estimates land ratio, which is defined as the ratio between the nominal value of land transport and the sum of the land and maritime transport based on data of obtained from the World Trade Service (WTS). We apply a Tobit model with country origin–destination (OD) pairs to sample data. Furthermore, we accumulate as many country OD pairs as possible to improve the results. Land ratios express modal share and are key indicators that explain how modes compete, which can then be used for demand forecasting to predict international cargo values. We also discuss the effects of cross-border land corridors and the possible barriers to selecting them by examining data summaries of the selected OD pairs and residual analyses of Tobit results.

The remainder of this study is organized as follows. Section 2 provides a literature review that deals with the cross-border land corridor and maritime transport by evaluating their performances based on key factors. Section 3 describes the data sources and how we handle data samples. Section 4 describes in detail the Tobit model and 11 explanatory variables that support decision-making. The estimated results are then discussed in Section 5. Section 6 concludes this article.

2. Literature Review

Several studies have evaluated cross-border land and maritime transport problems by evaluating their performance based on key factors. Moon et al. [8] performed a comparative analysis of selected sea and land transport routes between the Republic of Korea and Europe using the TOPSIS technique. This technique uses quantitative factors that include transport distance, time, and cost, and qualitative factors that include reliability, flexibility, frequency, information service, and safety. Transakul et al. [9] used an analytic hierarchy process to evaluate factors that facilitated cross-border trade. They set cost, time, and complication as the intermediary factors with transparency, technology, policy, and infrastructure as sub-factors, and concluded that transparency was of the greatest importance at the sub-factor level. Banomyong [10] developed the logistics macro-level scorecard based on the four components of a logistics system (i.e., infrastructure, institutional framework, service providers, and traders) to evaluate a system's capability in terms of strengths and weaknesses. With this scorecard, the author benchmarked the North–South and the East–West Economic Corridors of the GMS from physical and non-physical aspects. Four stages of land economic corridor development were also proposed. Regmi and Hanaoka [11] used a time–cost–distance method to highlight the importance of improving hard and soft infrastructures to assess two important intermodal transport corridors linking north, east, and central Asia. Conditions of transport infrastructure, facilities, and clearance processes at ports and border crossings emerged as significant constraints to intermodal transport operations along the corridors. Transport time and costs were sometimes affected by poor infrastructure quality (e.g., only one railway track, lack of locomotives, and low operational frequency of freight trains). Jain and Jehling [12] described a multi-method approach that involved spatial and non-spatial analyses to investigate disparities along a proposed corridor and examined its integration within the existing settlement structure. They found that the policies affecting transport corridors had a risk of leaving peripheral areas marginalized. Fraser and Notteboom [13] applied the resource and capability approach to the context of corridors connecting a port system to contestable hinterlands in southern Africa. Capacity expansions of seaport and corridor networks as resources in conjunction with efficient transport services/operations as capabilities were found to be important to guaranteeing the attractiveness of port–corridor combinations. Rodemann and Templar [14] conducted a study on intercontinental rail transport between Asia and Europe by performing a literature review with interviews. They identified enablers and inhibitors of intercontinental rail freight using the PESTLE analysis. Enablers for rail transport included investment into transport infrastructure, transport capacity, transport reliability, high security, intergovernmental agreement, geography, climate, CO_2 emissions, and energy consumption. Lim et al. [15] derived relevant factors to be considered in the development of transit trade corridors and derived eight underlying factors that affected their design: development and policy implications; safety, security, and political concerns; environmental protection; financing and investment; soft infrastructure; hard infrastructure; geography and landscape; and corridor performance. Wiegmans and Janic [16] proposed a methodology for assessing the performance of long-distance intercontinental intermodal rail/road and sea shipping freight transport corridors and assessed their performance between China and Europe as part of the Belt and Road Initiative. These performances were assumed to be dependent of infrastructural and technical/technological capabilities, such as railway lines, intermodal terminals, rolling stock, and support facilities and equipment. Panagakos and Psaraftis [17] proposed a methodology for freight corridor performance monitoring using key performance indicators. Zhang et al. [18] investigated cold chain-mode choices between containerized transport and reefer bulk shipping. Chain-mode is used to schedule shipments by considering different reefer bulk planning methods, sailing speed optimizations, cargo value depreciation, and greenhouse gas emissions. Wang et al. [19] analyzed the effect of green logistics on international trade using an augmented gravity model and the data of 113 countries and regions over the period of 2007–2014. The explanatory variables were classified into seven categories: economic, environmental, trade facilitation, geographical, political, cultural, and entry cost. Göçmen and Erol [20] examined the allocation of export containers to transport modes in Turkey and European countries by incorporating social risks, such as human accidents and deaths, and ecological risks, such as emissions and noise pollution. A mixed-integer programming-based mathematical model with a fuzzy-based approach was proposed to decide the containers allocation. Tadić et al. [21] evaluated of the location selection and development of dry port terminals as a prerequisite for the establishment of an ecological, economic, and socially sustainable logistics network. In their study, the infrastructure criteria, which included distance and transport, indirectly considered the ecological and economic sustainability of the dry port locations. A new hybrid model of multicriteria decision-making was then developed.

A few studies investigated mode choices between cross-border land and maritime transport. Feo et al. [22] and Arencibia et al. [23] applied the discrete choice model to find freight shipper preferences based on attributes of cost, transit time, punctuality, and service frequency, resulting in the development of explanatory variables related to the different transport modes. A stated preference survey was used for data collection, because it required fewer data. Jiang et al. [24] explored current and prospective hinterland patterns of the China Railway Express using the binary logit model and assessed the impacts of fixed utility, freight costs, and transport time. They determined that shippers were more inclined to select maritime shipping because of the high value of fixed utility. Li et al. [25]

analyzed the influence of geographical factors on the land ports-of-entry (POEs) and sea POEs cross-border logistics routes choice in China, Myanmar, and Vietnam by using the conditional logit model. The results show that there are significant differences in the characteristics and their influencing factors, which are reflected in the scale of freight, distance, duration, transport expense, infrastructure quality, geographical location, and characteristics of the shippers and POEs. Baindur and Viegas [26] used an agent-based modeling approach to find the important factors for mode choices by shippers.

Table 1 summarizes a review of the literature and indicates the methodology, regions or countries, transport mode, and with or without border crossing. This study focuses on OD pairs from the countries and areas in the world where land and maritime transport can compete in long distance inter-regional but not intra-regional cross-border transport that is different from other studies.

Substantive research on the evaluation of land corridors have been conducted, but they vary by the purposes, methods, and sizes of the corridor examined. They also allow for quantitative and qualitative factors to be considered simultaneously. However, it is not still clear how to deal with performance indicators related to cross-border land and maritime transport while considering the influence of the differences of freight volume. Additionally, all of the related studies dealt with specific corridors, and there were none that generalized the factors for worldwide use. Thus, this study develops a model to identify the factors that lead to the selection between the two given transport modes with built-in inter-regionality and worldwide applicability.

Table 1. Summary of literature review.

Papers	Methodology	Regions or Countries	Transport Mode	Border Crossing
Moon et al. (2015) [8]	TOPSIS analysis	Sea and land transport routes between the Republic of Korea and Europe	Inland and maritime	√
Transakul et al. (2013) [9]	Analytic hierarchy process	East–West Economic Corridor of Greater Mekong Subregion	Inland	√
Banomyong (2008) [10]	Logistics Macro-Level Scorecard	North–South and the East–West Economic Corridors of Greater Mekong Subregion	Inland	√
Regmi and Hanaoka (2012) [11]	Time-cost-distance method	Important intermodal transport corridors linking North-East and Central Asia	Inland	√
Jain and Jehling (2020) [12]	Spatial and non-spatial analysis	Delhi–Mumbai Industrial Corridor in India	Inland	
Fraser and Notteboom (2014) [13]	Resource and capability corridor appraisal model	Corridors connecting a port system to contestable hinterlands for southern Africa	Inland	
Rodemann and Templar (2014) [14]	PESTLE analysis	Intercontinental rail transport between Asia and Europe	Inland	√
Lim et al. (2017) [15]	Exploratory and confirmatory factor analysis	Transit trade corridors in the Northeast Asia region	Inland	√
Wiegmans and Janic (2019) [16]	"what if" scenario approach	Intercontinental freight transport corridors spreading between China and Europe	Inland and maritime	√
Panagakos and Psaraftis (2017) [17]	Key Performance Indicators estimation	Green Corridor in the North Sea Region	Inland and maritime	√
Zhang et al. (2020) [18]	Mixed integer linear programing model	(Numerical example only)	Maritime	
Wang et al. (2018) [19]	Augmented gravity model	113 countries and regions all over the world	Unspecified	√
Göçmen and Erol (2018) [20]	A mixed-integer programming-based mathematical model with a fuzzy-based approach	Between Turkey and Europe	Inland and maritime	√
Tadić et al. (2020) [21]	Hybrid multicriteria decision-making model combined Delphi, AHP, and CODAS methods in a grey environment	Western Balkans region	(Dry port)	
Feo et al. (2011) [22]	Discrete choice model	Door-to-door road transport and short sea shipping in the Sea of south-west Europe	Inland and maritime	√
Arencibia et al. (2015) [23]	Discrete choice model	Freight flows between Spain and Europe.	Inland and maritime	√
Jiang et al. (2018) [24]	Discrete choice model	China Railway express focusing on its hinterland patterns	Inland and maritime	
Li et al. (2020) [25]	Conditional logit model	China, Myanmar, and Vietnam	Inland and maritime	√
Baindur and Viegas (2011) [26]	Agent-based modeling	Atlantic–Mediterranean Transition Region	Inland and maritime	√

3. Data

A database that provides the nominal trade value of transport modes in OD pairs by country is needed to identify the important factors that facilitate the selection of land transport. The data sorted by commodity and mode can be partially obtained by examining those provided by the statistical institutions of some countries. However, many countries do not have an adequate amount of data. Therefore, we use the WTS data provided by IHS Markit, Ltd. [27].

The WTS provides data from 75 countries and 31 areas. The areas consist of two or more countries classified by 11 regions. For example, one area in western Africa includes Burkina Faso, Mali, and Niger, and another area in Central America includes El Salvador, Honduras, and Nicaragua. All data items, except total trade nominal value, exclude intra-European trade. Therefore, intra-European trade cannot be selected as a sample in this study.

We extract the OD pairs from the countries and areas in which land and maritime transport can compete. First, the countries and areas are selected based on the following four criteria: (1) areas consisting of four or more countries that are excluded, because it is difficult to express the representative values among four or more countries to calculate the explanatory variables; (2) areas containing both landlocked and non-landlocked countries that are excluded, because landlocked countries have no sea port in their territory and the selection conditions are too different; (3) the countries in an area that are physically connected by land; and (4) countries or areas that do not connect with a land border to other countries or areas that are excluded, because they have no opportunity to select land transport (e.g., an island country).

Next, the OD pairs are selected using the following additional two criteria: (5) origins and destinations that are located in the same or a nearby region and (6) land ratio or maritime ratios that are greater than 1% in an OD pair. The term "nearby region" used in criterion (5) indicates regions that geographically neighbor each other. For example, freight transport between China and Germany is not examined in this study, because the two countries are not adjacent, and the distance between them is extremely large. In this case, maritime transport would be superior to land transport. Regarding criterion (6), maritime ratio includes the nominal maritime values over the sum of those of land and maritime. If the land or maritime ratio is less than 1%, the two transport modes are no longer considered to be competing.

The pairs of regional classifications examined as inter-regional cases in this study are listed in Table 2. Pair 5 is an intra-regional pair between EU and non-EU countries, but we decided to include it because the border control exists between these countries. Based on the results of the described selection process, we used 280 OD pairs comprising 64 countries and nine areas (i.e., Benin and Togo; Burkina Faso, Mali, and Niger; Belize and Guatemala; Costa Rica and Panama; El Salvador, Honduras, and Nicaragua; Latvia, Estonia and Lithuania; French Guiana, Guyana and Suriname; Iran and Iraq; and Oman and Yemen) for the Tobit-model analysis.

Table 2. Selected regional pairs for the inter-regional cases.

Pair 1	Africa	Western Asia
Pair 2	Central America and the Caribbean	North America
Pair 3	Central America and the Caribbean	South America
Pair 4	East Asia	Indian Subcontinent
Pair 5	European Union	Other European Countries
Pair 6	European Union	Western Asia
Pair 7	Indian Subcontinent	Western Asia
Pair 8	Other European Countries	Western Asia

4. Methodology

We used a Tobit model to find the important factors that facilitate the selection of land transport. We applied land ratio, which has upper and lower limits, as a dependent variable. This way, the Tobit model should yield more desirable results than the ordinary least-squares method, which is otherwise widely applied when the range of the dependent variables is limited.

The Tobit model is defined by Equation (1). The model aims to determine the best-fitting model to describe the relationship between the dependent variable, y, and the set of explanatory variables, $x_{1.i}, \ldots, x_{p.i}$, by estimating the intercept, α, the coefficients, $\beta_1, \ldots, \beta_p$, and their significance levels. The Tobit model supposes that there is a latent variable, y_i*, expressed as a linear combination of explanatory variables, intercepts, and coefficients. Additionally, there is a normally distributed error term, u_i, which is used to capture random influences on the relationship between explanatory and dependent variables. The dependent variable is equal to the latent variable whenever the latent variable is in the range of zero to one:

$$y_i = \begin{cases} 0 & if \quad y_i^* \leq 0 \\ y_i^* & if \quad 0 < y_i^* < 1 \\ 1 & if \quad y_i^* \geq 1 \end{cases}, \tag{1}$$

where y_i^* is a latent variable: $y_i^* = \alpha + \sum_{j=1}^{p} \beta_j x_{j.i} + u_i$.

$$Land\ Ratio[\%] = \frac{Overland\_Other\ Trade\ Nominal\ Value\ (USD\ Thousands)}{Total\ Trade\ Nominal\ Value\ (USD\ Thousands) - \ Airborne\ Trade\ Nominal\ Value\ (USD\ Thousands)}. \tag{2}$$

The total trade nominal value of the WTS data has three components: overland/other trade nominal value, seaborne trade nominal value, and airborne trade nominal value. Overland/other trade nominal value indicates land transport. We use Equation (2) to express the land ratio to best show the ratio of land transport to the total trade nominal value. Air transport offers high-speed deliveries at high costs. Thus, airborne trade is generally limited to specific commodities having high value and small size, such as electronic components, semiconductors, computer equipment, and parts. However, the difference between the defined land ratio and the land ratio without excluding airborne trade value from the denominator is less than 1% in 224 of the 280 samples, because we excluded the OD pairs covering large distances by criterion (5) of the OD pair selection process. In relatively short-distance cases, road transport has a similar function as air transport for offering high-speed transport at high costs. Therefore, excluding the airborne trade value does not significantly affect the results.

In this study, we selected 11 explanatory variables based on several existing studies. For each variable, we next explain the definition, selection justification, calculation method, and the year to be used for its calculation. Note that, if either the origin or destination is an area, the mean is used for the input.

- Gross Domestic Product (GDP) per capita. The definition of GDP per capita (USD) is the GDP divided by mid-year population. It is used in our model, because it expresses a proxy value of the economic power of shippers or forwarders who can pay the transport costs. Moreover, our target countries have different economic powers that are related to the transport cost as a typical factor for mode choice [22,23]. The cost of land transport is generally higher than that of maritime transport, and a country wielding economic power can almost always afford to use the mode having the higher cost. Thus, the expected sign is positive. We calculate the mean of the origin and destination country/area as the input value of the OD pair, because the shipper or forwarder who pays the transport cost between the OD countries/areas depends on the trade contract [28].

- Distance. The distance is measured by connecting the main cities in the origin country/area and the destination country/area with the main cities of the country/area in-between the two. The cost per distance of road and rail transport was higher than that of maritime transport, whereas the road and rail transport have a lower cost for short distances [29]. The distance variable represents the degree to which maritime transport is superior to land transport from a cost perspective. Thus, the expected sign is negative. Distance data were taken from the maps prepared by the Geospatial Information Authority of Japan [30] and are presented in kilometers. We selected the capital city as the main city. However, the largest economic city was selected in some countries. If the origin or destination was an area, the city used to measure the distance was selected as the main city of the highest GDP country of the included countries.
- Export of manufacturing commodity. The fact that transport flows were highly heterogeneous is undoubtedly a critical aspect when analyzing freight transport [31]. The value of the cargo being transported was included as heterogeneous and can affect the choice of transport mode. We used the ratio (percentage) of manufacturer exports over the total amount of merchandise exports from the origin country/area. We assumed that manufacturing products had a higher value than did other products, such as agricultural raw materials and fuels. Thus, the expected sign was positive. We selected Sections 5 (chemicals), 6 (basic manufactures), 7 (machinery and transport equipment), and 8 (miscellaneous manufactured goods) and excluded division 68 (non-ferrous metals) as manufacturing commodities from the Standard International Trade Classification [28].
- Landlocked country (dummy). A landlocked country does not have a port in its territory. Thus, it often requires more cost and time to trade [32,33]. The dummy variable is equal to one if the origin or destination country is a landlocked country. Otherwise, it is set to zero. The expected sign is positive, because land transport should be superior to maritime transport.
- Neighboring country/area (dummy). This dummy variable is set to one if the origin and destination country/area shares a land border. Otherwise, the variable is set to zero. We assume that a border crossing is an obstacle to land transport, because the cargo must pass through customs, immigration, and quarantine, which leads to longer transport times and higher costs [11]. However, if an OD pair neighbors the country, the number of border crossings can be only one. Thus, the expected sign is positive.
- Number of land borders. This variable represents how many times the cargo must cross a border when being transported by road or rail. This represents an additional obstacle during land transport. Thus, the expected sign is negative.
- Country risk. Euromoney [34] calculates country risk by conducting a consensus survey of expert opinions from 186 countries. The scores express a social network of economic and political risk for each country. We assume that the country risk affects land transport, especially at borders where ethical conflicts, corruption, or bribes may occur [35]. The scores range from 0 to 100. A higher score indicates a lower country risk value. Thus, the expected sign is positive. We calculate the mean of the origin and destination country/area as the input value of the OD pair. The year of data used in this study is 2011.
- Infrastructure level. The level of investment in land infrastructure (e.g., highways and railways) affects the time and cost of land transport. Most research in the literature review [9,10,13] assumed it to be a critical factor. Thus, we use three indicators to express the road conditions between the origin and destination. First is the ratio of total road length to total land area (km/km^2). Second is the ratio of paved road length to total road length (percentage). Third is the ratio of total railway length to total land area (km/km^2). These data were derived from The CIA World Factbook [36]. Many studies integrated indicators that used principle component analysis, wherein the first principle component is used as the input value [33,37]. We also implemented three indicators, and the first principle component held more than 60% of the variable

information. Therefore, we use the mean of the first principle component of the origin country/area and destination country/area as the input value of the OD pair, which has both positive and negative values. More land infrastructure thus provides better conditions for land transport. Thus, the expected sign is positive.

- Port access time. Transport time is a significant factor for mode choice [22,23]. Thus, port access time, a component of transport time, is used to represent the port accessibility of a major city. We use the sum of the export lead time in an origin country/area and the import lead time in the corresponding destination country/area as the input value of the OD pair. The unit is a day [38]. The definition of export lead time is the median time (the value for 50% of shipments) from shipment point to port of loading, and the import lead time is the median time (the value for 50% of shipments) from port of discharge to arrival at the consignee. Longer port access time is, therefore, better for land transport. Thus, the expected sign is positive.
- Port infrastructure level. Port infrastructure level represents the development level of port infrastructure in the origin and destination countries/areas. This is a critical factor for the same reason as the infrastructure level. These data reflect the quality of port infrastructure [38]. This index ranges from 1 to 7 and measures the perception of a country's port facilities as assessed by business executives. Because higher values indicate better port quality, the expected sign is negative. We calculate the mean of the origin and destination countries/areas as the input value of the OD pair. In the case of a landlocked country, we use the index value of the quality of port of the country that the landlocked country generally used at the import and export [39].
- Maritime transport frequency. It was compared the performances of rail/road and sea shipping freight transport corridors in terms of the transport service frequency in operational performances [16]. Thus, we use the linear shipping connectivity index as the maritime transport frequency between the origin and destination countries/areas [38]. This index captures how well countries are connected to global shipping networks based on five components of the maritime transport sector: number of ships, container-carrying capacity, maximum vessel size, number of services, and number of companies deploying container ships in a port. The index generates a value of 100 for the average index. Therefore, the values range from zero to more than 100. Because higher values better reflect maritime transport services, the expected sign is negative. We calculate the mean of the origin and destination as the input value of the OD pair. For a landlocked country, we use the general index value of the country of the landlocked country, similar to the port infrastructure-level variable.

We selected the pass-through countries/areas to calculate the values of distance, number of land borders, infrastructure level, and country risk when the origin and destination countries/areas did not neighbor each other and had two or more connected countries/areas between them. For example, if the origin country was Thailand, and the destination country was Vietnam, Cambodia was the pass-through country. Likewise, if the origin country was Nigeria, and the destination country was the Ivory Coast, the pass-through countries were Benin, Togo, and Ghana. We determined the pass-through countries by the following priorities. First was the route having a land corridor developed by a regional or international donor based on the study of Arnold [2], starting from the corresponding country or the neighboring country. Second was the route having the fewest border-point crossings, and third was the route having the shortest distance.

The overall summary of variables is given in Table 3. As seen in Table 4, there is no pair having a correlation coefficient greater than 0.7 between explanatory variables. Therefore, all variables were used to conduct the Tobit model analysis in the next section.

Table 3. Summary of variables.

Variables	Max	Min	Mean	Standard Deviation	Expected Sign
Land ratio [%]	98.96	1.07	42.80	37.39	
GDP per capita [USD]	70,728	853	15,918	14,776	+
Distance [km]	7728	81	2496	1651.4	−
Export of manufacturing commodity [%]	94.0	0.1	44.8	30.9	+
Landlocked country	1	0	0.11	0.32	+
Neighboring country/area	1	0	0.33	0.47	+
Number of land border	12	1	2.98	2.25	−
Country risk [index]	84.64	29.80	53.23	11.18	+
Infrastructure level [index]	2.0333	−1.3722	−0.1895	0.8909	+
Port access time [days]	16.0	2.0	5.4	2.6	+
Port infrastructure level [index]	6.7	2.7	4.3	0.7	−
Maritime transport frequency [index]	139.1	4.7	40.7	23.2	−

Table 4. Correlation coefficients between the explanatory variables.

	1	2	3	4	5	6	7	8	9	10	11
1 GDP per capita	1.00										
2 Distance	0.15	1.00									
3 Export of manufacturing commodity	0.01	0.21	1.00								
4 Landlocked country	−0.09	−0.10	−0.01	1.00							
5 Neighboring country/area	−0.18	−0.38	−0.26	0.01	1.00						
6 Number of land border	0.41	0.56	0.33	−0.04	−0.61	1.00					
7 Country risk	0.67	0.09	0.04	−0.09	−0.04	0.14	1.00				
8 Infrastructure level	0.43	0.17	0.61	0.09	−0.33	0.57	0.37	1.00			
9 Port access time	−0.03	−0.22	−0.53	0.06	0.32	−0.31	−0.49	−0.19	1.00		
10 Port infrastructure level	0.66	0.21	0.29	−0.10	−0.27	0.49	0.58	0.50	−0.37	1.00	
11 Maritime transport frequency	0.18	0.28	0.56	−0.01	−0.10	0.16	0.46	0.33	−0.39	0.52	1.00

5. Results and Discussion

5.1. Summary of the Land Ratio

If an OD pair locates neighbors connected by a land border, it may be advantageous to select land transport over maritime, as explained by the neighboring dummy. Figure 1 presents the average value of the land ratio dividing neighbors and non-neighbors in each region. The average land ratio of neighbors is higher than non-neighbors among the OD samples in all regions. Therefore, we understand that border crossing is a bottleneck for land transport, because the cargo must cross the borders more than once if the OD pairs are non-neighbors. For neighbors, the average values of the land ratio in the region are greater than 50%, except for east Asia and South America.

In east Asia, the only five samples of neighboring OD pairs are Malaysia–Thailand (57.24%), and vice versa (57.80%); China–Vietnam (32.52%), and vice versa (33.50%); and Singapore–Malaysia (53.56%). The land ratio of China–Vietnam is lower than most neighboring OD pairs in other regions, because the main industrial cities in China (e.g., Shanghai) are located in northern coastal areas, and the main Vietnamese industrial city, Ho Chi Minh City, is located in southern Vietnam. Thus, land transport has few advantages. Malaysia–Singapore was excluded, because this OD pair does not satisfy criterion (6) of the OD pair selection, which is less than 1% of the maritime ratio. This is understandable, because Singapore is an island country, and the two are connected by the Johor–Singapore Causeway. The reason why the land ratio of Singapore–Malaysia is only 53.56% is that

Malaysian vehicles can drive in the territory of Singapore without permission. However, only permitted Singapore vehicles, including trucks, can enter the territory of Malaysia based on Malaysian law [40]. Therefore, maritime transport is also used from Singapore to Malaysia.

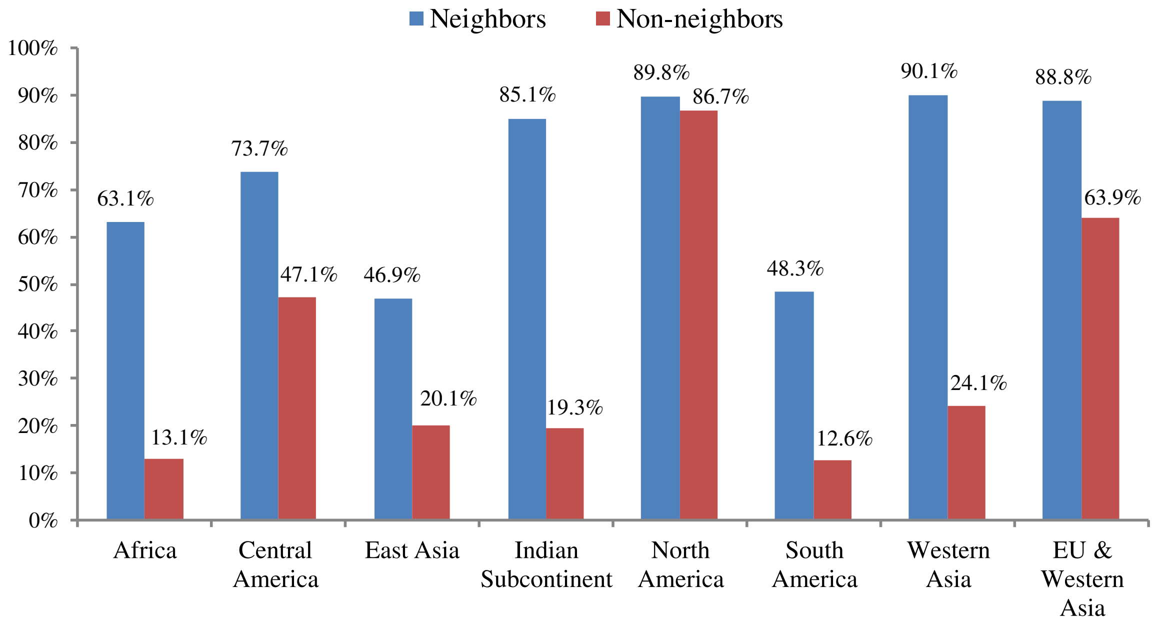

Figure 1. Average land ratio of neighbors and non-neighbors by region.

In South America, there are 26 samples of neighboring OD pairs. Among them, the land ratios of 10 OD pairs were between 12 and 24%, including Chile–Peru, Argentina–Chile, Brazil–Peru, Brazil–Venezuela, Brazil–French Guiana/Guyana/Suriname, and the reversals of each. Therefore, the average value is less than 50%. Geographical conditions of borders in these OD pairs are very tough to pass by truck, because the Andes Mountains and the Amazon rainforest exist along the borders. In Africa, the land ratio of some neighboring OD pairs is extremely low, because the Sahara Desert exists between them. As described later, such geographical conditions affect the gap between the actual land ratio and that predicted by the estimated model.

Among the non-neighboring OD pairs, the average values of the land ratios in North America, EU, and western Asia (i.e., Middle East countries except Egypt and including Turkey, following the WTS definition) were greater than 50%, because most countries of these areas are developed. Thus, shippers and forwarders may select land transport with relatively higher tariffs. Additionally, these countries have better quality land infrastructure. Among the EU countries, there are no physical and institutional barriers, which can encourage the use of land transport.

The reason for the high land ratio in the EU and western Asia is that Turkey is either the origin or the destination country in western Asia. It has a high land ratio with many non-neighboring European countries, such as the Czech Republic (95.39 and 95.09), Hungary (95.27 and 94.19), and even Romania (95.16 and 95.26) connected through the Black Sea. The land ratio between Turkey and The Netherlands, Belgium, Portugal, and four north European countries have relatively lower values: ~79–80%.

Some cross-border land corridors may contribute the higher land ratio among non-neighboring OD pairs. In North America, the CANAMEX corridor connects Canada and Mexico through the United States by a series of highways under the North American Free Trade Agreement. Thus, both Canada–Mexico (85.87%), and vice versa (87.63%), have high land ratios. In Central America, although this region is divided into three areas without a single country as an independent OD, there are mid-land ratio values between Belize/Guatemala–Costa Rica/Panama (47.02%), and vice versa (47.09%). However, Mexico–El Salvador, Honduras, and Nicaragua (89.03%), and vice versa (89.29%), and Mexico–Costa Rica and Panama (78.92%), and vice versa (83.46%), have high land ratios, owing to their connections by the Pan-American Highway. In east Asia, Thailand and Vietnam are not neighboring countries, with Cambodia between them. However, the land ratio is relatively high, as with Thailand–Vietnam (66.56%), and vice versa (65.02%), because the Southern Economic Corridor, one of the GMS corridors, may contribute to the land connectivity between Ho Chi Minh City and Bangkok.

5.2. Model Estimation

The results of the Tobit model estimation performed for all 280 samples are summarized as the base case in Table 5. We obtained that distance, export of manufacturing commodity, landlocked country, neighboring country/area, number of land borders, country risk, infrastructure level, port access time, and maritime transport frequency were significant. Additionally, the expected sign, apart from a few land borders, GDP per capita, and port infrastructure level, was not significant.

Table 5. Results of Tobit model estimation.

	Base		**Exclude Two European Inter-Regions**		**Neighbors (without Landlocked Countries)**		**Non-Neighbors**	
Variable	Coeff.	Std Errors	Coeff.	Std Errors	Coeff.	Std Errors	Coeff.	Std. Errors
Intercept	−0.2698	0.1941	−0.4002 *	0.2117	0.0533	0.3135	−0.0613	0.2358
GDP per capita	−0.0000	0.0000	0.0000	0.0000	−0.0000	0.0000	−0.0000 *	0.0000
Distance	−0.0001 ***	0.0000	−0.0001 ***	0.0000	−0.0001 ***	0.0000	−0.0001 ***	0.0000
Export of manufacturing commodity	0.0030 ***	0.0008	0.0027 ***	0.0008	0.0024 *	0.0014	0.0032 ***	0.0008
Landlocked country	0.2169 ***	0.0476	0.0735	0.0674	-		0.2112 ***	0.0542
Neighboring country/area	0.2799 ***	0.0400	0.3155 ***	0.0472	-		-	
Number of land border	0.0462 ***	0.0123	−0.0196	0.0194	-		0.0358 ***	0.0123
Country risk	0.0106 ***	0.0020	0.0018	0.0023	0.0022	0.0039	0.0129 ***	0.0024
Infrastructure level	0.0559 *	0.0294	−0.1381 ***	0.0378	−0.0635	0.0599	0.0940 ***	0.0339
Port access time	0.0171 **	0.0075	0.0046	0.0079	0.0241 *	0.0127	0.0014	0.0093
Port infrastructure level	0.0291	0.0351	0.1410 ***	0.0388	0.1057 *	0.0618	−0.0307	0.0421
Maritime transport frequency	−0.0019 *	0.0010	−0.0024 **	0.0010	−0.0013	0.0021	−0.0019 *	0.0010
Adjusted R squared	0.5622		0.5396		0.4153		0.6192	
Number of samples	280		210		81		188	

(***; **; * show significance at the 1%, 5%, and 10% level, respectively).

As shown in Figure 1, there are high land ratios between the EU and western Asia, although they have many border crossings. This might affect the estimated results of the base case that includes a significantly positive sign for the number of land borders. Therefore, we examined the Tobit model excluding two European-related cases. One is EU countries and western Asia, and the other is the other European countries and western Asia. The result in Table 4 demonstrates that the number of land borders is not a significant variable, but the sign became negative.

Interestingly, landlocked country, country risk, and port access time are not significant. There are many landlocked countries in Europe, such as Austria, Czech Republic, Hungary, Slovakia, and Switzerland, and these countries have good connections with land infrastructure to both neighbors and non-neighbors. Therefore, the landlocked country variable became insignificant after removing these European countries from the samples. We can also understand why the number of land borders is significant with the positive coefficient in the base case and becomes insignificant for the same reason. Port access time might also have similar reasons, in that it becomes insignificant, because these European landlocked countries have shorter port access times to Antwerp, Hamburg, and Rotterdam ports. The country risk scores of most European countries are relatively higher than others, indicating lower risk. Thus, country risk may not explain the land ratio after removing the European countries. From this result, we can assume the country risk may not affect the mode choice of developing and emerging countries. The port infrastructure level was significant, but it was opposite of the expected sign.

Next, we examined the Tobit model separated into two groups—OD neighbors and OD non-neighbors—for determining which factors were significant, except for the neighboring effect of each. In the case of OD neighbors, the OD pairs for which the origin or destination was a landlocked country were excluded from the samples, because most have a high land ratio, owing to their borders being connected by land. The number of land borders was also excluded, because the value is one in all samples. The sample size is 81 in the neighboring case and 188 in the non-neighboring case.

The estimated result of the non-neighbors fits more than the neighbors, as indicated by the McFadden's R-squared value; it has a similar result to the base case. In the case of neighbors, only distance was significant at the 1% level. However, export of manufacturing commodity, port access time, and port infrastructure level were significant at the 10% level. This result suggests that distance was a core factor and that infrastructure quality was important to selecting the transport mode between two countries/areas if they are neighbors, but not for landlocked countries.

We discuss the high residual error between the actual and predicted values of the base model for specifying why these occur. Samples having greater than 2θ or less than −2θ standardized residual error were classified as having high residual errors in this study. All samples having high residual error among OD pairs are summarized in Table 6, where 1θ was 22.4% in the base case in Table 5. It is noted that the predicted values are sometimes greater than 100% or smaller than zero, because these values are the estimated values of the latent variables in Table 6. The reasons why these samples have high residual error can be classified into five factors: geographical conditions, country relationships, regulations, distances, and infrastructure levels. For the first three factors, the predicted values were higher than the actual ones. Thus, we need to find the reasons beyond the 11 explanatory variables.

First, as explained, the actual land ratios in the four OD pairs of North Africa listed in Table 6 are very low, owing to the Sahara Desert. However, each OD pair is a neighboring country/area. There are also the Arabian Desert between Egypt and Bahrain, and the Libyan Desert between Israel and Libya, which might be a barrier to using land transport. We excluded the samples of the two opposite OD pairs, because their land ratios were less than 1%, which does not satisfy criterion (6) of the OD pair selection. In South America, the Darien gap exists in the border area between Panama and Colombia covered by tropical rain forest and river deltas. Therefore, the actual value of the land ratio is low, because the area has a missing link in the Pan-American highways between Central and South America.

Second, political antagonism between two countries might be an obstacle to crossing the land border, because the cargo and drivers are rigorously checked at all stops. Thus, it takes much more time to pass through. The political relations between Egypt and Israel, as well as Pakistan and Iran, are poor. The relation between Israel and Saudi Arabia is also historically poor, and Israel is located between Egypt and Saudi Arabia. Thus, the land ratio is low between them. We excluded the samples of the opposite OD pairs, because their land ratios were less than 1%. Therefore, almost no cargo is transported by land between these countries.

Table 6. Samples with high residual error.

Factors	Region	Origin	Destination	Actual Value	Predicted Value	Residual Error	Std. Residual Error
Geographical Conditions	Africa	Algeria	Burkina Faso, Mali, Niger	4.8%	55.7%	−50.9%	−2.27
		Burkina Faso, Mali, Niger	Algeria	4.1%	58.0%	−53.9%	−2.40
		Libya	Burkina Faso, Mali, Niger	4.1%	55.9%	−51.8%	−2.31
		Burkina Faso, Mali, Niger	Libya	3.8%	58.8%	−55.1%	−2.45
	Africa and Western Asia	Egypt	Bahrain	2.9%	48.5%	−45.5%	−2.03
		Israel	Libya	5.1%	66.2%	−61.1%	−2.72
	Central America and North America	Costa Rica, Panama	Colombia	7.9%	61.5%	−53.6%	−2.39
Country Relationship	Africa & Western Asia	Egypt	Saudi Arabia	6.0%	54.7%	−48.7%	−2.17
		Egypt	Israel	7.1%	96.0%	−88.9%	−3.96
		Israel	Egypt	5.5%	111.8%	−106.3%	−4.74
	Indian Subcontinent and Western Asia	Pakistan	Iran, Iraq	3.6%	68.6%	−65.0%	−2.90
Regulation	East Asia	Singapore	Malaysia	53.6%	109.4%	−55.8%	−2.49
Distance	North America	Canada	Mexico	85.9%	27.1%	58.8%	2.62
		Mexico	Canada	87.6%	39.8%	47.9%	2.13
Infrastructure Level	Central America and North America	Costa Rica, Panama	Mexico	83.5%	19.4%	64.1%	2.86
		El Salvador, Honduras, Nicaragua	Mexico	89.3%	41.3%	48.0%	2.14
	South America	Bolivia	Brazil	98.8%	48.2%	50.6%	2.25
		Bolivia	Argentina	92.9%	45.9%	47.0%	2.10

Regulation problems between Singapore and Malaysia have been already explained; only permitted vehicles of Singapore can enter the territory of Malaysia.

Finally, the last six OD pairs in Table 6 have high residual error, because their predicted values are much lower than the actual ones. The reason for Canada–Mexico, and vice versa, is the longer distance between them. However, the CANAMEX corridor may contribute to an actual higher land ratio. Regarding last four pairs, the values of infrastructure levels for these OD pairs are lower than the mean values. However, the Pan-American Highway may contribute the high land ratio of the mode choice between Mexico and Central American countries. Additionally, it is inconvenient to select maritime transport for Bolivia, owing to it being a landlocked country.

6. Conclusions

We performed a Tobit model analysis to identify the significant factors needed to select land transport for cross-border freight among countries, areas, regions, and cross-regions. Eight variables were identified as significant in the base model: distance, export of manufacturing commodity, landlocked country, neighboring country/area, country risk, infrastructure level, port access time, and maritime transport frequency. The number of land borders was also found to be significant, but was not its expected sign. The case that excluded European countries, distance, exports of manufacturing commodity, neighboring country/area, and maritime transport frequency was significant. The landlocked country variable became insignificant after removing European countries, because European landlocked countries have good connection via land infrastructure to not only neighbors, but also to non-neighbors. We can also conclude that the country risk calculated by Euromoney may not affect the mode choice in developing and emerging countries. In the case of selecting sample ODs from neighbors, apart from landlocked countries, distance was the most significant factor of selecting land transport. Infrastructure quality was also important, but most other factors were insignificant. On the other hand, the estimated result of the non-neighbors was similar to the base case.

We also statistically analyzed why some OD pairs had higher or lower land ratios than expected and why there were high residual errors between the actual and predicted land ratios. We discovered the reasons, which included geographical conditions; country relationships; regulations for lower actual values than the predicted ones; and the effect of cross-border land corridors in North, Central, and South America and southeast Asia, for higher actual values than the predicted values. These results can contribute to facilitating the development projects of cross-border land corridors for international agencies and donors so that they can carefully consider these factors in the improvement of land transport infrastructure via greater investments in paved roads and railways. This particularly useful to countries and regions that wish to overcome the geographical disadvantages and establish adequate regulations to mitigate vehicle entry permissions. A limitation of this study is that factors related with environmental impact were not considered. Environmental problems can be more significant factors in inter-regional transport if a global carbon tax is implemented in the world without exceptions.

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Impact on Myanmar's Logistics Flow of the East–West and Southern Corridor Development of the Greater Mekong Subregion—A Global Logistics Intermodal Network Simulation

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Abstract: This study focuses on container shipping in Myanmar, which is expected to grow manifold in the near future, given the country's rapid economic growth rates. This study simulates the impact of Myanmar's logistics policies on container shipping. These initiatives include the improvement of the East–West Corridor of the Greater Mekong Subregion and the development of the Southern Corridor and Dawei port. The global logistics intermodal network simulation model including both maritime shipping and land transport, is applied to the land-based southeast Asia (ASEAN) region. The estimated results obtained for several different scenarios are crosschecked and compared with the available information on observed flows. Based on the simulation results, the authors conclude that policies that reduce cross-border barriers and improve service levels in Dawei port would result in Thailand using Myanmar's ports for their cargo as well.

Keywords: global logistics simulation; intermodal freight transport network; economic corridor; Myanmar; terrestrial ASEAN; Greater Mekong Subregion; East–West Corridor; Southern Corridor; Dawei port; GLINS model

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1. Introduction

In recent years, with the growth of the world economy, globalization, and the subsequent expansion of trade, the importance of international maritime container transport is increasing. Whereas developed countries remain the nucleus of global trade, emerging and developing countries are rapidly increasing their participation in international trade, which is simultaneously a reason and a result of the remarkable economic growth achieved by these countries. The ASEAN region is currently the focus of attention, not only because of its high economic growth, but also because of its proximity to China, which is promoting the Belt and Road Initiative.

Myanmar is considered the last new frontier in Southeast Asia, with a GDP growth rate of 6–8% since 2011 [1]. However, most of Myanmar's logistics infrastructure was developed during the British colonial era, and is in urgent need of upgradation and renewal. In other words, significant growth of investment in Myanmar's logistics infrastructure is required and expected in the future. Hence, in this context, for ensuring efficient use of limited resources to improve the national economy, it is significant to propose the best scenario based on quantitative policy simulations on logistics infrastructure. Further, formulating a sustainable infrastructure policy is currently important, not only from an economic point of view but also from the environmental point of view. In this respect, the intermodal simulations in this study will contribute to a quantitative discussion on the environmental impact of different modes of transport, based on their characteristics.

2. Literature Review

As summarized by Shibasaki [2], several studies, such as Tavasszy et al. [3], based on a path size logit model and ITF-OECD [4], based on a shortest path search model, developed a global intermodal logistics simulation model other than those developed by the authors (which will be explained later). As discussed in Holguín-Veras et al. [5], in studies on large-scale logistics simulations including transport mode choice, it is generally difficult to develop a model to contain various elements similar to those in supply chain models because the data is unavailable, thus, a simpler model tends to be used. Even if such simulation models are applied to developing countries, obtaining data is much more difficult; additionally, the capacity constraint of infrastructure is more serious in developing countries due to the insufficient infrastructure, although the traffic growth rate is much faster there. Recently, several studies conducted logistics network simulation for emerging and developing countries, such as Aritua et al. [6], focusing on South Africa and India using a gravity model, Meersman et al. [7], comparing generalized chain cost (which was defined in Hassel et al. [8]) of each route in the Eurasian continent in the context of China's Belt and Road Initiative, Verhaeghe et al. [9] developing the network optimization model by combining the path size logit model [3] with a genetic algorithm and applying to Indonesia, and Kawasaki et al. [10] and Shibasaki and Kawasaki [11] applying the same concept model [2,12,13] as this study to the African continent and the South Asian region, respectively.

Among them, Table 1 summarizes related literature for quantitative policy simulations on international logistics infrastructure in the ASEAN region and Myanmar. Several studies have implemented an international freight simulation model using the similar model in this paper, including Shibasaki et al. [14], Iwata et al. [15] and Kosuge et al. [16]. Shibasaki et al. [17] developed an international logistics simulation model for the ASEAN region and analyzed the impact of a batch of logistics policies on the entire ASEAN region, but did not focus on specific policies in each country such as Myanmar. Iwata et al. [15] focused on Lao PDR and the surrounding countries and used a logistics simulation model to evaluate land transport development and port development, but focused specifically on Laos, which is a landlocked country, and did not focus on Myanmar. Kosuge et al. [16] conducted a logistics simulation for the future of Cambodia, but the other regions of land-based ASEAN countries (hereafter referred to as 'terrestrial ASEAN'), which consist of Cambodia, Lao PDR, Thailand, Vietnam and Myanmar were simplified and not focused upon. Another similar simulation model was developed by Kawasaki et al. [17], an inland cargo flow model that takes into account the additional costs caused by the variability of shipment time at the border and ports. They analyzed five scenarios for cross-border transport between Laos and ports in Thailand and Vietnam to evaluate the effect of improving the reliability of the border and ports, but they did not focus on Myanmar.

Several studies have focused on the Greater Mekong Subregion (GMS) in particular. Kawasaki et al. [18] used data on the preference of shippers engaged in cross-border transport in the GMS to estimate the value of shipping time variability, but this had not been linked to individual country policy analysis. Further, Strutt et al. [19] used a database to simulate trade facilitation and analyzed the GMS development policies; Stone and Strutt [20] examined multiple scenarios on the potential for GDP growth in the GMS; and Tansakul et al. [21] focused on the East–West Corridor (EWC) in the GMS and applied the Analytical Hierarchy Process to examine the effects of various factors enhanced by the trade facilitation. However, scopes of these researches were not based on a logistics network specific.

Table 1. Summary of literature review on quantitative policy simulations on international logistics in the terrestrial ASEAN region and Myanmar.

Papers	Developing a Simulation Model Considering Both Maritime and Land Transport Network	Including the Entire Terrestrial ASEAN	Analyzing Myanmar's Policy
Shibasaki et al. [14]	x	x	
Iwata et al. [15]	x	x	
Kosuge et al. [16]	x	x	
Kawasaki et al. [17]	x	x	
Kawasaki et al. [18]	x		
Strutt et al. [19]			
Stone and Strutt [20]		x	x
Tansakul et al. [21]		x	
Kudo and Kumagai [22]			x
Black and Kyu [23]			x
Zin [24]			x
Nam and Win [25]			x
Sukdanont et al. [26]	x *		x
Isono and Kumagai [27]	x **	x	x
Isono [28]		x	
Shepherd and Wilson [29]		x	
Sy et al. [30]		x	
Opasanon and Kitthamkesorn [31]		x	
Jiang et al. [32]	x		
Suvabbaphakdy et al. [33]		x	
Zheng et al. [34]		x	
This study	x	x	x

* Only coastal (domestic) maritime shipping is considered; ** includes both the maritime and land transport network in a simplified manner, but mainly focuses on economic impact.

Several simulation studies focused on Myanmar's logistics network and related policies. Kudo and Kumagai [22] used a general equilibrium geographic model to simulate a bipolar economic system with Yangon and Mandalay and compared the results among the different GRDP growth scenarios in Myanmar, but the simulation was not based on a logistics network and the area covered was only within Myanmar. Black and Kyu [23] analyzed Myanmar's imports and exports with a focus on Mandalay's dry ports, but did not consider Myanmar's trade relations with other countries, such as its relationship with ASEAN on land. Zin [24] also focused on Myanmar's dry ports, but did not consider their relationship with neighboring countries. Nam and Win [25] focused on Myanmar's intermodal system with a focus on inland waterway transport, but their interest was also limited to domestic Myanmar. Sukdanont et al. [26] conducted a route specific cost analysis of coastal and road intermodal transport in the region, but only analyzed freight transport in some specific routes between Thailand and Myanmar. Isono and Kumagai [27] simulated the development of Dawei port using the Geographical Simulation Model (IDE-GSM) on the global intermodal transport network including both maritime and land transport; however, their focus was on estimating the economic impact of the port on the surrounding areas and the simulation was not based on a detailed logistics network. Isono [28] similarly applied the IDE-GSM to estimate the economic effects of the infrastructure projects in Thailand, including the Southern Corridor (SC) in the GSM, but the simulations were not based on a detailed logistics network and did not focus on Myanmar.

Regarding other logistics simulations for the ASEAN region from the different viewpoints, Shepherd and Wilson [29] developed a gravity model to analyze the correlation between trade facilitation and various indicators in the ASEAN region. Similarly, Sy et al. [30] used a panel data to build an extended gravity model for the ASEAN region and analyzed the correlations between logistics performance and trade value, but none of them were based on a detailed logistics network and there were no policy analyses. Opasanon and Kitthamkesorn [31] developed a linear regression model and conducted a simulation case study of Thailand's largest customs, but the analysis was limited to the customs rather than a broader infrastructure policy. Moreover, some studies have focused on ASEAN's relationship with other regions. Jiang et al. [32] simulated the impact of the trade and multimodal transport corridors jointly constructed by the provinces of western China and the ASEAN countries on the neighboring countries, and calculated the choice behavior of freight transport using a logit model. However, the trade routes considered were limited and did not focus on Myanmar's infrastructure policy. Suvabbaphakdy et al. [33] simulated bilateral trade between 16 countries, including the ASEAN, but did not focus on individual countries and not use a detailed logistics network. Zheng et al. [34] developed and simulated a system dynamics model of regional economic development and air logistics interaction in Guangxi Zhuang Autonomous Region, but the emphasis was on China.

In summary, as shown in Table 1, there are no papers that satisfy all the following criteria: (1) developing a detailed logistics simulation model considering both maritime and land networks, (2) including the entire terrestrial ASEAN region and, (3) analyzing Myanmar's policy. Therefore, this study applies the existing network assignment model to simulate global maritime container shipping and land transport in terrestrial ASEAN region. Using the model, scenario simulations of current and future logistics infrastructure policies in Myanmar, which is one of the terrestrial ASEAN countries penetrated by several corridors of the GMS, are performed. The simulations also include the impact on the entire terrestrial ASEAN countries.

3. International Logistics Environment in Myanmar

Figure 1 shows a logistics network in Myanmar including the major nodes and corridors, which are described below.

Thilawa and Yangon ports are important centers of international logistics and gateways to international trade in Myanmar. These ports are located in or near Yangon, the largest city of Myanmar, which accounts for more than 10% of Myanmar's total population and about 25% of its GDP (Institute of Developing Economies). Most of the maritime containers in Myanmar are handled at either of these ports. As Yangon port is the older port and is narrow, it has limited scope for development to accommodate and meet the future, burgeoning demand for container handling. It cannot be maintained as the only gateway port of Yangon city, therefore, Thilawa port is being developed to accommodate the increased volumes of import and export cargo that are expected in conjunction with Myanmar's future development. Moreover, the surrounding area has been designated as a special economic zone, and many factories of foreign companies have expanded into the area and are expected to grow. In the rest of this study, Thilawa and Yangon port are collectively referred to as Thilawa port.

The EWC is one of the most important economic corridors in the GMS [36]. This corridor runs from east to west through Vietnam, Laos, Thailand and Myanmar. Focusing on the part in Myanmar, the main land transport route between Yangon and Bangkok (Thailand) overlaps the EWC from Yangon to Tak in Thailand, which is an important section from the perspective of Myanmar's international logistics environment. Trade between Myanmar and Thailand is currently conducted mainly by land, and this route is most commonly used. Although the Thai section of the EWC is well maintained, its Myanmar section is often flooded during the rainy season due to unpaved roads.

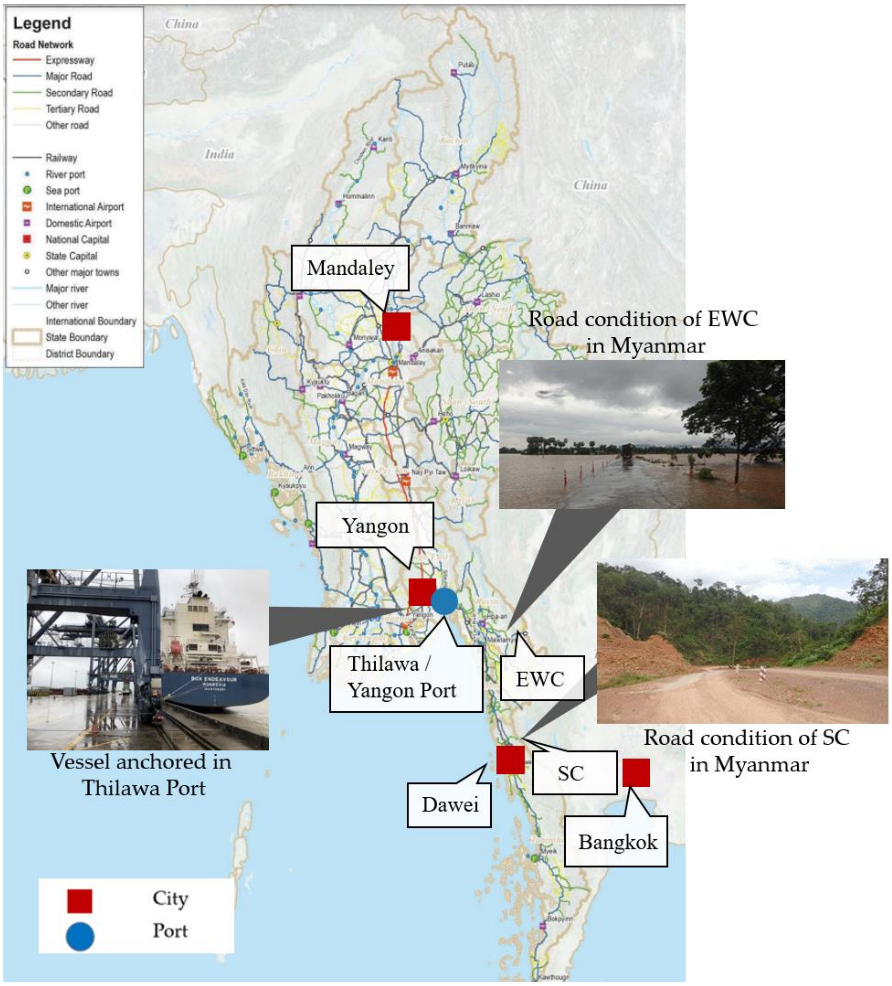

Figure 1. Logistics network in Myanmar including the major nodes and corridors. Source: Japan International Cooperation Agency (JICA) [35].

The SC, which is also part of the GMS economic corridor, runs from Ho Chi Minh City (Vietnam), through Phnom Penh (Cambodia) and Bangkok, to Dawei, which is a provincial city in southern Myanmar, about 600 km south of Yangon. Although the road between Dawei and Phu Nam Long on the Thai border has not yet been developed and this section of the road does not function as a corridor, the Thai stakeholders have positioned Dawei as an outer port of the Thai metropolitan area, for transport to India and Europe. Conversely, Myanmar's stakeholders are skeptical about the benefits of the port to Myanmar, as the Dawei–Bangkok route traverses through its territory; therefore, the priority of development is different between both countries. Such controversial projects should be carefully and quantitatively examined through the policy simulation model.

As mentioned above, there are many open issues regarding the development of a logistics infrastructure and its impacts in Myanmar; therefore, it would be useful to quantitatively verify each of them through simulation analysis.

4. Simulation Model

4.1. Overview of the Model

The global logistics intermodal network simulation (GLINS) model used in this study is based on the model developed by Shibasaki [2,12,13] and then applied in Shibasaki et al. [37]. The model also considers international land transport, in the sense that it does not use maritime shipping, not only maritime shipping and their hinterland transport. Figure 2 shows the structure of the model. The major difference between this study's model and the models used in Shibasaki et al. [14] and Iwata et al. [15] is that their models also endogenized the decision on liner services by shipping companies; therefore, they had major challenges in practical aspects such as model fitness to the actual and policy scenario analysis, which made it difficult to simulate individual infrastructure policies. In this study's model, the level of liner services provided by shipping companies is exogenously given as a scenario, and the model is specialized for cargo assignment so that the model fitness and the accuracy of individual policy simulation can be significantly improved.

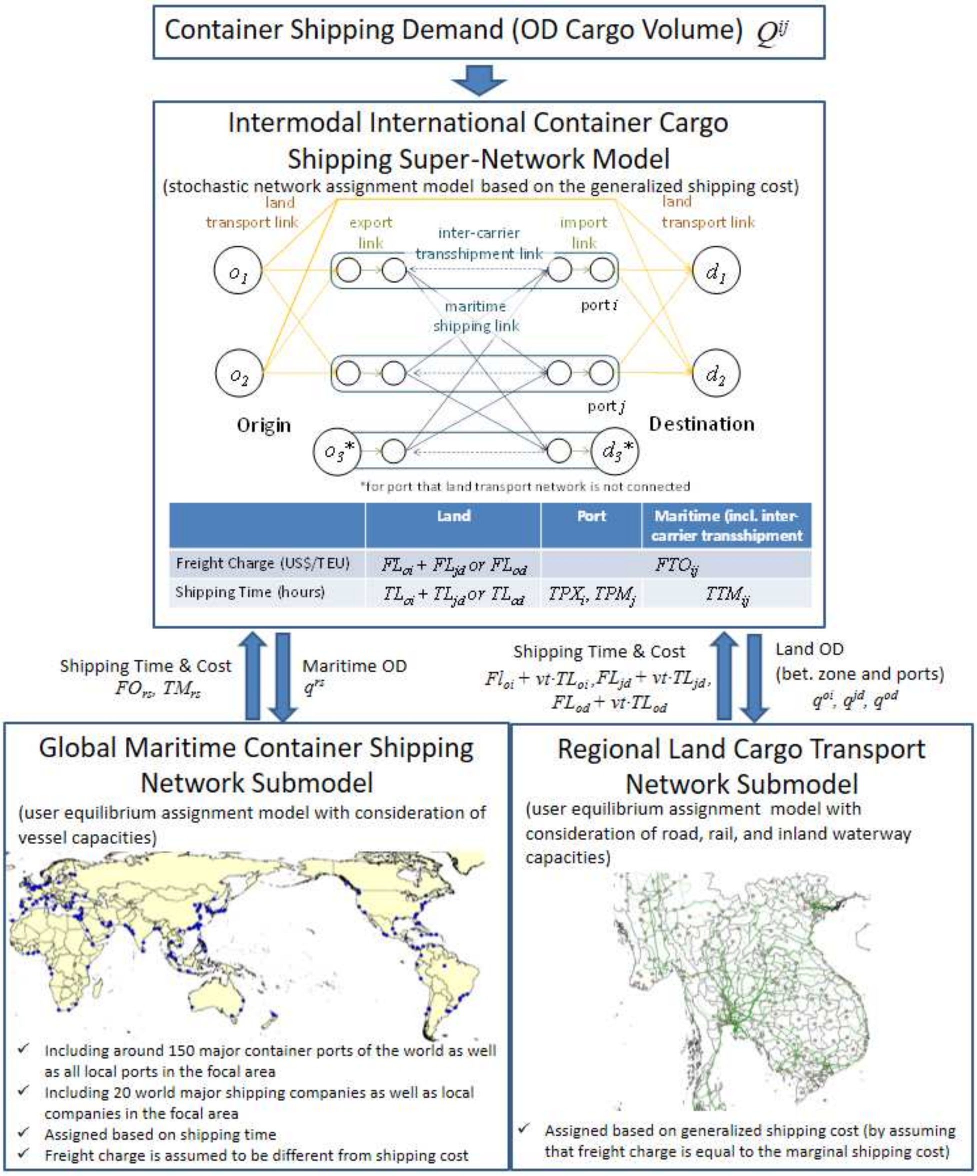

Figure 2. Structure of the GLINS (global logistics intermodal network simulation) model. Source: Modified Shibasaki [2].

The GLINS model is composed of two submodels, one based on the real network on the sea and the other based on land. There is one upper model on an intermodal virtual network that integrates them. In the upper model, a stochastic network assignment (Dial assignment) is used to allocate cargo to flow on other paths than those with the lowest link cost. In the assignment calculations for the submodels of maritime shipping and land transport networks, the user equilibrium assignment is applied to take the effects of congestion into account. As described in Section 2, consideration of the congestion effect is essential, especially for the simulations in developing countries, because capacity constraints of infrastructure are very critical there.

There are two main inputs in the GLINS model: network data, including distance, level of service and transport volume, for sea, port and land; and the interregional cargo shipping demand (OD matrix). The output is the container flow at each link, and by aggregating the output, the container handling volume at each port and the overall flow between ports can be calculated.

The GLINS model incorporates the cross-border coefficient λ_a, which is defined as the rate of the procedure cost and time of land-transit cargo to those of normal import/export cargo if crossing land national borders, as shown in Equation (1).

$$u'(x_a) = u(x_a) + \lambda_a(CBO_a + vt \cdot TBO_a) \quad (1)$$

where x_a is a flow of link a, $u(x_a)$ is ordinary cost for a link (USD/TEU), $u\prime(x_a)$ is cost for a link that crosses the national boder, CBO_a is addional monetary cost (USD/TEU) in border-crossing (which is set by country based on World Bank Group [38]), TBO_a is addional time (USD/TEU) in border-crossing (same as above) and vt is shipper's time value of freight (USD/TEU/hour). As stated in Section 2, the quantitative data for the simulations, including other parameters in all cost functions, is generally difficult to obtain especially for developing countries. Therefore, in the model of Shibasaki [2,12,13], they are often approximated by the interview survey results with stakeholders and alternative indicators are used to supplement the data.

4.2. Input Data

Based on Shibasaki et al. [14] (which is a previous study on logistics model simulation for Southeast Asia), the interregional shipping demand of cargo and maritime and land transport networks in 2016 is generated.

For a detailed analysis of the terrestrial ASEAN network, we added the ports of Da Nang and Khu Inong in Vietnam, Sihanoukville in Cambodia and Songkhla in Thailand to the 173 ports worldwide with an annual handling volume of more than 500,000 TEU (20-foot equivalent unit), including empty containers, as in Kosuge et al. [16]. In addition to the top 20 local carriers, 14 local liner shipping carriers are added from MDS Containership Databank [39] to ensure that the coverage of vessel capacity calling at each port in the terrestrial ASEAN region is more than 95%. Regarding the land network, in addition to the missing road link in Myanmar, the inland water transport along the Ayeyawaddy River is included. Moreover, because the zonal subdivision of Myanmar becomes more detailed (on a prefectural basis) as described below, the nodes are set to be more than one in each zone and road links are added. In the simulation, the following effects are varied for each scenario: the cross-border coefficient of the EWC and trucking speed in its Myanmar section; the presence, truck speed and cross-border coefficient of the SC; and the presence of Dawei port and the liner services that call there. The other information on each link remains fixed and unchanged.

The interregional cargo shipping demand (OD matrix) to/from the terrestrial ASEAN countries, (obtained from the World Trade Service (WTS) data by IHS [40]), is divided into zones based on their regional share of the economic index shown in Table 2. Gross regional product (GRP), is used as a regional indicator for dividing the OD matrix for Myanmar. It is estimated by dividing the GDP of the country, by the land cover data for agriculture, and night light data representing manufacturing and service industries, obtained from Kudo and Kumagai [22].

Table 2. Zoning method for each terrestrial ASEAN country.

Country	Zone	Indicator	Source
Myanmar	70	GRP	Kudo and Kumagai [22]
Thailand	77	GRP	Statistics Ministry of Thailand [41]
Vietnam	62	Trade volume	Finance Ministry of Vietnam [42]
Cambodia	24	Sales and GDP growth by region	Kosuge et al. [16]
Laos	17	GRP	Kudo and Kumagai [22]

4.3. Model Calculations

The GLINS model has a nested structure in which the stochastic network assignment model on the virtual intermodal network is the upper model and the user equilibrium assignment models on the real network in each mode are the lower models. As proposed by Shibasaki [13], the solution to the entire model is obtained by using one set to find the solution to each of the lower-order and upper-order models, and then performing iterative calculations until convergence is reached. As convergence is not guaranteed for the calculation of the entire model, we check it ex-post. However, this still does not guarantee uniqueness of the solution, which is an issue to be addressed in the future.

5. Model Validation

In this section, we confirm the reproducibility and validity of the model in terms of container throughput in port and modal shares in the terrestrial ASEAN countries. For the modal share, we focus on the international transport route between Myanmar and Thailand and conduct a sensitivity analysis of the variables included in the cost function.

5.1. Baseline Scenario Setting and Container Throughput

Based on the results of our field survey in Myanmar and related literature (Japan Marine Equipment Association [43] and Ministry of Land, Infrastructure, Transport and Tourism (MLIT) [44]), the following scenario is adopted as the baseline scenario for this analysis.

- Railway service: Speed—10 km/h; Frequency—7 trains/week; Handling time—24 h; Distance-proportional cost—1.75 USD/TEU/km,
- Inland waterway transport service: Speed—10 km/h; Frequency—7 services/week; Handling time—48 h; Distance-proportional cost—0.75 USD/TEU/km,
- Level of service in the EWC: Truck speed in Myanmar/Laos/Vietnam section—20 km/h; Thai section—40 to 50 km/h,
- Cross-border coefficient: $\lambda_a = 0.4$,
- The SC and Dawei port: not available,
- Variance parameters for stochastic assignment: $\theta = 0.01$,
- Shipper's time value of freight: $vt = 0.5$ (USD/TEU/hour).

The land cargo flows estimated in the baseline scenario are shown in Figure 3.

Table 3 compares the model-estimated laden container throughputs (excluding transshipment containers) in the ports of the terrestrial ASEAN region with the observed figures of 2016. The maximum error rate between the country-based estimated and observed throughputs is found in Cambodia, which represents the necessity of calibration adopted in Kosuge et al. [16]. Specifically, they calibrated cross-border coefficient λ_a based on the interview and field surveys; therefore, the model fitness would be improved if the coefficients were similarly fine-tuned for each terrestrial ASEAN border. The error rates for countries other than Cambodia are only a few percent.

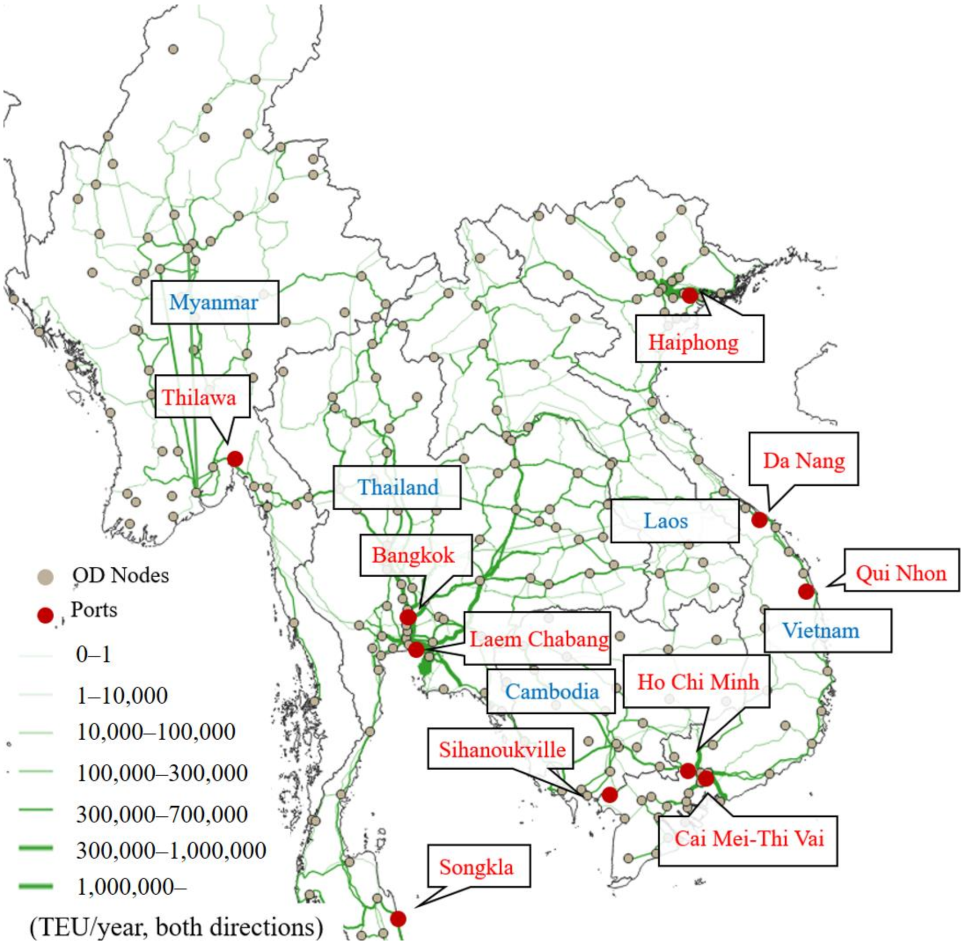

Figure 3. Land cargo flows of the baseline scenario estimated in this study (as of 2016).

Table 3. Estimated laden container throughput in each port in the terrestrial ASEAN region (baseline scenario, 2016).

Country	Port	Observed (A) (TEU)	Estimate (B) (TEU)	Difference (A)–(B) (TEU)	Error Rate
Vietnam	Haiphong	708,921	3,141,070	2,432,149	304.1%
	Da Nang	233,815	141,384	−92,431	−39.5%
	Qui Nhon	76,840	27,764	−49,076	−63.9%
	Ho Chi Minh	4,354,555	2,407,315	−1,947,240	−44.7%
	Cai Mep Thi Vai	947,317	815,257	−132,060	−13.9%
	Vietnam Total	6,321,448	6,532,790	211,342	3.3%
Cambodia	Sihanoukville	367,880	303,614	−64,266	−17.5%
	Cambodia Total	367,880	303,614	−64,266	17.5%
Thailand	Laem Chabang	5,105,178	5,430,096	324,918	6.4%
	Bangkok	974,112	462,490	−511,622	−52.5%
	Songkhla	86,135	546,910	460,775	534.9%
	Thailand Total	6,165,424	6,439,496	274,072	4.4%
Myanmar	Thilawa	319,146	333,225	14,079	4.4%
	Myanmar Total	319,146	333,225	14,079	4.4%

Further, the largest difference between the port-based estimated and observed throughput is found in Vietnamese ports, including Hai Phong in the north and Ho Chi Minh and

Cai Mep in the south. This is because the value of trade in each province is used as an indicator in the regional division of container shipping demand in Vietnam, as shown in Table 2. More specifically, according to our estimation, the container shipping demand in the Red River Delta and the Northern Priority Economic Region centered on Hanoi, the largest city in the north, would share 32.1% of the total cargo volume in Vietnam in this study whereas that in the Southeast and the Southeast Priority Economic Region centred on Ho Chi Minh City, the largest city in the south, share 45.9%. However, the trade value we adopted in this study includes cargoes other than container cargoes. Among them, air cargo accounts for a large share in value terms; for example, Korean companies have been producing significant quantities of IT-related equipment in and around Hanoi since 2009 which are exported mainly by air. According to Inter National Civil Aviation Organization [45], in Vietnam, the air cargo volume is almost the same at Hanoi airport (314,312 tons, 2016) and Ho Chi Minh City (304,314 tons). Therefore, the actual share of container shipping demand in the southern region, mainly Ho Chi Minh City, would be much larger than that in the northern region, mainly Hanoi, rather than our estimation. In this manner, the maritime container shipping demand in the northern part of the country may be overestimated if the country's container shipping demand is divided according to regional trade value. The improvement on this point is an issue for the future.

Similarly, the estimated throughput in Bangkok port is smaller than the observed figure, whereas the estimated throughputs in the two adjacent ports, Laem Chabang and Songkhla, are larger than observed. This is mainly because the capacity constraint of the port is not taken into account and the calculation of equilibrium assignment does not converge. In particular, the calculation results of container throughputs between Bangkok and Laem Chabang port are heavily fluctuated, because Bangkok port is located nearer to Bangkok, the capital city of Thailand, thus, the hinterland transport cost from it is much cheaper whereas Laem Chabang port provides many liner services with larger containerships resulting in cheaper maritime shipping cost. Incorporating the port capacity constraint and incremental assignment into the model are possible solutions as a further research. Meanwhile, the estimated result in Thilawa, Myanmar, is the same as the country-specific error shown in Table 3, because it is only included as Myanmar's container port in the model.

5.2. Model Share and Sensitivity Analysis of International Transport between Myanmar and Thailand

Figure 4 compares the model-estimated modal share of the international transport between Myanmar and Thailand (land transport vs. maritime shipping) with several variations of the cross-border coefficient λ_a between Thailand and Myanmar, and the observed ones obtained from the WTS Data [40]. As shown in the figure, if $\lambda_a = 0.4$, the share of land transport is 85.4%, which is closest to the observed share of 83.2%. Further, the figure indicates that if the cross-border coefficient λ_a between Thailand and Myanmar increases (i.e., the cost and time of crossing the land border increases), cargo between the two countries shifts from land transport to maritime shipping and the land share decreases.

In summary, although errors at/of container throughput are observed in some ports, the authors consider that the model with the proper cross-border coefficient is confirmed and validated as a whole.

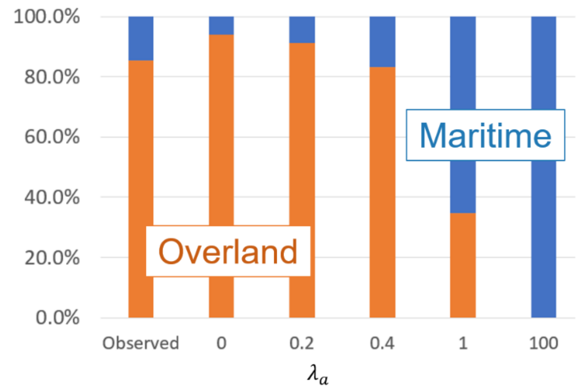

Figure 4. Shares of land transport for Myanmar–Thailand transport for each cross-border coefficient and observed values.

6. Policy Simulations for GMS Economic Corridors

In this section, the model developed in the previous section is used to analyze the policy scenarios on the GMS economic corridors as follows:

Scenario 1 (S1): Infrastructure development of the EWC.

Scenario 2 (S2): Construction and improvement of the SC and Dawei port.

6.1. Infrastructure Development of the EWC

Among the main land transport routes between Myanmar and Thailand, the section between Yangon and Tak in Thailand is duplicated or overlapped with the EWC. However, whereas its Thai section has been improved, the Myanmar section has not yet been fully developed as described in Section 3. In the following scenarios, we assume the transport environment in the Myanmar section of the EWC and border barriers on the EWC are improved. Specifically, (a) the improvement of truck speed in the Myanmar section of the EWC and (b) the simplification of customs procedures on the Myanmar–Thailand border (Myawaddy–Mestho) on the EWC are assumed as shown in Table 4.

Table 4. Scenarios set for infrastructure development in the EWC (East–West Corridor).

Scenario	Truck Speed in Myanmar Section of the EWC (km/h)	Cross-Border Coefficient λ_a on Myanmar–Thai Border on the EWC
Base	20	0.4
S1-1	50	0.4
S1-2	80	0.4
S1-3	20	0
S1-4	20	0.2
S1-5	20	0.6
S1-6	20	1

6.1.1. Truck Speed Improvement in the EWC

Regarding the scenarios with varying truck speeds in the EWC (S1-1 and S1-2), Figure 5 shows the estimation results of the cargo volume passing through the EWC at the Myanmar–Thai border (in both directions, the same applies hereinafter unless otherwise noted) and the container throughput of Thilawa port (sum of export and import but only laden containers—the same applies hereinafter unless otherwise noted). The cargo volume passing through the EWC increases by 0.7% (+1087 TEU) in S1-1 and 4.9% (+7514 TEU) in S1-2, compared with the baseline scenario, as truck speeds of the Myanmar section of the

EWC increase. Meanwhile, the container throughput in Thilawa port remains unchanged in S1-1 and decreases by 1.7% (−5564 TEU) in S1-2 from the baseline scenario.

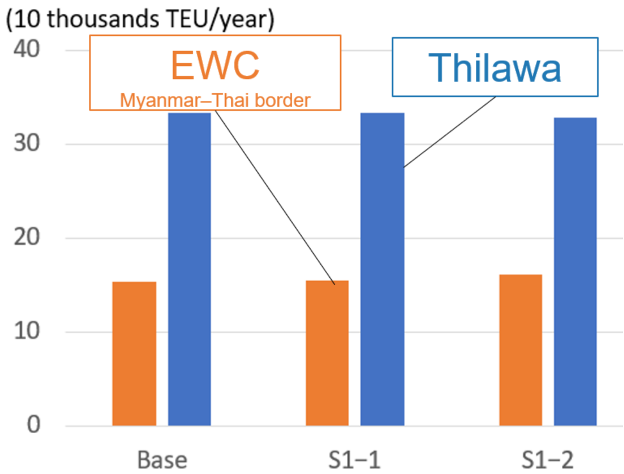

Figure 5. EWC transit cargo volumes and container throughput in Thilawa port based on truck speed improvement scenarios.

In summary, as the truck speed of the EWC increases, the cargo volume passing through the EWC increases whereas the container throughput in Thilawa port decreases, but insignificantly.

6.1.2. Border Barrier Change in the EWC

Figure 6 shows the estimation results of cargo volume passing through the EWC at the Myanmar–Thai border and the container throughput in Thilawa port for the scenarios on changes in the cross-border coefficient λ_a between Myanmar and Thailand on the EWC. Note that the cross-border coefficient on the EWC is changed from the baseline scenario whereas those in other borders are not changed, unlike the sensitivity analysis on the cross-border coefficient shown in Section 5.2.

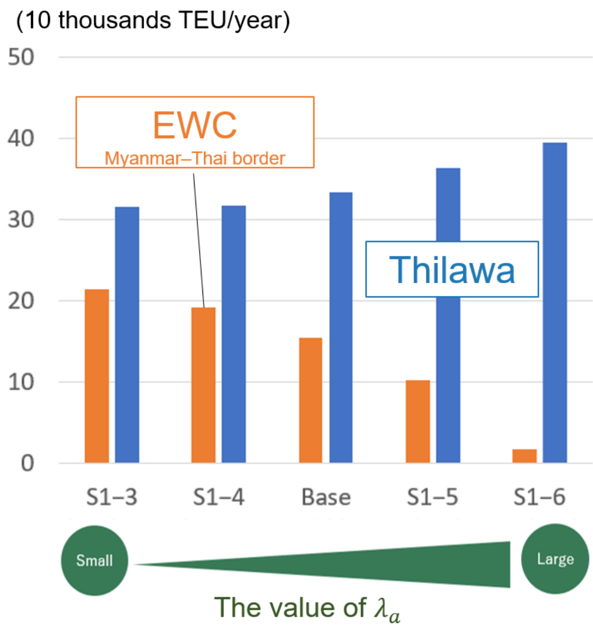

Figure 6. EWC transit cargo volumes and container throughput in Thilawa port in the EWC cross-border coefficient change scenario.

Figure 6 reveals that the cargo volume passing through the EWC decreases as the cross-border coefficient on the EWC increases. Meanwhile, the container throughput in Thilawa port increases proportionately as the cross-border coefficient increases; but decreases less with a reduction in the cross-border coefficient. Figure 7 shows the difference in land cargo flows in S1-3, which is the case where the cross-border coefficient λ_a is zero, compared with the baseline scenario. As shown in the figure, cargo flow in the EWC at the Myanmar–Thai border in S1-3 increases significantly (59,874 TEU) compared with the baseline scenario and 4037 TEU are shifted from the land border in northern Myanmar.

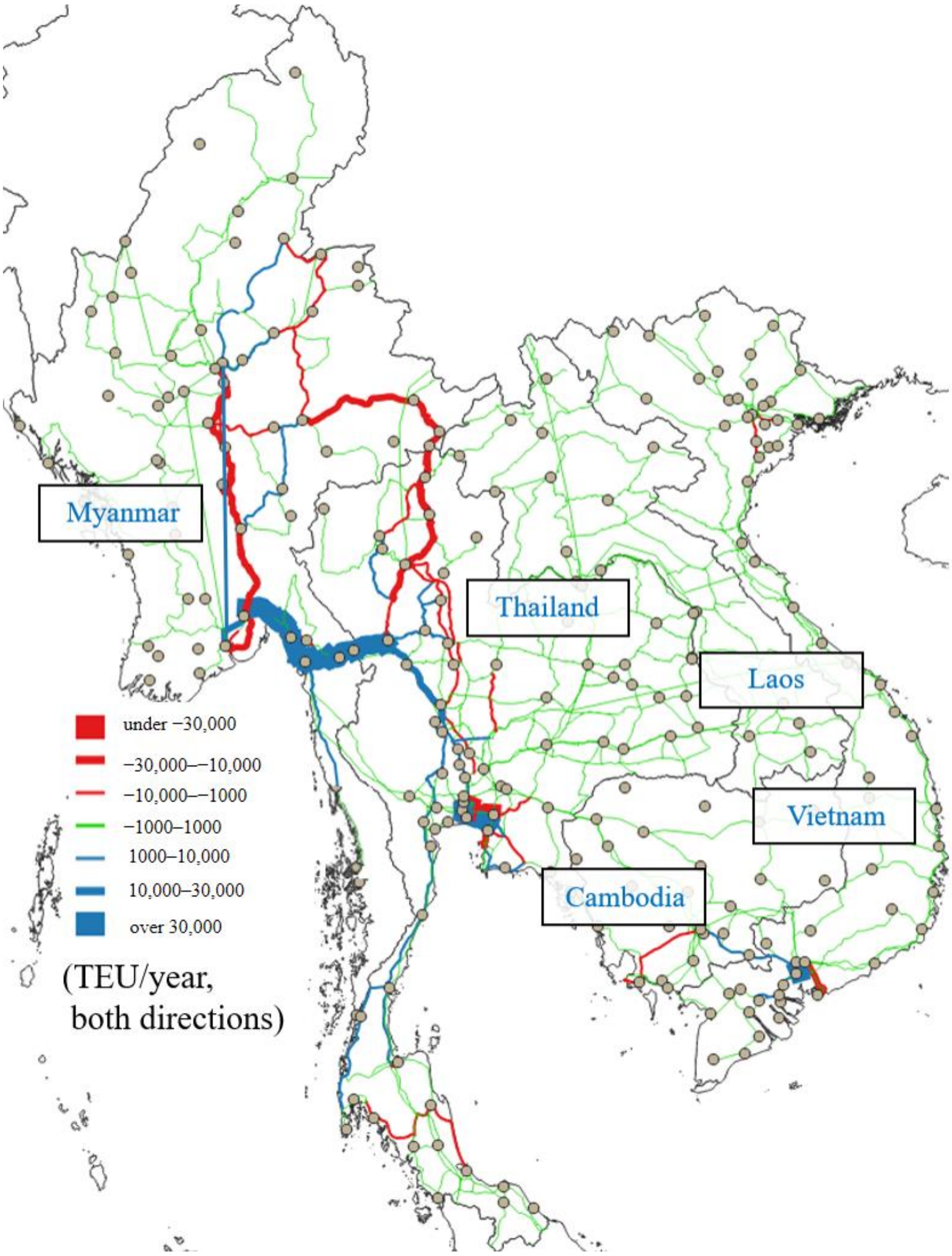

Figure 7. Difference in land cargo flows in S1-3 from the baseline scenario.

One of the reasons why the decrease in container throughput in Thilawa port is not large, is that some cargo (10,400 TEU) to and from the regions in Thailand located close to the border with Myanmar, now use Thilawa Port via the EWC instead of Thai ports such as Laem Chabang and Bangkok. Another reason is that the shift from maritime shipping to land transport to and from Thailand weakens the attraction of Thai ports and enhances that of Thilawa port. The decrease in cargo flow to and from Laem Chabang port can be observed in Figure 7.

Figure 7 also reveals that the improvement of the EWC does not significantly affect countries of terrestrial ASEAN other than Myanmar and Thailand, because the trade volume between Myanmar and these countries is small and more than two international borders have to be crossed if land transport is used. Similar geographical coverage of the affected countries is observed in the other scenarios including the S2 scenarios for the SC and Dawei port.

6.2. Construction and Improvement of the SC and Dawei Port

As mentioned in Section 3, the Myanmar section of the SC (between Dawei and Poonamrong) is still undeveloped. Currently, most of the international maritime containers in Myanmar are exported and imported at Yangon or Thilawa port. However, both are river ports with insufficient water depth to accommodate large vessels. Further, these ports are geographically far from the trunk liner service route between East Asia and Europe, which makes it difficult for these ports to attract large vessels. On the other hand, Dawei port in southern Myanmar, has a geographic advantage enabling the development of a deep-water terminal and in being closer to the trunk route than Yangon. Moreover, if the SC becomes available, it will also be closer to Bangkok. From the Thai side, the SC and Dawei port can be positioned as an outer port of Thailand providing a significant shortcut to India, Africa and Europe, avoiding going around the Malay Peninsula and Malacca Strait by vessel. Based on these backgrounds, the impacts of the development of the SC and Dawei port are simulated. Specifically, two policies are envisioned: (a) the development of the SC; and (b) the establishment and increase of liner services calling at Dawei port.

The specific settings of each scenario are shown in Table 5. In S2-1, the link between Dawei and Phu Nam Rong, Thailand, is added as the SC. In S2-2 to S2-4, among 22 liner services that called at Yangon or Thilawa port in 2016, 21 services to/from Southeast Asia and Northeast Asia are assumed to call at Dawei port. The difference between the three scenarios are the timing of port calls: for northbound, southbound and both directions. Further, the truck speed of the SC is changed in S2-5 and S2-6. Moreover, in S2-7, all 14 services connecting Colombo or southern Indian ports (e.g., Chennai) with Southeast Asia or the innermost ports of the Bay of Bengal (i.e., Bangladesh ports and Kolkata/Haldia in India) are assumed to call at Dawei port. Finally, in the last two scenarios, the connection to Europe is considered. In S2-8, the Asia–Mediterranean Sea–East coast of North America service, which returns to Europe from Laem Chabang port, is changed to return from Dawei port. Additionally in S2-9, not just one service that calls at Chennai on the Asia–Europe route, but two services with the largest vessel size on the Asia–Europe route are added (all services are assumed to call at Dawei port only for westbound voyages).

Figure 8 shows the container throughput at Dawei and Thilawa ports and the estimated volume of cargo passing through the EWC and SC at the Myanmar–Thai border in each scenario. Table 6 shows their breakdown by import and export or by direction.

6.2.1. Development of the SC

First, we examine the results of S2-1, which adds the SC to the land transport network, allowing travel at 20 km/h, but does not include the opening of Dawei port. The cargo volume passing through the SC at the Myanmar–Thai border is 66,364 TEU, whereas the cargo volume passing through the EWC at the Myanmar–Thai border decreased by 46,130 TEU, as shown in Figure 8 and Table 6. Hence, the SC becomes a competitor to the EWC for transport between Bangkok and Yangon. However, the total cargo volume passing through the EWC and SC in S2-1 increases by 13% compared to the volume passing through the EWC in the baseline scenario, indicating that these corridors in Myanmar are more frequently used in S2-1 as a whole. Meanwhile, the container throughput in Thilawa port decreases to 329,378 TEU in S2-1 from 333,225 TEU in the baseline scenario; this quantum of decrease is smaller than the quantum increase in the corridors. This may be due to the opening of the SC which caused the shifting of cargo to land transport via the SC from maritime shipping via Thai ports. This may have resulted in weakening the attraction of Thai ports and expanding the hinterland of Thilawa port. Figure 9 describes the difference in land cargo flow in S2-1 from the baseline scenario and reveals that container flows near Thai ports, north of Bangkok and along the EWC are decreasing, whereas container flows along the SC are increasing.

Table 5. Scenario settings for the development of the SC (Southern Corridor) and Dawei port.

Scenario	Availability of the SC and the Pattern of Calls at Dawei Port	SC Speed (km/h)
Base	Without the SC and Dawei port	–
S2-1	SC only added	20
S2-2	In addition to S2-1, all services calling at Thilawa port call at Dawei port for northbound	20
S2-3	In addition to S2-1, all services calling at Thilawa port call at Dawei port for southbound	20
S2-4	In addition to S2-1, all services calling at Thilawa port call at Dawei port for both northbound and southbound	20
S2-5	Same as S2-4	10
S2-6	Same as S2-4	40
S2-7	In addition to S2-4, 14 new South Asia services call at Dawei port	20
S2-8	In addition to S2-7, 1 new European services call at Dawei port	20
S2-9	In addition to S2-9, 3 new European services call at Dawei port	20

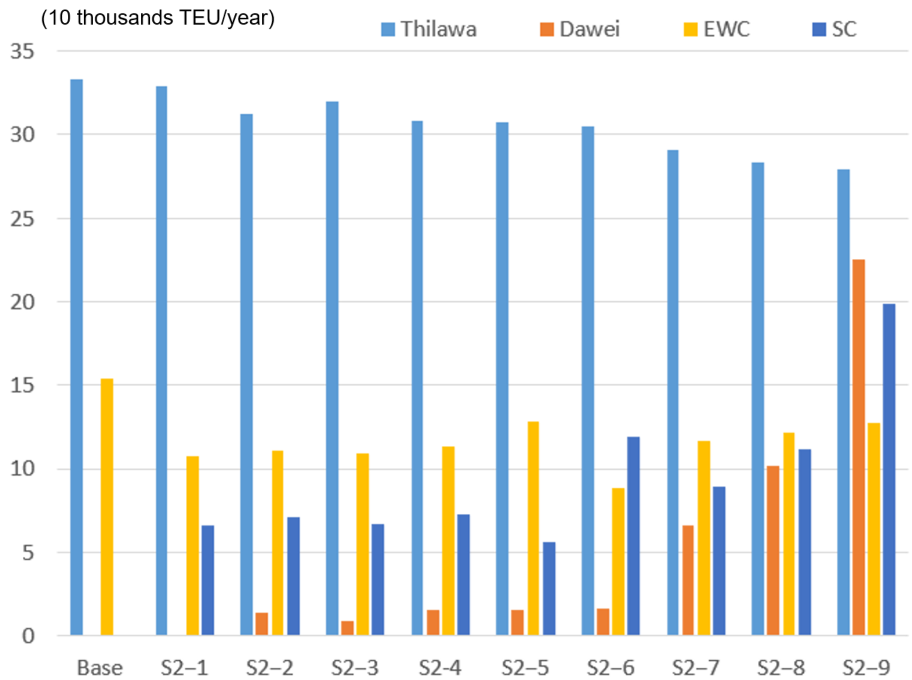

Figure 8. Container throughput of Dawei and Thilawa ports and cargo volume passing through the EWC and SC at the Myanmar–Thai border in each scenario.

Table 6. Breakdown of container throughput in Thilawa and Dawei ports and the cargo volume passing through the EWC and SC at the Myanmar–Thai border by direction (or by import/export) in each scenario (TEU/year).

Scenario	Thilawa		Dawei		EWC		SC	
	Export	Import	Export	Import	Thailand to Myanmar	Myanmar to Thailand	Thailand to Myanmar	Myanmar to Thailand
S2-1	107,820	221,559	0	0	83,747	24,008	62,832	3532
S2-2	106,753	205,934	3490	10,085	87,314	23,823	67,338	3481
S2-3	103,074	216,453	4318	4164	85,363	25,243	64,341	3501
S2-4	103,584	204,381	5820	9763	88,268	24,925	69,187	3463
S2-5	103,552	204,250	5782	9785	102,785	25,872	53,740	2516
S2-6	103,572	203,755	5784	9763	71,286	24,928	87,130	3509
S2-7	93,582	196,868	34,248	31,724	88,918	27,391	79,720	9146
S2-8	92,422	197,121	39,082	39,088	88,908	28,843	83,282	14,172
S2-9	87,884	186,456	160,734	49,732	99,420	29,034	172,304	13,377

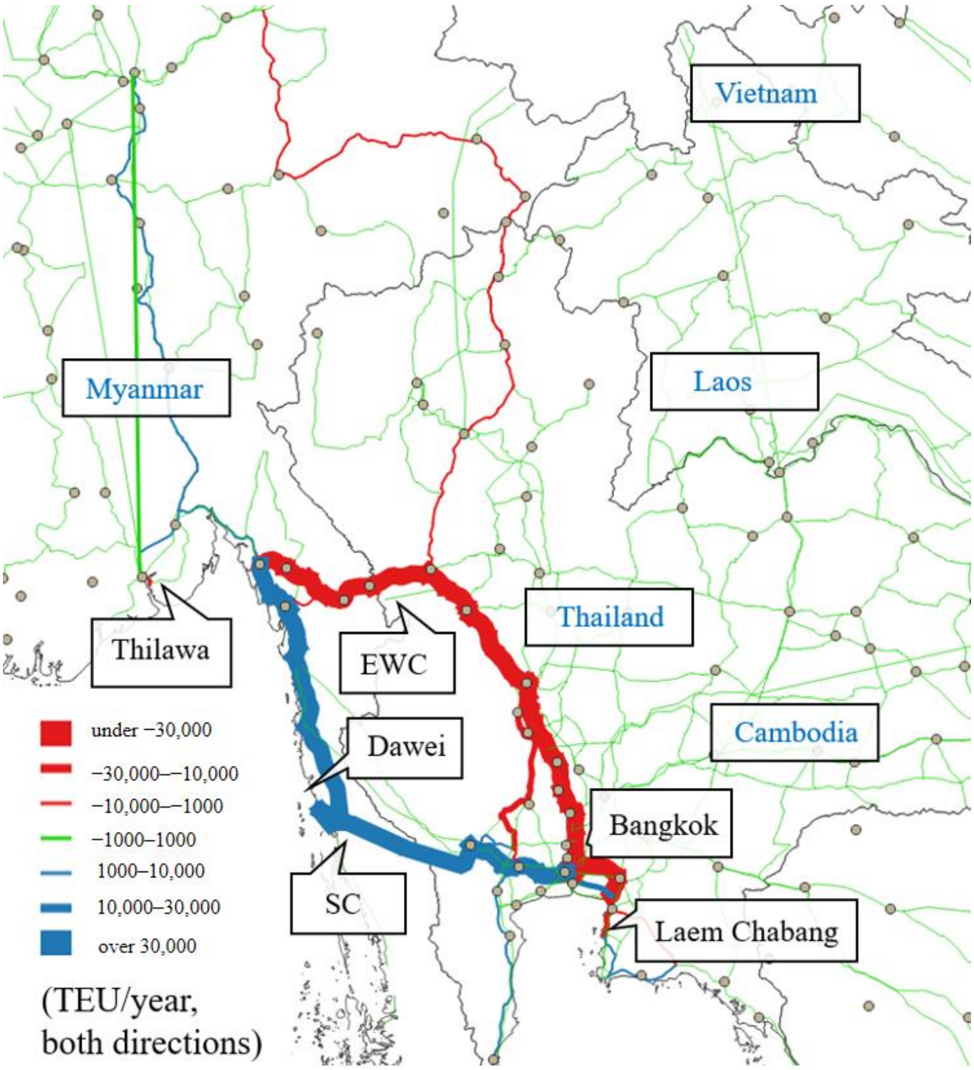

Figure 9. Difference in land cargo flows around the SC in S2-1 from the baseline scenario.

6.2.2. Opening of Dawei Port and the Calling of Liner Services that Call at Thilawa Port

In S2-2, S2-3 and S2-4, we assume the opening of Dawei port and, that all the liner services calling at Thilawa port will also call at Dawei port, except for one service connecting to Colombo port. In other words, Dawei port is positioned as a feeder port of major Southeast Asian ports such as Singapore and Malaysian ports in these scenarios. As shown in Figure 8 and Table 6, the container throughputs in Dawei port are around 10,000 TEU in these scenarios, which are lower than for Thilawa port. The cargo volumes passing through the EWC and SC at the Myanmar–Thai border increase slightly from S2-1 (up to 4000−5000 TEU). Table 6 reveals that some cargo imported from Malaysia and Singapore shifts to Dawei from Thilawa port in S2-2. This is because the import container volume in Dawei port in S2-2, (where northbound liner services call at Dawei port), is larger than in S2-3, in which southbound liner services call at Dawei port. Regarding Thilawa port, import container volume in S2-2 is smaller than in S2-3. Moreover, most containers exported from Dawei port in S2-2 and imported into Dawei port in S2-3 are considered as domestic transport to and from Thilawa port; in other words, some cargo between Yangon and Thailand via the SC is transported by maritime shipping between Thilawa and Dawei ports. The results in S2-4 have both characteristics of S2-2 and S2-3. In particular, the export container volume from Dawei port as well as the cargo volume from Thailand to Myanmar passing through the EWC and SC are largest among the three scenarios.

In S2-5, in which truck speed in the SC is decreased from S2-4, the cargo volume passing through the SC decreases and that passing through the EWC increases, whereas, in S2-6, where truck speed in the SC is increased from S2-4, the cargo volume passing through the SC increases and that passing through the EWC decreases. There are no significant changes in the container throughput in Thilawa and Dawei ports in these scenarios.

6.2.3. Calls of Bay of Bengal Service to Dawei Port

In S2-7, based on the setting in S2-4, 14 trans-Bay of Bengal services are assumed to call at Dawei port, linking southern Indian ports in the Bay of Bengal (e.g., Chennai port) and Colombo port with Southeast Asian ports, or the innermost ports of the Bay of Bengal including Bangladesh's Chittagong port and India's Kolkata and Haldia ports. As shown in Figure 8, the container throughput in Dawei port increases by 50,389 TEU compared to S2-4 and the cargo volume passing through the SC at the Myanmar–Thai border increases by 16,216 TEU. In other words, cargo to and from Thailand is transported to the east coast of India and other areas via Dawei port if direct liner services connect to these ports.

Figure 10 shows the difference in land cargo flows estimated in S2-7 from those in S2-1. From the figure, it is apparent that the cargo flow to/from Thai ports such as Bangkok and Laem Chabang decreases, shifting to the SC, and that some cargo to/from northern Thailand is heading to Dawei port via the EWC, instead of using Thai ports.

6.2.4. Calls of European Service to Dawei Port

In addition to the setting in S2-7, we assume that one European service calls at Dawei port in S2-8 and three additional European services call there in S2-9. As shown in Figure 8 and Table 6, the laden container throughput at Dawei port increases by 12,198 TEU in S2-8 from that in S2-7, and further by 132,296 TEU in S2-9. The annual laden container throughput in Dawei port is estimated at 210,466 TEUs in S2-9, which is comparable to that of Thilawa port. The cargo volume passing through the SC at the Myanmar–Thai border, as also shown in Figure 11, increases by 8588 TEU in S2-8 and further by 88,227 TEU in S2-9, indicating that approximately two-thirds of the additional cargo handled at Dawei port is cargo to/from Thailand via the SC. The remaining cargo is shifted from Thilawa port or from Thai ports, coming from northern Thailand via the EWC.

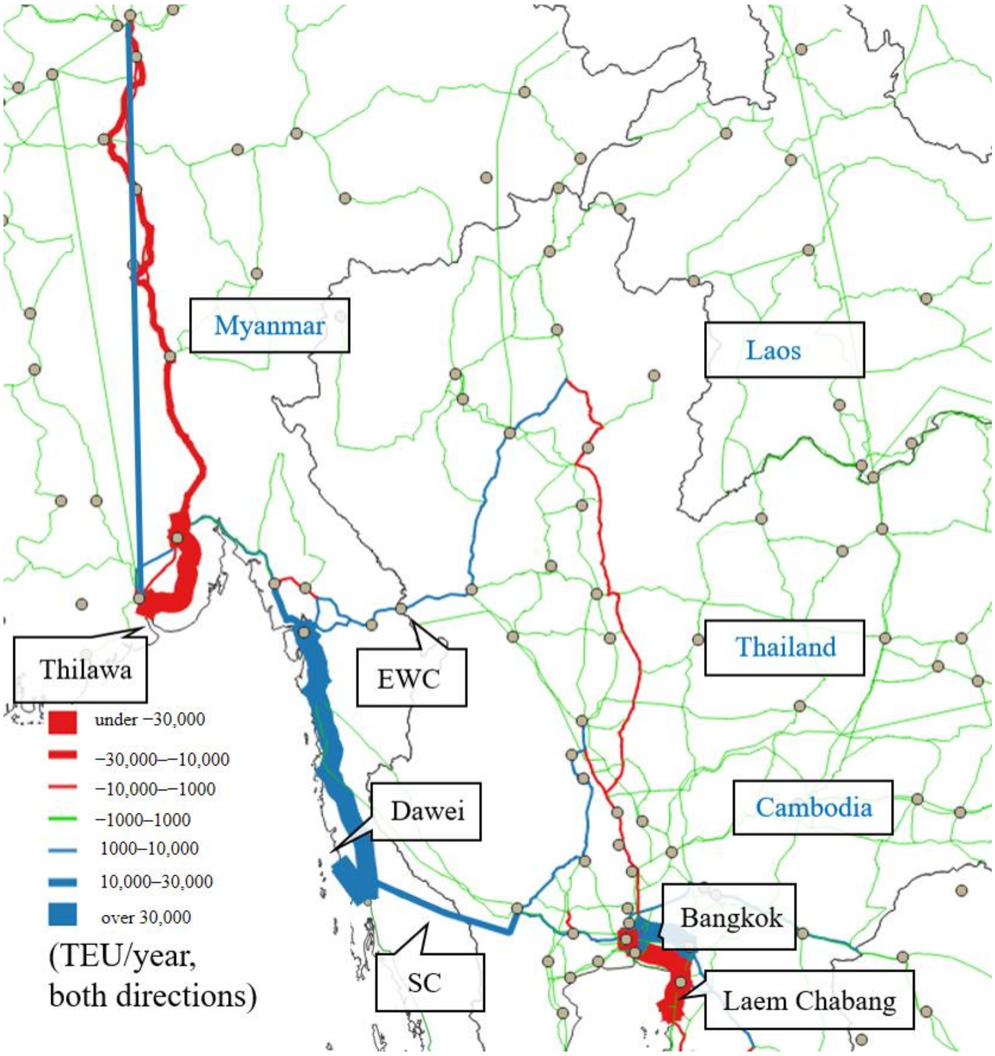

Figure 10. Difference in land cargo flows around the SC in S2-7 compared with S2-1.

6.3. Summary of Policy Simulations

In the EWC scenarios, the effect of increasing truck speed through road improvements on transport volume was limited, whereas a change in the cross-border coefficient λ_a significantly affected transport volume. Specifically, if the cross-border barrier on the EWC is removed (i.e., $\lambda_a = 0$), transit cargo volume would increase by about 40%. Conversely, the volume handled by Thilawa port would not decrease significantly, mainly because cargo to and from the regions in Thailand located close to Myanmar's border shifted to using Thilawa port via the EWC from Thai ports. The shift from maritime shipping to land transport to and from Thailand also weakened the attraction of Thai ports and enhanced the advantages of Thilawa port.

The development of the Myanmar section of the SC encouraged the shift of some portions of cargo, not only from the EWC and Thilawa port, but also from the Thai ports, even though Dawei port was not constructed. Moreover, the Dawei port scenarios showed that the addition of liner services at Dawei port would significantly increase the use of the SC. In these scenarios, significant shifting of cargo from Thai ports to Dawei port was observed, especially in the scenarios where European services were added. Specifically, in S2-9 (which optimistically assumes an increase in port-call services to Dawei port), the volume of cargo handled at Dawei port would increase to 210,466 TEU, whereas the SC transit cargo volume at the Myanmar–Thai border would be 185,681 TEU.

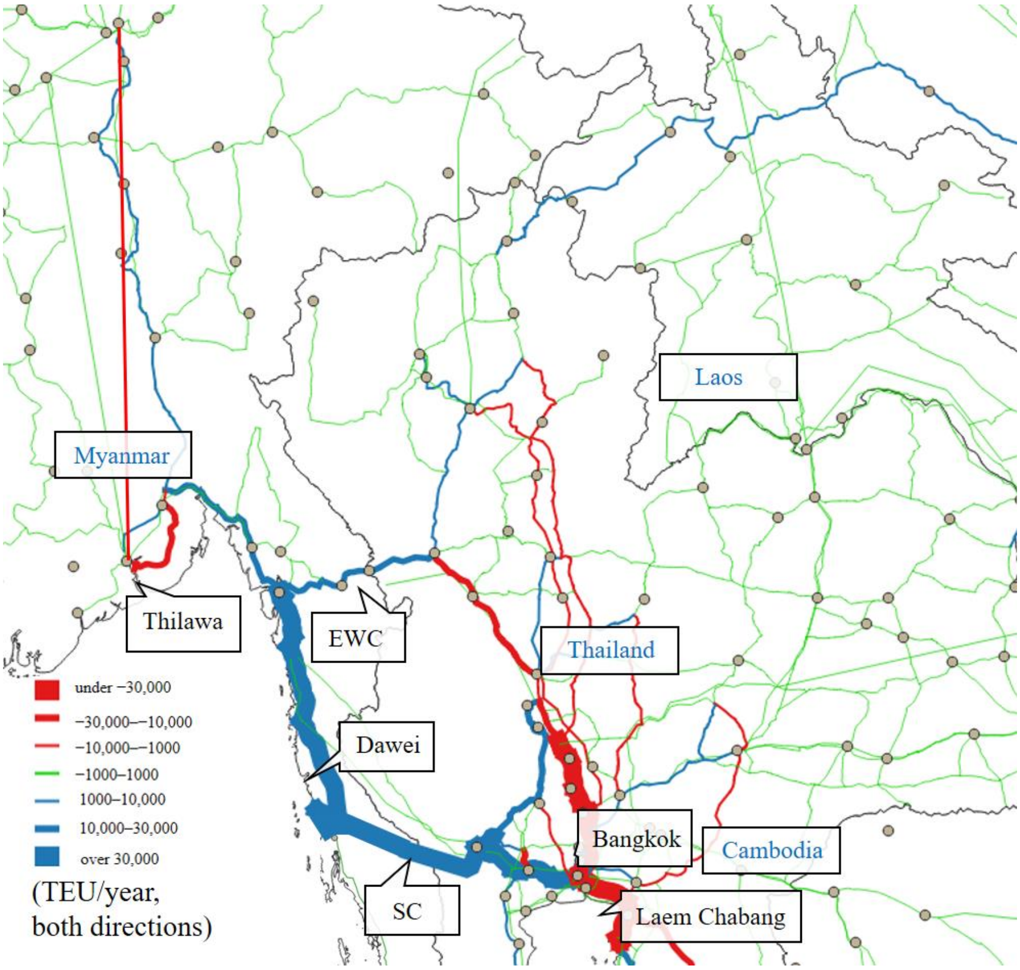

Figure 11. Difference in land cargo flows around the SC in S2-9 compared with S2-7.

Regarding the other countries of the terrestrial ASEAN, there was no significant effect of these infrastructural development policies, because their trade volumes with Myanmar are small and more than two international borders have to be crossed if cargo are transported by land.

7. Conclusions

In this study, we simulated the international cargo flows in the terrestrial ASEAN region focusing on Myanmar, by using the GLINS model, which was developed by Shibasaki [2,12,13]. Based on the results of the field survey, we updated the input data including detailed zone subdivision and consideration of inland water transport links in Myanmar. We confirmed the validity of the model by comparing the results with observed values of port container throughput and modal share of transport between Myanmar and Thailand, and by conducting a sensitivity analysis to change the cross-border coefficient λ_a.

Using the developed model, we analyzed policy scenarios for the improvement of the GMS-EWC and the development of the GMS-SC and Dawei port, which are currently planned in Myanmar. Simulations of improvements in truck speed and border barriers in the EWC showed that the improvement in speed has a small effect on the traffic through the EWC but, if the border barrier is reduced, the use of the EWC would increase and the container throughput in Thilawa port would decrease. Simultaneously, as some cargo to and from northern Thailand began to use Thilawa port via the EWC, the reduction in container throughput in Thilawa port would also become relatively low.

The scenarios for SC and Dawei port showed that the development of the SC would not only encourage the shift of cargo from the EWC, but also increase the share of land transport between Thailand and Myanmar. Furthermore, the scenario for the opening of Dawei port showed that the use of the SC would be expected to increase as the number and variations of liner services calling at Dawei port increase, resulting in a shift of Thai cargo to Dawei port. The significant increase in container throughput in Dawei port was deemed comparable to that of Thilawa port, if the services to connect to eastern India and Europe were added. Thus, unlike the previous models by the authors [14,15], we can simulate individual policies such as the development of the EWC, SC and Dawei port, and obtain reasonable results. Some findings of this study reinforce the implications obtained from previous studies that analyzed individual policies in Myanmar. The results in this study indicated that the combination of opening a new port and a transport corridor would give a more significant and wider impact on cargo flows even for a neighboring country (Thailand), as with Black and Kyu [23] and Isono and Kumagai [27]. This study also revealed that the development of a new port and transport corridors may reduce the congestion of Thilawa port, as Zin [24] pointed out on the dry port in Myanmar.

Meanwhile, there are still several issues to be addressed. First, the validity of the model should be further enhanced. For instance, the calibrations on cross-border coefficient at each national border and consideration of air cargo in the process to make the OD matrix are necessary. As regards to Thailand, model accuracy may be affected by the fact that Laem Chabang and Bangkok ports, which are of different sizes, are located close to each other; therefore, we can consider applying other methods of network assignment. Moreover, the model could be applied to various other policy simulations. For instance, as Nam and Win [25] pointed out, domestic intermodal hinterland transport network including rail and inland water transport should be focused on in further studies. Moreover, although this study focused on the relationship with Thailand, the simulation on the connection with Chinese land networks is also necessary, because Myanmar has a large volume of trade with China and China is also interested in Myanmar to connect with by land for promotion of the Belt and Road Initiative. Further, especially in developing countries, infrastructure investment should be planned based on the expected future economic growth of the country concerned; therefore, the simulations taking into account the future economic growth of terrestrial ASEAN are necessary such as Isono and Kumagai [27]. Furthermore, as mentioned at the beginning of this paper, environmentally sustainable infrastructure development is an essential issue currently. Thus, it is also important to discuss the simulation results of this study from an environmental aspect, especially by quantifying the environmental impact caused by the development of the GMS economic corridor and new ports, as indicated in Sukdanont et al. [26] and Comi et al. [46].

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