運輸計劃季刊
第四十九卷 第四期
民國一〇九年十二月
頁 315～頁 334

Transportation Planning Journal
Vo1. 49 No. 4
December 2020
PP. 315～334

兩岸物流輸配送路徑選擇規劃模式

INCORPORATING CUSTOM INSPECTION TIME INTO A ROUTE SELECTION MODEL FOR TIME-SENSITIVE FREIGHT ACROSS THE TAIWAN STRAIT

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(108 年 10 月 1 日收稿，109 年 12 月 23 日第一次修正，109 年 12 月 22 日第二次修正，109 年 12 月 20 日定稿)

摘　要

兩岸歷經小三通、大三通陸續開放，2012 年起更進一步簽訂海峽兩岸經濟合作架構協議（ECFA），經貿交流更為密切，惟小三通航運市場時常受外在因素高度影響，經營管理不易。本研究透過資料蒐集與專家訪談，考量不同運具與路徑的運輸時間、成本，以及不同海關的平均清關時間，建立兩岸物流路徑選擇之決策支援模式，依據不同情境與實例分析驗證模式可行性與應用性。研究結果發現起始地和目的地之運輸距離與時間、以及通關效率是主要影響兩岸輸配送路徑選擇因素，尤其兩岸通關環境與效率又深受當權者改變與法規增修影響。以廣州沿岸附近港口為例，雖然擁有離台灣較近的運輸距離，但冗長的通關時間往往影響貨運承攬業者選擇為轉運場站之意願。此外，過往小三通雖然通關效率較高，但近年來因政治或肺炎疫情因素時而封關。本研究亦探討其他可能替選路徑，作為業者未來執行業務之參考依據。

關鍵詞： 兩岸物流；小三通；路徑選擇

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ABSTRACT

Starting from 'Mini-Three-Links' in 2001,'Three-Direct-Links' in 2008, and the Economic Cooperation Framework Agreement (ECFA) signed in 2012, Taiwan has experienced a deeper economic engagement with China. Although the 'Mini-Three-Links' has been often unilaterally restricted, the total trading amounts across the Taiwan Strait in 2018 still rank first among all countries and regions trading with Taiwan. In order to assist freight forwarders quantifying and optimizing the route selection decision, the study starts from a typical transportation network modeling approach and then considers the objectives of jointly minimizing the total system costs and time based on different custom inspection time settings. A nonlinear time-dependent function with a penalty function is formulated to reflect the characteristics of time-sensitive freight and to avoid significantly exceeding the maximum allowable delivery time, while also considering the custom clearance and quality inspection processes within the studied network. Findings show that custom clearance and quality inspection time of cargos do affect the system performance, especially for terminals near the Quanzhou area. In addition, political issues and/or COVID-19 impacts on the 'Mini-Three-Links' closures are analyzed, to provide alternative path plans for targeted freight forwarders in Taiwan.

Key Words: *Logistics across the Taiwan Strait; Mini-Three- Links; Routes Selection*

I. Introduction

After decades of hostile intentions and angry rhetoric, relations between China and Taiwan started improving in the 1980s. The ban on bulk cargos in Taiwan shipped to China was lifted in 1987, and shipments are required to transfer at the third party ports. In 1995, the registered FOC (flag of convenience) vessels are allowed to transfer among the designated ports across the Taiwan Strait, but still no direct import and export operations. Over the past two decades, business logistics has grown in significance across the Taiwan Strait. The 'Mini-Three-Links' (i.e. the trade, mail, air and shipping services over the Taiwan Strait through certain authorized passenger and freight terminals) was launched in 2001, after government restrictions were lifted. Then the more complete and direct transportation channel, 'Three-Direct-Links,' including 16 airports, 48 sea ports, and 15 inland water ports in China with 8 airports and 11 sea ports in Taiwan, was opened in 2008. Furthermore, the Economic Cooperation Framework Agreement (ECFA) signed in 2012 has provided the most potentially significant free trade agreements across the Taiwan Strait. As shown in Table 1, the total trading, export, and import amounts between China and Taiwan in 2018 rank first among all countries and regions trading with Taiwan.

Table 1 Import and export trading amount in Taiwan, R.O.C. on 2018 (Source: Bureau of Foreign Trade, Taiwan, R.O.C., 2018.)

Import and Export Trading Countries (Regions) with Taiwan, R.O.C									
	Total amount of trade			Export			Import		
	Rank	Amount (million USD)	Rate (%)	Rank	Amount (million USD)	Rate (%)	Rank	Amount (million USD)	Rate (%)
CHINA	1	150,292	24.29	1	96,499	28.89	1	53,792	18.89
U.S.A	2	72,598	11.73	3	39,491	11.82	3	33,107	11.62
JAPAN	3	66,956	10.82	4	22,802	6.83	2	44,154	15.50
HONG KONG	4	42,812	6.92	2	41,402	12.40	28	1,409	0.495
KOREA	5	35,265	5.70	6	15,739	4.71	4	19,525	6.86
SINGAPORE	6	25,741	4.16	5	17,325	5.19	9	8,417	2.96
MALAYSIA	7	19,907	3.22	8	10,602	3.17	7	9,304	3.27
GERMANY	8	17,030	2.752	10	7,058	2.11	5	9,971	3.50
VIET NAM	9	14,470	2.34	7	10,771	3.23	17	3,698	1.30
AUSTRALIA	10	12,948	2.092	15	3,395	1.02	6	9,552	3.35

Although Taiwan has experienced a deeper economic engagement with China, uncertain custom clearance and quality inspection processes in ‘Three-Direct-Links’ may lower the forwarders’ willingness to route through this network. In accordance with our industrial partners’ data (including one of the world’s three largest international express companies, one international freight forwarder - King Freight International Corp., and one domestic freight forwarder in Taiwan - Apollo Logistics Ltd.), the average import and export cargo inspection rates of China are 25% and 15%, exceeding those in Taiwan (15% and 8%, respectively). When inconsistent documents (e.g. certificates of origin, animal or plant quarantine, and commodity inspection) are found during the inspection, shipments may need to be held from a few days to several months. The term “inconsistent” may involve different recognitions of tax rules, cargo categories, inspection standards, or other conditions. It should be noted that different requirements of customs clearance and inspection operations at terminals may significantly affect the cargo processing time and dwell costs. This issue is an important concern, especially for timeliness of delivery (e.g. for perishable goods, high technology products, holiday gifts, and contingent procurement in supply chains), because each unexpected cargo dwell case would increase uncertainties about the shipment arrival date and system reliability.

On the other hand, the average custom clearance and inspection operations at the

'Mini-Three-Links' are lesser and simpler than at other 'Three-Direct-Links' hubs. Most operations require transfer movements at designated terminals (e.g. Kinmen, and Matsu in Taiwan). Within the years 2001-2013, freights shipped through 'Mini-Three-Links' at Kinmen are gradually increased (see Figure 1.) Although the amount of shipments dramatically dropped on 2015, the entire performance becomes stable in recent years. However, the annually shipping amounts (in terms of tons) through 'Mini-Three-Links' at Matsu do not perform very well in the past decade, as shown in Figure 2.

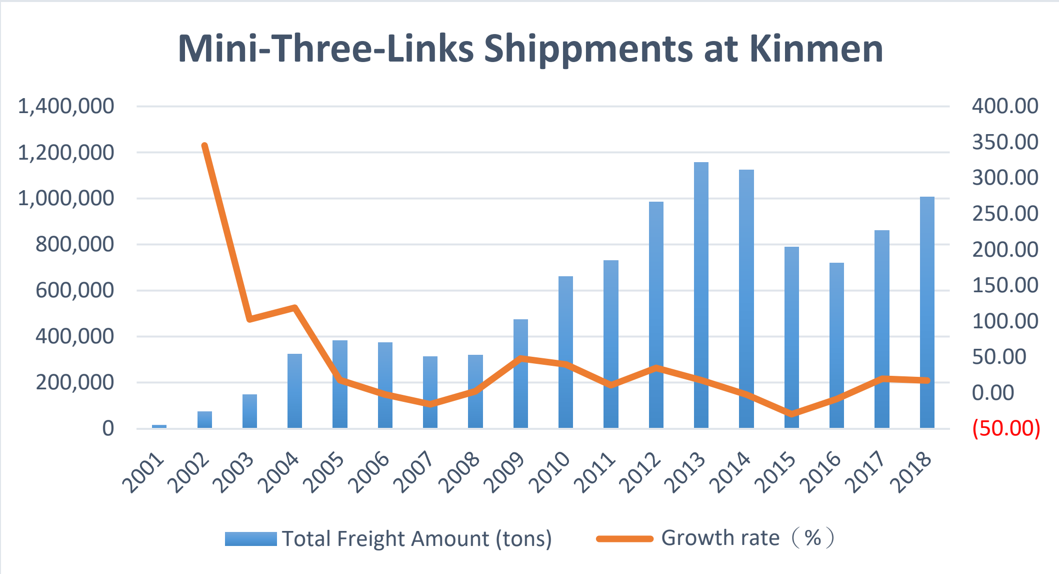

Figure 1　Statistics of shipment amounts and annual growth rate through Mini-Tree-Links at Kinmen (Source: Transportation Year Book, Taiwan, R.O.C., 2018.)

Although routing in 'Mini-Three-Links' could reduce the probability of having cargos inspected, there are still some drawbacks causing diminishing usage of this channel. Limited capacities and constrained mode choice (i.e. small size short-sea ships only) incur some logistics challenges in 'Mini-Three-Links.' In addition, 'Mini-Three-Links' has been unilaterally terminated by China's government on December 2014, to reform possible corruption and illegal imports at 'Mini-Three-Links' hubs. Thus, a major motivation for our study is to identify alternative routes for freight forwarders during the suspended periods.

Intuitively, commodities with lower and higher cargo values should be shipped via lower-cost and faster paths, respectively. However, practitioners are used to choose compromise solutions between the optimized transit time and the optimized transportation costs. Taking our practical partners' data for an example, from Shanghai, China to Budapest, Hungary, the transit

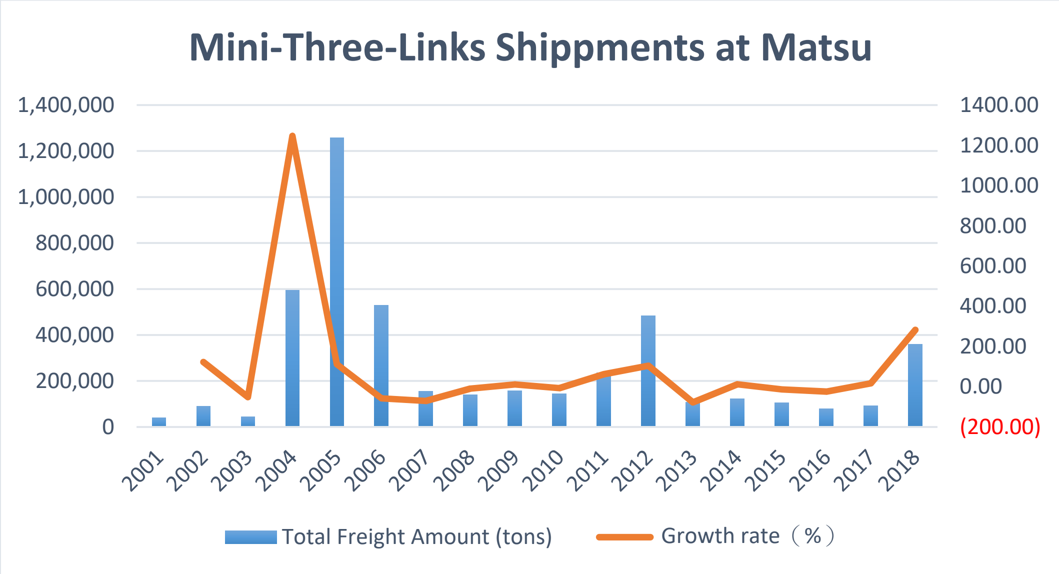

Figure 2 Statistics of shipment amounts and annual growth rate through Mini-Tree-Links at Matsu (Source: Transportation Year Book, Taiwan, R.O.C., 2018.)

days and costs of 1 FEU (i.e. 15.3 tons for air freight) are, respectively 6 days and 10 USD by truck-air-truck (mainly Air), or 39 days and 1 USD by truck-sea-truck (mainly Sea). If carriers ship these cargos by truck-rail-truck-air-truck (Rail-Air), the transit days and costs are 11 days and 9.4 USD, respectively. Moreover, if freight is shipped through truck-sea-truck-air-truck (Sea-Air), the transit days and costs are 16 days and 7 USD, respectively. Thus, freight forwarders must consider total transportation time, delivery deadlines and shipping costs in selecting the appropriate combinations of delivery routes, terminals, and modes.

In this study, freight forwarders across the Taiwan Strait are our main decision makers, who need to arrange delivery routes, terminals, and modes within the studied networks. Four different mode combinations are considered, namely truck-air-truck, truck-sea-truck, truck-sea express-truck, and truck-sea-truck through the ‘Mini-Three-Links.’ A multi-objective programming model of route selections is developed for jointly minimizing the total system costs and transportation time based on route selection results, while at the same time determining the choice of transfer terminals connecting different modes. A multi-hub, multi-mode, and multi-commodity network routing model with nonlinear time-dependent cargo value functions is developed for jointly minimizing the total system costs and total transportation time based on route selection results, while at the same time optimizing the choice of transfer terminals connecting to different modes, for time-sensitive freights and appointed delivery deadlines across the Taiwan Strait. In the next section, the literature is reviewed, while the model formulations and solution techniques are explained in Section 3. Numerical examples are presented in Section 4, and conclusions are summarized in Section 5.

II. Literature Review

Direct routing over the Taiwan Strait has been widely investigated, but very few studies consider quantitative approaches based on freight forwarders' viewpoints, while also analyzing the impacts of the unilaterally termination of 'Mini-Three-Links.' Most previous studies either focus on reducing operational costs (e.g. Lin and Chen [1], 2003; Perez-Mesa et al. [2], 2012), review qualitatively policy impacts (e.g. Chang et al. [3], 2006; Guo et al. [4], 2007), estimate the future annually trade volume (e.g. Yang [5], 2010), or focus on the cross-Strait routing strategies in aviation rather than in general freight systems (e.g. Chang et al. [6], 2011; Lau et al. [7], 2012.) Li [8] (2006), Yang and Shi [9] (2015) addressed that easier custom inspection processes the 'Mini-Three-Links' may result in the numerous illegal smuggle shipments. However, Lee [10] (2014) mentioned that the tax-saving incentives and efficient custom processes still maintain the competitiveness of the 'Mini-Three-Links,' rather than the maritime express and the 'Three-Direct-Links' operations.

Intermodal transportation planning has been studied significantly in the last decade, especially for the hub and spoke networks operations (SteadieSeifi et al. [11], 2014.) Although a wide variety of research studies have been conducted in the design of hub-based freight networks, intermodal freight transfer has its own characteristics and restrictions that should be considered in operations. Many previous studies investigate transfer efficiency in terminal operations (e.g. Sánchez et al. [12], 2003; Tongzon [13], 2009; Sharma and Yu [14], 2010), but seldom combine that with route selection. Chang [15] (2008) formulates a multiple-objective programming model to select best routes for shipments through the international intermodal network. Yang et al. [16] (2011) present an intermodal network optimization model to examine the competitiveness of 36 alternative routings for freight moving from China to and beyond the Indian Ocean. Perez-Mesa et al. [2] (2012) investigate the perishable agriculture products delivery cases in Spain and find that commodities shipped by truck-short sea-truck constitute a 14 percentage of the total travel cost reduction of those shipped by trucks only. It should be noted that most of above studies mainly consider the optimization of route selection, without considering customs clearance time inside the terminal. Ghane-Ezabadi and Vergara [17] (2016) developed an integrated mathematical model to combine the route and mode selection problems with the hub location choice issue in intermodal transportation. The authors modeled the amount of flow between two nodes, while considering the delays at hubs.

Route choice combined with transfer terminal selection across the Taiwan Strait poses significant logistic challenges because the cargo inspection time may vary at different terminals and delay transfers. Boschian et al. [18] (2010) find that customs clearance operations are the main bottlenecks of cross-border logistics systems. They propose a simulation-based information and communication technology approach to enhance the efficiency of the studied intermodal logistic system in relation to the customs operations. Liu and Yue [19] (2013) indicate the long and complex customs clearance process, the lack of consistency and transparency of procedures for freight inspection and valuation, the non-automated customs procedures and administration, the limitations of working hours at the customs, and the shortage of gates for receiving cargos cause severe delays at customs. Davis and Friske [20] (2013) address the trade-off costs between increasing security check levels and custom delay impacts. Cedillo-Campos et al. [21] (2014) suggest a two-stage freight examination process which could effectively reduce custom clearance time and still maintain the basic security level.

Several previous studies tend to formulate the intermodal routing problem as a multiple-objective problem due to conflicting purposes; however, different decision makers may focus on different objectives. In this study, users (e.g. shippers) and operators (e.g. freight forwarders) may have conflicting interests regarding service quality. Shippers may prefer to send cargos at the lowest prices while minimizing total shipping time; conversely, freight forwarders may choose a route with multiple transfers to create economies and reduce costs. Although shippers only know the origins, destinations, and items, we assume that decisions made by forwarders would also consider their customers' interest.

III. Model Formulation and Solution Techniques

The multi-objective mixed integer nonlinear programming model stems from Chang's [15] (2008) and improved from our previous studies (Chen and Lai [22], 2015), to assist the international freight forwarders developing a quantitative-based routing decision across the Taiwan Strait. First, instead of estimating the transfer schedule as a fixed time window based on the scheduled transportation modes and the amount of cargos in each shipment (e.g. Banomyong and Beresford[23], 2001; Ayar and Yaman [24], 2012), our study incorporates different freight inspection time settings at hubs within the studied networks into the optimization model. Second, to avoid the double counting on total transportation time in our previous study, a revised penalty function is proposed. Moreover, the improvements include different ranges of cargo weights, characteristics of timeliness freights, and evaluating the impacts of the termination at 'Mini-Three-Links.' All parameters and decision variables used in the formulation are listed below:

Sets

A = a set of arcs, where A = {$(i, j)| \, i, j \in$ N};

K = a set of transportation modes;

M = a set of cargo categories;

N = a set of nodes;

R = a set of the range of cargo weights;

S = a set of destinations;

O = a set of origins.

Parameters

A_i^k = the arrival time of cargos shipped by mode k at terminal i;

D_i^k = the scheduled departure time of cargos shipped by mode k at terminal i;

Q^m = the total amount of type m cargos at origins;

f_{ij}^{kmr} = the fixed costs to ship type m cargos with weight range r shipped by mode k at terminal i;

c_{ij}^{kmr} = the distance-based variable cost;

d_{ij} = the distance between nodes i and j;

t_{ij}^k = the total transportation time shipped by mode k through the link (i, j),

u_{ij} = the link capacity through (i, j);

λ_p = the unit penalty value;

TP_i^{kmr} = the estimated cargo processing time of type m cargos with weight range r at terminal i;

TE_i^{kmr} = the estimated cargo inspection time of type m cargos with weight range r at terminal i;

$T_{\max}^m$ = the maximum allowable shipping time of type m cargos.

Decision Variables

x_{ij}^{kmr} = flow of type m cargos with weight range r shipped by mode k on link (i, j);

y_{ij}^{kmr} = a binary decision variable representing 1 if the type m cargos with weight range r shipped by mode k through the link (i, j) or 0 otherwise.

The model is expressed as follows:

$$Minimize \;\; Z_C$$

$$= \sum_i \sum_j \sum_k \sum_m \sum_r \left(c_{ij}^{kmr} d_{ij} x_{ij}^{kmr} + f_{ij}^{kmr} y_{ij}^{kmr} \right) \tag{1}$$

$$+\lambda_p \left\{ \max\left(0, \; \sum_i \sum_j \sum_k \sum_m \sum_r \left\{ \begin{array}{l} \max\left[D_j^k, A_j^k + TP_j^{kmr} + TE_j^{kmr} \right] \\ -\max\left[D_i^k, A_i^k + TP_i^{kmr} + TE_i^{kmr} \right] \end{array} \right\} - T_{\max}^m \right) \right\}$$

$$Minimize\ \ Z_T$$

$$= \min \left\{ \sum_m T_{\max}^m \times Q^m ,\ \sum_i \sum_j \sum_k \sum_m \sum_r \begin{Bmatrix} \max\left[D_j^k ,\ A_j^k + TP_j^{kmr} + TE_j^{kmr} \right] \\ -\max\left[D_i^k ,\ A_i^k + TP_i^{kmr} + TE_i^{kmr} \right] \end{Bmatrix} x_{ij}^{kmr} \right\} \tag{2}$$

Subject to

$$\sum_j x_{ji}^{kmr} - \sum_{i,i\neq j} x_{ij}^{kmr} = \begin{cases} \sum_m Q^m & if\ \ i = O \\ -\sum_m Q^m & if\ \ i = S \\ 0 & otherwise \end{cases} \qquad \forall i, j \in N, \forall m \in M, \forall k \in K, \forall r \in R \tag{3}$$

$$\sum_m x_{ij}^{kmr} \le u_{ij} \quad \forall (i,\ j) \in A \tag{4}$$

$$x_{ij}^{kmr} \left[t_{ij}^k + \max\left(D_i^k\ ,\ A_i^k + TP_i^{km} + TE_i^{km} \right) - A_j^k \right] = 0 \tag{5}$$

$$y_{ij}^{kmr} \in \{ 0,1 \} \tag{6}$$

$$x_{ij}^{kmr} \in \text{ non-negative integer} \tag{7}$$

The first minimized objective function (Equation 1) is formulated as the sum of transportation cost of shipments with respect to both distance and weight. In addition, a penalty function is introduced if the total shipping time exceeds the maximum allowable delivery time. The second minimized objective function is formulated as the sum of total transportation time from origin to destination flows. Equation 3 expresses the flow conservation constraint. Equation 4 indicates the link capacity constraint. Equation 5 ensures the compatibility requirements between flow and time variables. Equation 6 defines the decision variable y as the binary variable. Equation 7 states the non-negative constraints for the decision variable x.

An efficient optimization algorithm must satisfy two requirements for finding the optimum: exploring the search space and exploiting the knowledge gained at the previously visited points. In accordance with our nonlinear multiple objective programming model, genetic algorithms (GAs) are well suited for solving such nonlinear programming problems with complex and nonlinear formulations (e.g. Yokota et al. [25], 1996; Gantovnik et al. [26], 2005). This algorithm could be applied to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems with discontinuous, non-differentiable, stochastic, or nonlinear objective functions and constraints. Sample codes for each objective are introduced as follows.

The first minimized objective function

```
for i ∈ N
y(i) = 0;
cost(i) = 0;
k = D(i, 2);
%    Define weight range
        if    x(i)>0 && x(i) < 100
              y(i) = 1;
              cost(i) = C(k, 1) * D(i, 1) * x(i) + F(k) * y(i);
        elseif    x(i) >= 100
              y(i) = 1;
              cost(i) = C(k, 2) * D(i, 1) * x(i) + F(k) * y(i);
        end
end
```

The second minimized objective function

```
for i ∈ N
time(i) = 0;
        if x(i) > 0
              leave_j = leave(i) + A(i, 3) + T(e, 1) + T(e, 2);
              settime = D(e, k);
              r = max(leave_j, settime);
              time(i) = ( r - leave(i) ) * x(i);
              leave(i) = r;
          end
  end
```

Through this work we seek to optimize the route selection decisions based on the considerations of two different objectives. There are three different route selection decisions optimized in this study, namely: 1. the economic route, which achieves the lowest transportation costs by minimizing the first objective function; 2. the fastest route, which achieves the lowest transportation time by minimizing the second objective function; 3. the compromise path, which is based on the following weighted approach to optimize the solutions between two different objectives.

To generate a systematic definition of non-inferior solutions, the weighting method is used to transform the multi-objective problem into a single-objective problem. Fatemeh and Tarokh [27] (2010) developed a k objectives compromising programming approach to minimize the distance between some reference point and the feasible objective region. This approach is also adopted in our study. When k objective functions of $\{z_1(x), z_2(x), \ldots\ldots, z_k(x)\}$ are considered to be optimized simultaneously, the problem is re-formulated as in Equation 8, based on the upper and lower bounds of each objective function.

$$Minimize \quad \left(\sum_{i=1}^{k} w_i^p \left| \frac{z_i(x) - z_{i,\min}}{z_{i,\max} - z_{i,\min}} \right|^p \right)^{\frac{1}{p}} \tag{8}$$

IV. Model Applications and Computational Results

The study starts from a typical transportation network modeling approach and then considers the objectives of jointly minimizing the total system costs and time based on route selection results. All programs are coded with Matlab GA toolbox and executed on a PC with Intel Core (TM) i5-6400 Duo-CPU 2.70 GHz processor and 16 GB of RAM.

Case 1: A Small Network Configuration

The studied network contains 7 nodes and 15 arcs, as shown in Figure 3. Three different modes (truck, sea, and air), two kinds of commodities (general and time-sensitive cargos), and two ranges of freight weights (greater or lower than 100 tons) are considered. Nodes 4 and 5 represent the transfer hubs within the ‘Three-Direct-Links,’ and node 6 represents the hub in ‘Mini-Three-Links.’ The parameter settings of link capacity, travel distance, and the estimated transportation time with different modes through links are listed in Table 2. Cargo processing time, custom clearance and examination time, and the estimated departure time are listed in Table 3.

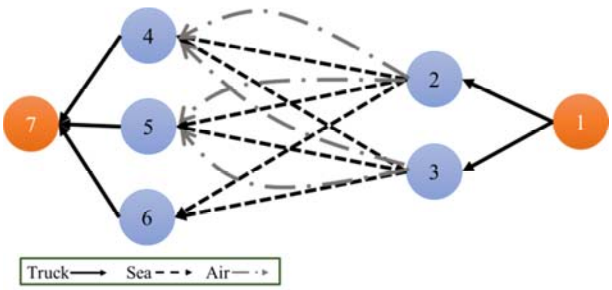

Figure 3　Network Configurations for the Tested Network.

Table 2　Inputs of Link Capacity, Distance, and Estimated Travel Time.

Mode	(i, j)	u_{ij} (tons)	d_{ij} (km)	t_{ij}^{k} (hours)
Truck	(1, 2)	500	80	1
	(1, 3)	500	280	3
	(4, 7)	500	100	1
	(5, 7)	500	230	3
	(6, 7)	500	796	10
Sea	(2, 4)	900	680	94
	(2, 5)	900	520	38
	(2, 6)	150	450	21
	(3, 4)	900	910	67
	(3, 5)	900	770	57
	(3, 6)	150	330	12
Air	(2, 4)	80	680	2
	(2, 5)	80	520	2
	(3, 4)	80	910	2
	(3, 5)	80	700	3

Table 3　Inputs of Cargo Processing, Custom Clearance and Examination, and Estimated Departure Time.

Mode	Node	Cargo Categories	TP_i^{kmr} (hours)	TE_i^{kmr} (hours)	D_i^k (hours)
Truck	2	General	2	6	9
		Time-sensitive	1	3	5
	3	General	2	6	12
		Time-sensitive	1	3	6
Sea	4	General	12	18	120
		Time-sensitive	10	12	96
	5	General	20	30	120
		Time-sensitive	12	12	96
	6	General	3	8	40
		Time-sensitive	2	6	30
Air	4	General	12	18	72
		Time-sensitive	12	12	60
	5	General	20	30	72
		Time-sensitive	12	12	60

We first analyze the economic path (the first objective), the fastest path (the second objective), and the compromise solutions for multiple objectives based on the equal weight settings, in accordance with our industrial partners' suggestions. It should be noted that various compromise routing solutions would be reached for different weight combinations. Although these values may be not fully consistent with the industry standards (i.e. different forwarders may have different settings), the model can use whatever inputs its users consider most applicable.

The optimized results in Case 1 are listed in Table 4. For example, cargos in Scenario 1 via the economic path are transported from node 1 to node 2 by trucks, from node 2 to node 4 by sea, and from node 4 to node 7 by trucks. Most cargos shipped on such a slow path are commodities with the lower time-sensitive setting. Conversely, most of the urgent commodities are delivered by air or sea through the 'Mini-Three-Links', due to the quickest transportation time and the shortest cargo inspection and customs clearance time, respectively. Cargos in Scenario 1 via the fastest path are transported from node 1 to node 2 by trucks, transferred by node 6 through the 'Mini-Three-Links', and from node 6 to node 7 by trucks. However, if the 'Mini-Three-Links' channel were terminated (in Scenario 2), cargos shipped via the fastest path are transported from node 1 to node 2 by trucks, from node 2 to node 4 by air, and from node 4 to node 7 by trucks.

Here we assume that both objectives have equal weights. A multiple-objective programming method suggested here can be applied for various stakeholders by using different weights. For example, cargos shipped in Scenario 2 via the compromise path are transported from node 1 to node 2 still by trucks, from node 2 to node 4 by sea, and from node 4 to node 7 by trucks. Node 5 is not considered due to its longer customs clearance and inspection time.

Table 4 Optimized Results in Case 1.

Scenarios	Economic Path	Fastest Path	Compromise Path
Scenario 1 (normal operations)	1→2−−4→7	1→2−−6→7	1→2−−6→7
Scenario 2 ('Mini-Three-Links' closure)	1→2−−4→7	1→2…4→7	1→2−−4→7

→ truck −− sea … air

Case 2: A Large-Scale Network Configuration

The studied network contains 31 nodes and 85 arcs. Four different mode combinations are considered, namely: truck-air-truck, truck-sea-truck, truck-sea express-truck, and truck-sea-truck through the 'Mini-Three-Links.' As shown in Table 5, nodes 1-4 represent the origin cities in Taiwan, nodes 5-12 denote the transfer hubs in Taiwan, nodes 13-26 indicate the transfer hubs in China, and nodes 27-31 represent the destinations of shipments. It should be noted that nodes 10-12 and nodes 8 and 23 are attributed to the 'Mini-Three-Links' and sea express hubs, respectively. All other settings are as in Case 1.

Table 5　A List of Node ID and Name.

		ID	Name	ID	Name
Origins in Taiwan		1	Yilan	2	Hsinchu
		3	Changhua	4	Tainan
Transfer Hubs in Taiwan		5	Keelung	6	Taipei
		7	Taoyuan	8	Taichung
		9	Kaohsiung	10	Penghu
		11	Matsu	12	Kinmen
Transfer Hubs in China	North China	13	Dalian	14	Tianjin
		15	Qingdao	16	Zhengzhou
	Central China	17	Shanghai	18	Ningbo
	South China	19	Xiamen	20	Shenzhen
		21	Hong Kong	22	Mawei
		23	Pingtan	24	Shijing
		25	Wutong	26	Quanzhou
Destinations in China		27	Tianjin City	28	Suzhou
		29	Kunshan	30	Fuzhou
		31	Dongguan		

Most input parameters and numerical examples were generated through extensive consultation with our industrial partners to closely replicate real world data. Due to confidentiality concerns, we are not able to present our partners' exact data. Some other parameters are provided by Kengpo et al. [28].

Overall optimized results based on the compromise paths are summarized in Table 6. Findings in this study show that most commodities should be transported by truck-sea-truck through 'Mini-Three-Links' networks due to their lowest transportation costs and lower customs clearance time. In addition, some time-sensitive commodities should be delivered by truck-sea express-truck due to the nearly fastest transportation time and relatively low shipping costs. Air becomes less competitive for delivering cargos across the Taiwan Strait due to its highest transportation costs and insignificant improvement of transportation time over sea express. It should be noted that sea express is a relatively new mode across the Taiwan Strait but still restricted to a few hubs and routes. We suggest that both the Taiwan and China governments should consider developing more routes for sea express, to achieve economies of scale within the service networks.

Table 6 Overall Optimized Results for the Large-Scale Network.

Destinations	Transfer Hubs & Modes
Tianjin City	• Economic Path: transferred through Kinmen and Shijing (Sea, through the Mini-Three-Links) • Fastest Path: transferred through Taoyuan and Tianjin (Air) • Compromise Path: (1) If shipped from Yilan, Hsinchu, or Changhua, transferred through Keelung and Tianjin (Sea) (2) If shipped from Tainan, transferred through Kaohsiung and Tianjin (Sea)
Kunshan / Suzhou	• Economic Path: (1) If shipped from Yilan, Hsinchu, or Changhua, transferred at Ningbo (Sea) (2) If shipped from Tainan, transferred through Kinmen and Wutong (Sea, through the Mini-Three-Links) • Fastest Path: Shanghai (Air) • Compromise Path: (1) If shipped from Yilan or Hsinchu, transferred at Keelung and Shanghai (Sea) (2) If shipped from Changhua, transferred through Taichung and Shanghai (Sea) (3) If shipped from Tainan, transferred through Kaohsiung and Shanghai (Sea)
Fuzhou	• Economic Path: transferred through Kinmen and Shijing (Sea, through the Mini-Three-Links) • Fastest Path: transferred through Taichung and Pingtan (Sea Express) • Compromise Path: transferred through Taichung and Pingtan (Sea Express)
Dongguan	• Economic Path: transferred through Kinmen and Wutong (Sea, through the Mini-Three-Links) • Fastest Path: Shenzhen (Air) • Compromise Path: (1) If shipped from Yilan, transferred through Matsu and Wutong (Sea, through the Mini-Three-Links) (2) If shipped from Hsinchu, Changhua, or Tainan, transferred through Kinmen and Wutong (Sea, through the Mini-Three-Links)

Taking the destination Dongguan for an example, the compromise paths are suggested as follows: (a) if shipped from Yilan, transferred through Keelung and Hong Kong by sea; (b) if shipped from Hsinchu or Changhua, transferred through Taichung and Pingtan by sea express; and (c) If shipped from Tainan, transferred through Kaohsiung and Hong Kong by sea. Although Hong Kong is not the nearest hub to Dongguan, Quanzhou is not considered due to its incredibly long customs clearance and inspection time. In practice, the average customs clearance time in Hong Kong and Quanzhou are 2 and 5-7 days, respectively.

In addition, political issues and/or COVID-19 impacts on the 'Mini-Three-Links' closures are analyzed, to provide alternative routing plans for targeted freight forwarders in Taiwan. When countering the 'Mini-Three-Links' closure, most general commodities would be transported by truck-sea-truck and transferred by the Hong Kong port due to their lowest transportation costs and lower customs clearance time. Moreover, most time-sensitive commodities would be delivered by truck-air-truck and transferred by the Hong Kong airport, due to the fastest transportation time. Detailed optimized results are listed in Table 7.

Table 7　Alternative Routing Plans Countering 'Mini-Three-Links' Closure

Scenarios	Economic Path	Fastest Path	Compromise Path
General cargos with normal operations	1→5--21→31	1→5--11--19→31	1→5--21→31
	2→8--21→31	2→8--12--19→31	2→8--21→31
	3→8--21→31	3→8--12--19→31	3→8--21→31
	4→9--21→31	4→9--12--19→31	4→9--21→31
Time-sensitive cargos with normal operations	1→5--21→31	1→5--11--19→31	1→5--11--19→31
	2→8--21→31	2→8--12--19→31	2→8--12--19→31
	3→8--21→31	3→8--12--19→31	3→8--12--19→31
	4→9--21→31	4→9--12--19→31	4→9--12--19→31
General cargos countering 'Mini-Three-Links' closure	1→5--21→31	1→7…21→31	1→5--21→31
	2→8--21→31	2→7…21→31	2→8--21→31
	3→8--21→31	3→7…21→31	3→8--21→31
	4→9--21→31	4→9…21→31	4→9--21→31
Time-sensitive cargos countering 'Mini-Three-Links' closure	1→5--21→31	1→7…21→31	1→7…21→31
	2→8--21→31	2→7…21→31	2→7…21→31
	3→8--21→31	3→7…21→31	3→7…21→31
	4→9--21→31	4→9…21→31	4→9…21→31

→　truck　--　sea　…　air

V. CONCLUSIONS

In practice, the decisions are usually made through discussions and influenced by the experience of senior customer service personnel. To improve such decisions, a quantitative method is developed for analyzing the regional routing selection decisions, while also considering the impacts of world disruptive events, such as the trade war, political issues, and the COVID-19 threats, with potential freight flow shift and moves. In addition, the usefulness of the numerical results can be enhanced by further developing a real-time dispatching decision support system and also examining the reliability of primary hubs and links within the service networks.

Although the Air mode seems less competitive across the Taiwan Strait, cargos whose shipping destinations are located far from the sea express hubs or having emergency purposes to avoid and respond to supply chain disruptions, should still be shipped by air. Conversely, though hubs at 'Mini-Three-Links' networks could save some cargo inspection and custom clearance time, forwarders should consider alternative routes in response to system closures. Furthermore, instead of operating sea express only between Taichung, Taiwan and Pingtan, China, enlarging the service area and including more transfer hubs connected by sea express would be the next consideration in facilitating future development of freight transportation systems over the Strait. It should be noted that maritime logistics across the Taiwan Strait have gradually become a low margin profit and high competition market, which may render air transportation even less competitive. Last but not least, inland waterway freight transportation system is also the majority of the domestic transportation network in China, which should be considered in our future research lines.

This study aims to provide a quantitative approach in the international intermodal logistics path planning, and several additional elements could be considered in future studies:

1. Extending the above models to major disruptions. Due to significant demand variations when major disruptions occur, some specific path plans and even emergency operations should be developed to respond to major system disruptions and recover from them. In addition, analyzing transitions and developing a transition plan between regular and emergency operations is also an important research issue.
2. The developed models could be enhanced by considering detailed transfers inside terminals, such as scheduling and operation problems of crane and other loading/unloading facilities, storage facilities design based on the limited capacity constraints, and cargo processing procedures subject to security concerns.
3. Analyzing multi-source delay propagation within the large scale and complex networks. The

interrelations among arrival, departure, and travel delays might affect the pre-planned paths.

4. The delivery paths and transportation modes may be more complex due to the characteristics of different type of goods (e.g. frozen goods, or fresh food.) The proposed model could be extended in cold-chain logistics while considering more parameters (e.g. temperatures, and humidity.)

Acknowledgement

The authors sincerely thank the King Freight International Corp., and Apollo Logistics Ltd. for their great support.

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