Modeling and Optimizing Intermodal Logistics Route across the Taiwan Straits

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Abstract: This paper specifies a decision support model devoted for freight forwarders to optimize intermodal logistics route selection across the Taiwan Straits. A multi-objective model is developed for jointly minimizing the total system costs and total transportation time of route selection results based on the estimated hub transfer impedances within the studied ‘Mini-Three-Links’ and the ‘Three-Direct-Links’ networks, while at the same time optimizing the choice of transfer terminals connecting different modes. Findings in this study show that most commodities should be transported by sea through the ‘Mini-Three-Links’ networks due to the lowest transportation costs and reduced freight inspection time. In addition, some higher value commodities should be delivered by sea express due to its low transportation time and costs.

Keywords: Intermodal Logistics Networks; Transfer Impedance; Route Selection; Across the Taiwan Straits

1. INTRODUCTION

In the last decade, Taiwan has experienced a deeper economic engagement with Mainland China. The ‘Mini-Three-Links’ (i.e. the trade, mail, and air and shipping services across the Taiwan Straits through certain authorized passenger and freight terminals) were launched in 2001, after government restrictions were lifted. Then a complete direct transportation channel, namely, ‘Three-Direct-Links,’ and the Economic Cooperation Framework Agreement (ECFA), signed in 2008 and 2010, respectively, have provided the most potentially significant free trade agreements across the Taiwan Straits.

According to the statistical results of countries trading with R.O.C. in 2013, as shown in Table 1 (in US dollars), the total trading amount between China and Taiwan ranks first among all countries (Regions).

Table 1. Statistics of Import and Export Trading Countries of R.O.C. (Source: Bureau of Foreign Trade Report, 2013)

<table>
<thead>
<tr>
<th>Name</th>
<th>Import and Export Trading Countries (Regions) with Taiwan, R.O.C.</th>
<th>Import</th>
<th>Export</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total amount of trade</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rank</td>
<td>Amount of money (US $)</td>
<td>Rate (%)</td>
</tr>
<tr>
<td>CHINA</td>
<td>1</td>
<td>121,621,186,471</td>
<td>21.276</td>
</tr>
<tr>
<td>JAPAN</td>
<td>2</td>
<td>66,561,464,334</td>
<td>11.644</td>
</tr>
<tr>
<td>U.S.A.</td>
<td>3</td>
<td>56,579,475,382</td>
<td>9.898</td>
</tr>
<tr>
<td>HONG KONG</td>
<td>4</td>
<td>40,590,735,466</td>
<td>7.101</td>
</tr>
</tbody>
</table>
Since a global reduction in the cost of transportation was a key to the rapid growth of global trade in the past two decades (World Bank report, 2009), offering customers efficient and economic logistic service becomes an emerging business strategy. Efficient international intermodal logistics service can significantly reduce transportation costs in global business, thereby also increasing the vehicle utilization rates, improving the utilization of existing transportation infrastructure, enhancing the system resilience, reducing the dwell time and storage requirements of freight at transfer terminals, and improving service level.

To achieve these goals, route choice combined with transfer terminal selection has been recognized as one of the crucial elements and challenges faced by international logistics carriers.

For the purposes of this study, intermodal freight transport is defined as the use of two or more modes to move a shipment from origin to destination, which includes the physical infrastructure, goods movement and transfer, and other relevant activities under a single freight bill. Most operations at intermodal freight terminals require transfer movements among modes to serve cargos with diverse destinations, especially for break-bulk, cross-docking, or transhipment systems. Transfer impedance is a significant concern in selecting intermodal transfer terminals along the routes, which involves various cargo processing activities (e.g. security check, unloading, sorting, loading, clear custom, and quality examination) inside the terminals. It should be noted that different requirements of custom clearing and inspection operations at terminals may significantly affect the cargo processing time and dwell costs. In practice, the average custom clearing time and examination operations at the ‘Mini-Three-Links’ are lesser and simpler than at other ‘Three-Direct-Links’ hubs. In this study, 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’ networks, as shown in Figure 1.

<table>
<thead>
<tr>
<th>Country</th>
<th>Freight Quantity</th>
<th>Average Clearing Time</th>
<th>Average Examination Time</th>
<th>Total Time</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINGAPORE</td>
<td>28,196,383,378</td>
<td>4.932</td>
<td>6.671</td>
<td>8</td>
<td>2.997</td>
</tr>
<tr>
<td>KOREA</td>
<td>26,915,434,375</td>
<td>4.708</td>
<td>3.932</td>
<td>4</td>
<td>5.573</td>
</tr>
<tr>
<td>SAUDI ARABIA</td>
<td>16,641,677,798</td>
<td>2.911</td>
<td>0.615</td>
<td>5</td>
<td>5.468</td>
</tr>
<tr>
<td>MALAYSIA</td>
<td>14,398,911,372</td>
<td>2.519</td>
<td>2.177</td>
<td>9</td>
<td>2.899</td>
</tr>
<tr>
<td>GERMANY</td>
<td>13,398,598,979</td>
<td>2.344</td>
<td>1.874</td>
<td>10</td>
<td>2.867</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>12,940,805,189</td>
<td>2.264</td>
<td>1.213</td>
<td>6</td>
<td>3.434</td>
</tr>
</tbody>
</table>

Figure 1. Freight Transportation Modes across the Taiwan Strait

Intuitively, commodities with the lower and the higher cargo values should be shipped via the lower-cost and quickest 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 Frankfurt, Germany, the transit days and costs of 1 FEU (i.e. 15.3 tons for air freight) are, respectively 4 days and 9.9 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 9 days and 9.1 USD. However, if freight were shipped through truck-sea-truck-air-truck (Sea-Air), the transit days and costs are 15 days and 8.3 USD. Thus, carriers must consider total transportation time and delivery deadlines of shipments and shipping costs in selecting the appropriate combinations of delivery routes, terminals, and modes.

Here we specify an optimal decision support model devoted to managing intermodal logistics route selections under various transfer impedances. The problem is formulated as a multi-objective programming problem. The rest of the paper is organized as follows. In the next section, the background research is presented, while the methodology is explained in Section 3. Numerical examples will be presented in Section 4 and conclusions will be drawn in Section 5.

2. BACKGROUND RESEARCH

Although a growing number of studies investigated direct routing over the Strait, these studies do not fully fit our requirements (i.e. an optimal logistics route selection model from freight forwarders’ perspectives.) Most of these studies either focused on reducing operational costs (e.g. Lin and Liu, 1999; Lin and Chen, 2003,) reviewed qualitatively policy impacts (e.g. Chang et al., 2006; Chiu, 2007; Guo et al., 2007,) estimated the future annually trade volume (e.g. Yang, 2010,) or focused on the cross-Strait routing strategies of the regional airlines (e.g. Chang et al., 2011; Lau et al., 2012.)

Several previous studies investigated transfer efficiency in order to measure performance of terminal operations (e.g. Kozan, 2000, Sánchez et al., 2003, Tongzon, 2009, Sharma and Yu, 2010, and Chen and Schonfeld, 2010), but seldom combined with route selections (Southworth and Peterson, 2000, and Chang, 2008). Route choice combined with transfer terminal selection across the Taiwan Strait poses significant logistic challenges since the cargo examination operations and time may vary at different terminals and hamper these transfers.

Rietveld (2000) first defines the term ‘transfer impedance,’ but focuses on non-motorized passenger transport modes such as walking and biking. Southworth and Peterson (2000) formulate an impedance transform function based on the ‘modal impedance’ and ‘link impedance’ concepts. They presume that if a less expensive mode is used at all it is used preferentially for as large a proportion of the trip as practicable, relegating more expensive modes to an access role, which means the lowest cost mode would be used predominantly. Thus, one mile of travel on the best type of facilities of that mode would incur one impedance penalty unit. The idea is sound, but still somewhat simplified and ignores the operations inside the transfer terminals, as in other previous studies (Min, 1991, Bookbinder, 1998, and Chang, 2008). In this study, the term ‘transfer impedance’ indicates the ‘node impedance’ within the studied network.

Min (1991) developed a goal programming model to assist three electronic device suppliers in Japan in choosing the most effective intermodal mix by minimizing cost and cargo dwell time inside the terminals, but also satisfying various on-time service requirements. Bookbinder and Fox (1998) applied the shortest path algorithms in planning intermodal freight routing from Canada to Mexico and analyzed the trade-off between the total transit time and cost. Chang (2008) formulated a multi-objective programming model to select best
routes for shipments through the international intermodal network. Yang et al. (2011) presented an intermodal network optimization model to examine the competitiveness of 36 alternative routings for freight moving from China to and beyond Indian Ocean. Perez-Mesa et al. (2012) investigated the agriculture products delivery cases in Spain and found that commodities shipped by truck-short sea shipping (SSS)-truck constitutes a 14 percentage of the total travel cost reduction but doubles the transportation time than shipped by trucks only. Morales-Fusco et al. (2012) further analyzed the average costs per shipment between SSS and truck operations, as shown in Figure 2.

![Figure 2. Comparisons of Average Costs per Shipment between SSS and Truck Operations](image)

Most of the above studies tend to formulate the intermodal routing problem as a multiple objective problem due to conflicting purposes. For freight transportation operations, users (e.g. shippers) and operators (e.g. freight forwarders) may have contradictory interests regarding service quality. Shippers may prefer to send cargos at the lowest prices while minimizing total shipping time; however, freight forwarders may choose a route with multiple transfers to create economies and reduce costs.

In this study, international logistics freight forwarders are our main decision makers, who need to arrange routes for shipments through logistics networks. Although shippers only know the origins, destinations, and items, we assume that decisions made by freight forwarders would also consider shippers’ interest. Several contributions in this study are listed below, such as:

1. A multi-objective programming model of route selections in intermodal logistic networks 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 to different modes.

2. 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, 2001; Ayar et al., 2012), our study incorporates different freight inspection time settings at hubs within the studied networks into the optimization model.

3. A soft penalty function is developed to prevent the total shipping time from exceeding the maximum allowable delivery time.

4. Most input parameters were generated through extensive consultation with our industrial partners (including one of the world three largest international express companies, one international freight forwarder – King Freight International Corp., and one domestic
freight forwarder in Taiwan - Apollo Logistics Ltd.) to closely replicate real world data.

3. MODEL FORMULATIONS

The studied intermodal logistics network includes multiple hubs, multiple modes, and multiple commodities. The network is given by $G = (N, E)$, where $N = \{1, \ldots, n\}$ is set of nodes and $E = \{(i, j) | i, j \in N\}$ is the set of links.

The model is expressed as follows:

$$\min Z_c = \sum_{i} \sum_{j} \sum_{k} \sum_{m} \left( c_{ij}^{km} d_{ij}^{km} + f_{ij}^{km} y_{ij}^{km} \right) + \lambda_p \max \left( 0, z_T - T_{\text{max}}^{km} \right)$$

$$\min Z_T = \sum_{i} \sum_{j} \sum_{k} \sum_{m} \left[ \max \left[ D_{ij}^{km} + TP_{ij}^{km} + TE_{ij}^{km} \right] - \min \left[ D_{ij}^{km} + TP_{ij}^{km} + TE_{ij}^{km} \right] \right] x_{ij}^{km}$$

$$\sum_{j} x_{ij}^{km} - \sum_{i} y_{ij}^{km} = \begin{cases} Q & \text{if } i = O \\ -Q & \text{if } i = D \\ 0 & \text{otherwise} \end{cases}$$

$$\forall i, j \in N, \forall m \in M, \forall k \in K, i \neq j$$

$$\sum_{m} x_{ij}^{km} \leq u_{ij} \quad \forall (i, j) \in A, \forall m \in M, \forall k \in K$$

$$x_{ij}^{km} \left[ t_{ij}^{km} + \max \left( D_{ij}^{km} + A_{ij}^{km} + TP_{ij}^{km} + TE_{ij}^{km} \right) - A_{ij}^{km} \right] = 0$$

$$y_{ij}^{km} \in \{0, 1\} \quad \forall (i, j) \in A, \forall m \in M, \forall k \in K$$

$$x_{ij}^{km} \in \text{non-negative integer} \quad \forall (i, j) \in A, \forall m \in M, \forall k \in K$$

All parameters and decision variables used in the formulation are listed below:

Sets

$E$: the set of links,
$K$: the set of transportation mode,
$M$: the set of cargo categories, and
$N$: the set of nodes.

Parameters

$A_{ij}^{km}$: the arrival time at node $i$,
$D_{ij}$: the scheduled departure time at node $i$,
$Q$: the total amount of cargos at origins,
$f_{ij}^{km}$: the fixed cost,
$c_{ij}^{km}$: the distance-based variable cost,
$d_{ij}$: the distance between nodes $i$ and $j$,
$t_{ij}^{km}$: the total transportation time shipped by mode $k$ through the link $(i, j)$,
$u_{ij}$: the link capacity through $(i, j)$,
$\lambda_p$: the unit penalty value,
$TP_{ij}^{km}$: the estimated cargo processing time the $m_{th}$ cargo category shipped by
mode \( k \) at node \( i \),

\[
TE_{i}^{km} : \text{the estimated cargo inspection time at node } i, \text{ and}
\]

\[
T_{\max}^{m} : \text{the maximum allowable shipping time of the } m_{th} \text{ cargo category.}
\]

**Decision Variables**

\[
\lambda_{ij}^{km} : \text{the amount of } m_{th} \text{ cargo category shipped by mode } k \text{ through the link } (i, j),
\]

\[
y_{ij}^{km} : 1, \text{ indicates the } m_{th} \text{ cargo category shipped by mode } k \text{ traveling through the link } (i, j); \text{ otherwise } 0.
\]

The first minimized objective function is formulated as the sum of transportation cost of shipments with respect to both distance and weight. In addition, a penalty function \( \lambda_{p} \max \left(0, Z_{T} - T_{\max} \right) \) is introduced if the total shipping time \( Z_{T} \) exceeds the maximum allowable delivery time \( T_{\max} \). The second minimized objective function is formulated as the sum of transportation time from origin to destination nodes. 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 of the decision variable \( x \).

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, such as: (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; (2) 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 (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 \( \{z_{1}(x), z_{2}(x), \ldots, z_{k}(x)\} \) are considered to be optimized simultaneously, some corresponding design references of \( \{z_{1}^{*}, z_{2}^{*}, \ldots, z_{k}^{*}\} \) are assigned based on the lower bound of each objective functions \( \{z_{1}^{\max}, z_{2}^{\max}, \ldots, z_{k}^{\max}\} \) (for the minimization problems). Thus, the problem is re-formulated as in Equation 8:

\[
\min \left( \sum_{i=1}^{k} w_{i} \left| \frac{z_{i}(x) - z_{i}^{*}}{z_{i}^{\max} - z_{i}^{*}} \right|^{p} \right) \left( \frac{1}{p} \right)
\]

Since the units of each objective function might be different, a normalization process is required. In order to express transfer impedances within the studied network, a node splitting transformation technique is applied. Every transfer node is split into two nodes (i.e. by adding a dummy node at the same location) so that transfer impedance is viewed as the dummy arc connected between the original and dummy nodes. The results in the next section are solved with the optimization software CPLEX. All programs are executed on a PC with Intel Core (TM) i7 CPU 2.93 GHz processor and 4 GB of RAM.
4. MODEL APPLICATIONS AND ANALYTICAL RESULTS

The studied network contains 28 nodes and 79 links, as shown in Figure 3. As shown in Table 2, nodes 1-4 represent the origin cities in Taiwan, nodes 5-11 denote the transfer hubs in Taiwan, nodes 12-21 indicate the transfer hubs in China, and nodes 22-28 represent the destinations of shipments. It should be noted that nodes 9-11 and nodes 7 and 13 are attributed to the ‘Mini-Three-Links’ and sea express hubs, respectively.

Two kinds of commodities (P1: textile materials and P2: electronics) are analyzed in this study. The allowable times for shipping P1 and P2 are 168 and 72 hours, respectively. Here we assume that textiles and electronics are relatively lower and higher value products, respectively. 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’ networks. Most input parameters and numerical examples were generated through extensive consultation with our industrial partners (including one of the world three largest international express companies, one international freight forwarder, and one domestic freight forwarder in Taiwan) 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 Chu et al. (1996), and Kengpo et al. (2014). Detailed settings are listed in Lai (2014).

Figure 3. The Network Configuration in the Case Study.

<table>
<thead>
<tr>
<th>Node ID</th>
<th>Node Name</th>
<th>Node ID</th>
<th>Node Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Yilan</td>
<td>15</td>
<td>Wutong</td>
</tr>
<tr>
<td>2</td>
<td>Hsinchu</td>
<td>16</td>
<td>Tianjin</td>
</tr>
<tr>
<td>3</td>
<td>Chiayi</td>
<td>17</td>
<td>Qingdao</td>
</tr>
</tbody>
</table>
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 different weight combinations would reach various compromise routing solutions. Although these values may be not fully consistent with the entire industry standards (i.e. different forwarders may have different settings), the model can use whatever inputs its users consider most applicable.

Tables 3 and 4 illustrate the example of inputs and parameters, which include: link capacity, travel distance, and the estimated transportation time with different modes through links.

<table>
<thead>
<tr>
<th>$(i,j)$</th>
<th>$u_{ij}$ (tons)</th>
<th>Distance (km)</th>
<th>$(i,j)$</th>
<th>$u_{ij}$ (tons)</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, 5)</td>
<td>900</td>
<td>74</td>
<td>(4, 7)</td>
<td>1000</td>
<td>158</td>
</tr>
<tr>
<td>(2, 5)</td>
<td>800</td>
<td>98</td>
<td>(4, 8)</td>
<td>1200</td>
<td>73</td>
</tr>
<tr>
<td>(2, 6)</td>
<td>700</td>
<td>79</td>
<td>(5, 9)</td>
<td>800</td>
<td>343</td>
</tr>
<tr>
<td>(2, 7)</td>
<td>750</td>
<td>85</td>
<td>(5, 16)</td>
<td>1300</td>
<td>1582</td>
</tr>
<tr>
<td>(2, 8)</td>
<td>1000</td>
<td>279</td>
<td>(5, 17)</td>
<td>1200</td>
<td>1217</td>
</tr>
<tr>
<td>(3, 7)</td>
<td>800</td>
<td>114</td>
<td>(5, 18)</td>
<td>1000</td>
<td>652</td>
</tr>
<tr>
<td>(3, 8)</td>
<td>730</td>
<td>127</td>
<td>(5, 19)</td>
<td>800</td>
<td>500</td>
</tr>
</tbody>
</table>

Table 4. Inputs of Transportation Time of Different Modes

<table>
<thead>
<tr>
<th>$(i,j)$</th>
<th>Transportation Modes</th>
<th>Transportation Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(5, 9)</td>
<td>Sea</td>
<td>25</td>
</tr>
<tr>
<td>(5, 17)</td>
<td>Sea</td>
<td>90</td>
</tr>
<tr>
<td>(5, 18)</td>
<td>Sea</td>
<td>60</td>
</tr>
<tr>
<td>(5, 19)</td>
<td>Sea</td>
<td>48</td>
</tr>
<tr>
<td>(5, 20)</td>
<td>Sea</td>
<td>32</td>
</tr>
<tr>
<td>(5, 21)</td>
<td>Sea</td>
<td>25</td>
</tr>
<tr>
<td>(6, 9)</td>
<td>Sea</td>
<td>57</td>
</tr>
<tr>
<td></td>
<td>Sea</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Sea</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Sea</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 3. Inputs of Link Capacity and Distance
The optimized results in Case H (i.e. shipments delivered from Hsinchu, Taiwan) are listed in Table 5. For example, cargos whose shipping ID is 2-22-1 via the economic path are transported from node 2 to node 7 by trucks, from node 7 to node 14 by sea (transferred by nodes 9 and 10 through the ‘Mini-Three-Links’), and from node 14 to node 12 by trucks. Most cargos shipped on such a slow path are commodities with the lower cargo value setting (e.g. textile materials.) Conversely, most of the higher value commodities (e.g. electronic parts) are delivered by air or sea express. Cargos whose shipping ID is 2-22-1 via the fastest path are transported from node 2 to node 6 by trucks, from node 6 to node 16 by air, and from node 16 to node 22 by trucks.

Here we assume that both objectives have equal weights. A multiple objective programming method suggested here can be applied in various stakeholders by using different weights. For example, cargos whose shipping ID is 2-22-1 via the compromise path are transported from node 2 to node 7 still by trucks, from node 7 to node 13 by sea express, and from node 13 to node 22 by trucks.

<table>
<thead>
<tr>
<th>Shipment ID</th>
<th>Economic Path</th>
<th>Fastest Path</th>
<th>Compromise Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-22-1</td>
<td>2→7→9→10→14→22</td>
<td>2→6...16→22</td>
<td>2→7=13→22</td>
</tr>
<tr>
<td>2-22-2</td>
<td>2→7→16→22</td>
<td>2→6...16→22</td>
<td>2→7=13→22</td>
</tr>
<tr>
<td>2-25-1</td>
<td>2→7→9→10→14→25</td>
<td>2→7=13→25</td>
<td>2→7→9→10→14→25</td>
</tr>
<tr>
<td>2-25-2</td>
<td>2→7→9→10→14→25</td>
<td>2→7=13→25</td>
<td>2→7=13→25</td>
</tr>
<tr>
<td>2-27-1</td>
<td>2→7→9→10→15→27</td>
<td>2→7=13→27</td>
<td>2→7→9→10→15→27</td>
</tr>
<tr>
<td>2-27-2</td>
<td>2→7→9→10→15→27</td>
<td>2→7=13→27</td>
<td>2→7→9→10→15→27</td>
</tr>
<tr>
<td>2-28-1</td>
<td>2→7→9→10→15→28</td>
<td>2→7...20→28</td>
<td>2→7=13→28</td>
</tr>
<tr>
<td>2-28-2</td>
<td>2→5→20→28</td>
<td>2→7...20→28</td>
<td>2→7=13→28</td>
</tr>
</tbody>
</table>

→ truck = sea express -- sea ... air

Overall optimized results are summarized in Table 6. Findings in this study show that most commodities with the lower cargo value setting should be transported by truck-sea-truck through ‘Mini-Three-Links’ networks due to the lowest transportation costs with less examination processes and time of freight. In addition, some higher value commodities should be delivery by truck-sea express-truck due to the nearly fastest transportation time and relatively low shipping costs. Air becomes less competitiveness to deliver cargos across the Taiwan Strait due to the highest transportation costs and insignificant improvement of the transportation time than sea express.

<table>
<thead>
<tr>
<th>Destinations</th>
<th>Transfer Hubs &amp; Modes</th>
</tr>
</thead>
</table>
| Tianjin City | • Economic Path: transferred through Kinmen and Shijing (Sea, through the Mini-Three-Links)  
• Fastest Path: Tianjin (Air)  
• Compromise Path: transferred through Taichung and Pingtan (Sea Express) |
| Kunshan      | • Economic Path:  
(1) If shipped from Yilan, Hsinchu, or Chiayi,  

5. CONCLUSIONS

Instead of arbitrarily making route selection decisions or over-simplifying them, this study contributes a method for optimizing the route selections based on the estimated hub transfer impedances within the studied ‘Mini-Three-Links’ and the ‘Three-Direct-Links’ networks. The decision process involves multiple and conflicting objectives to reflect users and service providers may have some conflicting interests regarding service quality. Even though the
proposed model and certain assumptions could be improved with greater complexity and realism, the tested case studies demonstrate the capabilities of our proposed models and optimize the routing selection decisions. The usefulness of the numerical results can be increased by further developing commercial software for real-time control operations and examining the reliability of primary hubs and links within the existing operational networks.

Although the Air mode becomes less competitive across the Taiwan Strait, cargos whose shipping destinations are located far from the sea express hubs or having emergency purposes (e.g. to avoid or respond to disruptions in the supply chain) should still be shipped via air. Ignoring the trade-off between economic and security considerations across the Taiwan Strait, we suggest that more hubs should be included within the ‘Mini-Three-Links’ networks to simplify the cargo examination time and custom clear processes, so as to reduce the total shipping time and decrease the cargo dwell time at terminals. Similarly, instead of operating the 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 issues to facilitate the development of freight transportation across the Taiwan Strait.

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REFERENCES


