AN OPTIMAL TRANSPORT ALGORITHM FOR MULTIMODAL TRANSPORT

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ABSTRACT

Because of rapid expansion of third party logistics, fierce competition in the transportation industry, and the diversification and globalization of transportation channels, an effective transportation planning by means of multimodal transport is badly needed. Accordingly, this study aims to suggest an optimal transport algorithm for the multimodal transport in the international logistics. Cargoes and stopovers can be changed numerously according to the change of transportation modes, thus being a NP-hard problem. As a solution for this problem, first of all, we have applied a pruning algorithm to simplify it, suggesting a heuristic algorithm for constrained shortest path problem to find out a feasible area with an effective time range and effective cost range, which has been applied to the Label Setting Algorithm, consequently leading to multiple Pareto optimal solutions.

Meanwhile, as a way of evaluating these multiple Pareto optimal solutions, this study has introduced a mathematical model and MADM model. Also, in order to test the efficiency of the heuristic algorithm for constrained shortest path problem, this paper has applied it to the actual transportation path from Busan, port of Korea to Rotterdam, port of Netherlands.

Key Words: *Multimodal Transport, Constrained Shortest Path, Label Setting Algorithm.*

1. INTRODUCTION

The multimodal transport means that it uses two or more transportation modes in delivering goods from a departure place to an arrival place in the different country. In general, ordinary transportation means a single transportation mode with the participation of freight forwarders. But the multimodal transport, which uses two or more transportation modes, usually makes use of a third party logistics company.

A third party logistics company is generally armed with NPS (Network Planning System), NOS (Network Optimization System), DSS (Decision Support System), cargo tracking system, and billing system, but most domestic third party logistics companies lack in management systems, thus being unable to provide enough information. They usually depend on traditional and conventional methods, consequently giving rise to cost increase.

According to the interview with officials of third party logistics companies, the transportation plans of most third party logistics companies are being made on a manual basis. So their manual work is likely to meet with difficulty for the increasing expansion of cargo volume.

In order to solve this problem, the third party logistics company should integratively consider the modes of transportation, routing, allocation, and scheduling. It also needs the system providing a transportation design suitable to the shipper. To this end, this study has suggested an optimal transport algorithm for multimodal transport.

The multimodal transport uses at least two or more modes of transportation that have differences in their cargo capacity, transportation time, transportation path, and transportation cost. Therefore, it has many differences from a single transportation mode, while including many constraints.

For the development of this algorithm, we have suggested a pruning algorithm in order to simplify the numerous routing paths to the maximum degree. Also, as an algorithm to select an optimal transportation path from among many selected routing paths, this study has selected the heuristic algorithm for constrained shortest path problem. To test the efficiency of these algorithms, we have applied them to the actual multimodal transport path from Busan port of Korea to Rotterdam port of Netherlands.

2. SHORTEST PATH AND QUICKEST PATH ALGORITHM

2.1. Shortest Path and Quickest Path Algorithm

A shortest path problem means how to find out, under a given network, the shortest path between a departure place to an arrival place, and minimize its time and cost. Until now, the shortest path problem has been used to prepare for a transportation plan with the least cost and the shortest distance from the departure place to the destination via certain nodes and stopovers. Currently, Dijkstra algorithm is widely used as a typical shortest path algorithm.

Next, the quickest path problem, which is a modification of the shortest path problem, is to seek the quickest path from the departure place to the arrival place under the given lead-time, capacity, and volume between nodes. This has been suggested by Moore, and developed into a confirmed algorithm by Chen and Chin [1,5].

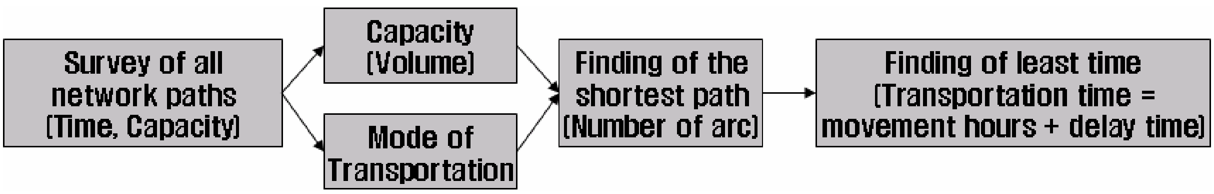

Figure 1. Quickest path problem

The very difference between the shortest path problem and the quickest path problem comes from the consideration of a cargo volume. Also, this is the most important consideration in the multimodal transportation, because each mode of transportation has the different capacity of its own.

In case of the shortest path problem, if the quickest path from the departure place to the arrival place has been found out, the detailed path from one node to the other node is to become the shortest path. This is possible in case of the shortest path algorithm because if the quickest paths from one node to the next node are repeated, the whole path can become the quickest path. However, in case of the quickest path algorithm, it is different. Although its detailed paths are not the quickest, the quickest path can be selected from the aspect of the entire path [7].

In conclusion, the difference between two algorithms comes from their cargo volume. Even if it is the shortest path, but the mode of transportation has a small cargo capacity, the time required in sending goods can take longer than other paths. Conversely, even if it has a large cargo capacity, but has long transportation hours, the entire time for goods delivery can be longer than other paths. Therefore, multimodal transport must take the transportation volume into consideration. In fact, the constraint coming from the transportation volume in the given path becomes a very important factor for multimodal transport.

2.2. Shortest Path and Quickest Path Algorithm

The constrained shortest path problem is an extended shortest path problem, generally known as a NP-hard problem. Taking account of the trade-off relationship between time and cost, Martins (1984) has succeeded in finding out multiple Pareto optimal paths, solving the problem by way of combination optimization. However, simultaneous consideration of two kinds of an objective function takes a long time in calculation, and he also has proved that it is impossible to test all the Pareto optimal solutions.

Because of this, there is only one objective function, and the other considerations will become constraints. Based on this proposition, the researches on the shortest path problem have been made actively. These researches are known as WCSPP (Weighted Constrained Shortest Path Problem). The objective function of WCSPP Linear Program Formulation, its constraints, and variables are defined as follows.

$$\min \sum_{a \in A} c_a x_a \quad \text{....(1)}$$

$$\text{such that} \quad \sum_{a \in \delta^+(i)} x_a - \sum_{a \in \delta^-(i)} x_a = \begin{cases} 1, \text{if i} = \text{s} \\ -1, \text{if i} = \text{t} \\ 0, \text{if i} \in \text{V} \setminus \{\text{s, t}\} \end{cases} \quad \forall i \in V$$

$$\sum_{a \in A} w_a x_a \le W$$

$$x_a \in \{0,1\} \;\; \forall a \in A$$

c_a : Transportation cost at the arc a
$\delta^+(i)$: a set of arcs leaving node i
$\delta^-(i)$: a set of arcs entering node i
w_a : the weight in the arc a
W : total weight
s : node of departure
t : node of arrival
V : a set of nodes in the whole graph

3. OPTIMAL TRANSPORTATION ALGORITHM

3.1. Multimodal Transport Network Planning

The multimodal transport network planning has two main considerations. One is cargo information, and the other is the mode of transportation. The major items of cargo information are the kinds of cargoes, the volume of cargoes, destination, and arrival date. And the information of transportation mode includes the kinds of transportation mode, full capacity, and stopover scheduling. The transportation network planning system or research in the past has been based on the single transportation, thus putting emphasis mainly on how to allocate the cargoes.

But in case of two or more modes of transportation, each node of transportation has different capacity, different scheduling, and also have ensuing different transportation time and transportation cost. In addition, cargo information is required to choose the mode of transportation. Therefore, the information on cargoes and mode of transportation should be taken into consideration together in the multimodal transport network planning. The relationship of these two factors is shown in Figure 2.

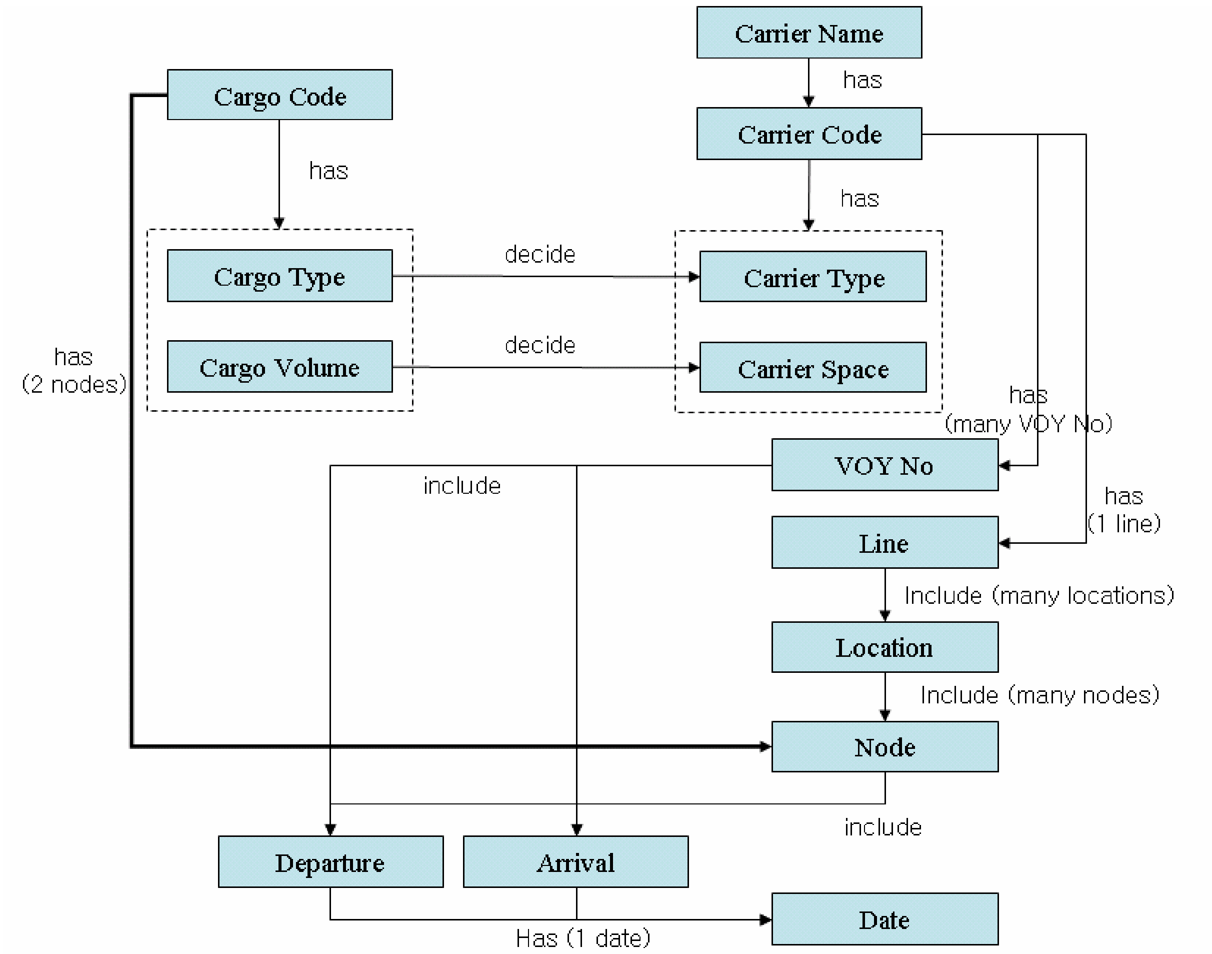

Figure 2. Relationship between cargoes and transportation modes

In the cargo loading, one unit of cargo cannot be separated, and all cargoes are supposed to be loaded in the mode of transportation. If there is a mode of transportation that cannot be loaded with one unit of cargo, the arc of this transportation mode will be precluded in the route generation. Also, the modes of transportation include the ship, airplane, and railway, and each transportation mode's destination – harbour, airport, and station - become its node. Transhipment between different transportation modes can be made in the "location," and there can be multiple nodes in the one location, and transhipment can be made only once in the same location. The transhipment into the other transportation modes may be allowed only by land. The transportation cost and time by land are supposed to be proportional to its distance. The definition of route components under the constraints of multimodal transport is shown in Figure 3.

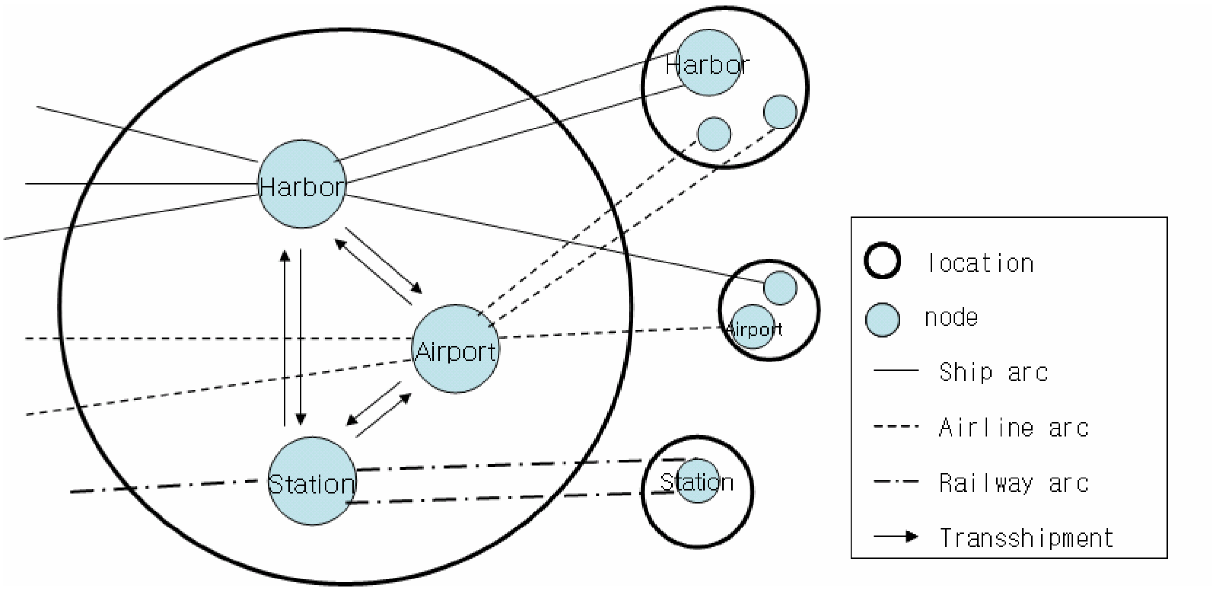

Figure 3. Definition of route components in the multimodal transport

As shown in Figure 4, the ship will be used when cargo volume is large, delivery period is not so tight, and low transportation cost is needed. But airlines will be preferred in case that the cargo is expensive, and has a tight delivery schedule, although the freight is quite high. Anyway, if multimodal transport is more economical than single transport in terms of cost and time, the usage of this algorithm will be on the increase. Also Figure 4 shows that in case of airline transportation, due to the long distance from the airport to the final destination, its land transportation demands much additional cost and time, sea transportation can be more effective.

Accordingly, if the final destination of cargo and the arrival place of transportation mode – i.e. airport, harbour, and railway station – are combined in a more favourable way at the time of transport network planning; it will greatly reduce the inefficiency caused by the single mode of transportation.

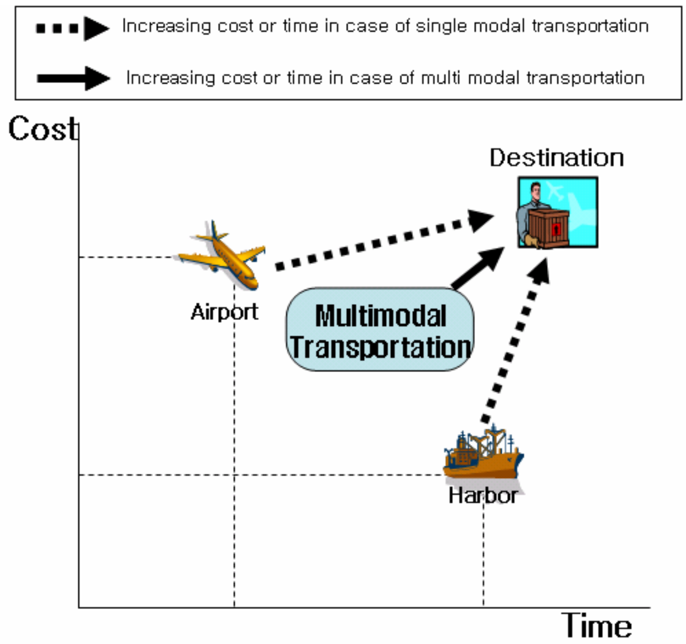

Figure 4. Necessity of multimodal transport

3.2. Pruning Algorithm

There can be numerous scheduling for the ship, airline, and railway that will satisfy the required arrival place and arrival time of certain cargoes. Also, in case of multimodal transport, even if the destination of certain cargoes is not included in the scheduling of the transportation mode, the stopover of the transportation mode that satisfy the final destination is included in the scheduling, this transportation mode has to be taken into consideration. Therefore, in order to upgrade the performance and efficiency of the algorithm that seeks an optimal path from among numerous paths of multimodal transport, it is quite effective to reduce the retrieval space to a great extent in advance. To this end, this study has used a pruning algorithm. If there are two arcs of "I" and "k" in the one node (n), the transportation cost (C) and transportation time (T) are to be composed of one pair like (C_n^k, T_n^k) and (C_n^l, T_n^l). Also, if both arcs are in a domination relationship, one arc will be eliminated by the pruning algorithm. The pruning rules run as follows.

- Pruning rule (1): The arc with a higher cost and longer required time in the one node is to be eliminated.

$$\text{If } C_n^l > C_n^k \ \ and \ \ T_n^l > T_n^k \ , \ \ (C_n^l, T_n^l) \text{ is eliminated by } (C_n^k, T_n^k)$$

- Pruning rule (2): If the cost of both arcs is the same in the one node, but their required time is different, the arc of longer required time is to be eliminated. Also, if the required time of both arcs is the same, but their cost is different, the arc of a higher cost is to be eliminated.

$$\text{If } (C_n^l = C_n^k \ \ and \ \ T_n^l > T_n^k) \ or \ (T_n^l = T_n^k \ \ and \ \ C_n^l > C_n^k),$$
$$(C_n^l, T_n^l) \text{ is eliminated by } (C_n^k, T_n^k)$$

- Pruning rule (3): If there is in the one node an arc that has an arrival date later than the latest departure date, this arc is to be eliminated.

If there are a departure arc (δ^+) and arrival arc (δ^-) in the one node, and the departure time of the departure arc is represented as $S_n^{\delta^+}$ and the arrival time of the arrival arc is represented as $A_n^{\delta^-}$, the arc $A_n^{\delta^-}$ larger than the maximum value of $S_n^{\delta^+}$ is to be eliminated.

$$\max(S_n^{\delta^+}) \ < (A_n^{\delta^-})$$

The pruning rule (3) is to be applied in the transhipment of multimodal transport. The pruning rule (1) and (2) is to be applied in the WCSPP algorithm introduced in the following section.

3.3. Heuristic Algorithm for Constrained Shortest Path Problem

The purpose of multimodal transport is to minimize transportation time and transportation cost. In the single transportation mode, the objective function for minimum cost and time can briefly be defined as follows.

$$\min \quad z_1(p) = \sum_{(i,j)\in p} h_{ij} + Q/lt_s^a + \partial/ut_t^a \text{....(2)}$$

$$\min \quad z_2(p) = \sum_{(i,j)\in p} c_{ij} + Q/lc_s^a + \partial/uc_t^a \text{....(3)}$$

$$s.t. \quad p \in P$$

h_{ij} : transportation time from node i to node j

c_{ij} : transportation cost from node i to node j

lt_s^a : loading hours of arc a at the departure node

ut_t^a : unloading hours of arc a at the arrival node

lc_s^a : loading cost of arc a at the departure node

uc_t^a : unloading cost of arc a at the arrival node

Q : cargo volume

P : the path from one node to the next

P : the path from departure to arrival

Formula 2 represents the minimization of total transportation time from the node i to j in the single transportation mode, and Formula 3 is the objective function representing the minimization of transportation cost. Also, in case of a single transportation mode, loading and unloading takes place only once at the departure place and arrival place respectively. And based on this, the time and cost for loading and unloading have been calculated. When these two objective functions are dealt with independently, the set of these two are as follows.

$$\mathrm{I} = (z_1(p), z_2(p))$$

But as mentioned above, if two objective functions are together taken into consideration, one objective function is in conflict with the other. Therefore, it is impossible to find out an optimal path satisfying both objective functions. Accordingly, it is significant how to deal with the correlationship of these two objective functions.

First, the objective function of WCSPP algorithm for multimodal transport is defined as follows. In case that the minimum time is an objective function, as shown in the Formula 4, the transportation time from one node to the next, loading time at the departure place, unloading time at the arrival time, and transhipment time (including loading and unloading time) have all together been taken into consideration. The minimum cost objective function of Formula 5 also takes account of the transportation costs at the arcs and the stevedoring costs at the nodes. Also, as the time and cost for stevedoring are proportional to the cargo volume, the cargo volume has been included. The objective function, constraints, and variables of WCSPP algorithm, a modified form of Formula 1 are defined as below.

$$\min \sum_{a\in A} (c_a x_a + Q/lc_n^a + Q/uc_n^a) \quad \text{....(4)}$$

$$\text{s.t.} \quad \sum_{a\in A} w_a x_a \le W_h$$

$$x_a \in \{0,1\} \ \ \forall a \in A$$

$$\min \sum_{a\in A} (h_a x_a + Q/lt_n^a + Q/ut_n^a) \quad \text{....(5)}$$

$$\text{s.t.} \quad \sum_{a\in A} w_a x_a \le W_c$$

$$x_a \in \{0,1\} \ \ \forall a \in A$$

c_a : Transportation cost at the arc a

h_a : Transportation time at the arc a

Q : Cargo volume

lc_n^a : Loading cost of arc a at one node

uc_n^a : Unloading cost of arc a at one node

lt_n^a : Loading time of arc a at one node

ut_n^a : Unloading time of arc a at one node

W_h : Time constraint

W_c : Cost constraint

The constraints of Formula 4 and Formula 5 are the same, but the constraint W_h in the Formula 4, which seeks minimum cost, becomes time, and the constraint W_c in the Formula 5, which seeks minimum time, becomes cost.

The constraint W at Formula 4 and Formula 5 is defined as follows in this study. First, the minimum cost and minimum time derived from the objective function Formula 2 and Formula 3 for the single transportation mode is to become the first constraints to WCSPP algorithm. And Formula 4 and Formula 5 under these constraints can bring the Z_1 point and Z_2 point as shown in Figure 5. Z_3 at the crossing point of these two points seems to be an optimal solution for the two objective functions. But Z_3 is an infeasible solution.

Accordingly, we have defined the area (area in the shade) in the three points as a feasible area. And so if the solution of this algorithm is in the feasible area, it will become a Pareto solution. The distance from T1 and T2 in the feasible area is defined as an "effective time range," which becomes a constraint scope to cost. And the distance from C1 and C2 is defined as an "effective cost range," which becomes a constraint scope to time. These two constraints scope of both effective time range and effective cost range have been applied to the Label Setting Algorithm mentioned below.

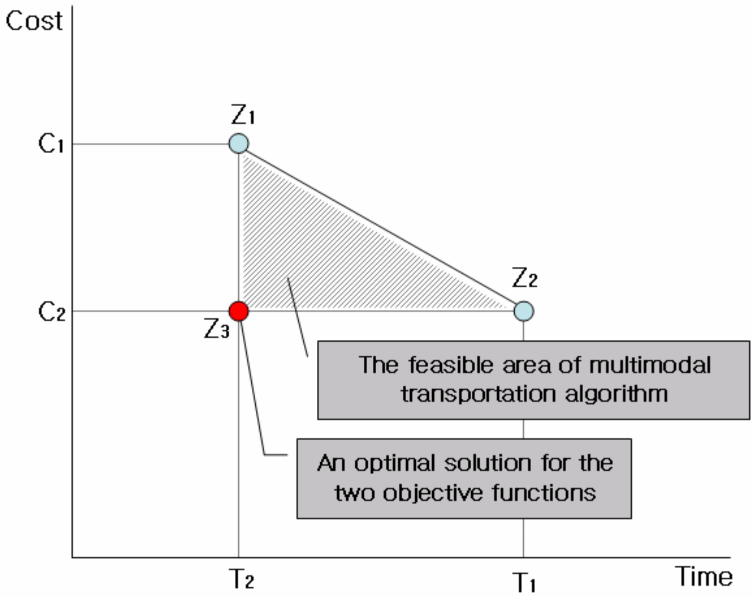

Figure 5. The feasible area of WCSPP Algorithm

3.4. A Solution for WCSPP

As a solution for WCSPP, this study has used Label Setting Algorithm that is one of dynamic programming. A brief explanation on Label Setting Algorithm will be given in this section, and then it will be applied to the actual case of multimodal transportation in the next chapter. Label Setting Algorithm developed by Descrochers, et al. (1998) uses the method to put labels to each node, and each label is composed of a pair (weight and cost). In the label (W, C) W refers to the qth weight in the node i, and C refers to the qth cost in the node i. wij and cij respectively refers to the weight and cost from node i to node j. The Label Setting Algorithm is generally performed as follows.

Step 0: Initialization
Gathering Labels = {(0,0)}, gathering Label$_i$ = Φ , $i \in V \setminus \{s\}$

Step 1: Selection expansion of Label
If all Label is indicated, end; All efficiency Label creation;
If not, there is a Label which is not indicated from the Label$_i$ and when W_i^q is a smallest value, the q is on the course where the weight price is included indication.

Step 2: Label (W_i^q , C_i^q) expansion
All $(i,j) \in \delta^+(i)$ and at the time of $W_i^q + w_{ij} \le W$ one, If ($W_i^q + w_{ij}$, $C_i^q + c_{ij}$) exists by (W_j^q , C_j^q) is not governed in node j not to be, Label$_j$= Label$_j \cup \{(W_i^q + w_{ij}, C_i^q + c_{ij})\}$ become
Indicate label (W_i^q , C_i^q)
Move to step 1

By using two or more variables, this Label Setting Algorithm can generate the shortest path problem, and this problem becomes a MOSP (Multi-Objective Shortest Path) Problem, that is to say, becomes a NP-hard problem. This study has applied the Label Setting Algorithm that was developed for a MOSP problem by Martins.

In the application of Label Setting Algorithm to the multi-modal transport planning, the above-mentioned values of “effective time range” and “effective cost range” have been used as its constraints. If the values derived from the algorithm exist in the feasible area, they can be Pareto’s optimal solutions.

4. TESTS

4.1. Definition of Problems

The path to Rotterdam of Netherlands starting from Busan of Korea is a typical international trade channel between Asia and Europe. At present, the major multimodal transport paths between these two areas can be summarized as in Table 1.

Table 1. Major multimodal transport paths between Busan and Rotterdam

Transportation Mode	Multimodal Transport Paths’ Name
Ship + Railway	- TSR (Trans Siberian Railway) - TCR (Trans China Railway) - TMR (Trans Manchuria Railway) - TMGR (Trans Mongolia Railway) - Black Sea - ALB (Siberian Land Bridge) - CLB (Canadian Land Bridge)
Ship + Air carrier	- Busan port (ship) → Oakland (air) → Rotterdam Airport - Busan port (ship) → LA (air) → Rotterdam Airport - Busan port (ship) → Vancouver (air) → Rotterdam Airport

In case of sea transportation except the major multimodal transport paths as shown in Table 1, the sea paths connecting Far East, Southeast Asia, and Europe are mainly used, and these sea paths runs to about 40, which have stopovers making stevedoring possible. Therefore, it can be said safely that the number of multimodal transport paths between Busan and Rotterdam reaches at least tens up to hundreds to the maximum. Because of this, this test data has dealt with only those major multimodal transport paths mentioned in the Table 1. Based on this data, a total of 54 paths have been generated.

Table 2. Transport path alternatives between Busan and Rotterdam

No.	Transport paths	Hours	Cost
1	Busan → (ship) → Singapore → (ship) → Rotterdam	30	120
2	Busan → (air) → Hong Kong → (ship) –> Rotterdam	27	130
3	Busan → (ship) → Rotterdam	29	135
...	...	...	...
54	Busan → (ship) → Hong Kong→ (ship) → Singapore → (ship) → Rotterdam	34	190

Actually, more number of multimodal transport paths could be generated between Busan and Rotterdam, but this number has come from the data of each transporter that we are now keeping. By using the pruning algorithm, the 54 paths have been reduced to 25. Those paths eliminated by the pruning algorithm have usually caused too much costs and long hours because of frequent transhipment. In actual cases there is, on the average, no transhipment more than 4. Therefore, this test has included only the transhipment ranging from two to four.

4.2. Optimal Path Test Results and Analysis

Figure 6 shows the solutions derived from WCSPP algorithm and Label Setting Algorithm. A total of 25 paths have been tested, and Label Setting Algorithm has been performed 25 times. The numerals denoted in the graph means {time (H_i^q), cost (C_i^q)}, that is to say, the final label value from the departure place to the destination. The Pareto optimal solutions generated from Label Setting Algorithm numbered 32, and only 19 from among these have been denoted in the graph, and the rest (13 paths) have been eliminated because it was out of feasible area.

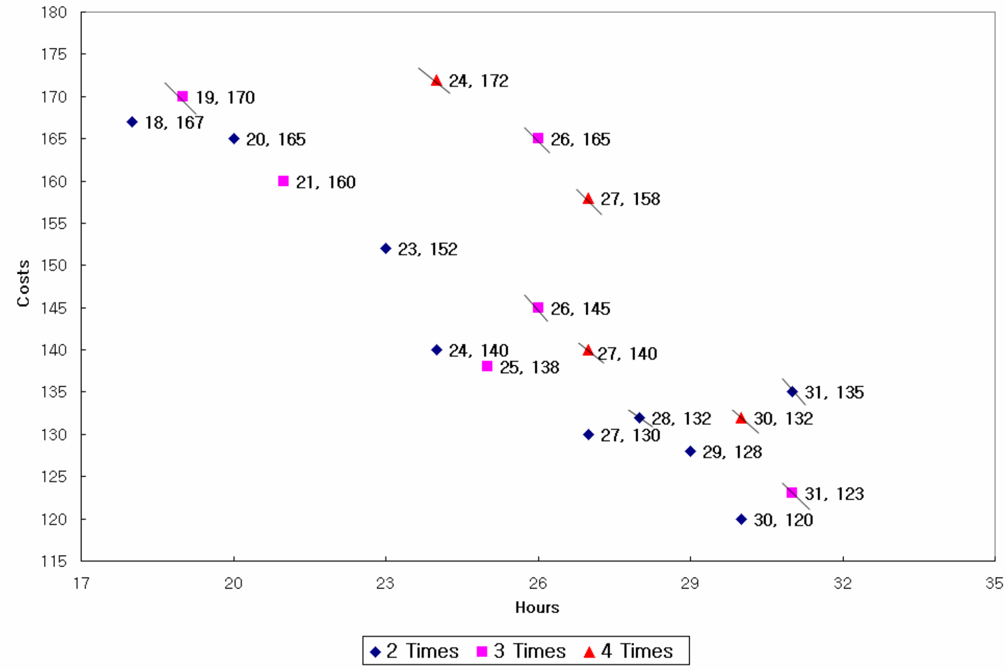

Figure 6. Label Setting Algorithm test results denoted in the feasible area

But as the 19 values generated from the first test are also in a domination relation, the pruning algorithm (1) and (2) are to be applied. By the pruning rules, 10 paths have been eliminated, and 9 paths have been selected as Pareto optimal solution. As shown in Table 3, the paths with the transhipment of four times have all been eliminated, but 7 paths with the transhipment of two times and 2 paths with the transhipment of three times have remained.

Table 3. Results of Tests

Transhipment Times	Pareto's Optimal Solutions
2 times	(18,167), (20,165), (23,152), (24,140), (27,130), (29,128), (30,120)
3 times	(21,160) (25,138)

4.3. Evaluation of Pareto Optimal Solution

A user (shipper) can select one from among the 9 Pareto optimal solutions. But each user can have a different preference in terms of time and cost. Because of the preference of users, it could not be easy for each user to select one from among the 9 Pareto optimal solutions. However, in order to help user's selection, we can use the evaluation method by means of value satisfaction of optimal solution.

To this end, this study has suggested two kinds of evaluation methods. The first is a mathematical model as shown in Figure 7. Among the values of the straight lines connecting the Z_3 point of a discretionary optimal solution and 9 Pareto optimal solutions, the shortest value has been evaluated as the optimal alternative. To this end, the value of time and cost has been normalized.

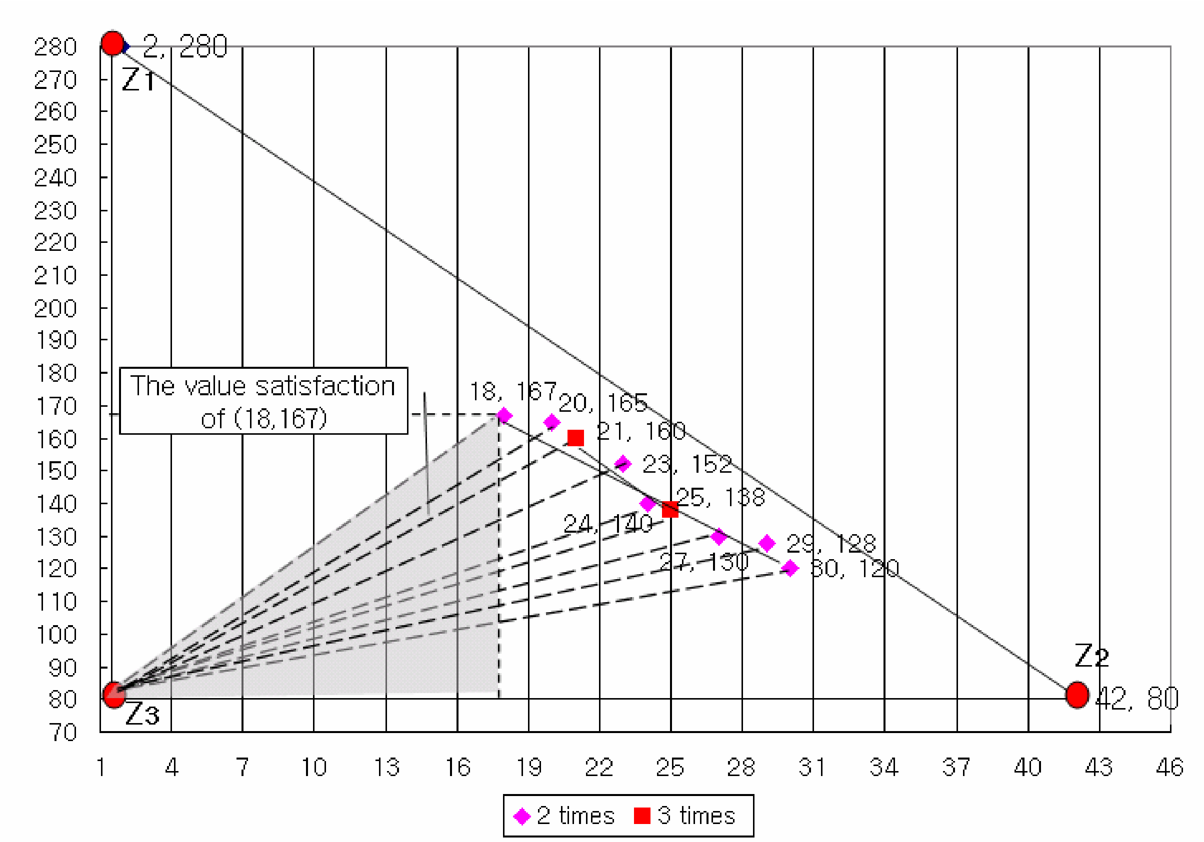

Figure 7. Evaluation of the value satisfaction of optimal solution

Table 4. Normalized values

Transhipment Times	Normalized Values
2 times	(0.080, 0.150), (0.090, 0.147), (0.105, 0.124), (0.110, 0.103), (0.125, 0.086), (0.135, 0.082), (0.140, 0.068)
3 times	(0.095, 0.138), (0.116, 0.100)
Z_3	(0.0, 0.0)

Table 4 shows the normalized values of discretionary optimal solution Z3 and the 9 alternatives. As time and cost have a different size, its relative distribution is denoted as the values between 0 and 1. By using these values, the user's value satisfaction for the 9 Pareto optimal solutions has been generated, and the results are shown in Table 5.

By using the mathematical model, Table 5 shows that the highest degree of value satisfaction is (24, 140).

Table 5. Results of value satisfaction evaluation

Transhipment Times	Pareto's Optimal Solutions	Distance with Z_3
2 times	(18,167)	0.0289
	(20,165)	0.0297
	(23,152)	0.0264
	(24,140)	***0.0227***
	(27,130)	0.0230
	(29,128)	0.0249
	(30,120)	0.0242
3 times	(21,160)	0.0280
	(25,138)	0.0255

The second evaluation method is MADM (Multi-Attribute Decision Making). By using MADM, many negotiation items with a different measuring criterion can be normalized by the same criterion, so that each negotiation items will be compared. MADM can not only show the evaluation values of each alternative, but also give a subjective weight to the items, consequently helping to seek an optimal solution.

MADM method is mainly used for the solution of the problems having many alternatives and attributes, thus aiming to decide the order of preference for many alternatives. At his point in time, the weight carrying the significance of many attributes has a critical influence upon the final result. Because of this, an easy and convenient method should be used for a decision maker. In this respect, the entropy measure is widely used in many fields to confirm and check the difference between given data. Accordingly, the entropy measure concept is being used in the MADM in order to confirm, check, and evaluate the items in the MADM problem. But in case that a certain attribute among many alternatives has the same evaluation value, it will be eliminated because it cannot contribute to the selection of the alternatives [3].

Table 6. MADM Evaluation Results

Transhipment Times	Pareto's Optimal Solutions	MADM Evaluation Results
2 times	(18,167)	0.102
	(20,165)	0.090
	(23,152)	0.100
	(24,140)	0.124
	(27,130)	0.126
	(29,128)	0.114
	(30,120)	***0.127***
3 times	(21,160)	0.095
	(25,138)	0.121

According to the result (0.127) of MADM evaluation, (30,120) has been generated as an optimal alternative. However, this result is different from the result of the mathematical model. The reason is that in case of MADM evaluation, the entropy denoting the weight and correlationship degree of each alternative is determined first, and then each alternative is evaluated by means of the entropy value.

5. CONCLUSION

This study has suggested an optimal transport algorithm for multimodal transport that can practically be used by third party logistics. To this end, WCSPP algorithm has been applied together with a pruning algorithm and Label Setting Algorithm. Also, in order to evaluate multiple Pareto optimal solutions, the mathematical model and MADM model have been introduced. In addition, this paper has applied these algorithms to the actual multimodal transport path from Busan of Korea to Rotterdam of Netherlands in order to test its validity. From now on, in an effort to upgrade the performance of these algorithms, we will continue to gather data and perform tests.

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