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A Simulation Based Vehicle Distribution Planning System

양 병 희*, 이 영 해**

Abstract

Many vehicle routing methods have been suggested, which minimize the routing distances of vehicles to reduce the total transportation cost. But the more considerations the method takes, the higher complexites are involved in a large number of practical situations. The purpose of this paper is to develop a vehicle distribution planning system using heuristic algorithms and simulation techniques for home electronics companies. The vehicle distribution planning system developed by this study involves so complicated and stochastic conditions such as one depot, multiple nodes(demand points), multiple vehicle types, multiple order items, and other many restrictions for operating vehicles. The proposed system is compared with the nearest neighbor method and the savings method in terms of total logistics cost and driving time. This heuristic algorithm and simulation based distribution planning system is efficient in computational complexity, and give improved solutions with respect to the cost as well as the time. This method constructs a route with a minimum number of vehicles for a given demand.

* 교육사령부 BCTP단 ** 한양대학교 산업공학과

1. Introduction

The aggregate material costs of Korea business circles are colossal ones that form about 14% of gross national product(GNP) in 1995. Now, the material problems are inducing us the more interests as the core part of new business stategies. Particularly, the cost related to transportation and distribution has charged of 44.5% of the total material costs. Therefore, each enterprise will be required transport and distribution system that minimizes cost and time in managing customer's order to improve quality of service and keep superior position in selling competition with other enterprises.

Many vehicle routing methods have been suggested, but it is not easy to find the one satisfying both theoretical and practical conditions. The more considerations the method takes, the higher its complexity increases in a large number of practical situations. This resulted from difficulty in treating additional restricted condition and there are many practical problems in existing common distribution software such as not corresponding with system property of each company.

The purpose of this paper is to develop a heuristic algorithm and computer program for a distribution planning system of electric home appliances. The vehicle distribution planning system using heuristic and simulation is effective vehicle routing method not destroying the unit of goods. This study involves complicated and stochastic conditions such as one depot, multiple demand points, multiple vehicle types, multiple order items, and other many restrictions for operating vehicles.

Simulation is a technique that has been employed extensively to solve this kind of problems. Simulation models are abstractions of systems. They could be built quickly, explained to all project personnel, and changed when necessary. The implementation of recommendations to improve system performance is an integral part of the simulation methodology[1].

The farthest and nearest node from a depot are considered as a seed node to construct an initial route. To select a node inserted into a route, we use branch and bound method of Belmore-Malone. Using this method we can easily get an initial route, avoid the need to reconstruct the route if the farthest node is regarded later, and generate distribution routes in a relatively small computaional time.

The proposed heuristic algorithm is more efficient than the conventional nearest neighbor method in total logistics cost and driving time. The results of this vehicle distribution planning system are about the number of events(orders), the number of used vehicles, traveling time, and the logistics cost per distribution route. Therefore, the vehicle distribution planning system can be used to any companies whose vehicles are under circumstances considerd in this paper.

2. Literature Review

The distribution planning problem in which vehicles based at a central facility (depot) are required to visit -during a given time period- geographically dispersed customers in order to fulfill known customer requirements. The problem appears in a large number of practical situations concerning the distribution of commodities and is known by the generic name : the *vehicle routing problem*. This is also known in the literature as the 'vehicle scheduling' [Clarke & Wright, 1964; Gaskell, 1967], 'truck dispatching' [Dantzig & Ramser, 1959; Christofides & Eilon, 1969; Krolak, Felts & Nelson, 1972] or simply 'delivery problem' [Hays, 1967].

Generally, the vehicle distribution planning problem can be classified as the vehicle routing problem (VRP), the vehicle scheduling problem (VSP), and the vehicle routing and scheduling problem (VRSP)[2]. The VRP is to start at a depot and to supply transporting goods for customers with vehicles that have constraints of loadage and traveling distance. Therefore, the vehicle distribution planning problem of this paper can be thought as the extended problem of the VRP.

Optimization algorithms for solving the VRP are the generalized matching problem [Christofides & Thornton, 1982], a method based on Benders decomposition which consists of travelling salesman problem [Fisher & Jaikumar, 1978] and a branch and bound algorithm. On the other hand, heuristics for the VRP are the savings algorithm [Clarke & Wright, 1964], the sweep algorithm [Gillett & Miller, 1974], and the two-phase method [Christofides, 1979; Fisher & Jaikumar, 1981]. Optimization algorithms for the VRP are so simple and available programming, but these are difficult to apply them to complex system with various constraints. To overcome this restriction in calculation, and find approximate solution in short time, so heuristics were studied[3].

Most heuristics for the VRP are processed by repeating of the route construction procedures and the route improvement procedures. The route construction procedure is organized the vehicle route that insert minimal cost node to present route when select random node. The route improvement procedure uses the k-optimal method to improve it after the approximate solution was obtained within a short time[4].

However, it is a very important matter that have not been found the absolutely excellent heuristics in measure of performance in comparison with every all situation of the VRP. Whenever a heuristic method is developed, the heuristic algorithm is proposed that it is superior to conventional method in specific experimentation, but it can not be asserted absolute excellence under every general situations in real-world problems[3,6].

The VRP are assumed that supply and demand of customers and distance between nodes are known deterministic, but these are stochastic to dynamic change against circumstance under the vehicle distribution planning system. Today, the study of the stochastic VRP takes a very interesting field[7].

3. A Vehicle Distribution Planning System

A vehicle distribution planning system of this paper is assumed that one depot and a set of nodes within m sections that is divided by the distance between points. First, we construct the time matrix that includes the traffic restriction and the other vehicle elements on the basis of the depot, each nodes, and distance between nodes. Now, we develop a vehicle distribution planning system using heuristic algorithm and simulation. And determine the routes of distribution, type of vehicle, load amount, driving time and logistics cost for home electronics companies. At this time, we assume that all kinds of vehicle have same speed, and the number of usable vehicles are stochastic because they are changed return rate according to order quantity and distance between nodes.

The order amount of each node is computed by loading rate of vehicle accoding to the volume that it is unit per item of electric home appliances. Practically, single distribution is done main principle as a service for customers, but the delivery distribution is available within the limits of unit of goods in specific case that the order amount is exceeded loading rate of vehicles.

A vehicle logistics distribution planning system is shown in Figure 1.

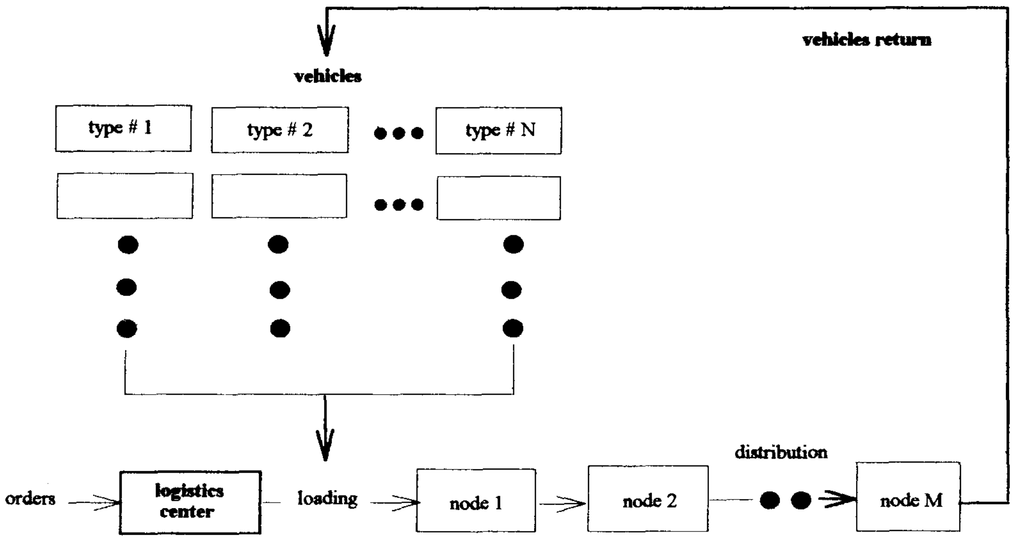


Figure 1. Vehicle Distribution System

The distribution route of this paper can be defined five assumptions:

1. A distribution route starts from the depot and ends at the depot.
2. The cost and time variables are independent respectively.
3. Every order amount must be sent within the fixed time in consideration of sevice for customers, and returned goods does not be considered.
4. The loading rate of vehicles is different according to kinds of vehicle and a route.
5. The route must be minimized total driving time and logistics cost traveled by the vehicles simultaneously.

A vehicle logistics distribution planning system of Figure 1 can be defined by the following mathematical model.

Nomenclature

N : node number. node 0 is the depot.

M_k : available vehicle number.

U_k : load capacity of vehicle.

V_{ik} : distribution loadage of vehicle K.

D_{io} : order quantity of item 0 in the node I. $D_{00} = 0$

W : maximum distribution time of a route

F_{ijk} : fixed cost of vehicle K from node I to node J

V_{ijk} : additional cost of vehicle K from node I to node J

C_{ijk} : distribution cost of vehicle K from node I to node J. $C_{ijk} = F_{ijk} + V_{ijk}$.

T_{ijk} : distribution time of vehicle K from node I to node J.

X_{ijk} : $\begin{cases} 1, & \text{if vehicle K drive from node I to node J.} \\ 0, & \text{otherwise} \end{cases}$

Mathematical Model

$$\text{Minimize} \quad TC = \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{M} (C_{ijk} \sum_{k=1}^{V} X_{ijk}) \tag{1}$$

$$\text{Minimize} \quad TT = \sum_{i=0}^{N} \sum_{j=0}^{N} \sum_{k=1}^{M} (T_{ijk} \sum_{k=1}^{V} X_{ijk}) \tag{2}$$

Subject to

$$\sum_{i=0}^{N} X_{ijk} - \sum_{j=0}^{N} X_{jik} = 0 \text{ , k =1,2,...,M , i=1,2,...,N} \tag{3}$$

$$\sum_{i=1}^{N} V_{ik} \le U_k \qquad , k = 1, 2, \ldots, M \tag{4}$$

$$\sum_{k=1}^{M} V_{ik} \le D_{io} \qquad , i = 1, 2, \ldots, N \tag{5}$$

$$Y_i - Y_j + N \sum_{k=1}^{V} X_{ijk} \le N-1, \quad i, j = 1, 2, \ldots, N (i \ne j) \tag{6}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} D_{io} X_{ijk} \le U_k \qquad , k = 1, 2, \ldots, V \tag{7}$$

$$\sum_{i=1}^{N} \sum_{j=1}^{N} T_{ij} X_{ijk} \le W \qquad , k = 1, 2, \ldots, V \tag{8}$$

$$X_{ijk} = 0 \text{ or } 1, \quad \forall\, i, j, k \tag{9}$$

$$Y_i \ge 0 \quad ; \text{ real number}$$

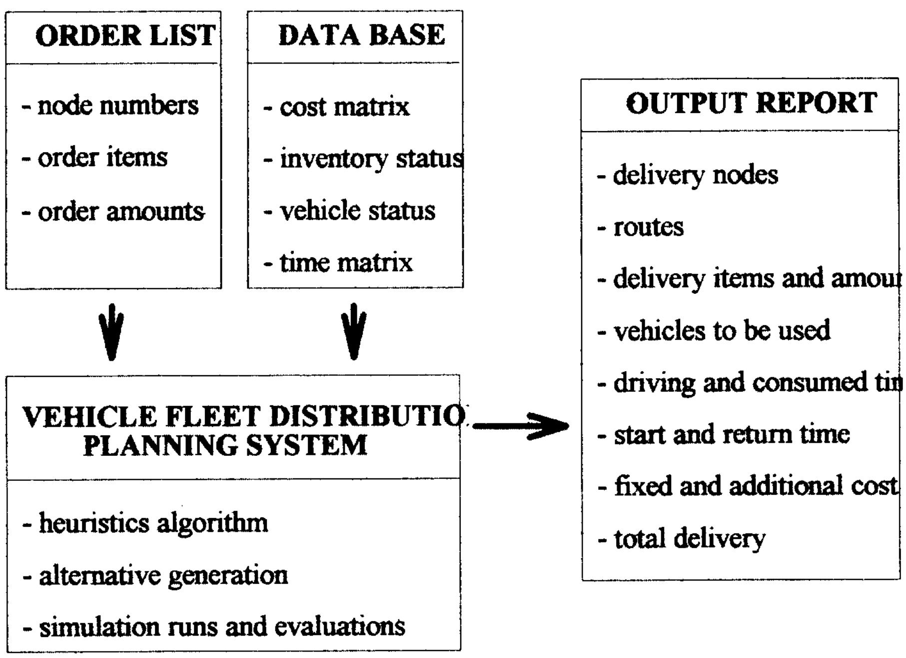
In above mathematical model, equation (1) is an objective function that minimize total distribution cost, and (2) is an objective function that minimize total distribution time. (3) is a constraint of route continuity that vehicle must leave after visits a node, and (4) mean that distribution loadage of vehicle K is not exceeding load capacity of vehicle.

(5) is a condition of order quantity in node, and (6) is preventive constraint of subtour by Miller et al.[6]. (7) is load capacity of vehicle in each route, constraint (8) is maximum distribution time of a route, and (9) is integer condition.

Generally, the vehicle distribution system is a NP-complete problem in mathematics, so the route construction procedure is similar to repeated traveling salesman problem (TSP).

As the complex situations such as multiple nodes, multiple vehicle type, colossal item of goods, and other many restrictions for operating vehicles are included, we can not obtain the real solution by using mathmatical programming or optimization algorithms for the VRP because of serious calculating time. Therefore, it is necessary to use heuristic methods and simulation in the complicated vehicle distribution system.

Application areas for simulation are numerous and diverse. As a technique, simulation is one of the most widely used method operations research and management science. In order to do simulation in the vehicle distribution planning system, we should make imitation or environmental objects that reflect the major characteristics of the real-world, which we call a model. The proposed vehicle distribution planning system of this paper is to obtain the practical solutions for complex and stochastic logistics data using simulation. we develop a heuristic algorithm, define the effective alternatives, do pilot run simulation and comparing alternatives, and suggest the output of sequential simulation. The suggested vehicle distribution planning system is shown in Figure 2.



Figuer 2. Structure of Vehicle Distribution Planning System

When the simulation runs, we consider the alternatives as follow:

Alternative #1: We select the seed node that is the farthest one of the farthest area among non distributed nodes.

Alternative #2: We select the seed node that is the nearest one of the nearest area among non distributed nodes.

Now, we explain a heutistic algorithm in a vehicle distribution planning system from step 1 to step 6.

Step 1: Select the type of vehicle. First, deciside the single route as node within the limit to load of vehicle. Single route is included only one node in each route. If searching of single route is finished at all type of vehicle, return to step 2.

Step 2: Select the type of vehicle. Insert node, R_u that has minimized logistics cost and is within the limit to load of vehicle. Consider the constructed route as follow:

$$\text{merged route ; } (R_0 , \ldots , R_u , \ldots , R_m)$$

where R_0 is depot and R_m is ending node. Now, select the alternative, and run simulation. At this time, make a Hamiltonian Cycle for selected node according to branch and bound method of Bellmore-Malone. Hamiltonian Cycle is defined as exactly one distributed route between each node from the depot[6]. Generally, it is that VRP is known the searching problem of Hamiltonian Cycle with minimum delivery cost. Repeat step 2 for each kinds of vehicle. If searching of merged routes are finished at all type of vehicle, return to step 3.

Step 3: Search the delivery disrtibution amount for a node exceeds the upper bound of loading capacity, then above all make single route, and make merged route for surplus goods of loading capacity through step 2. If finished, return to step 4. And not finished, return to step 2.

Step 4: Search the omitted nodes in the route construction procedures, combine additional route in consecutive for each item and vehicle. If finished, return to step 5.

Step 5: Search the route which has minimum load, V_{min} among the determined routes, R. Select any node within the limit load of vehicle of the other route, reconstruct the route between the nodes, and compare it with an initial solution. It reconstructed route is redused the total delivery cost and time, reconstructed route is selected the improved route. If the improved route is determined, then return to step 6.

Step 6: Stop the simulation and summarize the report.

A simplified flowchart of above distribution planning system is given in Figure 3.

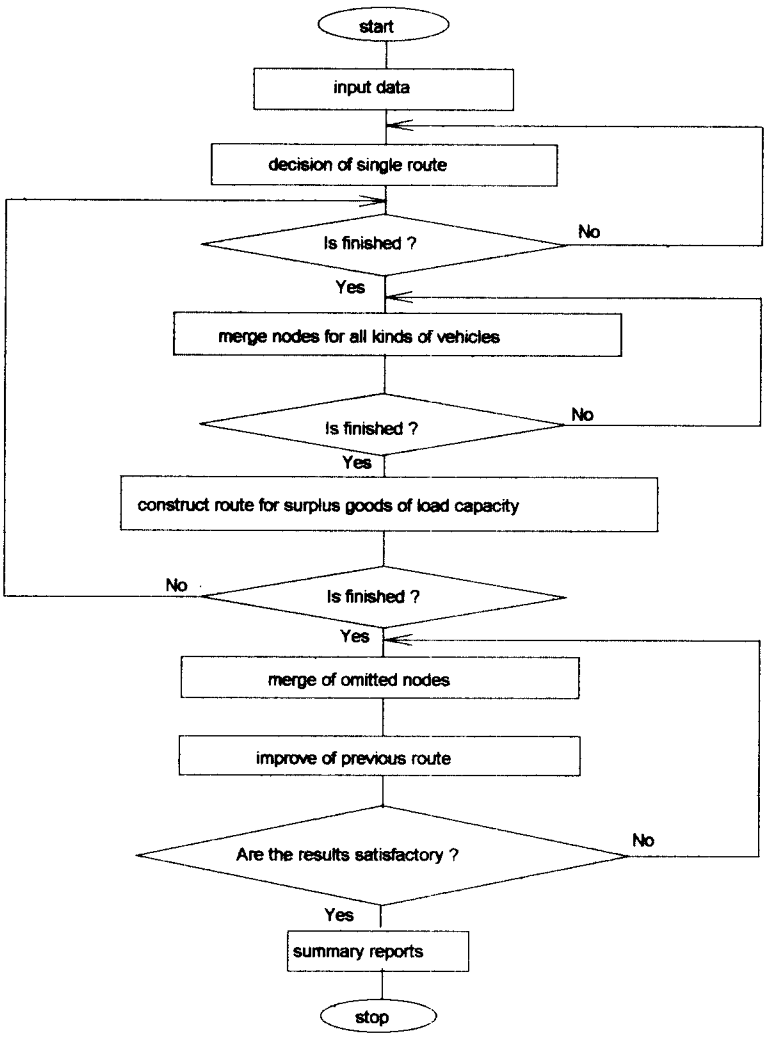


Figure 3. Flow Chart of Heuristic Algorithm

4. Experiments and Evaluations

We apply the vehicle distribution planning system using simulation. This simulation is based on about 2,000 items which is transported to LG manufacturing company with the material material distribution system of electric home appliance. These items are distributed from about 500 nodes which are classified by distance between nodes centering around one depot.

We assume 16 nodes at the point of any order treatment on X month Y day year Z, and types of distribuion vehicle are 2.5 ton and 5 ton. The volume of each node is the load per unit (%) for items, and total order amount (%) is the volume* quantity. This data is shown in table 1, and the standard matrial disribution cost is shown in table 2. The distribution cost is classfied as the fixed cost for area and the additional cost by one node. For example, when any route is included 2 nodes in C area and 3 nodes in B area, the logistics cost of 2.5 ton is 36,300 + (5-1)*3,600 = 50,700 Won.

Table 1. Example: Order Amount for Each Nodes

AREA	NODE	ITEM	QUANTITY	VOLUME(%)	ORDER AMOUNT(%)
A	3	728	20	1	20
	6	1273	22	3	66
		1961	34	2	68
	9	1388	2	2	4
B	14	1470	35	1	35
	16	638	15	3	45
	18	1388	46	4	184
C	33	1275	48	2	96
		1269	6	5	30
	40	1061	29	3	87
	45	450	49	3	147
D	50	264	43	2	86
		216	9	4	36
	59	633	34	3	102
	65	187	25	3	75
G	71	1539	29	3	87
	73	633	34	3	102
	79	586	6	5	30

Table 2. Standard Material Handling Distribution Cost

TYPE	FIXED COST (Won)					ADDITIONAL
VEHICLE	A (15Km)	B (20Km)	C (25Km)	D (30Km)	G (45Km)	COST (Won)
2.5 ton	30,500	33,000	36,300	40,300	49,500	3,600
5 ton	54,100	58,100	64,100	71,600	88,100	4,500

When constructing routes, it is assumed that upper bound limit of 2.5 ton load is 105 %, low bound limit is 90 %, the capacity of 5 ton is 170 % to 185 %. 18 vehicles(2.5 ton; 15, 5 ton; 3) are available at the current time. When choosing the kind of vehicle, we must consider efficiency with respect to distribution amount and driving cost.

The real time required at each nodes is data that is considered the elements of traffic control and condition of restriction, and equal speed of kinds of vehicle. This time network is shown table 3.

Table 3. Time Matrix

(unit : min)

NODE	0	A 3	A 6	A 9	B14	B16	B18	C33	C40	C45	D50	D59	D65	G71	G73	G79
0	0	20	10	16	40	40	45	40	50	60	60	60	60	85	130	140
A 3	20	0	15	15	50	45	50	47	57	67	65	55	65	85	135	145
A 6	10	15	0	15	45	45	50	40	50	60	55	55	60	85	130	140
A 9	16	15	15	0	45	40	40	50	60	60	65	55	60	85	130	140
B14	40	50	45	45	0	20	35	40	35	45	35	30	45	90	120	130
B16	40	45	45	40	20	0	15	40	25	45	35	35	35	90	130	130
B18	45	50	50	40	35	15	0	45	40	50	40	40	30	85	125	125
C33	40	45	40	50	35	30	30	0	20	45	30	30	40	80	80	80
C40	50	50	50	60	35	25	25	20	0	35	25	25	40	80	80	80
C45	60	60	60	70	40	35	35	25	25	0	25	30	40	80	80	80
D50	60	60	65	65	35	35	40	35	25	15	0	10	15	50	70	80
D59	60	55	60	60	30	35	40	40	30	30	10	0	15	55	65	75
D65	60	70	60	70	40	45	45	40	30	25	15	15	0	35	45	60
G71	70	75	70	80	75	70	70	40	40	50	50	45	30	0	30	40
G73	130	135	130	140	90	80	80	75	80	60	55	55	40	20	0	17
G79	140	150	140	150	95	90	90	80	95	70	55	55	45	30	18	0

We must transport order goods without breaking parts unit of item to serve customers and to hand loading goods. To select the best alternative, we simulate pilot run for alternative #1 and #2 in the real condition of above vehicle distribution planning system. The proposed results are compared with the nearest-neighbor heuristic (NNH) method because the current system has been applied the NNH. Table 4 is illustrated as follow.

Table 4. Pilot Simulation Run for Selection Alternatives

DIVISION		PILOT SIMULATION RUN OUTPU		CURRENT SYSTEM OUTPUT (NNH)
		ALTERNATIVE #1	ALTERNATIVE #2	
ROUTE NUM.		10	10	11
VEHICLE NUM.		5ton; 3, 2.5ton; 7	5ton; 3, 2.5ton; 7	5ton; 3, 2.5ton; 8
TOTAL COST		505,500 Won	477,300 Won	551,000 Won
TOTAL TIME		1,245 min	1,341 min	1,371 min
EFFECT-IVENESS	COST	109.0 %	115.4 %	100 %
	TIME	110.1 %	102.2 %	100 %

As a result of pilot run, the alternative #1 is more efficient (9.0% in cost and 10.1% in time) than the current system. On the other hand, the alternative #2 is more efficient (15.4% in cost and 2.2% in time) than the NNH. Alternative #1 is superior to alternative #2 in driving time, and alternative #2 is more efficient in logistics cost. Computer run time of this suggested system is not considered because it can be processed in real-time. Therefore, we can select important estimation factor as the scales of optimun alternative from the system manager's viewpoint. And we get the distribution route in table 5 by simulation for alternative #1 and by NNH for application of current system.

As a result of simulation, the suggested method in this paper is more efficient than the savings[Clarke & Wright] algorithm that is a popular heuristics(7.0% in cost and 4.3% in time), as well as the NNH. The computational results for each method are summarized in Figure 4.

Table 5. Comparition of Alternative #1 and NNH

NUM	APPLICATION OF ALT.#1				APPLICATION OF NNH			
	ROUTE	TIME	COST	ORDER	ROUTE	TIME	COST	ORDER
①	0- D_{59}-0	120	40,300	102 x	0- A_3- A_6- A_9-0	66	37,700	90 x
②	0- C_{33}-0	80	36,300	96 x	0- A_6- B_{14}-0	95	36,600	103 x
③	0- B_{18}-0	90	58,100	184 x	0- B_{18}-0	90	58,100	184 x
④	0- D_{65}- G_{79}-0	260	53,100	105 x	0- B_{16}- C_{33}-0	120	39,900	75 x
⑤	0- C_{33}- D_{50}- B_{14}-0	145	47,500	101 x	0- C_{33}-0	80	36,300	96 x
⑥	0- A_6- A_9- A_3-0	60	37,700	92 x	0- C_{40}-0	100	36,300	87 x
⑦	0- D_{50}- G_{71}-0	180	92,600	173 x	0- C_{45}- G_{79}-0	280	92,600	177 x
⑧	0- C_{45}-0	120	36,300	105 x	0- D_{50}- G_{71}-0	180	92,600	173 x
⑨	0- B_{16}- C_{40}- $\overline{C_{45}}$-0	170	73,100	174 x	0- D_{50}-0	120	40,300	36 x
⑩	0- A_6-0	20	30,500	66 x	0- D_{59}-0	120	40,300	102 x
⑪	-	-	-	-	0- D_{65}-0	120	40,300	75 x
SUM	5ton; 3, 2.5ton; 7	1245	505,500	1198 x	5ton; 3, 2.5ton; 8	1371	551,000	1198 x

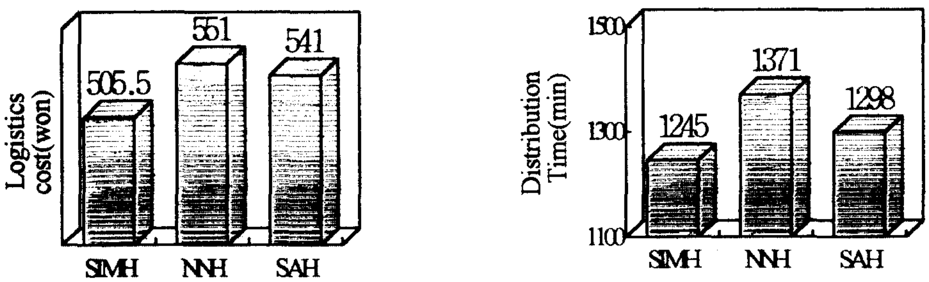


Figure 4. Computational Results for Each Method

When a system manager would like to focus on minimizing the time required for service of customer rather than reducing logistics cost of the company, the alternative #1 is chosen. We carry out an additional simulation as a real system an object using the selected alternative. We code the proposed system in C language, and take experiments on IBM-PC 486 DX2-50. We can see input data of vehicle distribution planning system in table 6.

Table 6. Input Data

* real time required from depot and node to node (file)
* volume and quantity of each items, order amount of nodes (file)
* type and quantity of vehicle : user define (2.5 ton; 120, 5 ton; 25)
* number of node : user define (80 nodes)
* items of order : user define (2000 items)
* event number of ordering point : user define (200 events)

Simulation results for the above data are decided total 73 routes (2.5ton; 56, 5ton; 17). Any one of 56 distribution routes for 2.5 ton is shown in table 7.

Table 7 shows the order amount (98%) of 65,73,80th node in 6,7th area and optimal distribution route. Driving cost is 62,700 Won, Total logistics cost in some day is 527,600 Won, driving time is 310 min, and start from depot at 08:00, return at 15:10. And the number of available trucks are remained 87. With this output, we can control operation of this system, forecast number of vehicles precisely. Therefore, we can control the total distribution planning system efficiently. The output summary of the routes 73 are shown in table 8.

Number of routes are 2.5 ton; 56 and 5 ton; 17 for 200 events at any order processing point. Total driving time is 9,635 min, total consumed time included of loading and release time is 13,765 min, and total logistics cost is 3,214,600 Won.

Table 7. Example of 2.5 Ton Route

```
*************************** OUTPUT SUMMARY ***************************
   7  80    541   13   4   52
   7  80   1174    8   1    8
   6  73   1805    3   1    3
   6  65    626    7   6   35
Used truck: 2.5 ton
Total Volume: 98
Logistics Center(0) -> 65: 110 -> 80: 40 -> 73: 20 -> 0: 140 Logistics C
Driving time: 310
Loading time: 60
Release time: 60
---------------- TOTAL TIME ----------------
Opening time: 8 hour
Comeback time to Logistics Center: 15 hours 10 min.
The number of available trucks: 87
---------------- TOTAL COST ----------------
Setup cost: 55500 won
Via cost: 7200 won
Driving cost: 62700 won
Total logistics cost(SUM): 527600 won
```

Table 8. Output Summary

```
***********************************************************************
****                       OUTPUT SUMMARY                          ****
***********************************************************************
        EVENT NUMBER           :              200
        USED  2.5 TON          :               56
        USED   5 TON           :               17
        TOTAL DRIVING TIME     :             9635  Min
        TOTAL CONSUMED TIME    :            13765  Min
        TOTAL LOGISTICS COST   :          3214600  Won
***********************************************************************
```

This study is done on a vehicle distribution planning system using heuristic algorithms and simulation technique. It is considered the rate of load for multi-type vehicle with non-breaking the unit of home electronics companies, and minimizing the route which is satisfied many complex restrictions. It is possible to treat the real time because the route construction procedures and the route improvement procedures are very simple(run time to 200 order events ; 1 min 40 sec needs). This is especially useful for practical and complicated distribution planning system ; multi-node and type of vehicle, terrible order items(over 2,000 items), and various order events(1,000 events are processed simultaneously).

When we applied the alternative #1 for this method to the electric appliance distribution planning system of LG manufacturing company, we could reduce 11% of total logistics cost, and save 20% of total distribution time directly. Additionally, we can operate vehicles intentionally, predict number of vehicles needed correctly, so it is easy to demand and supply vehicles, we can know the start and return time of distribution vehicle. Also, all infomation of program is processed in file, we can apply this method to similar distribution system if it is needed form of infomation.

5. Conclusions

Simulation model have been operated many alternatives easily and defined more closer to the real-world system than mathematical models numerical programming, so simulation technique is more effective in the application of real system. With the suggested vehicle distribution planning system, we can determinate more economical route than the output of the NNH, reduce the logistics cost and driving time simultaneously. Therefore, we can decide that which vehicle, which node, what order items and quantity, when they return, and how much logistics cost ? Especially, we improved service system for customer by reducing distribution time and updated the level of system's management with analytical logistics work.

From now, we should develop popular software by enforcing data base system for user to treat particular situations and additional restrictions of vehicle distribution system.

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