THE NETWORK DESIGN OF CHINA'S NORTHEAST COLD CHAIN

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ABSTRACT

Yet logistics base in China has a refrigerated storage facilities installed areas, the number of those is very limited and is generally insufficient. According to these especial points, a new construction cold chain logistics network design strategy is required from how to use the existing refrigerated warehouses to new issue.

For example, however refrigerated storage facility is supplied, can it satisfy all demand of this area? Then does it have optimized location of this area? If future demand expansion, adding that already other refrigerated storage facilities matter? Or, add another refrigerated facilities, optimum cold chain established a network matter? So on. Above problems can be occurred. In order to solve facing many of these issues of distribution network, northeast area in China has been selected as a subject, and we designed a new cold chain distribution network.

Keywords: Cold chain, Integer programming, Logistics network design, Logistics cost

1. INTRODUCTION

In 2012, China recorded gross domestic product of CNY 353,480 (by September) and a growth rate of 7.7% from the same period last year. Although the speed of China's economic growth has slightly slowed down from the past, the country's economic growth continues to display a trend of increase based on the domestic demand (especially consumption). In line with the expansion of domestic market, China's international trade is also increasing.

According to an announcement of Chinese Meat Association, 2011 in China recorded 894,000 tons of meat export and a growth rate of 1.1% from the same period in the previous year. However, the country's import increased by 23.1% from the previous year to 1.905 million tons. As a result of an increase in the domestic meat demand, China's domestic price continuously increased, leading to a trend of increase in the country's meat import as a preparatory measure. Logistics business to import, store and transport frozen food is an attractive business. However, foreign logistics companies are facing difficulties as they endeavor to enter China's frozen logistics market due to lack of facilities and inferior road conditions in China. In other words, although the frozen food consumption increases in line with an expansion of China's domestic frozen freight market, According to report of China Warehousing Association, China is recording a loss of CNY 100 billion or more a year due to a lack of cold chain infrastructures in the country. At present, China uses discarded refrigerated containers that have previously been used in ships. These containers do not produce proper refrigeration function. In addition, there are no vehicles especially designed for container transportation. All of these factors add to difficulties in successful cold chain operation. In other words, refrigeration technology for transport using general vehicles is inferior and this leads to problems in keeping standard freshness of products, and thus in logistics and distribution of frozen food items.

As a result of such problems, refrigerated freight transport in China accounts for only around 10 - 20% of total transport freight, which is significantly lower than 80 - 90% in the advanced countries in Europe as well as the U.S. and Japan. As of 2011, the area of refrigerated and frozen storage facilities in China measures 70 million square meters. This is far insufficient to satisfy the refrigerated transport market demand. The annual average increase rate of refrigerated and frozen facilities construction in 2009~2011 is 7.94% and most constructions are to build large-scale storage facilities. The performance of refrigerated and frozen facilities construction for wholesale and retail business is unsatisfactory as a whole.

This study targets the northeastern part of China and aims at solving the problems of logistics network design to distribute imported frozen meat products that enter the country through Dalian Port at the minimum cost. The problems in logistics network design are as follows.

1) To select distribution center locations?
2) To decide the number of distribution centers?
3) To decide the size of distribution centers?
4) To decide which of the central and regional distribution centers are to distribute which products at which level?
5) To decide which products are to be distributed at which level from regional distribution centers to consumers?

For designing of a cold chain logistics network for a foreign invested logistics company that enters the refrigerated distribution market in China, the purpose of this study is to propose the optimal solution for a cold chain logistics network that minimizes the total cost.

2. LITERATURE REVIEW

Studies on logistics network design using a deterministic model have been developing since a study by Geoffrion et al. (1974) On a design of a logistics network for multiple products. This model has since expanded to studies on more realistic issues, such as growth, storage and distribution. On the subject of a logistics network design, a number of studies have been conducted in relation to single/multiple-step network, multi-stage network, ability restraining network and single/ multi-product network.

Studies on the single-step facility locations without limitations in facility capacity were conducted by Melkote and Deskin (2001)

In addition, studies on multi-stage facility locations with capacity limitations were conducted by Chardaire et al. (1999) and studies on facility locations for multiple products were conducted. Brown et al. (1987) suggested a mixed integer programming model for production and distribution system of multiple products and implemented it in a similar decomposition method as of the algorithm of Geoffrion et al. (1974)

In addition, Cohen et al. (1988) studied a mixed integer programming method for a network flow model of multiple products in order to find an optimal product flow in the integrated logistics.

Studies conducted over a number of periods of times were conducted by Beamon et al. (2004) and Melachrinodis et al. (2000) conducted a study to design a multi-period and multi-purpose mixed integer programming model to suggest the optimal relocation bases.

This study was differentiated from the existing studies as it took into consideration the multi-layer network design and dynamic aspects.

There are other studies on implementation of a logistics network design in the form of hub and spoke. These studies are divided into the cases of

Amiri (2006) conducted a study focusing on the issues of distribution network design in logistics system. This study also used the mixed integer programming model and suggested a heuristic solution.

Fleischmann et al. (2006) studied the issues concerning supply of materials and distribution of finished products in the global market over a long period of time by suggesting a strategic programming model for optimized allocation of BMW's diverse products.

Hugo and Pistikopoulos (2005) conducted a study focusing on the issues of production capacity expansion and transportation-linked allocation to satisfy market demands, and thus suggested materials flow and production profile that are optimized to various layers within the logistics network.

Ko and Evans (2007) mentioned that 3PL companies must determine orders of the related decision-making processes for customers who want improvement in the forward and recovery logistics systems and suggested the mixed integer nonlinear programming for an integrated dynamic logistics network design to achieve forward and recovery logistics integration and optimization.

Melachrinoudis and Min (2000) conducted a study to assess implementation possibility of the multi-period and multi-purpose mixed integer nonlinear programming within dynamic changes in regions that have been proposed from a viewpoint of supply network. In the 2000s, a number of studies considering issues of both the location selection and inventory were conducted by Teo et al. (2004) suggested a set-covering model to design a network between distribution centers and retailers under a determinate demand of retailers, while Daskin et al. (2002) suggested a set-covering model to create the optimal logistics with inventory cost and that their studies could be carried out more efficiently when demand of each distribution center was determinate or in Poisson distribution.

Dogan and Goetschalckx (1999) suggested a mixed integer linear model targeting multiple products for integrated logistics design and used Bender's decomposition algorithm to solve large-scale problems.

Erlebacher and Meller (2000) studied a model to minimize transportation cost between retailers and distribution centers and between manufacturers and distribution centers and inventory cost, fixed cost and operating cost in distribution centers.

Eskigun et al. (2005) studied a logistics network design considering the selection of transportation means, selection of distribution center locations and the required time and suggested a solution more efficient than the rationally calculated time as a Lagrangian heuristic model.

The previous studies on logistics network design focused on the initial-phase design of the existing logistics networks and a majority of them aimed at minimizing transportation cost as well as costs associated with facility capacity and vehicle routes considering several characteristics. However, there is still a lack of optimized model design that preferentially takes into consideration the overall cost within the range of study in addition to individual costs incurring in logistics network design. Accordingly, this study attempted at designing optimal networks under two scenarios where the existing refrigerated facilities are used while customers' demand fluctuations based on constrain conditions, the variable costs and the fixed costs are compositely taken into consideration and where the existing facilities are used without considering these factors.

3. LOGISTICS NETWORK MODEL DESIGN

3.1. Logistics Network Model Design

The main purpose of this study is to minimize logistics cost between nodes and links in solving the problems of cold chain logistics network design in the northeastern part of China. For freights gathered from producing districts through CDCs, the issue is limited to the problem of selecting RDCs from the candidates, which is solved using an object function on logistics cost minimization. In this study, the cold chain logistics network analysis in the northeastern part of China was modeled as shown in [Fig.1]

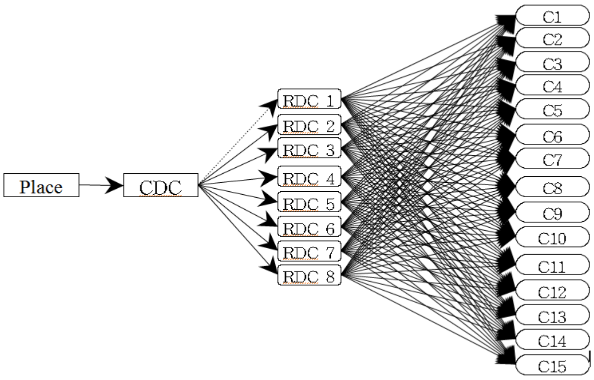

Figure 1: Logistics Network Flow

3.2. Minimum Cost Calculating Formula

The scope of this study consists with various nodes from producing districts to CDCs and from places of import through RDCs to demand areas. In this study, customers are selected as places of demand and logistics cost is comprised of transportation cost between each node and the fixed cost of RDCs.

The purpose of this study is to find RDCs and logistics network that minimize the total logistics cost. The optimal RDC selection lead to implementation of a logistics network and the formula to calculate the minimum logistics network cost is expressed as of the following.

$$\textbf{minimize} \sum_{ijkl} C_{ijkl} X_{ijkl} + \sum_{k} [F_k \ Z_k + V_k \sum_{l} \left(\sum_{i} D_{il} \right) Y_{kl}$$

This is a model formulation for a problem of multi-variety warehouse location using mixed integer linear programming method.

Constraining Factors:

The usable production capacity cannot be exceeded.

$$\sum_{kl} X_{ijkl} \leq S_{ij} \text{ for all } ij$$

All demands must be satisfied.

$$\sum_j X_{ijkl} = D_{il} Y_{kl} \text{ for all ikl}$$

Each consumer must be supplied with products from a single warehouse.

$$\sum_k Y_{kl} = 1 \text{ for all } l$$

Warehouse processing amount must be kept between $\underline{V}_k$ and $\overline{V}_k$

$$\underline{V_k} \leq \sum_l (\sum_i D_{il}) Y_{kl} \leq \overline{Y_k}$$

And, For all $X_{s,}$ $X \geq 0$

For all $Y_{s,}$ $Y = 0 \text{ or } 1$

For all $Z_{s,}$ $Z = 0 \text{ or } 1$

Where,

i = Number of item

j = Number of CDC

k = Number of RDC

l = Number of demand area

$\underline{V_k}, \overline{V_k}$ = RDC point k for the min. and max. allowed annual retention and operating cost

F_k = Fixed cost at RDC point k (fixed cost of the annual retention and operating cost)

V_k =Variable cost at RDC point k (variable cost of the annual retention and operating cost)

C_{ijkl} =Average unit cost in production, landing and transportation process from CDC j through RDC k to customer area l

X_{ijkl} =Transport amount of item i from CDC j through RDC k to customer area l

Y_{kl} =1 if warehouse k handles supply for customer area l, 0 if not

Z_k =1 if warehouse k is open 0 if not

3.3. Logistics Cost Calculating Method

In this study, the total logistics cost is comprised of fixed and variable costs. Fixed cost is divided into depreciation cost of warehouses, capital cost, insurance premium, sales and administrative cost and labor cost. Variable cost consists of handling and transportation cost, which fluctuates according to land transportation cost by distance and the amount of demand. A hierarchical structure of total logistics cost [Fig. 2].

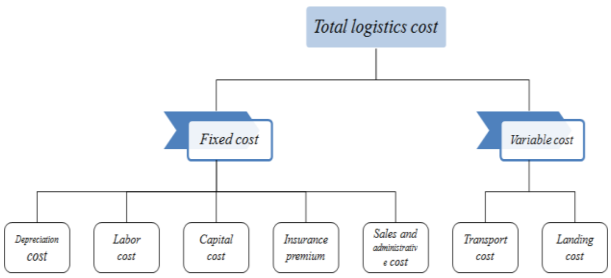

Figure 2: Structure of total logistics cost

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4. BASIC DATA COLLECTION

4.1. Demand in Each Demand Area

To find demand in each demand area, data outlining the amounts of frozen food consumption in each city were obtained. To calculate the amount of demand for imported frozen meat foods, the national daily average consumptions per person and total number of customers in each demand area were found. In addition, the ratio of meat food export to import in China was assumed as 5:5. As for the import of meat, it was assumed that the products are imported frozen, and thus the percentage of frozen meat to total amount of imported meat is 100%. Accordingly, the total annual demands in each demand area were estimated as the total amounts of import and annual average meat consumption per person is calculated as the total of annual average consumption of beef, pork and poultry that are mainly consumed in China.

Table 1: Annual Consumption by City

Unit: Ton

Consumption	Population (10,000 persons)	Annual Average Mean Consumption per Person	Imported/ Exported Meat Ratio	Frozen Meat to All Imported Meat	Demand
Dalian	303.4	0.03517	50%	100%	53,307
Yingkou	89.85	0.03517	50%	100%	15,800
Anshan	147.05	0.03517	50%	100%	25,858
Liaoyang	73.91	0.03517	50%	100%	12,997
Benxi	95.33	0.03517	50%	100%	16,763
Shenyang	513.83	0.03517	50%	100%	90,357
Fushun	138.70	0.03517	50%	100%	24,390.
Tieling	44.64	0.03517	50%	100%	7,849
Dandong	78.88	0.03517	50%	100%	13,871
Panjin	60.82	0.03517	50%	100%	10,695
Fuxin	77.79	0.03517	50%	100%	13,679
Jinzhou	93.36	0.03517	50%	100%	16,417
Chaoyang	58.68	0.03517	50%	100%	10,318
Huludao	99.56	0.03517	50%	100%	17,507
Qinhuangdao	84.50	0.03517	50%	100%	14,859
Total Demand	-	-	-	-	344,673

Source: 1) China City Statistical Yearbook, National Statistics of china, 2011.
2) Meat industry, second five development plan, China Meat Association, 2012.

4.2. Land Distance to Each Demand Area

The inland transportation cost is calculated with freight charges per ton - kilometer and distances. The results of measuring land distances to each demand area are listed in <Table 3>. For simple expression, names of the cities have been expressed with codes (see <Table 2>) Use the style labeled with "List 1" to create an enumerated list. Insert one blank line before starting the list.

Table 2: Input Code per City

Input Code per City					
DL	Dalian	SY	Shenyang	FN	Fuxin
YK	Yingkou	FS	Fushun	JZ	Jinzhou
AS	Anshan	TL	Tieling	CY	Chaoyang
LY	Liaoyang	DD	Dandong	HL	Huludao
BX	Benxi	PJ	Panjin	CH	Qinhuangdao

Names of 14 cities, the demand areas, were converted into codes. Then, land distances to and between each cities were measured as shown in <Table 3>

Table 3: Expressway and urban road network

Unit: km

	DL	YK	AS	LY	BX	SY	FS	TL	DD	PJ	FN	JZ	CY	HL	CH
DL	0														
YK	220	0													
AS	292	84	0												
LY	319	110	30	0											
BX	388	177	97	73	0										
SY	386	179	95	69	78	0									
FS	431	214	134	108	84	46	0								
TL	458	249	165	139	143	73	59	0							
DD	330	280	232	237	205	282	289	348	0						
PJ	260	61	97	122	192	155	201	228	324	0					
FN	435	205	186	194	262	205	251	244	419	143	0				
JZ	363	144	184	216	279	234	284	312	482	93	112	0			
CY	480	250	291	297	365	308	354	373	517	200	141	106	0		
HL	418	187	229	262	324	283	329	356	454	137	164	52	127	0	
CH	585	371	396	422	529	453	457	523	621	314	331	219	294	167	0

Source: China Expressway and urban road network, Shandong Province Map Publishing, 2011

4.3. Freight Charge per Ton-Kilometer

The freight charges for road transportation in China are calculated by dividing freights into grade 1, 2 and 3 general freights and hazard goods. Freight charges vary according to the item grade (See <Table 4>).

Table 4: Road Freight Grades

Road Freight Grades			
Grade 1	Grade 2	Grade 3	Hazard Goods
Coal, sand, stones and rocks,	Sand, water, grasses, cement	Oils, marble, rubber	Oils, explosive, fuses

Source: http://wenku.baidu.com/view

Freight charges for road transportation are as shown in <Table 5>. In this study, freight charges for each demand area are calculated based on long-distance transportation of 30km or more.

Table 5: Freight Charges according to Freight Grade

Unit: CNY(ton/km)

Grade & distance	Grade 1	Grade 2	Grade 3	Hazard Goods
1Km	1.75	2.013	2.275	2.625
5Km	0.88	1.012	1.144	1.32
10Km	0.76	0.874	0.988	1.14
15Km	0.66	0.759	0.858	0.99
20Km	0.56	0.644	0.728	0.84
25Km	0.46	0.529	0.598	0.69
30Km or more	0.35	0.400	0.460	0.53

4.4. Handling Cost

Handling cost is paid by ton of loading and unloading works. The standard landing tariffs in China are as shown in <Table 6>. Han cost varies according to the item type. In this study, which focuses on frozen foods, the landing cost for grade 2 freights (4.4/ ton) is applied.

Table 6: Landing Tariff

Unit: CNY/Ton

	Loading Cost	Unloading Cost	Total Landing Cost
Grade 1	1.8	1.2	3.0
Grade 2	2.2	2.2	4.4
Grade 3	4.0	3.8	7.8
Hazard Goods	4.0	3.8	7.8

5. OPTIMAL CALCULATION

5.1. Using Existing Refrigerated Logistics Warehouses in Dalian

When selecting three RDS, the selection would be carried out considering two already decided RDCs. For a solution with which the total logistics cost is minimized, RDCs in Dalian, Shenyang and Yingkou were selected. The total logistics cost in this case is CNY 91,268,719, which is lower than the cases where one RDC (Dalian) and two RDCs (Dalian and Shenyang) are selected. The logistics network composition is as shown in [Fig 3]

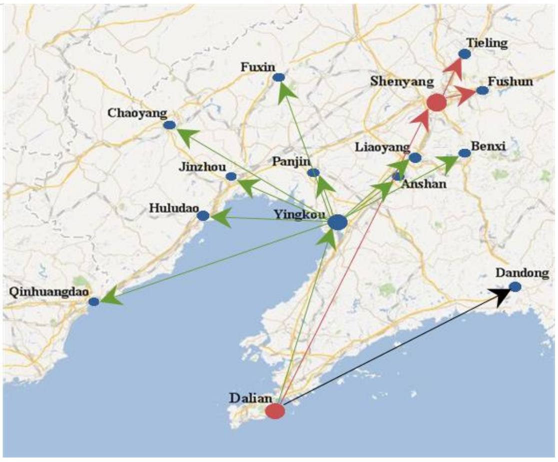

Figure 3: Logistics Network Composition when 3 RDCs are selected

Constraint conditions in this case are as follows. First, sizes of warehouses in Dalian, Shenyang and Yingkou (W1, W2 and W3) must satisfy total demand in each consumption area.

Second, ① Constraint condition is applied with actual volume of the existing refrigerated warehouses in Dalian (70,000 tons/ year), ② Constraint condition is applied with actual volume of the existing refrigerated warehouses in Shenyang (172,400 tons/ year).

Third, three out of eight RDCs are selected and the formula is as follows.

$$zW1+zW2+zW3+zW4+zW5+zW6+zW7+zW8 = 3$$

When selecting three RDCs, if RDCs in Dalian and Shenyang are the existing refrigerated warehouses of fixed capacities, the selection is limited to actual capacity of each warehouse. Aa for Yingkou, a condition that a single RDC can satisfy demand of the entire area was set. In this case, freights are sent to Dalian and Shenyang for as much as the available capacity of the proposed warehouses. On the other hand, all freights can be sent to Yingkou RDC. The results estimated using an optimization model also indicate a fixed capacity (Dalian and Shenyang) and a maximum capacity (Yingkou) rather than an appropriate capacity of the three RDCs. Therefore, the capacity of warehouses in Dalian, Shenyang and Yingkou are adjusted and the fixed costs are calculated again. The results of calculating fixed/ variable costs and total logistics cost are as shown in <Table 7>

Table 7: Transportation Amounts in 3 RDCs and Logistics Cost Calculation Results

Unit: CNY/Ton

3 RDC	Transportation Amount	Fixed Cost	Variable Cost	Logistics Cost
Dalian→ Dalian	53,307	21,225,420	895,558	
Dalian→ Dandong	13,871		2,002,972	
Shenyang→ Shenyang	90,357	14,753,412	14,348,690	
Shenyang→ Fushun	24,390		4,321,908	
Shenyang→Tieling	7,850		1,475,800	
Yingkou→ Yingkou	15,800	8,430,024	1,459,920	
Yingkou→Anshan	25,859		3,258,234	
Yingkou→ Liaoyang	12,997		1,772,791	
Yingkou→ Benxi	16,764		2,735,885	
Yingkou→ Panjin	10,695		1,249,176	
Yingkou→ Jinzhou	16,417		2,462,550	
Yingkou→ Fuxin	13,679		2,385,618	
Yingkou→ Chaoyang	10,319		1,985,376	
Yingkou→ Huludao	17,508		2,927,337	
Yingkou→ Qinhuangdao	14,859		3,578,048	
Total	344,672	44,408,856	46,859,863	91,268,719

5.2. Selecting Optimal Warehouse Position without Taking into Consideration the Existing Refrigerated Warehouses

If the existing refrigerated warehouses are not taken into consideration, Yingkou is selected as the optimal solution. In designing an optimal logistics network, the total logistics cost is estimated as CNY 69,199,910. This is lower than a case where Dalian is selected as the solution. The logistics network composition is shown in [Fig. 4].

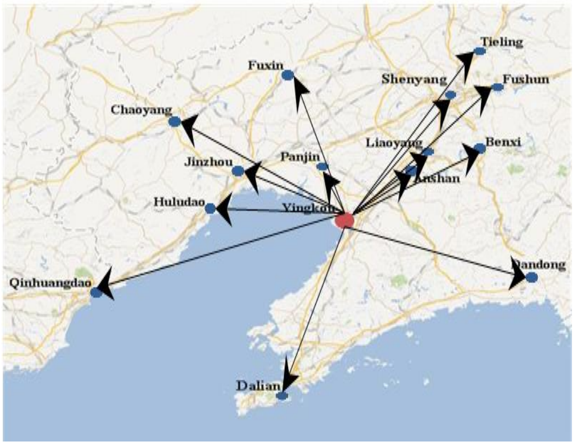

Figure 4: Logistics Network Composition when 1 RDC is Selected (2)

In case of a one RDC, the total logistics cost was estimated as CNY 69,199,910 based on calculations of transportation amounts, variable costs and fixed costs in each consumption area. The results of total logistics cost calculation are as shown in <Table 8>.

Constraint conditions in this case are as follows. First, sizes of warehouses in Yingkou (W3) must satisfy total demand in each consumption area.

Second, the following formula must be satisfied by selecting one distribution center in Yingkou out of eight RDCs

$$zW1+zW2+zW3+zW4+zW5+zW6+zW7+zW8 = 1$$

Table 8 Transportation Amounts in 1 RDC and Logistics Cost Calculation Results

Unit: CNY/Ton

1 RDC	Transportation Amount	Fixed Cost	Variable Cost	Logistics Cost
Yingkou-Dalian	53,307	12,052,764	9,829,811	
Yingkou-Shenyang	90,357		14,818,550	
Yingkou- Yingkou	15,800		1,459,920	
Yingkou- Anshan	25,859		3,258,234	
Yingkou-Liaoyang	12,997		1,772,791	
Yingkou- Benxi	16,764		2,735,885	
Yingkou-Panjin	10,695		1,249,176	
Yingkou-Jinzhou	16,417		2,462,550	
Yingkou-Fushun	24,390		4,341,420	
Yingkou-Teiling	7,850		1,507,200	
Yingkou-Dandong	13,871		2,835,232	
Yingkou-Fuxin	13,679		2,385,618	
Yingkou-Chaoyang	10,319		1,985,376	
Yingkou-Huludao	17,508		2,927,337	
Yingkou-Qinhuangdao	14,859		3,578,048	
Total	344,673	12,052,764	57,147,148	69,199,912

6. OPTIMAL TREND OF TOTAL LOGISTICS COST ACCORDING TO CHANGES IN RDC COUNT

6.1. Using Existing Refrigerated Warehouses in Dalian and Shenyang

When the existing refrigerated warehouses in Dalian and Shenyang are taken into consideration, the fixed costs display a trend of a decrease and then an increase according to changes in the number of RDCs. When one and two RDCs are selected, the total logistics cost is higher than when three RDCs are selected. This is because, first, a large amount of demand exists in Dalian and Shenyang and, second, the fixed costs in Dalian and Shenyang are high. Therefore, fixed costs increase when one and two RDCs are selected and then decrease when three RDCs are selected.

It picks up an upward trend and continues the increase when four or more RDCs are selected. As for variable costs, they decrease significantly when one, two and three RDCs are selected. Then, the value gradually drops when four or more RDCs are selected. This pattern corresponds to the phenomenon detected in this study. The trend of total logistics cost according to changes in RDC count is shown in [Fig. 5]

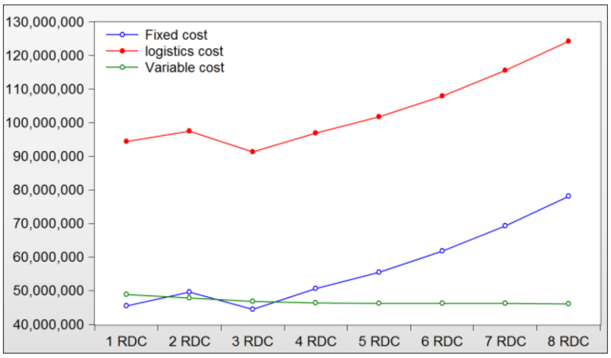

Figure 5: Total Logistics Cost Fluctuation according to Changes in RDC Count (1)

6.2. Using Existing Refrigerated Warehouses in Dalian and Shenyang

When the existing refrigerated warehouses in Dalian and Shenyang aren't taken into consideration, fixed costs display a trend of continuous increase according to changes in the RDC count. Variable costs significantly decrease when one and two RDCs are selected. Variable costs decrease slightly when two-seven RDCs are selected and then again start to decrease significantly when eight RDCs are selected. Total logistics cost increases continuously as the number of RDCs increases. Therefore, the case of one RDC selection is estimated as an optimal solution. The trend of total logistics cost according to changes in RDC count is as shown in [Fig. 6]

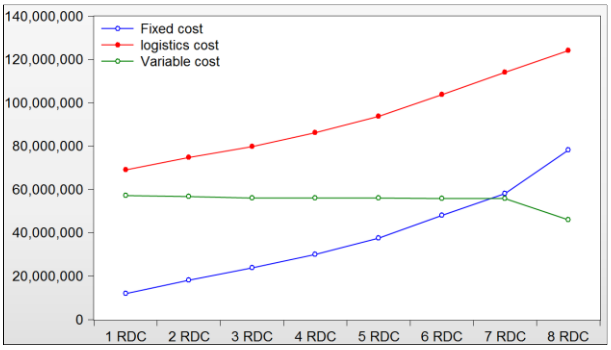

Figure 6: Total Logistics Cost Fluctuation according to Changes in RDC Count (2)

7. CONCLUAION

This study aimed at demonstrating the significant contributions of cold chain network design to logistics base network optimization. In China, frozen food imports increase rapidly in line with an expansion of the domestic market for cold chain products. Accordingly, the country faces a necessity of a cold chain logistics network design. Some logistics bases in China have refrigerated and frozen warehouse facilities installed. However, the number is extremely limited and the facilities are insufficient as a whole. Accordingly, China is in need of various strategies for cold chain logistics network design that cover from a method using the existing refrigerated warehouses to a method of building new facilities. For example, it is necessary to address such problems as which refrigerated warehouse facilities can satisfy total demands of the respective areas, whether the facilities are built on optimal locations in the respective areas and, in case of expansion in future demand, if it is necessary to establish an optimal cold chain network by adding to the existing refrigerated facilities or building other facilities. In this study, a cold chain logistics network was designed targeting the northeastern part of China in order to solve such issues in the logistics network. The effects of the optimized cold chain network solution derived from this study are summarized as of the following. First, if the existing refrigerated warehouses in Dalian and Shenyang are taken into consideration, fixed costs display a trend of a decrease and then an increase according to changes in the RDC count. In addition, the total logistics cost is higher when one and two RDCs are selected than when three RDCs are selected. This is because, first, a large amount of demand exists in Dalian and Shenyang and, second, the fixed costs in Dalian and Shenyang are high. Therefore, fixed costs increase when one and two RDCs are selected and then decrease when three RDCs are selected. It picks up an upward trend and continues the increase when four or more RDCs are selected. As for variable costs, they decrease significantly when one, two and three RDCs are selected. Then, the value gradually drops when four or more RDCs are selected. This pattern corresponds to the phenomenon detected in this study.

Second, when the existing refrigerated warehouses in Dalian and Shenyang are not taken into consideration, fixed costs display a trend of continuous increase according to changes in the RDC count. Variable costs significantly decrease when one and two RDCs are selected. They decrease slightly when two - seven RDCs are selected and then again start to decrease significantly when eight RDCs are selected. Total logistics cost increases continuously as the number of RDCs increases. Therefore, the case of one RDC selection is estimated as an optimal solution.

ACKNOWLEDGMENTS

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