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세 가지 형태의 컨테이너 차량을 고려한 총괄수송계획
Aggregate Transportation Planning Considering Three Types of Container Vehicles

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Abstract

At the present time, container transportation plays a key role in the international logistics and the efforts to increase the productivity of container logistics become essential for Korean trucking companies to survive in the domestic as well as global competition. This study suggests an approach for determining fleet size for container road transportation with dynamic demand. Usually the vehicles operated by the transportation trucking companies in Korea can be classified into three types depending on the ways how their expenses occur; company-owned truck, mandated truck which is owned by outsider who entrust the company with its operation, and rented vehicle (outsourcing). Annually the trucking companies should decide how many company-owned and mandated trucks will be operated considering vehicle types and the transportation demands. With the forecasted monthly data for the volume of containers to be transported a year, a heuristic algorithm using tabu search is developed to determine the number of company-owned trucks, mandated trucks, and rented trucks in order to minimize the expected annual operating cost. The idea of the algorithm is based on both the aggregate production planning (APP) and the pickup-and-delivery problem (PDP). Finally the algorithm is tested for the problem how the trucking company determines the fleet size for transporting containers.

1. Introduction

At the present time, container transportation plays a key role in the international logistics and the efforts to increase the productivity of container logistics become essential for Korean trucking companies to survive in the domestic as well as global competition. The operation and design problems related to container transportation are very complicated due to the elements such as the coverage areas, sizes of the containers, material types in the container, transportation modes, etc..

This study suggests an approach for determining fleet size for container road transportation with dynamic demand. Usually the vehicles operated by the transportation trucking companies in Korea can be classified into three types depending on the ways how their expenses occur; company-owned truck, mandated truck which is owned by outsider who entrust the company with its operation, and rented vehicle (outsourcing)[9]. From the operational point of view, the first two are essentially the same except how the drivers are paid. For the driver of company owned truck, fixed salary is paid while the driver of mandated truck is paid by the amount which is proportional to his workload. For a given set of transportation orders, the manager of the trucking company has to allocate the transportation orders to three different types of trucks taking account of the vehicle routing as well as dispatching.

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According to Bodin et al.[3] and Savelsbergh and Sol[16], container transportation problems belong to Pickup-and-Delivery problems. Cullen, Jarvis and Ratliff[6] performed representative research on the problems. Dumas, Desrosiers and Soumis[7] added the time windows constraint to the problem and Psaraftis[13,14] also studied the problem considering dynamic behavior. Determining truck fleet size in the presence of a common-carrier option was carried out considering the vehicle types by Ball et al.[2]. They formulated the problem and described some approximate solution strategies.

Based on Nam and Logendran[11], many researchers have also suggested a variety of analytical and heuristic approaches for APP [1,12,17] since Bowman's study[4]. Recently, APP is focused on the application in the real world problem[5,18].

2. Problem Statement

Usually volume of containers to be transported by the trucking company is fluctuated every month. At the end of the year the transportation trucking company determines how many vehicles for three types are required next year. The number of company-owned and mandated vehicles determined at the beginning of the year will not be changed over six months. But, the changeover from company-owned vehicles to mandated vehicles will be allowed six months later. At this time there occurs additional changeover cost. The objective of this study is to determine the number of three types of vehicles required for the first six months as well as for the latter six months to meet container transportation demand next year at the aim of minimizing annual operating cost.

To describe our problem, we need some assumptions; First, there exist combined vehicles only which can transport two 20' containers or one 40' container at once. Second, containers to be transported between O-D pair are both 20' and 40'. Third, once the number of vehicles for each type is determined at the beginning of the year, we shall not be able to change the fleet size for each vehicle type over six months and some company-owned vehicles may be changed over to mandated vehicles six months later.

This problem is similar to the APP problem. APP is performed to best utilize the human and equipment resources of a company to meet some anticipated consumer demand[11]. In the typical APP, the dynamic demand is satisfied through the change of the resources every month. On the contrary, this study assumes that the changes in the fleet sizes of company-owned and mandated vehicles will be allowed once only six months later. And the surplus monthly demands not covered by both company-owned and mandated vehicles are all met by rented vehicles.

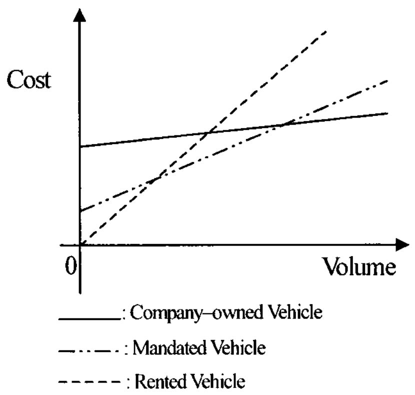

Figure 1. Cost structures for three types of vehicles.

Cost structures for operating three types of vehicles in Korea are depicted in Figure 1. The cost of a company-owned vehicle is the sum of the fixed cost and the variable cost proportional to the transportation volume. The fixed cost includes vehicle purchasing cost, labor cost, insurance cost, etc. and is calculated as the equivalent monthly cost. The cost function of a mandated vehicle is similar to one of the company-owned vehicle, except that the fixed cost is much lower and variable unit cost is much higher than those of company-owned vehicle. Rented vehicle has only variable cost that is proportional to the shipping amount.

3. Problem Model and Solution Algorithm

We present a mathematical model to describe the framework of the problem and to derive the logic of the solution algorithm. The following notations are introduced to formulate the problem.

$I = \{i \mid i = 1,2,3\}$: set of vehicle types where type 1 is company-owned, type 2 is mandated, and type 3 is rented vehicle.

$T = \{t \mid t = 1,2,\ldots,12\}$: planning period, i.e., 12 months

$T_1 = \{t \mid t = 1,2,\ldots,6\}$

$T_2 = \{t \mid t = 7,8,\ldots,12\}$

$n(t)$: amount of containers to be transported at period t

n_{it} : amount of containers to be transported by vehicles with type i at period t

$N(t)$: number of vehicles required to meet $n(t)$ at period t

N_{it} : number of vehicles with type i at period t

$C_i(t)$: operating cost for vehicle with type i at period t

F_i: monthly fixed cost of vehicle with type i where $F_3 = 0$

V_i : unit variable cost for containers to be transported by vehicle with type I

R : unit changeover cost

Since some of company-owned vehicles determined at the beginning of a year can be changed over the mandated vehicles six months later, the decision variables N_{1t} and N_{2t} are equivalently defined in two parts: (N_1^1, N_2^1) and (N_1^2, N_2^2) which denote the numbers of company-owned and mandated vehicles required for the first six months and the second six months, respectively.

$$N_{it} = \begin{cases} N_i^1, & i = 1,2,\ t \in T_1 \\ N_i^2, & i = 1,2,\ t \in T_2 \end{cases}$$

The formulation of the problem can be written as follows:

$$\text{Minimize } TC = \sum_{t\in T} \sum_{i\in I} C_i(t) + R \cdot (N_1^1 - N_1^2) \qquad (1)$$

$$\text{where } \ C_i(t) = F_i N_{it} + V_i n_{it}$$

Subject to

$$\sum_{i\in I} n_{it} = n(t) \qquad t \in T \qquad (2)$$

$$N_1^1 + N_2^1 + N_{3t} \geq N(t) \qquad t \in T_1 \qquad (3)$$

$$N_1^2 + N_2^2 + N_{3t} \geq N(t) \qquad t \in T_2 \qquad (4)$$

$$N_1^1 \geq N_1^2 \qquad (5)$$

$$N_1^1 + N_2^1 = N_1^2 + N_2^2 \qquad (6)$$

$$n_{it} = f_i(n(t), C_i(t)) \qquad i \in I,\ t \in T \qquad (7)$$

$$N_{it} = g_i(n(t), C_i(t)) \qquad i \in I,\ t \in T \qquad (8)$$

$$N_{it}, n_{it} : \text{nonnegative integer} \qquad i \in I,\ t \in T \qquad (9)$$

The objective function (1) is calculated as sum of annual operating costs of three types of vehicles to transport containers required to satisfy twelve months' transportation demand and changeover cost. The constraints (2) represent that all the monthly demands should be shipped by all the three types of vehicles. The constraints (3) and (4) mean availability of three types of vehicles. The constraints (5) and (6) describe that company-owned vehicles used for first six months can be changed over the mandated vehicles for second six months. The constraints (7) and (8) indicate that the fleet sizing and mixing of the three types of vehicles as well as the amount of containers to be shipped by each of them are related to the operating cost and transportation volume. We should notice that it is a very difficult problem to represent the two constraints explicitly since they are defined on PDP which belongs to NP class.

A heuristic algorithm for this problem is as follows:

Step 1 (Derivation of Daily Demand)

1. Derive the average daily transportation volume for each O-D pair based on the monthly data units assuming that total working days per month are 25.
2. Set $n(t)$ as the sum of container volume for all

suppliers at period t.

Step 2 (Solving PDP)

1. Estimate $N(t)$ required to meet $n(t)$ calculated in Step 1.1 by the Insertion Heuristic[15] which is a well-known solution algorithm for VRP (vehicle routing problem).
2. Set the lower bound of N_1^1, N_1^L as Min $\{N_{1t}, t \in T\}$.
3. Set the upper bound of $N_1^1 + N_2^1$ as Max $\{N(t), t \in T\}$
4. Sort the tours made in Step 2.1 in the decreasing order based on the total amount of containers of each tour.

Step 3 (Tabu Search)

1. Definition of Total Cost
   1. Define $TC(N_1^1, N_2^1, \Delta)$ is the annual operating cost to meet $n(t)$ with $N_1^1, N_2^1, N_1^2, N_2^2$ and N_{3t} where $\Delta = N_1^1 - N_1^2$. Here N_{3t} is calculated as Max $\{0, N(t) - N_1^1 - N_2^1\}$ for $t \in T_1$ and as Max $\{0, N(t) - N_1^2 - N_2^2\}$ for $t \in T_2$.
   2. Assign the sorted tours obtained in Step 2.4 to the vehicles in the order of company-owned, mandated and rented vehicles.
2. Search
   1. Set an initial feasible solution (N_1, N_2, Δ) as $(N_1^L, 0, 0)$ and calculate TC.
   2. Insert the solution as the first configuration in both index list (IL) and candidate list (CL) and aspiration level (AL) is set TC.
   3. Using this configuration as a seed, perform perturbations on $N^1{}_1$, $N^1{}_2$ and Δ.
   4. For two new configurations generated evaluate TC and select the configuration with the lower cost. The perturbed element of the configuration is underscored to indicate that it is tabu. If this cost is smaller than AL, a star is assigned to this configuration and admitted to CL. If there exists a tie, the two configurations are admitted to the CL. On the other hand, if the cost is either equal to or greater than AL, the configuration is simply admitted to CL without assigning a star as it does not have any potential of becoming a new local optimum as the search progresses. If the seed already has a star, then the seed receives two stars as it is a new local optimum and is admitted IL. Subsequently, the new configuration is admitted to CL.
   5. If $N_1^1 + N_2^1$ is equal to the upper bound, Go to Step 3.2.6. Otherwise, using the next available configuration from CL as the seed, perform perturbations on N_1^1, N_2^1, and Δ. Go to Step 3.2.4.
   6. The best solution obtained for TC is the smallest of all local optima evaluated so far.

4. Numerical example

The algorithm presented above is applied to an example problem for examining its validity. The data set in the example problem is collected from a transportation trucking company in Korea.

Table 1 shows the forecasted monthly transportation demand for the forthcoming year. The transportation data should be transformed into daily demand considering the traffic ratio of 20 feet and 40 feet containers between O-D pairs. The traffic ratio represents a flow pattern between O-D pairs generated from the past demand data. The traffic ratio for 20 feet containers between O-D pairs is shown in Table 2. Daily transportation volume on January for 20 feet containers derived from the forecasted transportation demand and the traffic ratio is depicted in Table 3.

We assume that total operating time of each vehicle is 8 hours, and that loading and unloading time per container is 0.3 hours regardless of container size. The parameters representing the cost functions for company-owned, mandated and rented vehicles are summarized in Table 4. Table 5 represents monthly the minimum number of combined vehicles obtained by the PDP algorithm based on the Insertion Heuristic from the above data set and the travel time matrix between O-D pairs in Table 6.

Table 7 presents all of these configurations generated by tabu search, leading to identifying the 18th entry as the best solution for the example problem. It states that the number of company-owned and mandated vehicles are 54 and 9 for the first six months and 51 and 12 for the latter six months, respectively and the number of rented vehicles required each month are N_{31}=4, N_{33}=23, N_{34}=13, N_{36}=18, $N_{3,7}$=4, $N_{3,8}$=1, $N_{3,10}$=1 and N_{3t}=0 for t=2, 5,9,11,12 and minimum total cost is 10,595. Compared with the optimal solution derived from all enumerations, we found the same result.

5. Conclusion

This study suggested an approach for determining the fleet size and the vehicle mix for container road transportation with dynamic demand between O-D pairs, especially considering three types of vehicles operated. A solution algorithm was developed using APP and PDP, and tabu search was utilized to find an optimal or a near-optimal solution. The algorithm was tested based on the trucking company in Korea.

Table 1. Forecasted monthly transportation demand next year.

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
20feet	74	57	92	78	60	87	415	65	355	398	55	52
40feet	115	95	154	128	101	140	688	109	575	653	87	84
TEU	304	247	400	334	262	367	1791	283	1505	1704	229	220

Table 2. Traffic ratio for 20 feet containers between O-D pairs. (Unit: %)

	Umgung	Suyoung	Yongdang	Gamman	BCTOC	Port	Station	UTC
Umgung	0	1.93	0	0	0.72	0	0	3.62
Suyoung	5.8	0	0	3.14	0.72	0	0	0
Yongdang	0	0	0	0	1.21	6.28	0	3.14
Gamman	0	1.45	0	0	6.76	0	2.42	0
BCTOC	3.62	4.83	0.72	1.45	0	3.86	4.11	4.43
Port	0	0	1.21	0	2.17	0	0	6.76
Station	0	0	0	3.62	1.45	0	0	0
UTC	7	0	7	0	5.31	5.31	0	0

Table 3. Daily transportation volume for 20 feet containers on January.

	Umgung	Suyoung	Yongdang	Gamman	BCTOC	Port	Station	UTC
Umgung	0	1	0	0	1	0	0	3
Suyoung	4	0	0	2	1	0	0	0
Yongdang	0	0	0	0	1	4	0	2
Gamman	0	1	0	0	5	0	2	0
BCTOC	3	3	1	1	0	3	3	3
Port	0	0	1	0	2	0	0	5
Station	0	0	0	3	1	0	0	0
UTC	5	0	5	0	4	4	0	0

Table 4. Cost parameters.

Parameter	Volume
F1	60

	F2	10
	R	10
20feet	V1	1
	V2	5
	V3	7
40feet	V1	1.2
	V2	6
	V3	8.4

Table 5. Monthly minimum number of combined vehicles.

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
No. of Vehicles	67	56	86	76	59	81	67	64	56	64	51	49

Table 6. Travel time matrix between O-D pairs. (Unit: min)

	Umgung	Suyoung	Yongdang	Gamman	BCTOC	Port	Station	UTC
Umgung	0	50	30	40	30	30	30	35
Suyoung	50	0	30	40	30	35	35	35
Yongdang	30	30	0	10	30	35	35	25
Gamman	40	40	10	0	20	25	25	20
BCTOC	30	30	30	20	0	5	5	10
Port	30	35	35	25	5	0	5	15
Station	30	35	35	25	5	5	0	15
UTC	35	35	25	20	10	15	15	0

Table 7. Results obtained for the example problem.

Entry No.	Entries into CL	Total Cost	Entries into IL
1	(49,0,0)	10,927	
2	(51,0,0)	10,882*	
3	(51,0,0)	10,842*	
4	(51,1,0)	10,813*	
5	(51,2,0)	10,785*	
6	(51,3,0)	10,757*	
7	(51,4,0)	10,732*	
8	(51,5,0)	10,706*	
9	(51,6,0)	10,688*	
10	(51,7,0)	10,671*	
11	(51,8,0)	10,654*	
12	(51,9,0)	10,631*	
13	(52,9,0)	10,621*	
14	(53,9,0)	10,611*	

15	(54,9,0)	10,609*	
16	(54,9,1)	10,606*	
17	(54,9,2)	10,604*	
18	(54,9,3)	10,595**	(54,9,3)
19	(55,9,3)	10,602	
20	(55,9,4)	10,599**	(55,9,4)
21	(56,9,4)	10,605	
22	(56,9,5)	10,602**	(56,9,5)
23	(56,9,6)	10,609	
24	(56,9,7)	10,615	
25	(57,9,7)	10,623	
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