Optimization of International Inter-Modal Logistics Utilizing Genetic Algorithm

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Abstract: In recent years, inter-modal international logistics is becoming a big trend. Sea and air transport is a term of inter-modal international logistics. Sea and air transport is developing rapidly in recent years.
However, papers concerning sea and air transport can hardly be seen especially for mathematical formulation and its analysis. In this paper, we make mathematical formulation of the case single supply site and single demand site with multiple delivery date / different delivery quantities as of a fundamental one. Under certain constraints, minimum cost is pursued. Next, expansion is executed as for the case single supply site and multiple demand sites. Numerical example is examined and optimal solution is derived using genetic algorithm. Finally, formulation expansion is executed as for the case multiple supply sites and multiple demand sites. By formulating sea and air transport problem, it can be handled clearly and smoothly. Various solving methods should be examined hereafter.

Key words: inter-modal international logistics, sea and air, integer programming, logistics, genetic algorithm

1. PREFACE

In the evolving environment surrounding international logistics, intermodal transportation supported by containerization has become the mainstream concept. This is the method devised to come through the demand of complex international logistics which has a function of consistent and across-the-board control from production to consumption.

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There is no clear legal definition of inter-modal international logistics. At present, however, the definition of international multimodal transport of goods in the United Nations Convention on International Multimodal Transport of Goods, adopted at the UN Conference on Trade and Development (UNCTAD) on May 24, 1980, is generally accepted. It stipulates, "'International multimodal transport means the carriage of goods by at least two different modes of transport on the basis of a multimodal transport contract from a place in one country at which the goods are taken in charge by the multimodal transport operator to a place designated for delivery situated in a different country."

According to this, international multimodal transport has the following three prerequisites.

1. It must use at least two different modes of transport (by ship, rail, automobile, air plane).
2. It must be based on one transport contract, that is, on a through bill of lading.
3. It must be the transport of goods between two different countries.

It is, in other words, a "trinity" of "international", "multi-modal" and "comprehensive" transport services.

Sea and air transport is a form of inter-modal international logistics and is growing rapidly. The advantage of this method is as follows.

1. A smaller number of days required for transport compared to the sea-only mode.
2. Less expensive freight costs compared to air-only mode.
3. Possibility of timely transport of the proper amount in response to commodity demand.
4. Possibility of logistic cost saving, in inventory adjustment, storage fee, etc (Okita et al. 2004).

However, papers concerning sea and air transport can hardly be seen especially for mathematical formulation and its analysis. In this paper, we make mathematical formulation of the case single supply site and single demand site with multiple delivery date / different delivery quantities as of a fundamental one. Under certain constraints, minimum cost is pursued. Next, expansion is executed as for the case single supply site and multiple demand sites. Numerical example is examined and optimal solution is derived using genetic algorithm. Finally, formulation expansion is executed as for the case multiple supply sites and multiple demand sites. By formulating sea and air transport problem, it can be handled clearly and smoothly. Various solving method should be examined hereafter.

Mathematical formulation is executed and numerical example is exhibited in 2. 3. is a summary.

2. FOR THE OPTIMIZATION OF SEA AND AIR TRANSPORTATION

In pursuit of the optimization of sea and air transport, the following study was conducted. To simplify the problem, there is only one each of supply site and demand site in this hypothesis. As shown in Figure 1, there is a transit point. In the case of sea and air transport, it goes by "sea-transport" from the supply site to the transit point and by "air-transport" from the transit point to the demand site. If what is between the supply site and the transit point is the sea and between the transit point and the demand site is the sky, there can be multiple means of transport, as shown in Figure 1. Over the sea, sea-transport and air-transport are possible, and over the land, aside from the air-transport, rail and trucks are the possible

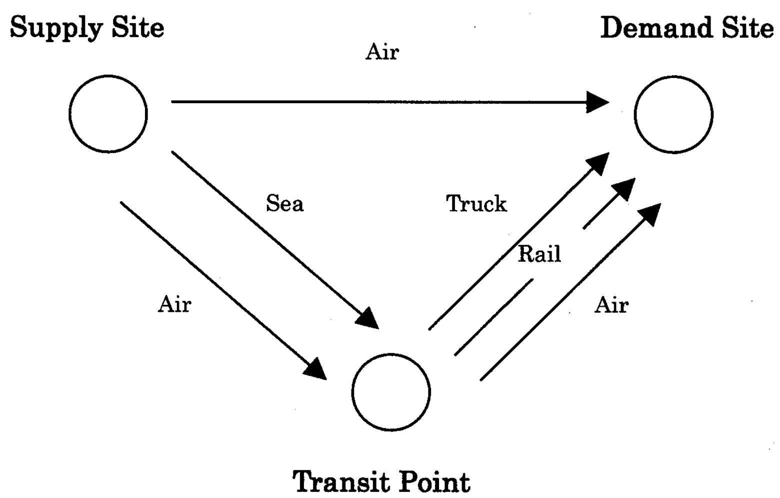

Figure 1: Sea and Air Transport

means of transport. Also, a variation such as "piggyback" may be used. In this study, air, rail and truck transport are considered. In real life, however, there is also a choice of using air-transport from the supply site directly to the demand site, without stopping at the transit point. But to solve the problem, it is possible to describe, as a matter of form, a case that does not use a transit point as if it had used a transit point, by choosing the parameter as air (1) with transit or air (2) without transit.

(1) Multiple delivery dates/different delivery quantity/a single demand site

Constraint a_l (quantity) must be delivered within N_l days (l=1, ⋯, m)
The least possible transportation cost to satisfy the above:
L_{ij}, is the distance between i and j, k expresses the means of transport x for absence/presence of transportation-transportation is $x_{ij}^l(k)$.
Different means of transport: $k=1$: sea, $k=2$: air, $k=3$: truck, $k=4$: rail
Time(days) required for transportation $N_{ij}(k)$ from i to j by means of k is expressed as

$$N_{ij}(k) = d_{ij}(k)L_{ij}+e_{ij}(k) \tag{1}$$

$d_{ij}(k)$, $e_{ij}(k)$: The constraint term and the proportional term
Firstly,

$$x_{12}^l(k) = 1{,}0 \qquad (k=1, 2), (l=1, \cdots, m) \tag{2}$$

$$x_{23}^l(k) = 1{,}0 \qquad (k=2, 3, 4), (l=1, \cdots, m) \tag{3}$$

$$\sum_{k=1}^{2} x_{12}^l(k) = 1 \qquad (l=1, \cdots, m) \tag{4}$$

$$\sum_{k=2}^{4} x_{23}^l(k) = 1 \qquad (l=1, \cdots, m) \tag{5}$$

$$\sum_{k=1}^{2} \{d_{12}(k)L_{12}+e_{12}(k)\} x_{12}^l(k) + \sum_{k=2}^{4} \{d_{23}(k)L_{23}+e_{23}(k)\} x_{12}^l(k) \leq N_l (l=1, \cdots, m) \tag{6}$$

$$\sum_{l=1}^{m} a_l = a_0 \tag{7}$$

Secondly, to seek the transportation cost minimization:

$$Z = \sum_{l=1}^{m} \left\{ \sum_{k=1}^{2} C_{12}(k) L_{12} x_{12}^{l}(k) + \sum_{k=2}^{4} C_{23}(k) L_{23} x_{23}^{l}(k) \right\} a_l \rightarrow Min \quad (8)$$

$C_{ij}(k)$ is a unit cost for transporting from i to j by means of k.

Hence, the following can be used for sea-and-air, but not in all cases limitlessly. As far as only these are considered as they are, there is little difference between these and the conventional transportation problems. However, as soon as the number of involved sites (Supply/Transit/Supply sites) becomes larger, the number of variables dramatically grows greater, to which application of Genetic Algorithm solution and Neural Network solutions may be appropriate.

There are various means to solve this problem. Focusing that variable takes 0 or 1, application of genetic algorithm would be a good method. Above case is rather simple, therefore calculation of all cases can be easily executed. As is well known, calculation volume amounts to be numerous or infinite in these problems when the number of variables increase. It is reported that GA is effective for these problems (Gen et al. (1995), Lin et al. (2005), Gen et al. (2005), Zhang et al. (2005)).

A. The variables

The numbers of variables are twenty.

$$x_{12}^{l}(k) = 1, 0 \qquad (k = 1, 2), (l = 1, \cdots, 4)$$
$$x_{23}^{l}(k) = 1, 0 \qquad (k = 2, 3, 4), (l = 1, \cdots, 4)$$

Therefore, set chromosome as follows:

$$x = (x_{12}^{1}(1), x_{12}^{1}(2), x_{12}^{2}(2), x_{12}^{3}(1), x_{12}^{3}(2), x_{12}^{4}(1), x_{12}^{4}(2), x_{23}^{1}(2), x_{23}^{1}(3), x_{23}^{1}(4), x_{23}^{2}(2), x_{23}^{2}(3), x_{23}^{2}(4), x_{34}^{3}(2), x_{23}^{3}(3), x_{23}^{3}(4), x_{23}^{4}(2), x_{23}^{4}(3), x_{23}^{4}(4)) \quad (9)$$

B. Initialize population

Initialization of population is executed. The number of initial population is N. Here set $N = 10$.

Set gene at random and choose individual which satisfy constraints.

C. Selection

In this paper, we take elitism while selecting. Choose P individual in the order which take minimum score of objective function.
Here, set P as N.

D. Crossover

Here, we take one-point crossover and the point lies between $x_{12}^{l}(k)$ and $x_{23}^{l}(k)$ from the characteristic of this problem.
Set crossover rate as

$$P_c = 0.7 \tag{10}$$

D. Mutation

Set mutation rate as

$$P_m = 0.01 \tag{11}$$

Algorithm of GA is exhibited at Table1.

Table 1: Algorithm of GA

Step1: Set maximum generation No. as $g_{\max}$, population size as P, crossover rate as P_c, mutation rate as P_m.
Step2: Set $t=1$ for generation No. and generate initial solution matrix $x_m(t)=(x_{ijkl}^{p})\ (p=1,\cdots,P)$.
Step3: Calculate objective function $Z(x_p(t))$ for all solution matrix $x_p(t)\ (p=1,\cdots,P)$ in generation t.
Step4: Set $t=t+1$
Until $t>g_{\max}$.
Step5: Crossover
Generate new individual by crossover utilizing the method of above stated D.
Step6: Mutation
Reproduce by mutation utilizing the method of above stated E.
Step7: Calculate objective function for reproduction of generation t.
Step8: Selection
Next generation is selected by elitism.
Go to Step4.

Considering the condition

$$\sum_{k=1}^{2} x_{12}^{l}(k) = 1 \qquad (l = 1, \cdots, 4)$$

$$\sum_{k=2}^{4} x_{23}^{l}(k) = 1 \qquad (l = 1, \cdots, 4)$$

introducing the variables

$$y_{12}^{l},\ y_{23}^{l} \qquad (l = 1, \cdots, 4)$$

which satisfy

$$\begin{cases} y_{12}^{l} = 1:\ x_{12}^{l}(1) = 1 & (l = 1, \cdots, 4) \\ y_{12}^{l} = 0:\ x_{12}^{l}(2) = 1 \end{cases}$$

$$\begin{cases} y_{23}^{l} = 1:\ x_{23}^{l}(2) = 1 & (l = 1, \cdots, 4) \\ y_{23}^{l} = 0:\ x_{23}^{l}(3) = 1 \\ y_{23}^{l} = -1:\ x_{23}^{l}(4) = 1 \end{cases} \qquad (12)$$

then (9) is abbreviated into the following 8 variables

$$x = (y_{12}^{1},\ y_{12}^{2},\ y_{12}^{3},\ y_{12}^{4},\ y_{23}^{1},\ y_{23}^{2},\ y_{23}^{3},\ y_{23}^{4}) \qquad (13)$$

Where

$$y_{12}^{1} = 1$$

corresponds to

$$(x_{12}^{1}(1),\ x_{12}^{1}(2)) = (1, 0)$$

and

$$y_{23}^{4} = -1$$

corresponds to

$$(x_{23}^{4}(2),\ x_{23}^{4}(3),\ x_{23}^{4}(4)) = (0, 0, 1)$$

(2) When there are multiple demand sites

The volume a_l^p, to be transported between different bases, is delivered to the point of demand within $N_l^p (l = 1, \cdots, m)$ time period. The variables are expressed as

$$a_l^p,\ N_l^p,\ x_{ij}^{l,p}(k),\ L_{ij}^p,\ d_{ij}^p(k),\ e_{ij}^p(k),\ C_{ij}^p(k) \qquad (p = 1, \cdots, n)$$

for multiple demand sites problem, p is expressed regardless of the details as $x_{12}^{l,0}(k)$.

The problem formulation of this case is as follows.

$$x_{12}^{l,0}(k) = 1, 0 \qquad (k = 1, 2), (l = 1, \cdots, m) \tag{14}$$

$$x_{23}^{l,p}(k) = 1, 0 \qquad (k = 2, 3, 4), (l = 1, \cdots, m), (p = 1, \cdots, n) \tag{15}$$

$$\sum_{k=1}^{2} x_{12}^{l,0}(k) = 1 \qquad (l = 1, \cdots, m) \tag{16}$$

$$\sum_{k=2}^{4} x_{23}^{l,p}(k) = 1 \qquad (l = 1, \cdots, m), (p = 1, \cdots, n) \tag{17}$$

$$\sum_{k=1}^{2} \{d_{12}^{0}(k)L_{12}^{0}+e_{12}^{0}(k)\} x_{12}^{l,0}(k) + \sum_{k=2}^{4} \{d_{23}^{p}(k)L_{23}^{p}+e_{23}^{p}(k)\} x_{12}^{l,p}(k)$$
$$\leq N_l^p (l = 1, \cdots, m), (p = 1, \cdots, n) \tag{18}$$

$$\sum_{p=1}^{m} \sum_{l=1}^{m} a_l^p = a_0 \tag{19}$$

$\left(\sum_{l=1}^{m} a_l^p = a^p \text{ Volume to be transported to the demand site } p\text{: } a^p\right)$

Under these conditions,

$$Z = \sum_{p=1}^{n} \sum_{l=1}^{m} \left\{ \sum_{k=1}^{2} C_{12}^{0}(k)L_{12}^{0}x_{12}^{l,0}(k) + \sum_{k=2}^{4} C_{23}^{p}(k)L_{23}^{p}x_{23}^{l,p}(k) \right\} a_l^p \rightarrow Min \tag{20}$$

<Specific Numerical Examples>

Table 2: Delivery Lots

8 Lots	**Delivery Time**
$a_1^1 = 5$	$N_1^1 = 3$
$a_2^1 = 10$	$N_2^1 = 15$
$a_3^1 = 20$	$N_3^1 = 16$
$a_4^1 = 50$	$N_4^1 = 20$
$a_1^2 = 6$	$N_1^2 = 3.5$
$a_2^2 = 11$	$N_2^2 = 14.5$
$a_3^2 = 19$	$N_3^2 = 15.5$
$a_4^2 = 51$	$N_4^2 = 19$

Table 3: Parameter for Constraints $(l = 1, \dots, 4)(p = 1, 2)$

	Speed	Days for Switching	Cost
$k=1$ **Sea**	$d_{12}(1)=1$ $d_{23}^1(1)=1$ $d_{23}(1)=1$	$e_{12}(1)=3$ $e_{23}^1(1)=3$ $e_{23}^2(1)=3$	$C_{12}(1)=1$ $C_{23}^1(1)=1$ $C_{23}^2(1)=1$
$k=2$ **Air**	$d_{12}(2)=0.02$ $d_{23}^1(2)=0.02$ $d_{23}^2(2)=0.02$	$e_{12}(2)=1$ $e_{23}^1(2)=1$ $e_{23}^2(2)=1$	$C_{12}(2)=7$ $C_{23}^1(2)=7$ $C_{23}^2(2)=7$
$k=3$ **Truck**	$d_{12}(3)=0.2$ $d_{23}^1(3)=0.2$ $d_{23}^2(3)=0.2$	$e_{12}(3)=1$ $e_{23}^1(3)=1$ $e_{23}^2(3)=1$	$C_{12}(3)=4$ $C_{23}^1(3)=4$ $C_{23}^2(3)=4$
$k=4$ **Rail**	$d_{12}(4)=0.2$ $d_{23}^1(4)=0.2$ $d_{23}^2(4)=0.2$	$e_{12}(4)=2$ $e_{23}^1(4)=2$ $e_{23}^2(4)=2$	$C_{12}(4)=3$ $C_{23}^1(4)=3$ $C_{23}^2(4)=3$

$L_{12}=10$ $L_{23}^1=5$ $L_{23}^2=6$

$\{a_i^1\}$ $(i = 1, \cdots, 4)$ and $\{a_j^2\}$ $(j = 1, \cdots, 4)$ have different demand site respectively. Therefore they can be solved independently. Solution result by GA is as follows.

First, we state for $\{a_i^1\}$. The expression by (9) is complicated. Therefore we use expression by (13). Initial population is exhibited in Table 4.

Table 4: Initial Population of $\{a_i^1\}$

(1, 1, 1, 1, 1, -1, 0, 1)
(1, 0, 0, 1, 1, 1, 0, 0)
(1, 0, 1, 0, 1, 1, 0, -1)
(1, 0, 0, 1, 1, 1, 0, 1)
(1, 0, 0, 0, 1, 1, 0, 1)
(1, 1, 1, 0, 1, -1, -1, 0)
(1, 1, 0, 1, 1, 0, 1, 1)
(1, 0, 1, 0, 1, 0, 1, -1)
(1, 1, 0, 1, 1, 1, 0, -1)
(1, 1, 0, 0, 1, 0, 1, 0)

Convergence process is exhibited in Table 5.

Table 5: Convergence Process of $\{a_i^1\}$

Generation	1	2	3	4	5	6
Minimum score in each generation	5100	5100	5100	4500	4500	4500
Average score in each generation	6605	5750	5230	5100	4900	4800

The problem is simple, so combination of genotype for crossover saturates in the 6-th generation.
(1, 0, 0, 0), (1, 1, 0, 0) genotype for former parts of one-point crossover and (1, 1, 1, -1), (1, 1, 0, -1), (1, 0, 1, -1) genotype for latter parts only remain. Even if mutation occurs, it does not satisfy constraint or it's objective function value is larger than minimum which has been already selected, and it does not be selected. Chromosome of which objective function becomes minimum is (1, 0, 0, 0) in former part of one-point crossover and (1, 1, 0, -1) in latter part.
This means that optimal solution is selected by the following means.

a_1^1 : Air & Air
a_2^1 : Sea & Air
a_3^1 : Sea & Truck
a_4^1 : Sea & Rail

Table 6: Initial Population of $\{a_j^2\}$

(1 , 1 , 1 , 1 , 1 , -1 , 0 , 1)
(1 , 0 , 0 , 1 , 1 , 1 , 0 , 0)
(1 , 0 , 1 , 0 , 1 , 1 , 0 , -1)
(1 , 0 , 0 , 1 , 1 , 1 , 0 , 1)
(1 , 0 , 0 , 0 , 1 , 1 , 0 , 1)
(1 , 1 , 1 , 0 , 1 , -1 , -1 , 0)
(1 , 1 , 0 , 1 , 1 , 0 , 1 , 1)
(1 , 0 , 1 , 0 , 1 , 0 , 1 , -1)
(1 , 1 , 0 , 1 , 1 , 1 , 0 , -1)
(1 , 1 , 0 , 0 , 1 , 0 , 1 , 0)

Table 7: Convergence Process of $\{a_j^2\}$

Generation	1	2	3	4	5	·····	504	505	·····	600
Minimum score in each generation	3660	3460	3460	3460	3460	·····	3460	3318	·····	3318
Average score in each generation	6234.5	4827.3	4830.2	4201.2	4201.2	·····	4126.7	3636.1	·····	3636.1

Now, let's examine $\{a_j^2\}$ part. Initial population of $\{a_j^2\}$ is exhibited in Table 6.

As it is a simple problem, combination of genotype for crossover saturates in the early stages and the improvement of solution is executed by mutation and the crossover afterwards. Solution converges after 500-th generation. Chromosome of which objective function becomes minimum is (1, 0, 0, 0) for the former part of one-point crossover and (1, 1, 0, -1) for the latter part. This means that optimal solution is selected by the following means.

a_1^2 : Air & Air

a_2^2 : Sea & Air

a_3^2 : Sea & Truck

a_4^2 : Sea & Rail

This coincides with the result of optimal solution by the calculation of all considerable cases therefore it coincides with a theoretical optimal solution. We take up simple problem and we can confirm the effectiveness of GA approach. Further study for complex problems should be examined hereafter.

<Result>

Table 8: Result

Lot	Means	Lead time	Cost	Selected Solutions	Selection Condition
$a_1^1=5$	Air & Air	2.3	525	◎	Delivery Time
$a_2^1=10$	Air & Air	2.3	1050		Delivery Time
	Sea & Air	14.1	450	◎	Min. Cost
	Sea &Truck	15	300		Overdue
	Sea & Rail	16	250		Overdue
$a_3^1=20$	Sea & Air	14.1	900		Delivery Time
	Sea &Truck	15	600	◎	Min. Cost
	Sea & Rail	16	500		Overdue
$a_4^1=50$	Sea & Air	14.1	2250		Min. Cost
	Sea & Truck	15	1500		
	Sea & Rail	16	1250	◎	
$a_1^2=6$	Air & Air	2.33	672	◎	Delivery Time
$a_2^2=11$	Air & Air	2.32	1309		Delivery Time
	Sea & Air	14.12	572	◎	Min. Cost
	Sea &Truck	15.2	374		Overdue
	Sea & Rail	16.2	308		Overdue
$a_3^2=19$	Sea & Air	14.12	988		Delivery Time
	Sea &Truck	15.2	646	◎	Min. Cost
	Sea & Rail	16.2	532		Overdue
$a_4^2=51$	Sea & Air	14.12	2652		Min.Cost
	Sea & Truck	15.2	1734		
	Sea & Rail	16.2	1428	◎	

(3) When there are multiple demand sites and supply sites

From a supply site to a demand site as in the case below:

Volume $a_l^{q,p}$ for $q \rightarrow p$ delivery, within $N_l^{q,p}(q = 1, \cdots, s)$, $(l = 1, \cdots, m)$, $(p = 1, \cdots, n)$

$x_{ij}^{l,q,p}(k)$ (l: lot, q: supply site, p: demand site)

$$\text{Supply Site} \xrightarrow{L_{12}^{q,o}} \text{Transit Point} \xrightarrow{L_{23}^{0,p}} \text{Demand Site}$$

p is expressed as

$$x_{12}^{l,q,0}(k) = 1, 0 \qquad (k = 1, 2), (l = 1, \cdots, m), (q = 1, \cdots, s) \tag{21}$$

q is expressed as

$$x_{23}^{l,0,p}(k) = 1, 0 \qquad (k = 2, 3, 4), (l = 1, \cdots, m), (p = 1, \cdots, n) \tag{22}$$

The problem formulation of this case is as follows.

$$\sum_{k=1}^{2} x_{12}^{l,q,0}(k) = 1 \qquad (l = 1, \cdots, m), (q = 1, \cdots, s) \tag{23}$$

$$\sum_{k=2}^{4} x_{23}^{l,0,p}(k) = 1 \qquad (l = 1, \cdots, m), (p = 1, \cdots, n) \tag{24}$$

$$\sum_{k=1}^{2} \{d_{12}^{q,0}(k) L_{12}^{q,0} + e_{12}^{q,0}(k)\} x_{12}^{l,q,0}(k) + \sum_{k=2}^{4} \{d_{23}^{0,p}(k) L_{23}^{0,p} + e_{23}^{0,p}(k)\} x_{23}^{l,0,p}(k) \leq N_l^{q,p}$$
$$(l = 1, \cdots, m), (q = 1, \cdots, s), (p = 1, \cdots, n) \tag{25}$$

$$\sum_{q=1}^{s} \sum_{p=1}^{n} \sum_{l=1}^{m} a_l^{q,p} = a_0 \tag{26}$$

Under these conditions,

$$Z = \sum_{q=1}^{s} \sum_{p=1}^{n} \sum_{l=1}^{m} \left\{ \sum_{k=1}^{2} C_{12}^{q,0}(k) L_{12}^{q,0} x_{12}^{l,q,0}(k) + \sum_{k=2}^{4} C_{23}^{0,p}(k) L_{23}^{0,p} x_{23}^{l,0,p}(k) \right\} a_l^{q,p} \rightarrow Min \tag{27}$$

3. CONCLUSION

In recent years, inter-modal international logistics was becoming a big trend. Sea and air transport was a form of inter-modal international logistics. Sea and air transport was developing rapidly in recent years.

However, papers concerning sea and air transport could hardly be seen especially for mathematical formulation and its analysis. In this paper, we made mathematical formulation of the case single supply site and single demand site with multiple delivery date / different delivery quantities as of a fundamental one. Under certain constraints, minimum cost was pursued. Next, expansion was executed as for the case single supply site and multiple demand sites. Numerical expansion was examined and optimal solution was derived using genetic algorithm. Finally, formulation expansion was executed as for the case multiple supply site and multiple demand site. By formulating sea and air transport problem, it could be handled clearly and smoothly. Various solving method should be examined hereafter.

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