

Article

Cost Effectiveness Analysis in Short Sea Shipping: Evidence from Northeast Asian Routes

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Abstract: Nowadays, roll-on/roll-off (Ro-Ro) is an important mode for short sea shipping (SSS) due to its advantages of fast and convenient load and unloading system. Despite the advantages, the market share of Ro-Ro is insignificant compared with lift-on/lift-off (Lo-Lo) in the Northeast Asian region that is geographically suitable for fostering SSS. Therefore, it is of utmost importance to have a better understanding of the effectiveness of Ro-Ro and Lo-Lo in the regional SSS market. For this purpose, this paper develops a model to estimate the total logistics cost of the two transportation modes. The total logistics costs of Ro-Ro and Lo-Lo are calculated on three major SSS routes between Korea and Japan. The results show that Lo-Lo outperforms Ro-Ro on most routes in terms of the cost effectiveness, and Ro-Ro is competitive only for high-priced and time-sensitive cargo. However, it is also documented that Ro-Ro transport has a significant impact on reduction in the total logistics costs when companies integrate the supply chain and improve the cooperative relationship to a high level.

Keywords: cost effectiveness; short sea shipping; roll-on/roll-off; lift-on/lift-off



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1. Introduction

It is generally accepted that containerization is one of the revolutionary transformations shaping the maritime industry since the 20th century. Container shipping comes with substantial benefits such as, efficient loading/unloading, cargo security during moving and transport flexibility. Especially, as the use of containers enables logistics service providers to realize improved door-to-door transportation by allowing efficient modal shift between sea and land, transport by containers play a core role in supply chain management nowadays. According, whereas the vast majority of merchandise trade is serviced by container shipping, the global volume of container transport has remarkably increased from approximately 50 million TEUs in 1996 to 148 million TEUs in 2020 [1]. Containerization is, however, a costly process as it is accompanied with a heavy investment in landside operations (terminals, handling equipment and yards) at the initial stage. Moreover, in the typical lift-on/lift-off (hereinafter referred to as of Lo-Lo) loading and unloading system, stuffing cargo in a container box requires rigid packaging to mitigate the external shocks generated during vertical handling of the ship-to-shore crane. In this regard, given the impact of loading/unloading system on cargo flow (for example, see [2]), there has been a great deal of practical effort to improve cost-efficiency in sea-land multimodal transportation, and ultimately, to realize seamless logistics.

Rapid and seamless sea-land multimodal transport is much more needed in short-sea shipping (SSS) than in ocean-going shipping. In an effort to reduce transit time in SSS, shippers transport a growing number of containers via roll-on/roll-off (hereinafter referred to as of Ro-Ro) ships where containers are directly loaded on a trailer or other types of self-propelled vehicles. Compared with Lo-Lo, Ro-Ro is capable of horizontal loading and unloading at the berth, and therefore, reduces port dwelling time as containers can

be quickly exited from the vessel by connecting a tractor with a trailer where a container is loaded on. Thus, the Ro-Ro type of handling allows quick modal shift from sea transportation to road transportation while accelerating the transit speed, which is instrumental in securing competitiveness edge in SSS. However, the reduced transit time via Ro-Ro transport comes at a cost: the freight rate of Ro-Ro is much more expensive than that of Lo-Lo. The main reason for the relatively expensive freight rate of Ro-Ro is that this type of shipping transport is carried out by, mostly, ferries. As a ferry ship has a limited loading capacity (usually a few hundred TEUs), the economies of scale are hardly realized, which is in stark contrast to a large-sized cellular ship using the Lo-Lo loading/unloading system. Therefore, the modal selection between Ro-Ro and Lo-Lo can be determined by the trade-off between the transit time and the freight rate.

Whereas a voluminous body of research in the relevant field has dealt with the European SSS market [3–8], this study focuses on the Northeast Asian region. The significance of the cost-effective analysis on the Asian SSS market is twofold. Foremost, Northeast Asia is a key building block of the global economic activity as the leading economies in this region (China, Japan, South Korea) account for approximately 22.3% (as much as 18.5 trillion US dollar in constant) of global GDP as of 2018 [9]. Since those countries are export powerhouses, they also play a pivotal role in the container shipping market, which is evident in the fact that the container port throughput in the Asian region recorded 484 million TEUs (Twenty-foot Equivalent Units), taking about a 64.4% share of the world total in 2017 [1]. As such, exporters and importers in Northeast Asia are quite concerned with the interplay between the transit time and the logistics cost of container transport in the SSS market for their supply chain management. Considering the economic power of the countries in the region, SSS has great economic significance by linking with various ports between countries [10]. The other interesting feature making the Northeast Asian SSS market distinguished from others is modal selection between transport alternatives arising from the geopolitical situation in the region. In Northeast Asia, land transport via road or railway is available only for domestic distribution, but not for cross-border movement of cargo. This is mainly due to the military tension between South and North Korea. As the border in the Korean Peninsula is heavily armed and tightly controlled, commercial activity between the two regimes is inviable, which hinders cross-border land transport between South Korea and China. This is in stark contrast to the European region, where SSS (especially the Ro-Ro type of shipping) has been promoted as a substitute for road transport in order to reduce congestion, CO₂ emissions and accidents [11]. Therefore, transport modal selection in the Northeast Asian SSS market lies between Lo-Lo and Ro-Ro without considering other alternative modes or routes.

In this paper, we develop a model to estimate the total logistics cost of Ro-Ro and Lo-Lo in the regional SSS market for better understanding of the cost effectiveness of the two transportation modes. Specifically, the cost effectiveness analysis in this study monetizes the effect of lead time reduction in Ro-Ro transport by considering the time value of cargo. Our results suggest that total logistics cost savings of Ro-Ro are, in general, insignificant and less competitive than Lo-Lo in the Northeast Asian SSS market. However, given that trade parties integrate the supply chain and improve the cooperative relationship to a high level, transport via Ro-Ro has a substantial impact on the reduction in total logistics cost and the entire supply chain cycle, which is consistent with the findings in the previous studies [6,12].

The remainder of this paper is structured as follows: Section 2 reviews the previous studies on SSS, transport mode selection and the time value of cargo. Section 3 describes the dataset employed in this study. Section 4 proposes a model for estimating the freight rate incurred by freight transport via Lo-Lo and Ro-Ro and calculates the total logistic costs. Finally, Section 5 summarizes the results of this study and concludes.

2. Literature Review

2.1. Short Sea Shipping

Despite its economic importance in the logistics industry, there is no unanimous agreement on the definition of SSS. For example, the European Commission stipulates that SSS is 'domestic and international water transportation of cargo and passengers between ports in Europe or in non-Europe countries but on a close coastline bordering Europe' [13]. In the USA, SSS is defined as 'transport that uses inland and coastal waterways between domestic ports as an alternative to traditional transport without crossing the ocean' [14]. Regardless of the strictness of various definitions, one generally agreed concept is that that SSS means relatively short distance maritime transportation compared with ocean-going shipping. In this regard, Europe is geographically favorable to the growth of SSS. Approximately 70% of manufacturing in Europe is located on land within 150–200 km of coastline [15]. The number of people living close to the coast is 250 million which accounts for 41% of European population [16]. Moreover, there are about 1200 seaports along the 70,000 km-long coastline of the region, making it the most concentrated area in the world [17]. Accordingly, Europe is the most developed SSS market, servicing, as of 2012, 1.8 billion tons of freight representing 60% of total maritime transport of goods within Europe [18].

On top of the geographical advantage, there have been several pan-European policies to foster SSS in an attempt to replace road transport [19,20]. Therefore, a strand of research reviews and evaluates those supporting policies. The EU aims to transfer 30% of road freight to rail or SSS by 2030 and to increase the transferred share to 50% by 2050. To realize this, EU has launched several policies for construction of logistics infrastructure and for supporting business operations of SSS market participants, such as Trans-European Transport Network (TEN-T, 1992–2001), Pilot Action for Multimodal Transport (PACT, 1992–2001), and Marco Polo II (2003–2013). However, those supporting programs are generally considered as unsuccessful: the market share of SSS stagnated at 33% during 1995–2015, whereas that of road transport increased from 47% to 51% for the same period. According to Suárez-Alemán et al. [12] and Suárez-Alemán [21], the main reason for the unsuccessful outcome is that most funding was channeled into subsidies for shipping companies or freight rate, which results in lack of input into the SSS network itself, such as port infrastructure.

Another bunch of studies compare the effectiveness of SSS on certain European routes and ports. Martínez-López et al. [5] analyze the effectiveness of SSS by estimating the transport cost and the transit time required for multimodal transportation (including SSS) for food on the Rosyth-Zeebrugge route of the North Sea. They document that SSS fails to have competitive advantage over road transportation. However, the analysis shows that SSS can be more competitive when it guarantees high operating frequency and high speed by using Ro-Pax ships (a specialized form of Ro-Ro for the carriage of commercial vehicles along with accommodation for passengers for shorter voyages). Suárez-Alemán et al. [22] calculate the general transport cost of multimodal SSS corridors from Spain to several European destinations (London, Paris, Berlin, Rome and Moscow) considering monetary cost, time cost and external cost. Compared with road transport, multimodal including SSS shows a significant time-saving effect on some routes. Martínez-Moya and Feo-Valero [23] developed a Foreland Port Connectivity Index and applied to Spanish ports to study their connectivity in terms of container Short Sea Shipping. Increasingly, stringent environmental regulations are also affecting SSS. Raza [24] examined the impact of external regulatory pressure on the adoption of green innovations in SSS and in turn, the impact of those innovations on the environmental and economic performance of SSS companies. Martínez-López et al. [25] introduced a calculation method to estimate a specific environmental charge in ports to incentivize Cold Ironing (process to supply onshore electric power to vessels) use in Short Sea Shipping, and examined the impact of a charge on SSS vessel operators' economic performance under different scenarios. Ramalho and

Satos [26] proposed a computing mechanism for external costs in an intermodal transport network including SSS to explore the impact of external costs in the competitiveness of SSS.

2.2. Transport Mode Selection

Transport mode selection can be seen as a part of the decision-making framework for planning the overall process of supply chain. Decision-making on the supply chain can be stratified into the strategic, tactical and operational levels, respectively. The strategic level is a logistics network design (e.g., plant location, production technology and production capacity) that takes into account both nodes and transportation channels; tactical levels include cargo flow management, production levels and inventory management; operational levels that transport mode selection belongs to include short-term schedules such as carrier selection and delivery of finished goods (for better understanding of the logistics network modeling principles by decision-making levels, see Schmidt and Wilhem [27]). A number of studies have examined transport model selection behavior and prediction and the Stated Preference (SP) method gains popularity in analyzing the relationship between specific factors and modal selection (SP refers to a family of techniques that use individual respondents' statements about their preferences in a set of transport options to estimate utility functions, such as conjoint analysis, functional measurement, trade-off analysis and transfer price method [28]). For example, Cullinane and Toy [29] collect the analysis results of existing freight transportation modes, routes and decision points and suggest the general modes of transport selection through contents analysis. Further, Kawasaki and Lau [30] develop a preference model for potential passengers of cruise ship tours.

Whereas the majority of research on mode selection highlights the choice between road transport and shipping transport, Russo et al. [6] compare the effectiveness Lo-Lo and Ro-Ro on some European logistics corridors. By applying the aggregate discrete choice model to simulate the cargo flow of Lo-Lo and Ro-Ro, they present some interesting findings. First, Lo-Lo is selected mostly when the distance is more than 1000 km whereas the possibility of selecting Ro-Ro is slightly higher than Lo-Lo on the routes with the distance less than 1000 km. Second, the possibility of selecting Lo-Lo increases if the destination is a hub port. Finally, the possibility of selecting Ro-Ro increases on a route having a regular service with high frequency. In this study, there is an exception: a high volume of Ro-Ro transportation is observed on Italy-Turkey route. Plausible explanations for this phenomenon are Turkey's rapid economic growth, geographical factors and strong cooperative relations between the two countries. Therefore, it is highly probable that the demand for Ro-Ro increases at a higher speed among countries with developed economies and close cooperation. Puckett et al. [31] examined the choice between trucking and SSS in the eastern coast of the North America region and suggested that shippers value high-frequency transport services. Arof [32] investigated the determinants of Ro-Ro operations between Southeast Asian countries. Finally, Santos et al. [33] suggested a methodology to design SSS services between Europe and North Africa using Ro-Ro transport.

2.3. Time Value of Cargo

The cargo time value is a part of the time value domain and has a high degree of similarity with the time value of currency. The concept has an important practical implication and is widely used for estimating the holding costs of cargo. For example, Alford and Bangs [34] created the concept of annual cargo holding costs. In their model, the time value of cargo is estimated by analyzing costs incurred by factors such as insurance, storage, taxes, transportation, depreciation, interest paid and obsolescence. In light of the framework proposed by Alford and Bangs [34], FedEx reclassified the elements into four types: capital cost, inventory service cost, storage and warehouse cost and inventory risk cost [35]. According to this model, the estimated annual holding cost of general cargo is between 23% and 26% of invoice value, whereas it is escalated to the range of 42–45% for high-tech cargo (see Table 1).

Table 1. Cargo Holding Cost proposed by FedEx.

Factors	General Cargo	Hi-Tech Cargo
capital cost	**	**
handling, insurance, taxes, transportation cost	1%	1%
storage and warehousing facilities cost	4%	8%
obsolescence, damage, pilferage cost	15%	30%
Total	23–26%	42–45%

Note: ** indicates the prevailing commercial paper rates, 3–6%. Source: Yang et al. [35].

Accordingly, there have been academic attempts to incorporate the time value of cargo into establishing the supply chain strategy. For example, Guan and Kazuo [36] review the evaluation methods for the time value of freight and calculate the time value coefficient of domestic freight by applying Random Utility Theory. Tao and Zhu [37] explored the factors that affect the value of time (VOT) at the macro/micro level based on statistical analysis and regression analysis and provide several suggestions to decrease errors in estimating VOTs (for better understanding of VOT, see Feo-Valero et al. [38]).

3. Data and Baseline Assumptions

3.1. Routes and Schedules

The East Asian countries, especially South Korea, China and Japan, have close economic cooperation. However, the convenience of transportation in this region is significantly lower than EU. Unlike Europe, countries in East Asia have seas between them, so that transport mode selection should be viewed as a competition between Lo-Lo and Ro-Ro, not between road transport and SSS. Currently, the share of Ro-Ro transport has meagerly stagnated. For example, the container port throughput of Busan via Ro-Ro recorded 138,000 TEUs in 2017, which represents 0.7% of the whole volume (20.5 million TEUs).

However, as the importance of rapid and seamless logistics elevates in the East Asia region, SSS via Ro-Ro transport gains growing attention. In order to facilitate trade flow, there have been cooperative schemes at the government-level, and one of the outcomes is ‘mutual access of trailer chassis’ between Korea and Japan, under which permitted trailers can be operated in both countries [39]. Currently, the pilot project allows 32 registered trailer chassis to be towed on the road of both Korea and Japan when they are transported via the Busan (South Korea)–Hakata (Japan) or Busan–Shimonoseki (Japan) route [40]. This process is expected to accelerate the establishment of a seamless logistics network between the two countries. Therefore, this paper highlights SSS routes between Korea and Japan and analyzes the cost effectiveness of Lo-Lo and Ro-Ro under the same conditions. As of 2018, there are a substantial number of liner shipping services linking 10 ports in South Korea and 60 ports in Japan [41]. Among the sea routes, this paper focuses on Busan–Hakata, Busan–Shimonoseki and Busan–Osaka routes on which both Lo-Lo and Ro-Ro shipping services are provided. The geographical description of the three SSS routes is shown in Figure 1, and details of Ro-Ro shipping services are presented in Table 2.

3.2. Shipping Freight Cost

From a shipper’s perspective, the selection of transportation mode is a balancing act considering the total freight cost, the transportation time and the service reliability. In the comparison of Lo-Lo and Ro-Ro, the service reliability is only a marginal difference since both are sea transportation via ships. Therefore, differences are arising from either the freight cost or the transit time. Two main sources of the cost to be borne by shippers using Korea–Japan routes are Ocean Freight (hereinafter referred to as OF) and Incidental Expense (hereinafter referred to as IE).



Figure 1. Geographical description of Busan–Hakata, Busan–Shimonoseki, Busan–Osaka routes. Source: adapted from Google Map.

Table 2. Ro-Ro Services on Korea–Japan Routes.

Company Name	Route (Vessel)	Frequency	Gross Tonnage	Passenger Capacity	Cargo Capacity
Korea Ferry	Busan–Hakata (New–Camellia)	Daily	19,961	522	220TEU Car: 41
Bukwan Ferry	Busan–Shimonoseki (HAMAYUU)	Daily	16,187	460	140TEU No. of Truck: 25
	Busan–Shimonoseki (SEONGHEE)		16,875	562	136TEU No. of truck: 76, No. of car: 30
PanStar	Busan–Osaka (PanStar Dream)	3 per week	21,535	681	220TEU

Source: Busan International Passenger Terminal Schedule Information, Busan Port Authority.

In this paper, we collected data relevant to the OF from the tariffs of shipping service providers for the selected routes. The OF for Ro-Ro is more expensive than for Lo-Lo (see Table 3). In the Busan–Hakata route, the OF for Lo-Lo and Ro-Ro are USD 200/TEU and USD 500/TEU, respectively; Lo-Lo of USD 350/TEU and Ro-Ro of USD 470/TEU in the Busan–Shimonoseki route; Lo-Lo of USD 250/TEU and Ro-Ro of USD 600/TEU in the Busan–Osaka Route. The freight charges for a 40-foot container (Forty-foot Equivalent Unit, FEU) are as twice as that of a TEU container.

Table 3. The Ocean freight of Lo-Lo and Ro-Ro in each route (USD per unit).

	Busan–Hakata		Busan–Shimonoseki		Busan–Osaka	
	Lo-Lo	Ro-Ro	Lo-Lo	Ro-Ro	Lo-Lo	Ro-Ro
TEU	200	500	350	470	250	600
FEU	400	1000	700	940	500	1200

Source: Tariffs of shipping service providers in each route.

The IE of container shipping is the cost incurred besides the shipping freight rate. IE includes many types and we, in this study, apply the cost incurred in Korea when exporting cargo to Japan using the dataset obtained from the Korea Customs and Logistics Association. In Korea, there are 6 types of IE: cargo handling charge (HCKR), documentation fee (DFKR), Advance Filing Rule charge (AFR), wharfage (WHA), seal charge (SC) and terminal handling charge (THCKR). It should be noted, however, that only wharfage and terminal

handling charge differentiate TEU and FEU as other kind of IEs are charged per bill of lading (B/L) or per container count. The level of each IE borne by shippers is listed in Table 4.

Table 4. Incidental expense incurred in Korea (USD).

Incidental Expense ¹	TEU ²	FEU ²
Cargo Handling Charge (HCKR) per B/L	30	30
Documentation Fee (DFKR) per B/L	36.5	36.5
Advanced Filing Rule charge (AFR) per B/L	30	30
Wharfage (WHA) per container	4	8
Seal Charge (SC) per container	7.3	7.3
Terminal Handling Charge (THCKR) per container	106	143.2
Total	214	255

¹ Source: Incidental Expense of Container Export from Korea, Korea Customs and Logistics Association. ² Note: As IEs are quoted in Korean Won (KRW), prices are converted to USD based on the average KRW-USD exchange rate of USD 1 = KRW 1096 for the period of January 2018–October 2018.

The OF and IE calculated in this study are for Full Container Load (FCL) cargo exported from Busan to Japan. Therefore, the total shipping freight costs for Lo-Lo and Ro-Ro can be expressed by Equations (1) and (2), respectively.

$$TF_{lo-lo} = OF_{lo-lo} + IE_{lo-lo} \tag{1}$$

where TF_{lo-lo} , OF_{lo-lo} and IE_{lo-lo} are the total shipping freight cost, OF and IE for a Lo-Lo transport, respectively.

$$TF_{ro-ro} = OF_{ro-ro} + IE_{ro-ro} \tag{2}$$

where TF_{ro-ro} , OF_{ro-ro} and IE_{ro-ro} are the total shipping freight cost, OF and IE for a Ro-Ro transport, respectively.

Equations (1) and (2) can be integrated into Equation (3) as follows:

$$TF_{i,\alpha}^j = OF_{i,\alpha}^j + IE_{i,\alpha}^j \tag{3}$$

where $TF_{i,\alpha}^j$ is the total shipping freight cost of a j type container (TEU or FEU) transported on route α (Busan–Hakata, Busan–Shimonoseki or Busan–Osaka) via i transport mode (Lo-Lo or Ro-Ro).

In addition, since there is no difference between Lo-Lo and Ro-Ro in charging IEs, the IE for a container consists of the following items shown in Equation (4).

$$IE_j = HCKR + DFKR + AFR + WHA_j + SC + THCKR_j \tag{4}$$

where IE_j , WHA_j and $THCKR_j$ are the IEs for a j type container (TEU or FEU).

3.3. Transportation Time and Time Cost

The transportation time for each route consists of two parts: the transit time for shipping voyage and the cargo handling time in the ports of origin and destination. We calculated the average of the shipping voyage time on each route from the navigation records of a Lo-Lo and a Ro-Ro ship operated during October 2018. Apart from the shipping transportation time, we collected data from port authorities and other relevant research.

Table 5 presents the transportation time for each route and compares those via Lo-Lo and Ro-Ro. For Lo-Lo transport, the transportation time is estimated 89.6 h for Busan–Hakata, 87.6 h for Busan–Shimonoseki and 109.8 h for Busan–Osaka, respectively. On the contrary, much less transit time is required for Ro-Ro transport on the same route, 26.1 h, 28.2 h and 37.8 h, respectively. The source of the reduced transit time via Ro-Ro is twofold. First, a Ro-Ro ship is much faster than a Lo-Lo ship, resulting in less sailing time on the sea. This is pronounced as the distance between ports increases (e.g., compare the distances of

Busan–Shimonoseki and Busan–Osaka). Second, Ro-Ro transport also requires much less time for cargo handling in ports due to its rapid horizontal loading/unloading system.

Table 5. Transportation Time of Lo-Lo and Ro-Ro on Korea–Japan Routes (hours).

Mode	Sector	Busan–Hakata (214 km)	Busan–Shimonoseki (227 km)	Busan–Osaka (680 km)
Lo-Lo	Port Handling in Korea ¹	24	24	24
	Sea Transportation ²	11.6	9.6	31.8
	Port Handling in Japan ³	54	54	54
	Total	89.6	87.6	109.8
Ro-Ro	Port Handling in Korea ¹	10	10	10
	Sea Transportation ²	7.1	9.2	18.8
	Port Handling in Japan ³	9	9	9
	Total	26.1	28.2	37.8

¹ Source: Korea Transport Institute (KOTI Logistics Brief) for the port handling time; ² Source: Marine Traffic (<http://www.marinetraffic.com>, accessed on 18 October 2018) for the sea transportation time; ³ Note: The port handling time in Japan is based on data on Shimonoseki port.

An exporter or an importer selects a transportation method that can maximize utility by considering factors such as the freight cost, the transportation time and cargo characteristics. Among them, the transportation time is the source of the time value of cargo. In general, the freight rate of high-speed transportation is relatively expensive. However, the reduced transit time via high-speed transportation results in increase in total utility through improving cash flows and reducing inventory costs. Therefore, if a shipper chooses a relatively fast transportation mode, it can be considered that the time value of cargo is generated by reducing the transit time.

To calculate the time value of cargo, it is of utmost importance to estimate the sensitivity to time that is determined by two factors: the characteristics and the value of cargo. Goyal and Giri [42] propose a classification based on the characteristics of the cargo (see Table 6). The first group is the easily obsolete cargo that depreciates when rapid changes of technology or new products are introduced (e.g., electronic products such as computers parts and mobile phones). The products in this group do not disappear or deteriorate over time, but are classified as easily obsolete because their value plummets. The second group is the easily decaying or deteriorating cargo that is vulnerable to damage, spoilage, dryness and vaporization including foodstuffs, dairy products and medicine, to name a few.

Table 6. Cargo Types Classified by Characteristics.

Cargo Type	Characteristics	Examples
Easily Obsolete Cargo	Depreciation over time due to replacement by latest products or changes in consumer preferences	Clothing, Books, Mobile Phones, Electronic Products
Easily Decaying or Deteriorating Cargo	For the short expiration date, it must be sold within a limited time, otherwise corruption, deterioration or volatilization may occur	Fresh Food, Fruits, Dairy Products, Flowers, Medicines
Others	Other than the above two types	Steel, Plastics

Source: Goyal and Giri [42].

Furthermore, as the number of high value-added cargo is rapidly increasing, there is the need for more detailed classification. In this regard, Zhang et al. [43] reclassify the cargo according to its value characteristics, and the results are presented in Table 7.

Table 7. Classification based on Value and Characteristics of Cargo Type.

Cargo Type	Characteristics	Examples
High-Priced and Time-Sensitive Cargo	High value and severe depreciation over time	Laptops, Cell Phones, Electronic Components, High-end Clothing, Mechanical Products, Toys
Expensive Cargo	High value but no significant depreciation occurs over time	Artwork, Luxury Furniture
Time-Sensitive Cargo	Low value of its own but severe depreciation over time	Fresh Food, Fruits, Dairy Products, Flowers, Fast-moving Consumer Goods
General Cargo	Low value and low depreciation over time	Steel, Construction Material, Chemical Products, Plastics, Rubber, Grain
Special Cargo	Value and its variability are special	Radioactive Material, Easily Damaged Cargo, Military Material

Source: Zhang et al. [43].

This study combines the cargo classification methods of Zhang et al. [43] and FedEx (in Table 1) to calculate the proportion of cargo holding cost to the cargo value by transport mode. As the cargo classification of FedEx consists of only General and High-Tech cargoes (see Table 1), some adjustments are needed for the grouping of Zhang et al. [43]. Therefore, whereas the category of special cargo in Zhang et al. [43] is excluded, the categories of expensive cargo and time sensitive cargo are integrated into expensive or time sensitive cargo (see Table 8). The annual holding cost for the high-priced and time-sensitive cargo, expensive or time-sensitive cargo and general cargo are 45% (the highest share of holding cost for High-Tech in Table 1), 42% (the lowest share of holding cost for High-Tech in Table 1) and 23%, respectively.

Table 8. Annual Holding Cost by Cargo Type.

Cargo Type	Examples	Annual Holding Cost
High-Priced and Time-Sensitive Cargo	Laptops, Cell Phones, Electronic Parts, Automobile Parts, High-end Clothing, Machinery Products, Toys	45%
Expensive or Time-Sensitive Cargo	Artwork, High-end Furniture, Fresh Food, Dairy Products, Flowers, Fruits	42%
General Cargo	Steel, Construction Material, Chemicals, Plastics, Rubber, Grain, Iron Ore, Coal, Crude Oil	23%

Based on the above classification, the following Equation (5) expresses the time cost in the cargo transportation process. Whereas existing time costs have been calculated on the annual basis, this study converted them into the hourly term as the distance and time of maritime transport between Korea and Japan is short.

$$TC_{i,a}^j = V_m^j \times \frac{\rho'_m}{365 \times 24} \times t_{i,a} \tag{5}$$

where $TC_{i,a}^j$ is the time cost when cargo loaded in container of type j is transported on route a through type i transport mode; V_m^j is the total value of type m cargo loaded in type j container; ρ'_m is the coefficient of annual holding cost of cargo; and $t_{i,a}$ is the time (hours) required for transport of type i transportation on route a .

3.4. Packaging Cost

The packaging is a logistical activity essential for protecting and maintaining cargo value during the transportation process. The impact of the quay crane used for container unloading is 14.8 G in the vertical direction, 12.7 G in the front-rear direction and 7.42 G in the left-right direction [44]. For Lo-Lo shipping, sturdy packaging is essential to protect the cargo. In contrast, the impact on the cargo in Ro-Ro transportation is reduced by approximately a third compared with Lo-Lo since the trailer loaded with cargo can embark directly or the container is handled with reach stacker.

The packaging method required for transportation is determined according to the degree of external impact received by cargo. To avoid the heavy impact on cargo and prevent following damage in Lo-Lo transportation, rigid and corrugated cardboard or wooden packaging (hereinafter referred to as general packaging) is required. In stark contrast, since Ro-Ro transportation has less impact on the container, it is possible to use simple packaging or even a special container that can be directly put into the production line or recycled. According to the estimation, simple packaging can save approximately 20% of the cost compared with general packaging [44]. The packaging cost for export containers in Busan (suggested by a packaging service provider) is approximately USD 64 per cubic meter (CBM). Therefore, the packaging cost per CBM of Ro-Ro can be estimated at USD 51.2. This study considers two scenarios. In the first scenario, both Lo-Lo and Ro-Ro users employ general packaging. In the scenario, Lo-Lo users employ general packaging, whereas Ro-Ro users employ simple packaging.

The inner dimensions of a TEU container and a FEU container are 33.1 CBM and 67.5 CBM, respectively. However, it is more realistic to assume that shippers cannot use the whole volume of a container box due to the dead space and the volume occupied by the packaging material. Therefore, this study assumes the loadable space to be 25 CBM for a TEU and 50 CBM for a FEU, respectively. Table 9 shows the inner dimension, the actual loadable space and the packaging cost by container types.

Table 9. Packaging Cost by Container Type.

	Unit	TEU	FEU
Inner Dimensions	CBM	33.1	67.5
loadable space	CBM	25	50
General Packaging Cost Per CBM	USD	64	64
General Packaging Cost Per Container	USD	1600	3200
Simple Packaging Cost Per CBM	USD	51.2	51.2
Simple Packaging Cost Per Container	USD	1280	2560

4. Empirical Results

4.1. Description of the Analysis

To analyze the cost effectiveness of Lo-Lo and Ro-Ro, this study summarizes the main stages incurred in the process of shippers exporting cargo from Korea to Japan and their respective costs. In addition, the total transit time is calculated by arranging the sea transportation time and port handling time of Lo-Lo and Ro-Ro on each route, and based on this, the time cost is derived. Finally, the packaging costs of Lo-Lo and Ro-Ro are calculated. Incorporating these results, this study presents the total cost of logistics in two modes of transportation. This process is graphically described in Figure 2.

To build this model, this study develops a program that inputs cargo and route-related information, and accordingly presents the total logistics cost as well as the recommended transportation method between Lo-Lo and Ro-Ro. Figure 3 shows the operation process and the logic of the program.

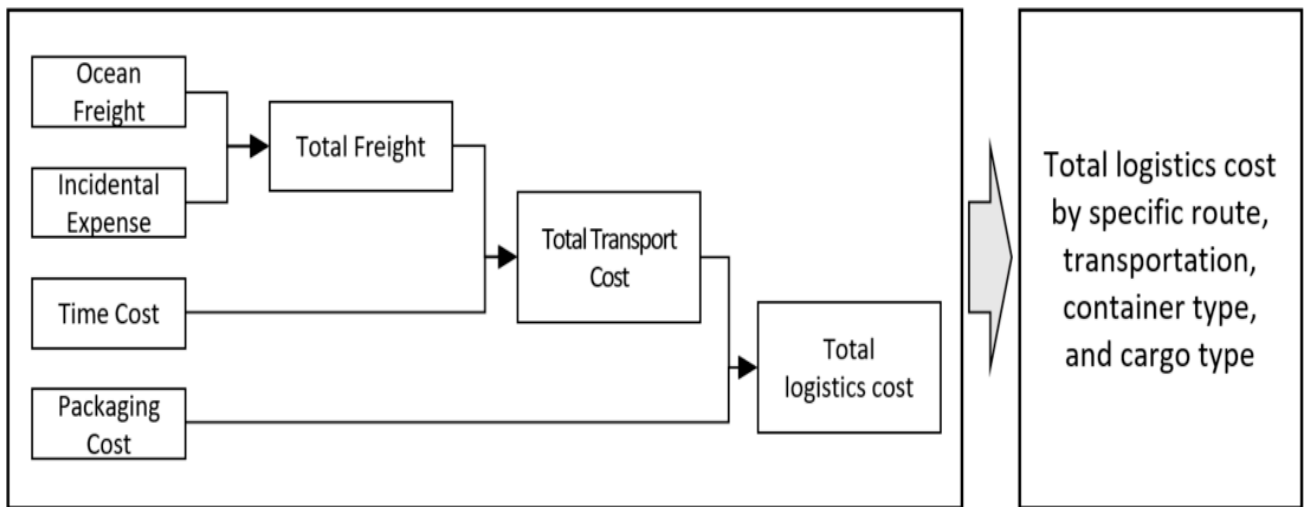


Figure 2. The Process of calculating total logistics cost.

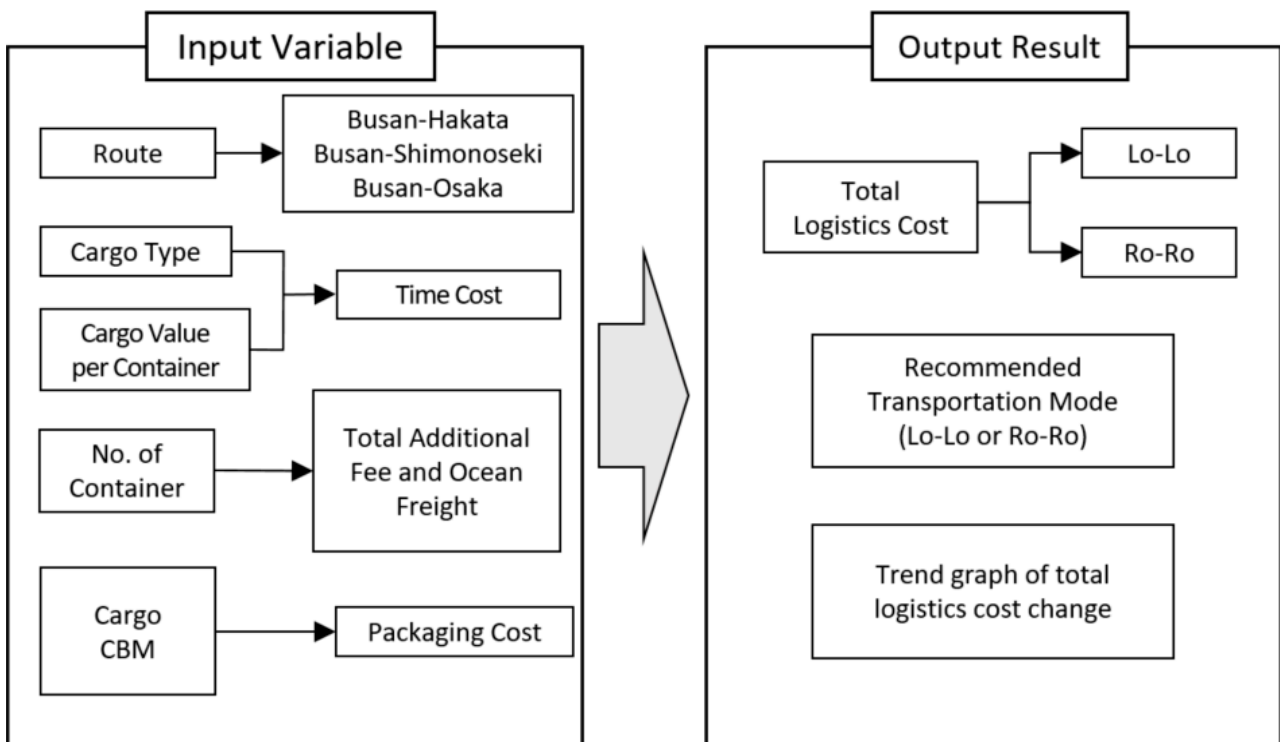


Figure 3. Transportation mode selection program.

4.2. Total Logistics Cost

This study defines the total logistics cost of the Busan–Japan route as the sum of the total freight, the time cost and the packaging cost. Equation (6) shows the total cost of logistics for each transport method and container type on the same route.

$$TLC_{i,a}^j = TF_{i,a}^j + TC_{i,a}^j + PC_{i,a}^j \tag{6}$$

Equations (3)–(5) can be substituted into Equation (6) to derive Equation (7) as follows:

$$TLC_{i,a}^j = n \times OF_{i,a}^j + n \times (HCKR + DFKR + AFR + WHA_j + SC + THCKR_i + V_m^j \times \frac{\rho'_m}{365 \times 24} \times t_{i,a} + n \times PC_{i,a}^j \tag{7}$$

where α indicates 3 routes between Busan and Japan, $\alpha \in A$, $A = \{1, 2, 3\}$ 1: Busan–Hakata, 2: Busan–Shimonoseki, 3: Busan–Osaka; i is the type of transportation, $i \in I$, $I = \{1, 2, \}$ 1: Lo-Lo, 2: Ro-Ro; j is the type of containers, $j \in J$, $J = \{1, 2, \}$ 1: 20ft, 2: 40ft; m is the type of cargo, $m \in M$, $M = \{1, 2, 3, \dots, m\}$; and $IE_{i,\alpha}^j$ is the incidental expense in Equation (4).

In estimating the total logistics cost, C# is used to develop a transportation mode selection program for Busan–Japan routes and the interface is presented in Figure 4. C# is a modern, universal and object-oriented programming language. As it is highly efficient and easy to develop a visual operation interface, C# is suitable for the needs of the current research.

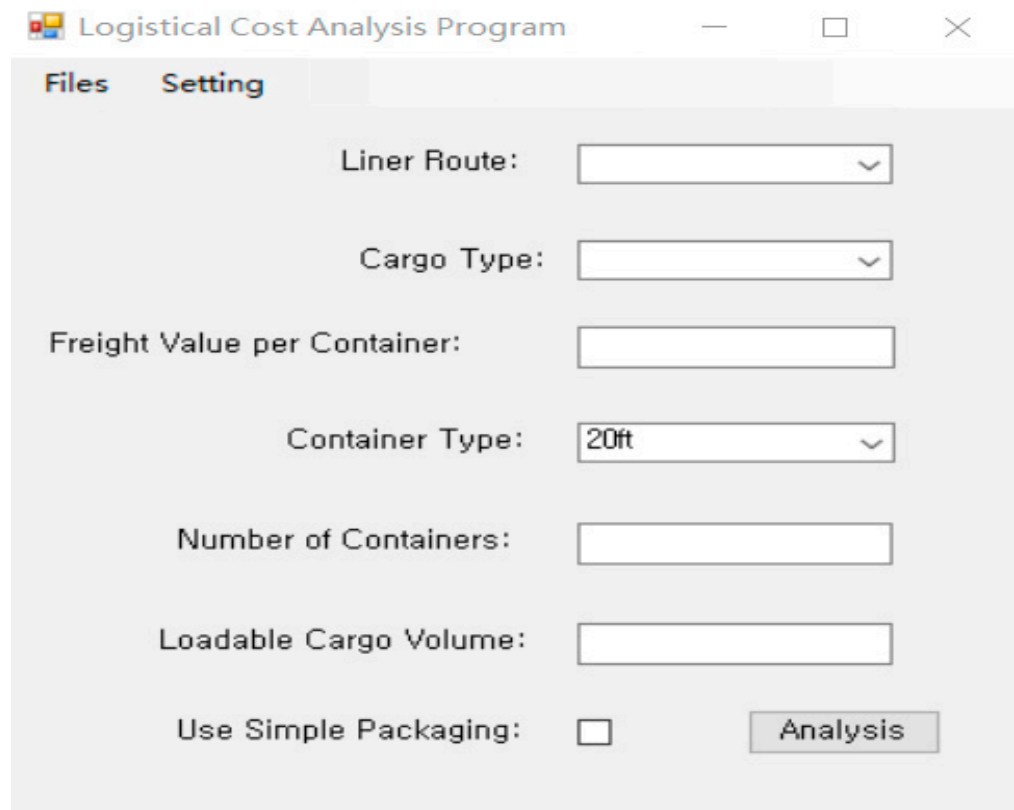


Figure 4. Total logistics cost estimating program for Busan–Japan route.

The program simultaneously calculates the total logistics costs of Lo-Lo and Ro-Ro on the three routes under two scenarios in a TEU container delivers general cargo and high-priced or time-sensitive cargo. The same general packaging is applied for both Lo-Lo and Ro-Ro and the volume loaded into the container box is assumed to be in the full state of 25 CBM.

Substituting data for freight (from Tables 3 and 4), the transportation time (from Table 5) and the packaging cost (from Table 8) in Equation (7), this study first derives the total logistics cost calculation formula for Lo-Lo and Ro-Ro on the Busan–Hakata route. The total logistics cost of Lo-Lo and Ro-Ro per TEU container for general cargo are shown in Equations (8) and (9). In addition, Figure 5 shows the total logistics cost function as the cargo value changes.

$$TLC_{1,1}^{1,G} = \$414 + V_m^1 \times \frac{23\%}{365 \times 24} \times 89.6 h + \$64 \times v \tag{8}$$

$$TLC_{2,1}^{1,G} = \$714 + V_m^1 \times \frac{23\%}{365 \times 24} \times 26.1 h + \$64 \times v \tag{9}$$

where $TLC_{1,1}^{1,G}$ is the total logistics cost when general cargo is loaded in a TEU container and transported through Lo-Lo on the Busan–Hakata route. $TLC_{2,1}^{1,G}$ is the total logistics cost when general cargo is loaded in a TEU container and transported through Ro-Ro on the same route. G means the general cargo, and v is the cargo volume (CBM).

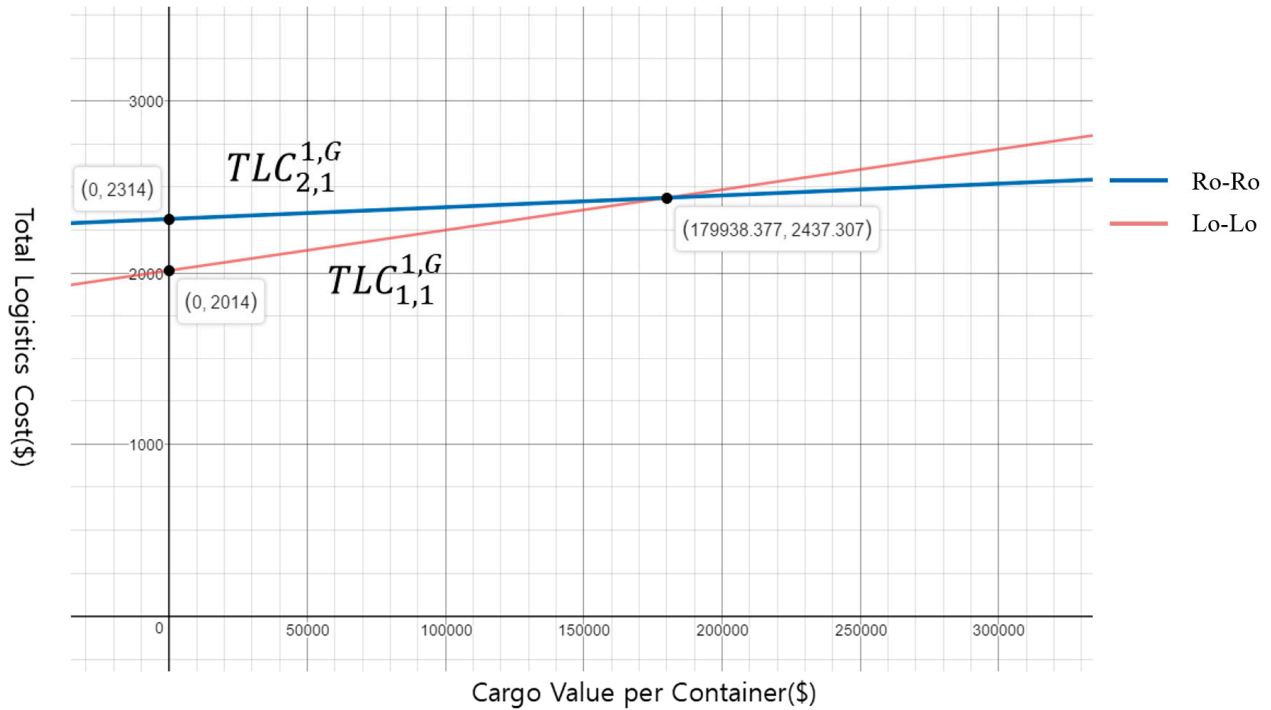


Figure 5. Changes in total logistics cost of Lo-Lo and Ro-Ro for general cargo (Busan–Hakata).

Considering the total logistics cost of transporting a TEU (25 CBM) of general cargo on the Busan–Hakata route, the break-even point is USD 179,938, which implies that it is better to choose Ro-Ro when the value of the cargo is more than the amount, whereas Lo-Lo is more preferable otherwise. Taking the steel products with the cargo value of USD 50,000 per TEU as an example, the results of calculating the total logistics costs for transportation by Lo-Lo and Ro-Ro are shown in Figure 6. According to the results, Lo-Lo is more economical since the total logistics cost of Lo-Lo is USD 2131, lower than USD 2348 for Ro-Ro when transporting a TEU of steel products from Busan to Hakata.

With the same logic, the total logistics costs of Lo-Lo and Ro-Ro per TEU container for high-priced and time-sensitive cargo are shown in Equations (10) and (11), respectively, and Figure 7 presents the total logistics cost function as the cargo value changes.

$$TLC_{1,1}^{1,HT} = \$414 + V_m^1 \times \frac{45\%}{365 \times 24} \times 89.6 h + \$64 \times v \tag{10}$$

$$TLC_{2,1}^{1,HT} = \$714 + V_m^1 \times \frac{45\%}{365 \times 24} \times 26.1 h + \$64 \times v \tag{11}$$

where $TLC_{1,1}^{1,HT}$ is the total logistics cost when expensive and time-sensitive cargo is loaded in a TEU container and transported through Lo-Lo on the Busan–Hakata route. $TLC_{2,1}^{1,HT}$ is the total logistics cost when expensive and time-sensitive cargo is loaded in a TEU container and transported through Ro-Ro on the same route. HT means the high value and time sensitive cargo.

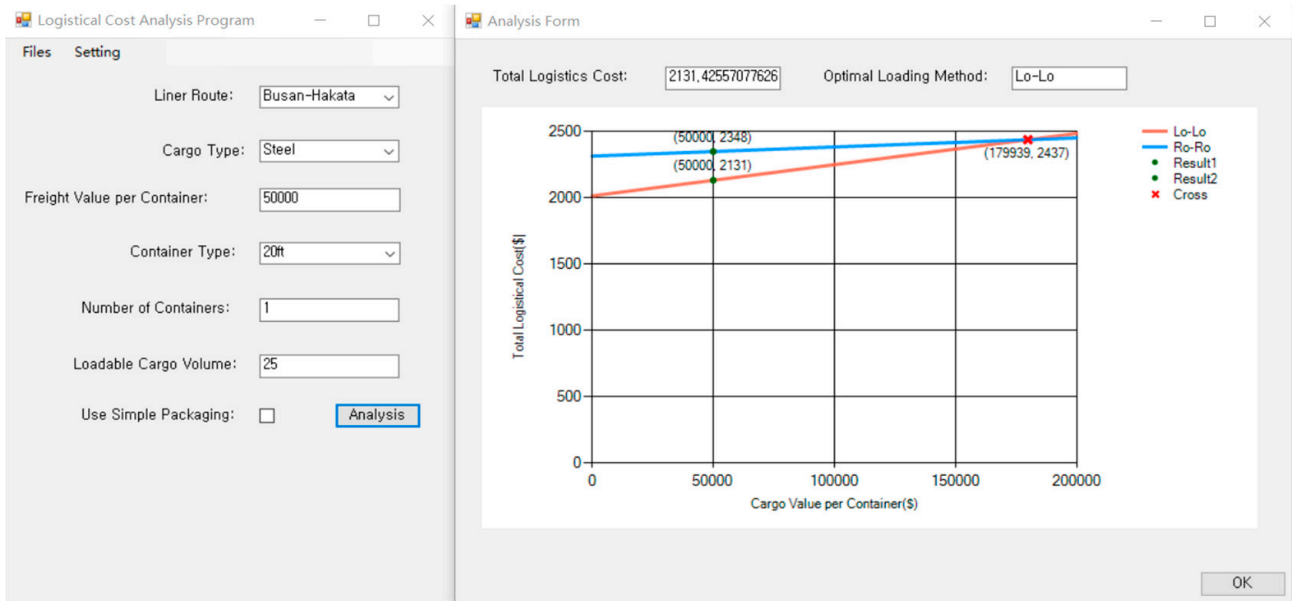


Figure 6. Results of transportation selection model for Busan–Hakata route (general cargo).

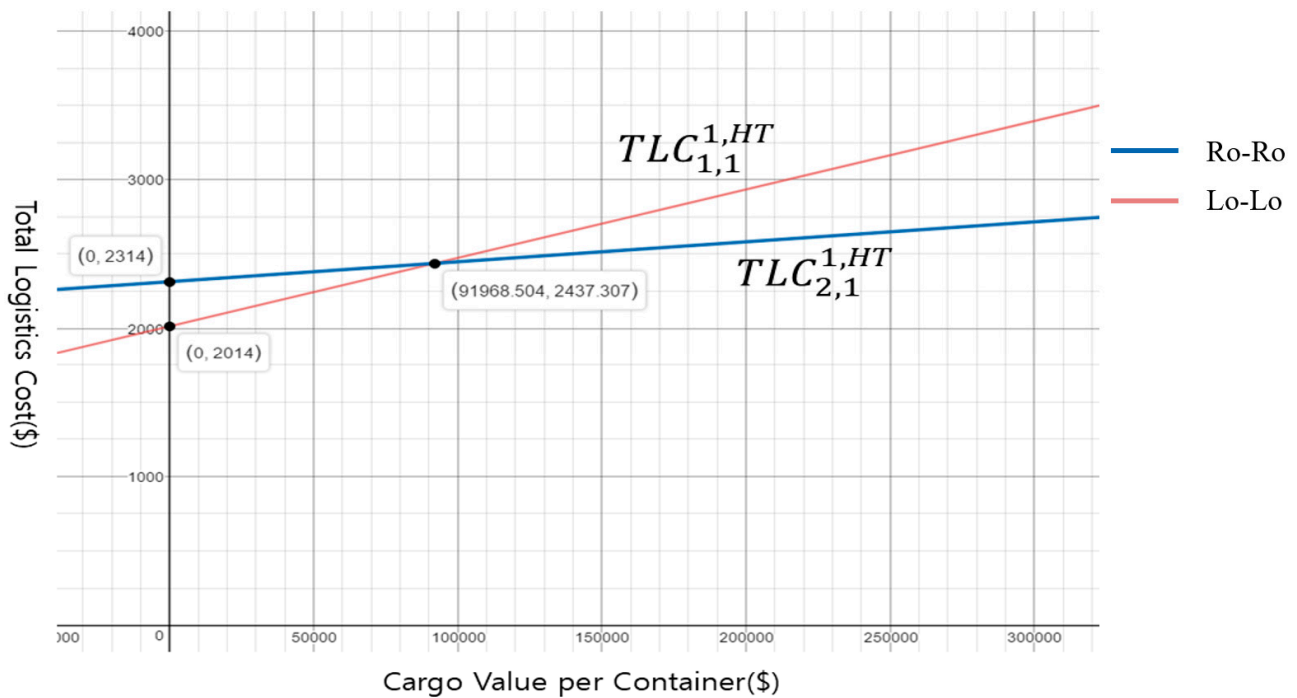


Figure 7. Changes in total logistics cost of Lo-Lo and Ro-Ro for high-priced and time-sensitive cargo (Busan–Hakata).

Considering the total logistics cost of transporting a TEU of high-priced and time-sensitive cargo on the Busan–Hakata route, it is better to choose Ro-Ro when the cargo value is more than USD 91,968, whereas Lo-Lo is more preferable when the value is less than that. Taking the auto parts as an example, assuming the cargo value of USD 100,000 per TEU, the results of calculating the total logistics costs for Lo-Lo and Ro-Ro transportation are presented in Figure 8. According to the results, Ro-Ro is more economical since the total logistics cost of Ro-Ro is USD 2474 whereas Lo-Lo transport costs USD 2448 per TEU.

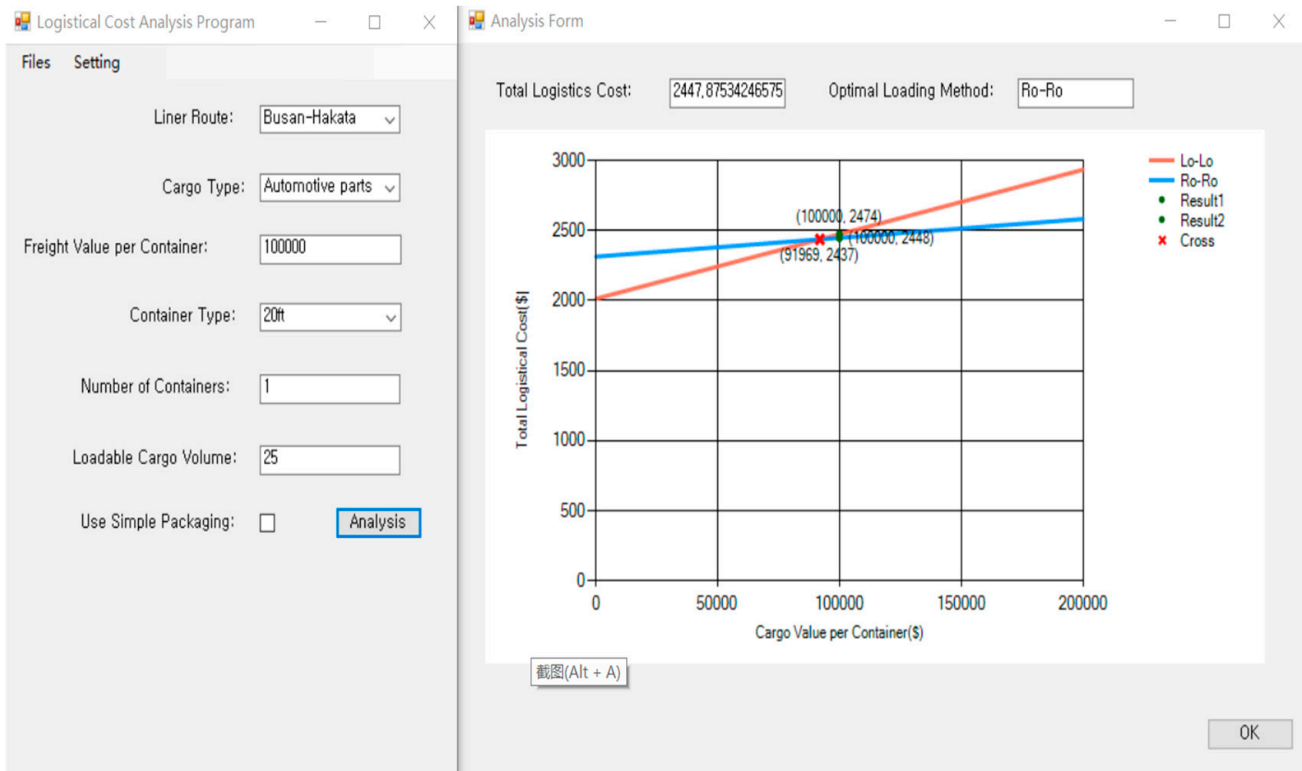


Figure 8. Results of transportation selection model for Busan–Hakata route (high-priced and time-sensitive cargo).

In the same way, the total logistics costs for the types of cargo on the two other routes (Busan–Shimonoseki and Busan–Osaka) are calculated and the results are summarized in Table 10. On the Busan–Hakata and Busan–Osaka routes, the total logistics cost of Ro-Ro is lower than that of Lo-Lo when the value per TEU of general cargo is approximately USD 180,000–185,000 or more whereas the break-even cargo value for high-priced and time-sensitive cargo is between USD 92,000 and 95,000 or more. On the Busan–Shimonoseki route, the total logistics cost of Ro-Ro is lower than Lo-Lo when the value per TEU of general cargo is USD 76,943 or more, and the USD 39,327 in case of the high-priced and time-sensitive cargo. Therefore, when both Lo-Lo and Ro-Ro employ general packaging, it can be seen that Ro-Ro is cost-competitive only when the cargo value is expensive.

Table 10. Break-even cargo value in transport mode selection on each route (Unit: USD).

Route	Busan–Hakata	Busan–Shimonoseki	Busan–Osaka
High-value and Time Sensitive Cargo	91,969	39,327	94,630
High-value or Time Sensitive Cargo	98,538	42,136	101,389
General Cargo	179,938	76,943	185,145

4.3. Case Analysis on Logistics Cost Reduction by Using Simple Packading in Ro-Ro

Company ‘N’, a leading Japanese automaker, is procuring auto parts from a number of Korean contractors. Previously, auto parts supplied by Korean contractors were collected at Busan port and loaded into a regular FEU container, then transported to Japan by Lo-Lo transport. To reduce the procurement time and logistics cost while increasing supply chain efficiency, ‘N’ has deployed trailer chassis that can freely travel to Japan and Korea under the government level agreement in 2012, which allows the automaker to change transportation mode from Lo-Lo to Ro-Ro. The transformation in auto parts supply chain

leads to significant performance improvement. First, the volume of cargo transported via Ro-Ro has increased from 122,386 CBM in 2013 to 328,781 CBM in 2017. Second, the delivery time of parts has reduced from 12 days to 3 days (However, it should be noted that the substantial reduction in delivery time is attributed to the time saving not only from the transition from Lo-Lo to Ro-Ro (see Table 5), but also from increased efficiency in supply chain integration). Third, as order frequency has changed from the monthly basis to daily basis, the order cycle has contracted from 60 days to 6 days. Finally, the inventory turnover period has reduced from 25 days to 3 days. Moreover, Ro-Ro transport allows 'N' to realize packaging cost reduction and seamless supply chain as the employment of simple packaging is possible in the new transport mode in which a tray that can be directly put into the assembly line and used repeatedly.

This study compares the total logistics cost of 'N's procuring auto parts on the Busan–Shimonoseki route. Although some studies point out that auto parts fall into the category of general cargo, this study defines the items as the high-priced and time-sensitive cargo. This is mainly because N Company implements a zero-inventory policy for auto parts; therefore, the requirement for meeting the lead time is of utmost importance. According to information on the number of containers transported (in FEU), the cargo volume and the cargo value, the average volume and value per FEU are calculated as 44.81 CBM and USD 32,420, respectively.

The results of calculating the total logistics cost of 'N' by inputting the data obtained above into the program are shown in Figure 9. According to the results, when simple packaging is used for the Ro-Ro option and general packaging for the Lo-Lo one, the total logistics costs of Ro-Ro and Lo-Lo per FEU container are USD 3546 and USD 3981, respectively. Given the total volume of 7388 FEU in 2017 that the automaker imported from Korea, the total logistics cost saved can reach to approximately USD 3,213,780 (USD 435 per FEU). In our analysis, the different packaging arrangements of the two modes result in a cost differential of USD 576 per FEU, sufficient to render Ro-Ro option more attractive financially.

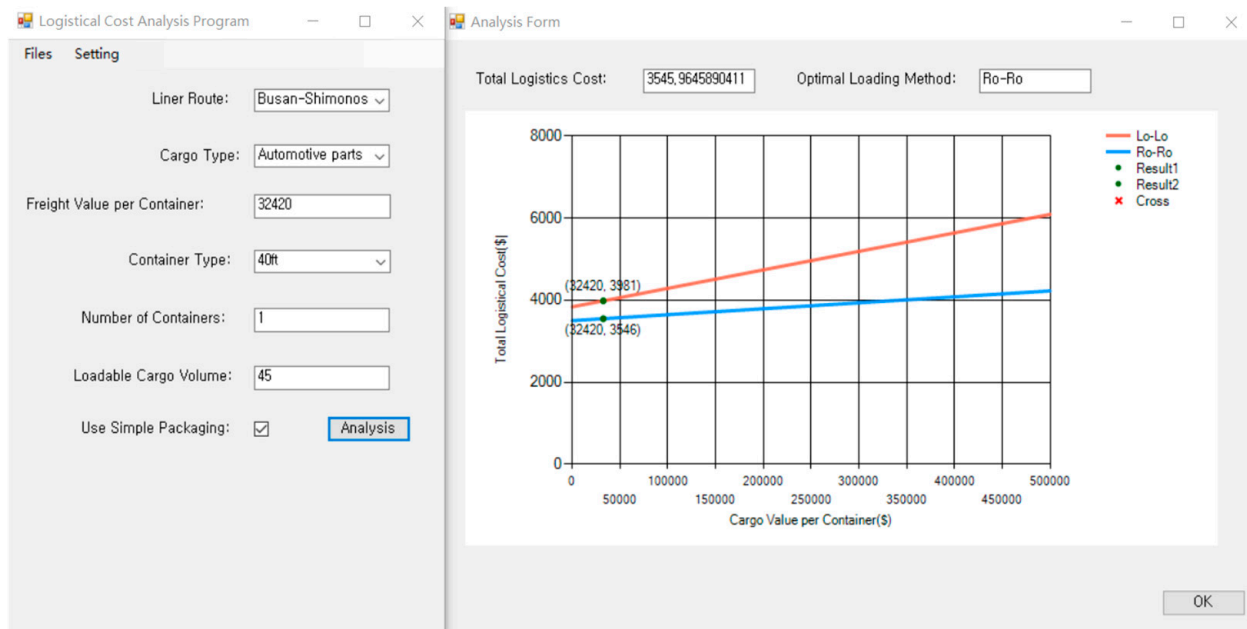


Figure 9. Comparison of total logistics costs via Lo-Lo and Ro-Ro per FEU.

5. Conclusions

5.1. Summary of Results

This study proposes a comparison model of total logistics costs of two major transport modes in SSS between Korea and Japan. Overall, saving in the total logistics cost by using Ro-Ro is insignificant or Lo-Lo is more competitive in some cases unless supply chain cooperation between trade parties is tightly integrated. Rather, Ro-Ro transport is cost-competitive only when the cargo is high-priced and time-sensitive. Specifically, for general cargo, the total logistics cost of Ro-Ro is lower than that of Lo-Lo when the cargo value per TEU is greater than USD 179,938, USD 76,943 and USD 185,145 for Busan–Hakata, Busan–Shimonoseki and Busan–Osaka routes, respectively. On the other hand, for high-value and time sensitive cargo, the tipping points for choosing Ro-Ro are USD 91,969, USD 39,327 and USD 94,630, respectively.

However, as shown in the case study, when companies integrate the supply chain and improve the cooperative relationship to a high level, Ro-Ro transport has a significant impact on reduction in the total logistics cost and on acceleration of the entire supply chain cycle. This is similar to the results of Russo et al. [6]. Moreover, the results also show that Ro-Ro has a distinct time-saving effect compared with Lo-Lo in port handling time, which is highlighted by Suárez-Alemán et al. [12].

5.2. Policy Implications

As the globalization of production has been unfolding since 1980s, the construction of reliable supply chain management is increasingly important. As such, a plethora of multinational companies are trying process innovation for their supply chain for the purpose of cost saving and optimization in logistics operation. This is of utmost importance for economic cooperation among neighboring countries. Since the rise of China in 1980s, the Northeast Asian economic bloc has taken a substantial share of the global economy. Therefore, further economic cooperation among countries in this region can contribute to the improved wealth in the rest of the world. In this regard, efficient logistics network via Ro-Ro transport in SSS can play a critical role in accelerating the integration of supply chain among manufacturing companies in the Northeast Asia. As the findings in the current research suggest, Ro-Ro shipping can be a cost-effective mode when companies in South Korea and Japan improve cooperative relationship to a high level. Thus, governments should jointly take efforts to eliminate potential hindrances to seamless logistics and supply chain integration among companies in the Northeast Asia.

5.3. Limitations and Suggestions for Future Research

Despite the valuable contribution of the findings in this study, there are some limitations. First, due to the difficulty of data collection, only SSS between Korean and Japan is analyzed in this study. Given the economic impact and mutual dependence in the Northeast Asia region, the inclusion of SSS in China can provide a better understanding of transportation mode selection. In addition, due to the concerns about leakage of commercial confidentiality, the public tariff of transportation costs is applied in the current study. Therefore, future research can reflect the actual market conditions in SSS by using contract freight rates.

Second, since the distance between Korea and Japan is relatively short, the reduction in transportation time by transforming from Lo-Lo to Ro-Ro is insignificant in the current study, which leads to the result that the time value of cargo accounts for a small share of the total logistics cost. Although the time shortened by choosing Ro-Ro includes not only the transit time but the overall lead-time, this is not considered in the cost estimation model of this study as there is no unanimously agreed standard. Therefore, future research can shed more light on the cost effectiveness in SSS by considering the door-to-door transport (for example, see [45]).

Third, whereas previous studies have explored the multifaceted aspects of transportation mode selection by considering transshipment, long-distance maritime transportation

and transport via road or air, this study relies on the difference in the total logistics cost between Lo-Lo and Ro-Ro in terms of the transportation time, the shipping freight rate and the packaging cost. However, by applying the same criteria, the general approach and calculation basis for the choice of Lo-Lo and Ro-Ro from the perspective of a shipper on a particular route is presented, and the actual impact of Ro-Ro can be added to the model more flexibly. Therefore, more significant results can be expected.

Finally, inclusion of other possible factors affecting the decision between Ro-Ro and Lo-Lo, such as perceived value of service frequency/attributes [46], environmental dimension and auxiliary costs (storage fee, consolidation cost, port due, to name a few) deserves further research attention.

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