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# A decision support approach to designing the inland logistics network in China

## **Cover Page Footnote**

The authors wish to thank the Korea Maritime Institute (KMI) for partly funding this research.

# A DECISION SUPPORT APPROACH TO DESIGNING THE INLAND LOGISTICS NETWORK IN CHINA

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## ABSTRACT

*With the unprecedented growth of international trade, a growing number of multinational firms have coped with logistical challenges of shipping products to and from unfamiliar territories in many countries. These logistical challenges include the cross-border transportation of products originated from inland port to another inland port isolated from major waterways. In particular, the lack of access to major waterways would not only constrain the intermodal transportation option, but also make door-to-door, containerized delivery services nearly impossible. Such a limited option would eventually lead to increased transportation costs and transit time, and thereby offset low-cost global sourcing advantages. To aid multinational firms in addressing the problem of determining the optimal supply chain link between inland origin and destinations ports, this article proposes a shortest-path model based decision support system. The usefulness of the proposed model-based decision support system was validated by its application to a real problem encountered by a multinational firm that would like to strengthen its foothold in the Chinese market.*

## INTRODUCTION

As trade barriers have begun to crumble, a growing number of firms are expanding their supply and customer bases into vast regions of the world. However, an opportunity to capitalize on cheaper sources of supply and greater market share in foreign markets can evaporate unless firms can control hidden costs associated with

global supply chain operations. These hidden costs may stem from high tariffs, excessive documentation, compliance with foreign rules and regulations, security concerns, mounting insurance costs, in-transit inventory carrying costs, incompatible communication, fuel surcharges, and logistical inefficiency. In particular, the "last mile" transportation from the port of entry to the final destination can dictate the

success of global supply chain operations. Despite the increasing use of containerized traffic that is secure and inexpensive, global supply chain planning based on port-to-port transit has become increasingly difficult due to worsening longshore labor troubles, port congestion, and demurrage fees. To cope with this logistical challenge, many multinational firms (MNF's) explore ways to enhance efficiency and visibility from port of entry to inland destinations (or from inland origins to port of exit). For example, the MNF may consider using rail shuttles as a means to transship imported container loads of goods to inland shippers in lieu of harbor trucks.

In recent years, the inland logistics network design garnered significant attention from government policy makers, because it will impact the viability of local firms clustered around inland cities and the subsequent regional economy. The inland logistics network design is primarily concerned with the development of minimum-cost and/or time intermodal, door-to-door logistics links between origin and destination ports that are isolated from major waterways and river/ocean ports. Key logistics issues to be addressed by the inland logistics design include:

1. Which port of entry (or exit) should be selected as an inland transfer point (transshipment location)?
2. Which intermodal combination (e.g., piggyback, all truck, all rail, and barge-truck, barge-rail) should be used for last-mile transportation from the port of entry (or exit) to the final inland destination (or origin)?
3. Which routes should be selected to minimize total logistics cost and/or time?

The inland logistics network design problem can typically arise in a practical situation where either importers or exporters are located in landlocked countries such as Mongolia and Uzbekistan. Another common inland logistics

scenario is the transshipment of imported or exported goods via inland transfer points to reach sources of supply or customer bases located in inland cities that are isolated or inaccessible from major waterways. In this study, for illustrative purposes, the authors look into an inland logistics scenario that arises in seven provincial regions along the Yangtze River Delta in China (see Figure 1). As shown in Table 1, China has emerged as the major trading partner with the United States. Indeed, almost half of goods manufactured in China were imported to the U.S. (USA Trade Online, 2003). After China's recent entry into the World Trade Organization (WTO), China's role as the major source of inexpensive products is expected to increase for years to come. For instance, China is known to be the biggest producer of many industrial commodities such as steel, coal, and grain (Feng et al., 2007). However, transportation of these commodities within inland locations in China can pose a number of logistical challenges for the importers, because these commodities are bulky and access to inexpensive means of transportation, such as barge and rail, is limited.

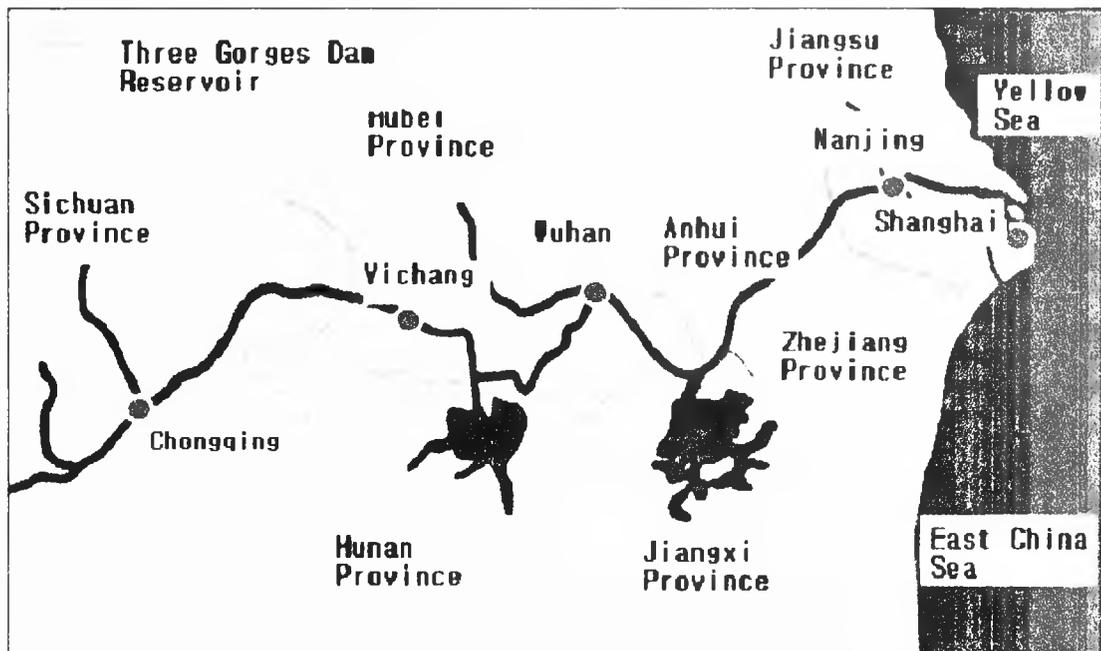
For example, railroads in China meet less than 45 percent of demand due to shortages in box-cars, locomotives, and dual tracks, while barge shipments are subject to extra surcharges for traveling through the Yangtze River (Min and Chen, 2003). Although trucks have been heavily used for short distances (e.g., less than 300 kilometers and/or 8 hours of driving distance), transportation cost via truck is ten times higher than rail freight cost (Min and Chen, 2003). As a matter of fact, logistics activities consume nearly 90 percent of the total order cycle time and 40 percent of the total sourcing cost in China (Hong Kong Trade Development Council, 2002). According to Gould (2001), logistics costs account for a staggering 24 to 34 percent of the total landed costs of appliances, tools, toys, and other basic goods sourced from China as opposed to 10 percent of the landed costs for the same type of products sourced from the U.S. and Europe. As of 2002, the total logistics expenditure in China accounted for 21.5 percent of the Chinese Gross

**TABLE 1**  
**CHINA'S MAJOR TRADING PARTNERS (IN US\$ MILLION)**

Exports			Imports		
Rank	Total	\$583,100.0	Rank	Total	\$552,400.0
1	US	\$132,946.8	1	Japan	\$88,936.4
2	Hong Kong	\$94,462.2	2	Taiwan	\$60,211.6
3	Japan	\$72,304.4	3	South Korea	\$57,449.6
4	South Korea	\$25,656.4	4	US	\$42,534.8
5	Germany	\$23,324.0	5	Hong Kong	\$40,877.6

Source: *World Fact Book*, 2004

**FIGURE 1**  
**PROVINCES ALONG THE YANGTZE RIVER**



Domestic Product (GDP), whereas the total logistics expenditure in the U.S. comprised a mere 9.3 percent of the U.S. GDP (Rodrigues et al., 2005; Wang, 2006).

Considering the increasing logistical challenges faced by MNF's sourcing and/or selling in China, this article proposes a decision-aid tool within a model-based decision support system framework that can optimally create the inland logistics network linking the port of entry (or exit), an inland transfer point, and an inland destination (or origin).

### PROBLEM SCENARIO

For purposes of this study, inland logistics refers to a series of transportation and distribution activities assuring door-or-door services involving inland destinations or origins remotely located from major waterways. These activities may encompass intermodal combinations, the port of entry/exit selection, inland transfer point selection, consolidation, product mixing, transshipment at an inland transfer point (or a transportation hub), and last-mile delivery/pickup arrangements. The inherent complexity of inland logistics calls for a systematic decision-aid tool that can help MNF's leverage low-cost sourcing options or broader customer bases, without incurring unnecessary costs. Nevertheless, no prior literature to date has developed a systematic decision-aid tool such as a mathematical model, a simulation model, and an expert system that can deal with inland logistics issues. To fill the void left by prior studies, the authors conducted an inland logistics case study inspired by the United Nations Economic Social Commission for Asia and the Pacific (UN ESCAP) and developed a model-based decision support system (DSS) that can solve the inland logistics network design problem.

To elaborate, the case study focuses on actual logistical problems encountered by seven inland cities along the Yangtze River Delta in China. These cities are: (1) Chengdu, Sichuan; (2) Chongqing, Chongqing; (3) Changsha, Hunan; (4) Xiangfan, Hubei; (5) Nanchang, Jiangxi; (6)

Hefei, Anhui; (7) Quzhou, Zhejiang. Since these cities represent regional provinces of high economic importance to China, future prosperity for China may depend heavily on the economic viability of these cities. As a matter of fact, the regions where the seven cities are located accounted for 39 percent of the total Chinese GDP, 32.8 percent of the total Chinese international trade volume, and 42.1 percent of foreign direct investment (FDI) in 2003 (The National Bureau of Statistics of China, 2004). As such, the Yangtze River Delta area was designated by the Chinese government as the region for high technology and heavy manufacturing and has emerged as the gateway to Central and Northern China's inland areas (Yam and Tang, 1996). However, over the last few years, there have been increasing concerns over logistics inefficiency caused by the lack of transportation infrastructure, chronic traffic congestion, mounting freight cost, bureaucratic government rules and regulations, and limited carrier and forwarder options within these regions. For example, when an international carrier goes beyond the navigating range, the ship-navigating fee is surcharged 30 percent for 10 miles or less, and 50 percent for over 10 miles. In addition, the international carrier is subject to trans-anchoring, mooring/unmooring, harbor and groundage fees, and terminal handling charges (Min and Chen, 2003).

Given the limited number and capacity of domestic barge carriers operated within the Yangtze River Delta, it would be very difficult for international shippers to take advantage of the cheaper mode of barge transportation. There are only three domestic barge carriers that can haul freight exceeding 100,000 TEU's (Twenty-foot equivalents). To make matters more complicated, ships or barges weighing more than 10,000 tons may not be able to navigate through the Yangtze River for most of the seasons due to the lower water level. Although the completion of the ongoing Three Gorge project would allow large freight liners to sail as far as Chongqing, the fluctuating water level of the Yangtze River poses another logistical challenge for bulk shipment. Alternative means of inexpensive

transportation such as rail often requires long waits for space booking and long delivery times (Min and Chen, 2003).

Considering the complexity in selecting the right mode of transportation for inland logistics, this study explores three modal selection options: (1) all rail; (2) all road (truck); (3) intermodal mix of barge and rail or barge and truck. In this study, the authors did not consider the option of using air due to the limited airport infrastructure for inland cities and prohibitively high freight cost. However, the possibility of utilizing direct shipment from port of entry to inland destinations, while considering the inland transfer point such as an inland river-port or an inland rail/truck terminal was explored. To solve this inland logistics problem, a multiple objective shortest path model was developed and then incorporated into a decision support system (DSS) framework. The details of the proposed model and DSS are provided in the following section.

### ARCHITECTURE OF THE MODEL-BASED DECISION SUPPORT SYSTEM

Figure 2 depicts the schematic architecture for the model-based decision support system (DSS) developed to enable viable inland logistics strategies. Within the DSS framework suggested by Sprague and Carlson (1982), the DSS is comprised of three components: (1) **database**, consisting of accurate, timely data necessary for model development; (2) **model base**, a computerized optimization model to determine the shortest route from the port of entry to inland destinations with or without inland transshipment; (3) **dialogue base**, a series of "if-then" or "what-if" rules for changes in mode of transportation, shipping routes, and transportation policy. The DSS can be used by international shippers/carriers associated with MNF's for inland logistics operations at minimum cost while minimizing the delivery time. The DSS will help MNF's make strategic decisions as to which inland transfer point to use as a transshipment facility, which shipping routes to take, and which combinations of transportation mode to assemble. The DSS is tested and validated

with real data furnished by both UN ESCAP and the Korea Maritime Institute (KMI). Unlike a stand-alone mathematical model whose efficiency relies on the accuracy of available data, this DSS allows for interfaces between databases and models and subsequently handles what-if scenarios in the case that model parameter values change over time.

### Database Management Subsystem

A model is only as good as the quality of the data that support it (Napolitano, 1998). To enhance data quality and avoid data redundancy, a database that contains two data sources, governmental and non-governmental, was developed. The database management subsystem (DBMS) is designed to supplement standard operating systems by allowing greater integration of data, complex file structure, quick retrieval and changes, and better data security (Turban and Aronson, 2001). Governmental sources include regulatory guidelines and reports issued by federal (e.g., Harbor Superintendent Department of China; China's Customs General Administration, the Chinese Ministry of Foreign Trade and Economic Cooperation; the Chinese Ministry of Communication; the Chinese State Development Planning Commission; the National Bureau of Statistics of China) and public transportation authorities. Non-governmental sources include public data files (e.g., published literature, websites and CD-ROMs) available from the World Bank, the World Trade Organization (WTO), the Chinese Transport Intelligence Limited, the Chinese Shipping Exchange, the Chinese Warehousing Association, and the Hong Kong Trade Development Council. In addition to raw data that were obtained by the above sources, more specific data categories that are relevant to inland logistics planning were created.

**Cost data.** Cost is one of the primary concerns of inland logistics planning. These costs include: navigating fees, trans-anchoring fee, mooring/unmooring fee, harbor fee, groundage fee, demurrage fee, terminal handling charge, freight rate, freight surcharge, port charge, loading/

**FIGURE 2**  
**AN ARCHITECTURE FOR THE MODEL-BASED DECISION SUPPORT SYSTEM**

**Data Base**

**1. Cost data**

- a. Navigation fee
- b. Trans-anchoring fee
- c. Mooring/unmooring fee
- d. Demurrage fee
- e. Unit freight rate
- f. Freight surcharge
- g. Loading/unloading cost
- h. Port charge
- i. Insurance cost
- j. Taxes

**2. Traffic data**

- a. Proximity to inland river-ports
- b. Port infrastructure and amenities
- c. Access to major highways/railways
- d. Transit time between nodes
- e. Government traffic rules and regulations

**Forecasting**

- Anticipated shipment size
- Cost change
- Infrastructure development



*Data request*

**Bi-objective Shortest Path Model**

- LINDO/LINGO
- Dijkstra's labeling procedures

*User interface*

**"What-if" Analysis**

- Changes in priority of multiple criteria (cost versus time)
- Alternative means of transportation
- Formulation of inland logistics strategies

unloading, transshipment cost, insurance cost, in-transit inventory carrying cost, taxes, and customs duties.

**Traffic data.** Important concerns of inland logistics operations include proximity to inland river-ports, break-bulk terminals, paved roads

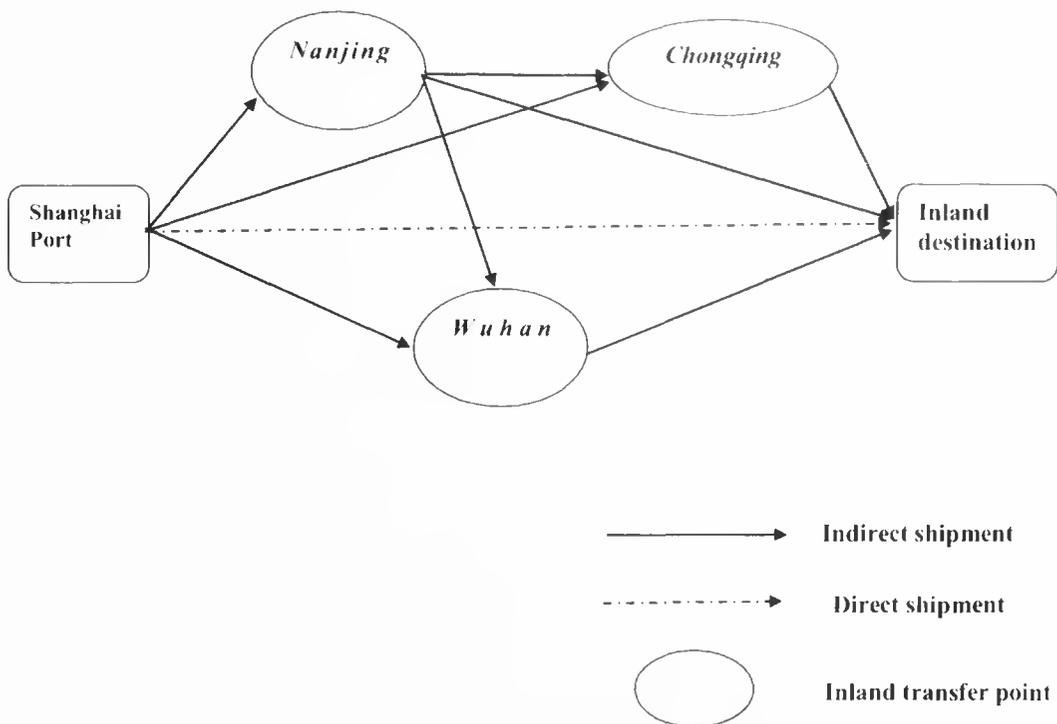
and major road arteries, access to forwarders and common carriers, seasonal water level at the Yangtze River, barge/rail/truck schedules, barge/rail/truck transit time, loading/unloading time, shipment transfer time, choke points, and compliance with the Chinese government traffic regulations and rules.

## Model Management Subsystem

As a core of the model base within the DSS framework, a shortest-path model was developed that considers multiple objective aspects of inland logistics planning. The shortest-path model is supported by a forecasting model that predicts any changes in the size of shipment between the port of entry and inland destinations. The shortest-path model will determine which route should be selected to minimize the total transportation cost, while speeding up the delivery process (see, e.g., Phillips and Garcia-Diaz 1981; Bertsekas, 1991 for detailed

features of the classical shortest path model). This decision includes the consideration of either direct or indirect shipment via an inland transfer point and optimal combination of the intermodal mix (see Figure 3). Since the use of a cheaper mode of transportation requires longer transit time, the goal of minimizing transportation cost is inherently conflicting with the goal of minimizing transit time. The presence of these conflicting goals requires the bi-objective model that makes an optimal trade-off between cost and time. The detailed mathematical formulation is presented on the following page.

**FIGURE 3**  
**VARIOUS ROUTING OPTIONS FOR INLAND DESTINATIONS WITHIN THE YANGTZE RIVER DELTA**



## Indices

$I$  = set of origin node (e.g., port of entry);  
{1, ...,  $NI$ }

$J$  = set of destination nodes (e.g., inland cities); {1, ...,  $NJ$ }

## Model Parameters

$C_{ij}$  = cost per unit flow of shipment from origin node  $i$  to destination node  $j$ ;  $i \in I, j \in J$

$T_{ij}$  = transit time between origin node  $i$  to destination node  $j$ ;  $i \in I, j \in J$

$\alpha$  = weight coefficient assigned to each objective ( $0 \leq \alpha \leq 1$ )

## Decision Variable

$X_{ij}$  = unit of traffic flow from node  $i$  to node  $j$ ;  
( $i \in I, j \in J$ )

## Mathematical Formulation

$$\text{Minimize } \sum_{i \in I} \sum_{j \in J} [\alpha C_{ij} + (1 - \alpha) T_{ij}] X_{ij} \quad (1)$$

Subject to:

$$\sum_{j \in J} X_{oj} = 1, o = \text{starting node}, \forall j \in J \quad (2)$$

$$\sum_{i \in I} X_{ij} - \sum_{j \in J} X_{ji} = 0, i \neq o, j \neq d \quad (3)$$

$$-\sum_{j \in J} X_{jd} = -1, d = \text{destination node}, \forall j \in J \quad (4)$$

$$X_{ij} \geq 0 \quad \forall i \in I, \forall j \in J \quad (5)$$

The objective function (1) minimizes total logistics costs, composed of shipping, loading/unloading, and transshipment costs, while minimizing transit time. Constraint (2)

guarantees that unit of traffic flow leaves the origin node (source). Constraint (3) represents a flow conservation constraint that ensures the conservation of unit of traffic flow as it moves through the inland logistics network. Constraint (4) specifies that unit of traffic flow arrives at the destination node. The shortest path can be identified as the connected sequence of arc  $(i, j)$  such that  $X_{ij} = 1$ . Constraint (5) assures the non-negativity of decision variable  $X_{ij}$ .

## Dialogue Management Subsystem Direct Shipment

At best, the model is an abstraction of real-world situations. Consequently, it cannot capture reality without running it more than once (Dyer and Mulvey, 1983; Min, 1989). Thus, the model should enable MNF's or public transportation planners to evaluate "what-if" scenarios associated with changes in the logistics strategy (e.g., a shift from cost savings to prompt delivery services or vice versa), accessibility to logistics infrastructure (e.g., inland transportation hubs, terminals, rail sidings) and government regulations and rules. In other words, the model's successful implementation depends on its flexibility for contingency planning. To enhance the model flexibility, the results of the model runs should be reported in user-friendly formats. These formats include standardized reports such as spreadsheets and tables summarizing cost saving opportunities and figures depicting routing options.

## MODEL-BASED DSS APPLICATION AND RESULTS

The developed DSS was applied to an actual inland logistics problem encountered by a MNF headquartered in Korea. To protect the confidentiality of the MNF, it is referred to as "Blue Star." The company sells its finished products to Chinese retailers and distributors located in inland cities throughout the Yangtze River Delta area. These products are often shipped to the major port of entry, Shanghai, which is equipped with gantry cranes that can handle containerized

shipments originating from foreign ports. To reach inland destinations, Blue Star explored several different transportation options that are available to the shipper. The selection of the particular mode of transportation also affects the shipping routes. For example, barge transportation cannot provide door-to-door service and thus necessitates transshipment through inland river-ports such as Nanjing, Wuhan, and Chongqing (see Figure 4). Since these inland ports are not on the direct path to final destinations, the use of barge creates a lengthy detour and takes more time to deliver the products. However, barge is still one of the cheapest modes of transportation and provides significant cost saving opportunities.

To solve both modal selection and shipping route problems described above, the authors developed the shortest path model under three different scenarios: (1) cost minimization; (2) transit time minimization; (3) best compromise between cost and transit time minimization. The results of the model experiment under these three scenarios are summarized in Table 2. As Table 2 indicates, the intermodal option (i.e., barge-rail) turned out to be the least expensive mode of transportation for each path, but the slowest mode of transportation. On the other hand, the all truck option turned out to be the most expensive mode of transportation, but with the fastest transit time (Figures 5 and 6). In fact, all truck is three

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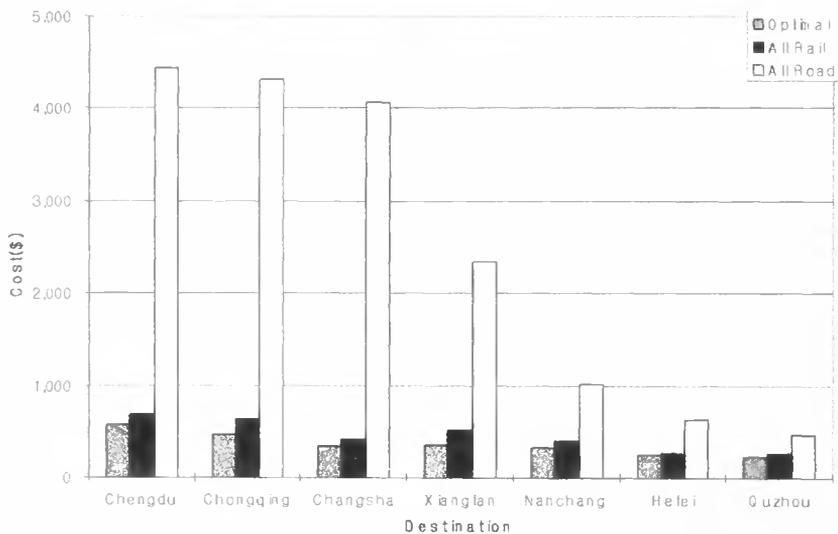
**FIGURE 4**  
**THE GRAPHICAL DISPLAY OF INLAND TRANSFER POINTS**



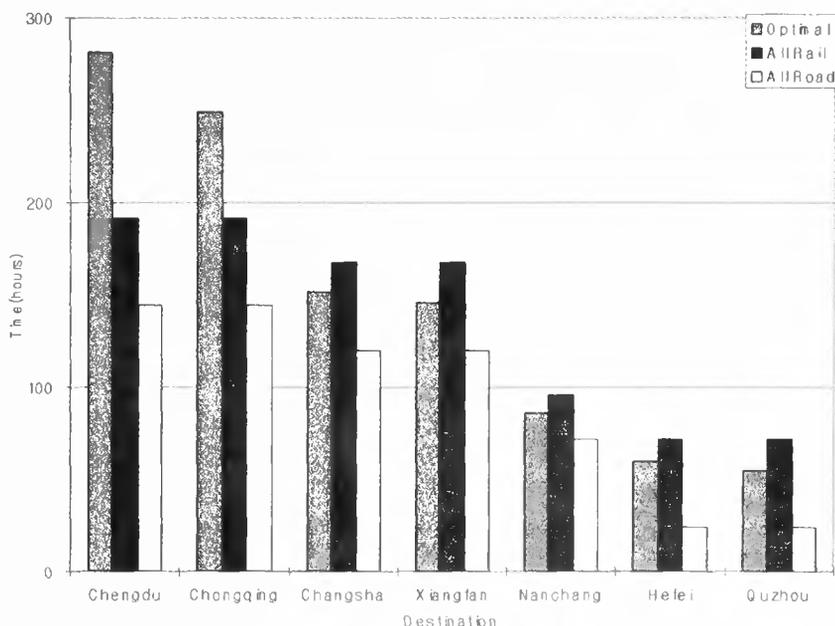
**TABLE 2**  
**THE COMPARISONS OF THE THREE ALTERNATIVE MEANS OF TRANSPORTATION**

From Shanghai to	Province	Intermodal (Barge-Rail)		All Rail		All Road	
		Cost (\$)	Time (hr)	Cost (\$)	Time (hr)	Cost (\$)	Time (hr)
Chengdu	Sichuan	555	275	700	220	4,440	144
Chongqing	Chongqing	453	310	690	200	4,320	144
Changsha	Hunan	530	282	850	240	4,070	120
Xiangfan	Hubei	580	292	610	185	2,350	120
Nanchang	Jiangxi	550	216	580	170	1,010	72
Hefei	Anhui	265	131	300	85	640	24
Quzhou	Zhejiang	110	30	110	30	470	24

**FIGURE 5**  
**THE COST COMPARISONS OF THE THREE ALTERNATIVES**



**FIGURE 6**  
**THE TIME COMPARISONS OF THE THREE ALTERNATIVES**



times as expensive as all rail on average, but nearly twice as fast as all rail. To summarize, by using the weight of 0.8 and higher to the cost criteria, the combination of barge-rail intermodal mix created the optimal routes for all inland destinations with an exception of Quzhou (see Table 3).

Also, it is worth noting that the transfer of shipments from barge to rail can take place at several inland river-ports such as Nanjing, Wuhan, and Chongqing. To elaborate, Nanjing is situated at the lower reaches of the Yangtze River and is currently open to navigation for 35,000 ton vessels all year long. It is capable of making river/sea transshipment and water/land transshipment with an annual cargo throughput of over 60 million tons. As the largest river-port along the Yangtze River

with an annual throughput capacity exceeding 400,000 TEU's, it has easy rail access with an 18 km port railway. Wuhan Port is located in the middle reaches of the Yangtze River and is designated as a Class 1 inland river-port. This port can handle vessels up to 3,000~5,000 tons. Frequent feeder service is available between Wuhan and other ports along the Yangtze River. The port can handle up to 900,000 tons in general cargo and 25,000 TEU's of container traffic a year. Chongqing Port is in the upper stream of the Yangtze River. This port is linked through the various railways of Chengdu-Yu, Xiang-Yu, Yu-Qian, and Yu-Huai, and the freeways of Cheung-Yu, Yu-Qian, Chongqing to Wuhan, and Chongqing to Changsha. Thus, Chongqing is suited for inland transfer. Its cargo throughput capacity reaches 9 million tons a year.

**TABLE 3**  
**THE SUMMARY OF THE OPTIMAL SHIPPING ROUTES**

<b>Destination</b>	<b>Criteria</b>	<b>Optimal Routes</b>
Chengdu (Sichuan)	Cost Time Multiple	Shanghai-(water)-Chongqing port-(rail)-Cheongdu Shanghai-(road)-Cheongdu Shanghai-(water)-Chongqing port-(rail)-Cheongdu
Chongqing (Chongqing)	Cost Time Multiple	Shanghai-(water)-Chongqing port-(rail)-Chongqing Shanghai-(road)-Chongqing Shanghai-(water)-Chongqing port-(rail)-Chongqing
Changsha (Hunan)	Cost Time Multiple	Shanghai-(water)-Wuhan port-(rail)-Changsha Shanghai-(road)-Changsha Shanghai-(water)-Wuhan port-(rail)-Changsha
Xiangfan (Hubei)	Cost Time Multiple	Shanghai-(water)-Wuhan port-(rail)-Xiangfan Shanghai-(road)-Xiangfan Shanghai-(water)-Wuhan port-(rail)-Xiangfan
Nanchang (Jiangxi)	Cost Time Multiple	Shanghai-(water)-Nanjing-(rail)-Nanchang Shanghai-(road)-Nanchang Shanghai-(water)-Nanjing-(rail)-Nanchang
Hefei (Anhui)	Cost Time Multiple	Shanghai-(water)-Nanjing-(rail)-Hefei Shanghai-(road)-Hefei Shanghai-(water)-Nanjing-(rail)-Hefei
Quzhou (Zhejiang)	Cost Time Multiple	Shanghai-(rail)-Quzhou Shanghai-(road)-Quzhou Shanghai-(rail)-Quzhou

Note: Multiple refers to the use of multiple criteria with assigned weight of 0.8 or higher for cost and assigned weight of 0.2 or lower for transit time.

### **CONCLUDING REMARKS AND FUTURE RESEARCH DIRECTIONS**

In the era of globalization, some supply chains include customers or suppliers that are located in inland regions isolated from major transportation arteries such as waterways. Despite increasing needs to reach inland customers or suppliers, a vast majority of the existing literature has overlooked the unique logistical challenges associated with last-mile transportation to and from inland regions. Since the failure to cope with these logistical challenges can lead to declining international trade and lagging economic development involving the inland

areas, this article reported on a mode-based DSS that can aid MNF's in making the decision as to which mode of transportation should be used and which routes should be taken to reach inland destinations at minimum cost and time. The DSS experimentation revealed that it presented promise in solving practical inland logistics problems that arose in the Yangtze River Delta area in China. The model can also provide valuable insights into various what-if scenarios, including the options of both direct shipment from the port of entry to inland destinations and indirect shipment via inland transfer points. Despite these merits, the proposed DSS points to a number of directions for future work:

- (1) The DSS can be expanded to include the element of risk and uncertainty involved in the inland logistics network design problem.
- (2) The theme of future research should include dynamic design of the inland logistics network which reflects the time-sensitivity of cost parameters over a multiple planning horizon.
- (3) In addition to the consideration of cost and time, future research can add another criterion such as delivery reliability to the multiple criteria decision.
- (4) A series of model experimentations with varying weights of the multiple criteria may yield insight into the sensitivity of model results to changes in the relative importance of multiple criteria.
- (5) Future research can explore how the backhaul option can influence the route structures and intermodal transportation choices.

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