International Journal of Management Science
Vol 8, No 2, November 2002

Determination of Fleet Size for LTL Transportation With Dynamic Demand*

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(Received Mar. 2002, Revised May 2002, Accepted Sep. 2002)

ABSTRACT

This study suggests an approach for determining fleet size for LTL(less-than-truckload) transportation with dynamic demand for on-time supply of the parts between the assembly line in an automobile company and its part suppliers in Korea. The vehicles operated by the transportation trucking companies in Korea in general 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 entrusts the company with its operation, and rented truck (outsourcing). With the forecasted monthly production data a year, a heuristic algorithm is developed to determine the number of company-owned trucks, mandated trucks, and rented trucks in order to minimize the expected annual operating cost, which is based on the solution technologies used in the aggregate production planning and vehicle routing problem. Finally the algorithm is tested for the problem how the trucking company transports parts for the automobile company.

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* This research has been supported in part by Grant No. 1999-1-315-001-3 from the interdisciplinary research program of KOSEF (Korea Science and Engineering Foundation).

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1. INTRODUCTION

Automobile industry is an integrated one which is related to several sectors such as mechanical, electric, electronic, material, and chemical industries. So, it is regarded as an economic measure indicating the level of technology of the country. The Korean automobile industry is ranked the sixth in the world and many efforts have been made to increase the productivity by both the company and the government. Since an automobile is composed of about 30,000 parts, the synchronized supply of the parts between the automaker and suppliers should be made for stable production and inventory control.

This study suggests an approach for determining fleet size for LTL (less-than-truckload) transportation with dynamic demand for on-time supply of the parts between the assembly line in an automobile company and its part suppliers in Korea. The automobile company considered in this study contracts a transportation trucking company for supplying parts between part suppliers and the assembly line. 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) [6]. 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 for the driver of mandated truck he 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.

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 production data a year, a heuristic algorithm 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 vehicle routing problem (VRP).

According to Nam and Logendran [8], many researchers have suggested a variety of analytical and heuristic approaches for APP [1, 9, 11] since Bowman's study [3]. Recently, APP is focused on the application in the real world problem [4, 12]. There have also been a number of studies for VRP based on Bodin et al. [2], who introduced the mathematical formulations and the solution algorithms in freight transportation fields.

In the next section, the problem of this study is described more precisely. A mathematical representation for the problem and a solution algorithm are presented in the section 3. In the section 4, the algorithm is tested for the problem how the trucking company transports parts for the automobile company in Korea. The final section provides conclusion.

2. PROBLEM STATEMENT

The automobile company considered in this study contracts a transportation trucking company for supplying parts between part suppliers and the assembly line. Figure 1 shows four transportation types for the purpose of steady provision of parts and minimum operating cost. For the part suppliers far away from the production line, parts are transported from suppliers to depot and then shuttle transportation is periodically operated from depot to automobile company's assembly line. While the parts are directly shipped to the assembly line from the suppliers when the suppliers are located in the neighborhood of the automobile company. According to the amount of parts required, transportation types are divided into direct shipping and tour shipping. Without loss of generality the direct shipment is applied for the suppliers with a lot of part amounts in volume.

There happen severe fluctuations in the monthly production for the automobile company since the company considered in this study has opened automobile plant and started production line recently. So, the production rates of the part suppliers are influenced by the fluctuations, and then the transportation trucking company also should determine how many vehicles are required and how to operate them. In addition to the above the problem, the aforementioned three types of vehicles are adopted considering Korean specific situation.

Therefore, this study deals with the problem which determines fleet size as well as types of vehicles transporting fluctuated monthly demands of parts at the aim of minimizing the expected annual operating cost.

This problem is very 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 [8].

The difference between this problem and APP is whether the number of vehi cles determined at the beginning of the year will be able to change or not. In the typical APP, the dynamic demand is satisfied through the change of the resources. On the contrary, this study assumes that the changes in the fleet sizes of company-owned and mandated vehicles will not be allowed. So the surplus monthly demands not to be covered by company-owned and mandated vehicles are met by rented vehicles only.

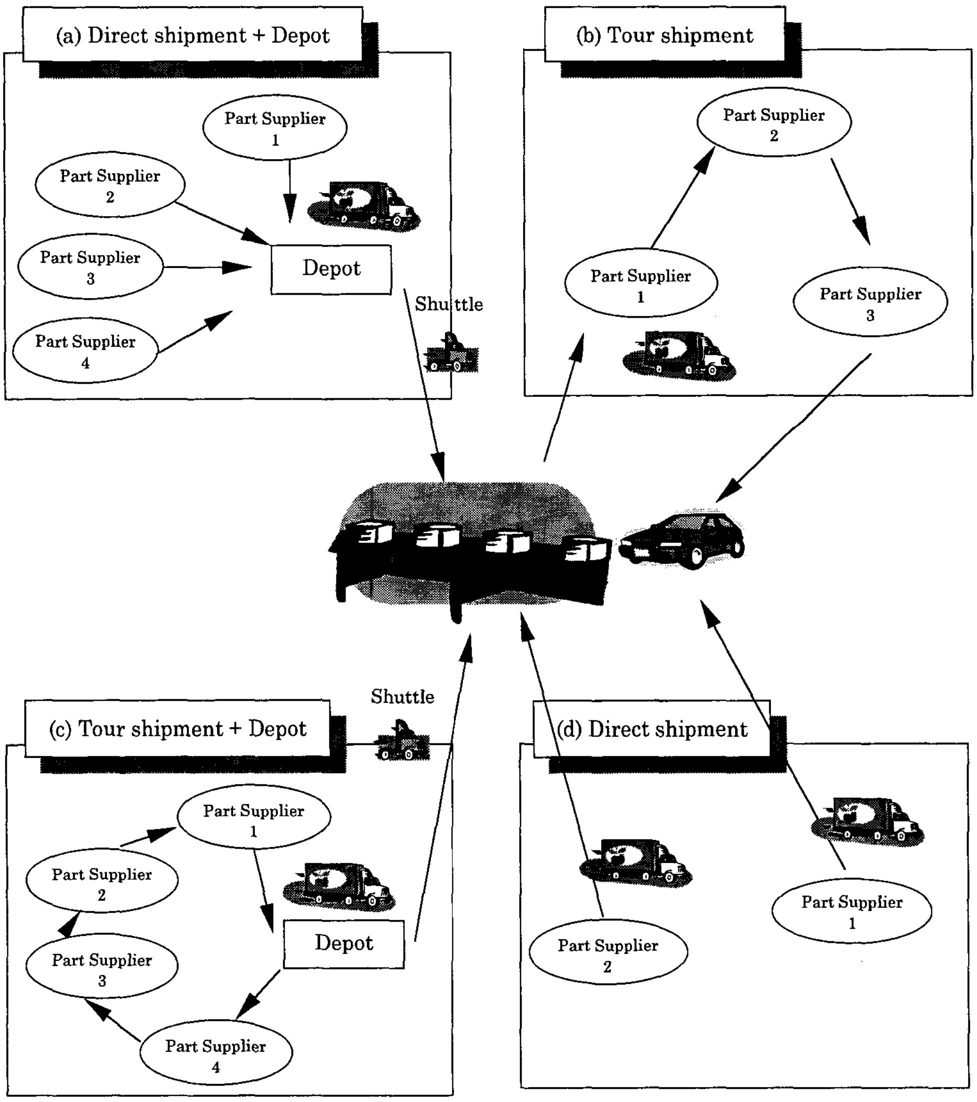

Figure 1. Four transportation types between the automaker and the part suppliers

Cost structures for operating three types of vehicles in Korea are depicted in Figure 2. The cost of a company-owned vehicle is the sum of the fixed cost and the variable cost proportional to the shipping volume. The fixed cost includes vehicle cost, labor cost, insurance cost, etc. and is calculated as the equivalent monthly cost. Mandated vehicle has a similar cost function, but the fixed cost is much lower compared with that of company-owned vehicle. Rented vehicle has only variable cost which is proportional to the shipping amount. It is more economical to operate the company-owned vehicle when the amount of parts loaded in vehicle is high, while in the opposite case rented vehicle is more economical. The operating cost of the trucking company also follows the pattern in Figure 2 and its manager estimates the break-even point (BEP) as about 70 pallets per company-owned vehicle in a working day.

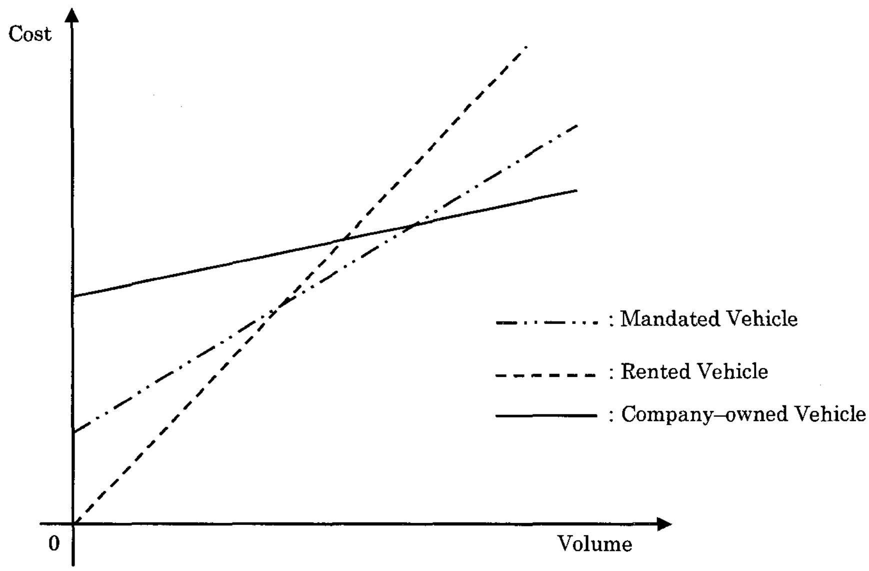

Figure 2. Cost structures for three types of vehicles in Korea

3. SOLUTION ALGORITHM

We present the mathematical representation 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 1 is company-owned, type 2 is mandated, and type 3 is rented vehicle.

$t = 1, 2, \cdots, T$: planning period

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

n_{it} : amount of parts 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 a vehicle with type i at period t

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

V_i : variable cost for parts to be transported by vehicles with type i

The problem can be formulated as follows:

$$\text{Minimize} \quad TC = \sum_{t=1}^{T}\sum_{i=1}^{3} C_i(t) \tag{1}$$

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

Subject to

$$\sum_{i=1}^{3} n_{it} = n(t) \qquad t = 1, 2, \cdots, T \tag{2}$$

$$\sum_{i=1}^{3} N_{it} = N(t) \qquad t = 1, 2, \cdots, T \tag{3}$$

$$n_{it} = f_i(n_t, C_i(t)\,(i = 1, 2, 3)) \qquad i \in I, \quad t = 1, 2, \cdots, T \tag{4}$$

$$N_{it} = g_i(n_t, C_i(t)\,(i = 1, 2, 3)) \qquad i \in I, \quad t = 1, 2, \cdots, T \tag{5}$$

$$N_{it},\ n_{it} : \text{nonnegative integer} \qquad i \in I, \quad t = 1, 2, \cdots, T \tag{6}$$

The objective function (1) is composed of annual operating costs of three types of vehicles to transport parts required to satisfy the monthly production demand a year. The constraints (2) represent that all the monthly demands should be shipped by the vehicles. The constraints (3) mean availability of three types of vehicles. The constraints (4) and (5) indicate that the fleet sizing and mixing of the three types of vehicles as well as part volume to be shipped by each of them are related to the operating cost and total part load. We should notice that it is a very difficult problem to represent the two constraints explicitly since they are defined based on VRP which belongs to NP class. In this study we assume that the number of company-owned and mandated vehicles determined at the beginning of a year will not change before the beginning of the next year. So, decision variables of the problem are N_1 and N_2 because N_{3t} can be easily calculated as Max $\{0, N(t) - N_1 - N_2\}$ where N_1 and N_2 denote constant value of N_{1t} and N_{2t} regardless of t, respectively.

From now on, a heuristic algorithm is introduced to solve the above model. The logic of the algorithm is based on both APP and VRP, and tabu search [6, 7] is utilized to find an optimal or a near-optimal solution.

Step 1 (Calculation of Part Volume)

1. Calculate the average daily part volume for each part supplier based on the monthly production data in transportation units assuming that total working days per month are 25.
2. Set $n(t)$ as the sum of part volume for all suppliers at period t.

Step 2 (Solving VRP)

1. Estimate $N(t)$ required to meet $n(t)$ calculated in Step 1.1 by the Insertion Heuristic [10] which is a well-known solution algorithm in VRP.
2. Set the lower bound of N_1, N_1^L as Min $\{N_{1t}, t = 1, \cdots, T\}$.
3. Set the upper bound of $N_1 + N_2$ as Max $\{N(t), t = 1, \cdots, T\}$
4. Sort the tours made in Step 2.1 in the decreasing order based on the total part volume of each tour.

Step 3 (Tabu Search)

1. **Definition of Total Cost**
   1. Define TC(N_1, N_2) is the annual operating cost to meet $n(t)$ with N_1, N_2 and N_{3t} for a year.
   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) as (N_1^L, 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 and N_2.
   4. For two new configurations generated evaluate TC and select the con-

figuration 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 $N_1 + N_2$ 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 and N_2. 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, which contracts an automobile company to transport parts required to assemble the automobile between the production line and part suppliers. In this example problem only the tour shipment in Figure 1-(b) is considered. Table 1 shows the monthly production data for the automobile company and the part volume of each supplier in pallet units. Unit size of a pallet is assumed to be 42,000 cm^3. Table 2 is a travel time matrix between any two points including the company. We assume that all vehicles have the same size of 100 pallets, but only the average 85% of capacity is used actually. It is also assumed that total operating time of each vehicle is 8 hours, and that the sum of loading and unloading time per pallet is one minute regardless of the characteristics of the parts. The parameters representing the cost functions for company-owned, mandated and rented vehicles are summarized in Table 3.

Figure 3 shows the locations of 21 part suppliers and the company plant and routing of all vehicles on February resulted from the Insertion Heuristic. Table 4 presents all of these configurations, leading to identifying the 5^{th} entry as the best solution for the example problem. It states that the number of company-owned and mandated vehicles are five and four, respectively and the number of rented vehicles required each month are $N_{35} = 1$, $N_{36} = 1$, $N_{37} = 2$, $N_{38} = 1$, $N_{3,11} = 1$, $N_{3,12} = 2$, and $N_{3t} = 0$ for t = 1, 2, 3, 4, 9, 10 and minimum total cost is 10,795.

Table 1. Production data for the automobile and the part volume for each supplier in pallet units.

	Month	1	2	3	4	5	6	7	8	9	10	11	12
	Forecasted Production Data per Day	550	300	350	400	550	600	650	550	400	450	600	700
Part Supplier	Unit Volume(cm^3)	Part Volume in Pallets											
A1	350	5	3	3	4	5	6	6	5	4	4	6	6
A2	490	7	4	5	5	7	8	8	7	5	6	8	9
A3	630	9	5	6	7	9	10	10	9	7	7	10	11
B1	1050	14	8	9	11	14	16	17	14	11	12	16	18
B2	1120	15	9	10	11	15	17	18	15	11	13	17	19
B3	1260	17	10	11	13	17	19	20	17	13	14	19	22
B4	1330	18	10	12	13	18	20	21	18	13	15	20	23
B5	1610	22	12	14	16	22	24	25	22	16	18	24	27
C1	1890	25	14	16	19	25	28	30	25	19	21	28	32
C2	2240	30	17	19	22	30	33	35	30	22	25	33	38
C3	2730	36	20	23	27	36	40	43	36	27	30	40	46
C4	2940	39	22	25	29	39	43	46	39	29	32	43	50
C5	3010	40	22	26	29	40	44	47	40	29	33	44	51
C6	3150	42	23	27	31	42	46	49	42	31	34	46	53
C7	3290	44	24	28	32	44	48	51	44	32	36	48	55
C8	3570	47	26	30	35	47	52	56	47	35	39	52	60
C9	3710	49	27	31	36	49	54	58	49	36	40	54	62
C10	4550	60	33	38	44	60	66	71	60	44	49	66	76
C11	4620	61	34	39	45	61	67	72	61	45	50	67	78
C12	4760	63	35	40	46	63	69	74	63	46	52	69	80
Total		643	358	412	475	643	710	757	643	475	530	710	816

Table 2. Travel time matrix

(unit: hour)

To / From	Assembly Line	A1	A2	A3	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Assembly Line		2.0	1.4	1.5	0.4	1.0	0.6	1.7	1.0	0.2	0.7	0.9	0.5	0.7	0.8	1.3	1.4	1.0	1.4	1.7	0.5
A1	2.0		0.9	1.5	1.9	1.0	1.4	0.4	1.6	1.8	1.9	1.4	1.5	1.7	1.3	1.2	1.0	1.0	0.6	0.3	1.2
A2	1.4	0.9		1.9	1.3	0.9	1.0	0.5	0.7	1.0	1.7	0.5	1.4	2.0	0.4	0.4	0.5	0.3	0.5	0.7	1.2
A3	1.5	1.5	1.9		0.6	1.0	0.9	1.7	2.0	1.1	0.4	1.4	0.5	0.2	1.8	2.3	2.4	1.6	1.4	1.2	0.7
B1	0.4	1.9	1.3	0.6		0.9	0.5	1.6	1.4	0.5	0.4	0.8	0.4	0.8	1.2	1.7	1.7	0.9	1.3	1.6	0.7
B2	1.0	1.0	0.9	1.0	0.9		0.4	0.7	1.0	0.9	0.9	0.4	0.5	1.2	0.8	1.3	1.3	0.5	0.4	0.7	0.3
B3	0.6	1.4	1.0	0.9	0.5	0.4		1.1	1.1	0.4	0.7	0.5	0.4	1.0	0.9	1.4	1.5	0.6	0.8	1.1	0.2
B4	1.7	0.4	0.5	1.7	1.6	0.7	1.1		1.3	1.5	1.6	1.1	1.2	1.9	0.9	0.8	0.6	0.6	0.3	0.6	1.0
B5	1.0	1.6	0.7	2.0	1.4	1.0	1.1	1.3		0.9	1.8	0.6	1.5	2.2	0.3	0.4	0.9	0.6	1.0	1.3	1.3
C1	0.2	1.8	1.0	1.1	0.5	0.9	0.4	1.5	0.9		0.9	0.4	0.6	1.2	0.7	1.2	1.3	0.9	1.2	1.5	0.6
C2	0.7	1.9	1.7	0.4	0.4	0.9	0.7	1.6	1.8	0.9		1.2	0.4	0.3	1.6	2.1	2.2	1.3	1.3	1.6	0.7
C3	0.9	1.4	0.5	1.4	0.8	0.4	0.5	1.1	0.6	0.4	1.2		0.9	1.5	0.4	0.9	1.0	0.4	0.8	1.1	0.7
C4	0.5	1.5	1.4	0.5	0.4	0.5	0.4	1.2	1.5	0.6	0.4	0.9		0.6	1.3	1.8	1.9	1.1	0.9	1.2	0.3
C5	0.7	1.7	2.0	0.2	0.8	1.2	1.0	1.9	2.2	1.2	0.3	1.5	0.6		1.9	2.4	2.5	1.7	1.5	1.4	0.8
C6	0.8	1.3	0.4	1.8	1.2	0.8	0.9	0.9	0.3	0.7	1.6	0.4	1.3	1.9		0.5	0.6	0.3	0.7	1.0	1.1
C7	1.3	1.2	0.4	2.3	1.7	1.3	1.4	0.8	0.4	1.2	2.1	0.9	1.8	2.4	0.5		0.5	0.7	0.9	1.1	1.6
C8	1.4	1.0	0.5	1.0	1.7	1.3	1.5	0.6	0.9	1.3	2.2	1.0	1.9	2.5	0.6	0.5		0.8	1.0	1.2	1.7
C9	1.0	1.0	0.3	0.9	0.9	0.5	0.6	0.6	0.6	0.9	1.3	0.4	1.1	1.7	0.3	0.7	0.8		0.4	0.7	0.9
C10	1.4	0.6	0.5	0.5	1.3	0.4	0.8	0.3	1.0	1.2	1.3	0.8	0.9	1.5	0.7	0.9	1.0	0.4		0.3	0.7
C11	1.7	0.3	0.7	0.2	1.6	0.7	1.1	0.6	1.3	1.5	1.6	1.1	1.2	1.4	1.0	1.1	1.2	0.7	0.3		0.9
C12	0.5	1.2	1.2	1.1	0.7	0.3	0.2	1.0	1.3	0.6	0.7	0.7	0.3	0.8	1.1	1.6	1.7	0.9	0.7	0.9	

Table 3. Cost parameters

Parameter	Volume
F1	80
V1	6.29
F2	15
V2	1.5
V3	2

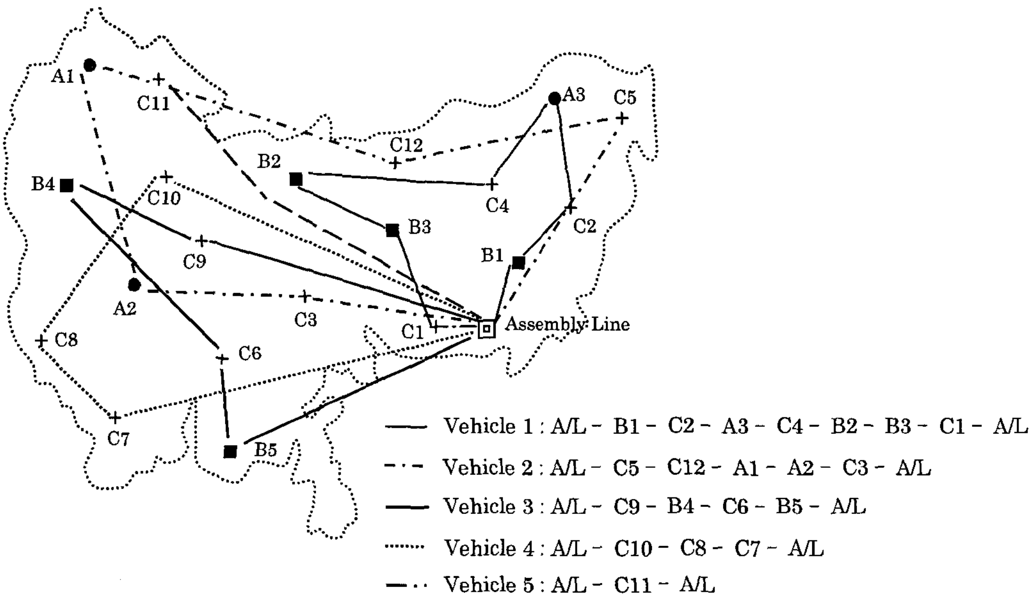

Figure 3. An example of routing for five vehicles required on February.

Table 4. Results obtained for the example problem.

Entry No.	Entries into CL	Total Cost	Entries into IL
1	(5, 0)	11,086 **	(5, 0)
2	(5, 1)	10,961 *	
3	(5, 2)	10,842 *	
4	(5, 3)	10,796 *	
5	(5, 4)	10,795 **	(5, 4)
6	(5, 5)	10,805	
7	(5, 6)	10,936	

5. CONCLUSION

This study suggested an approach for determining the fleet size and the vehicle mix for LTL transportation with dynamic demand for on-time supply of the parts between the assembly line in an automobile company and its part suppliers especially considering three types of vehicles operated in Korea. A solution algorithm was developed using APP and VRP, and tabu search was utilized to find an optimal or a near-optimal solution. The algorithm was tested based on the trucking company supplying parts for an automobile company in Korea.

Recently, many researches and system implementations have been performed about Supply Chain Management (SCM). This study also dealt with the supply chain between the automaker and part suppliers although the transportation cost only is reflected on the supply chain. Thus, we propose the problem considering the logistics cost including inventory cost of parts and the fleet sizing problem with uncertainty of demand as further research areas in SCM.

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