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A Pickup and Delivery Problem Based on AVL and GIS

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Abstract. The fundamental design issues that arise in the pickup and delivery system planning are optimizing the system with minimum cost and maximum throughput and service level. This study is concerned with the development of pickup and delivery system with customer responsive service level, DCM(Demand Chain Management). The distribution process and service map are consisted of manufacturing, warehousing, and pickup and delivery. First we formulated the vehicle pickup and delivery problem using GIS-VRP method so as to satisfy the customer service requests. Second, we developed a GUI-type computer program using AVL, automated vehicle location system. The computational results show that the proposed method is very effective on a set of test problems.

Keywords : pickup and delivery problem, GIS-based PDP, e-logistics

1. INTRODUCTION

Currently, the major trend of logistics system design is considered as synchronizing a series of interrelated business processes in order to (1) acquire raw materials and parts, (2) transform these raw materials and parts into finished products, (3) conduct value added activities to these products, (4) distribute and promote these products to either retailers or customers, and (5) facilitate customer responsive information services. As to the environment of information technology is coming fast and customer services improve, the logistics systems design activities improve customer responsive service and pickup-delivery performance implemented in e-logistics system. One of these customer responsive systems is the PDP system based on GIS. In this paper the terminology PDP system means a part of the supply chain process of pickup and delivery. The major technology needs of PDP system designers may be given by : (1) automated vehicle location system, AVL based on global positioning system (GPS), geographical information system (GIS) and truncated radio system (TRS), (2) efficient vehicle routing method for pickup and delivery problem, (3) freight and location information, and electronic tracing/tracking for customer responsive service, (4) customer responsive services with visual display, and (5) automation of material handling system. There are wide variety of research references on PDP, but most of these are concerned with solving previous concerning PDP with time windows and general traveling salesman problem based on *lp*-distance method(Cluff, C. K. (1987) and William *et al.* 2000). In this paper, we developed an integrated model considering both delivery and pickup problem in a system and dealt with a problem which belongs to GIS and AVL based PDP. The main difference between the conventional approaches and our problem lies in the fact, that we deal with a customer centric GIS-distance and AVL-based approach which provides practical distances. Thus, the results of solutions using GIS-PDP are much better than those by conventional approaches(Gillet, B. E. and Miller L. R. (1974)). This approach is also motivated by the fact that the exact way to compute the distances and show the visual out puts can be shown.

Figure 1 shows a schematic concept of customer responsive GIS-PDP model based on AVL and GIS. It will provide customers with various services based on e-logistics. In this research we developed AVL-based customer centric PDP system with two sub-systems: (1) AVL system for both vehicle pickup and delivery and (2) AVL-based PDP. Also we developed a GUI-type program which displays all the information in both graphical and text format.

2. CUSTOMER RESPONSIVE PDP SYSTEM

In first step of this study, we developed a customer

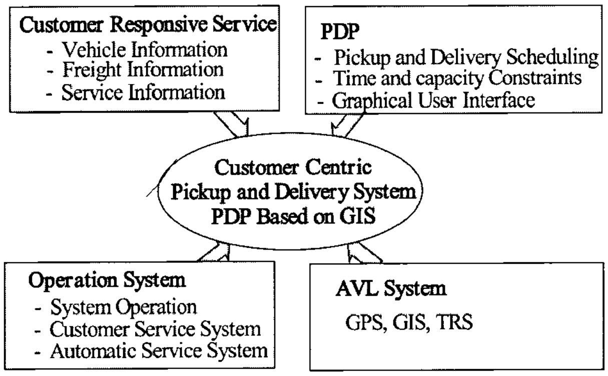

Figure 1. Customer Centric PDP Model

centric pickup and delivery model considering customer requests (orders) in advance and find the optimal routing schedules which satisfy the customer requests. The terminology "customer centric" means "customer oriented" and includes all the customers requests in the modeling and immediately shows them by visual outputs using internet or information networks :

- visual display of the locations of customers or supply centers in digital map,
- visual display of the input data(customer order) weight, volume of freight, service time wanted, origins and destinations to pickup and deliver,
- visual display of PDP routing schedule or vehicle and customer order,
- available number of vehicle and capacity,
- analysis report of customer service.

Thus the pickup and delivery problem is actually the same as TSP except for the additional constraint that origins must precede destination.

Thus, the solution procedure for the TSP can be utilized in a heuristic route procedure for single vehicle PDP. This PDP model has following optimizing goals and constraints:

- optimizing goals :
  - minimizing total traveling distance or time,
  - maximizing customer service,
  - logistics capability for customer service.
- constraints :
  - origin and destination have to be include in routing schedule,
  - time constraint to be served,
  - loading and unloading time ,
  - service capability constraint,
  - vehicle duty(time constraint).

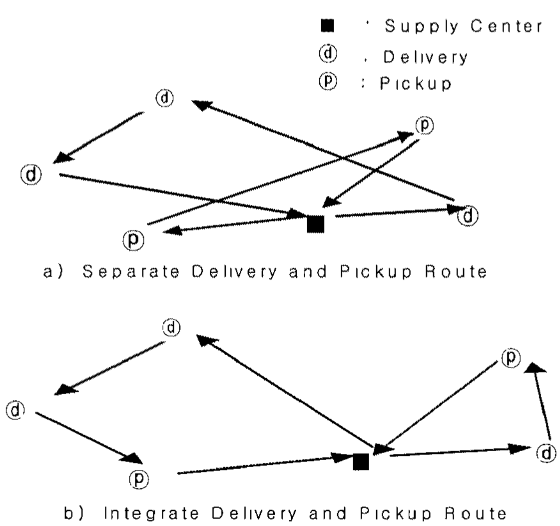

Figure 2. A simple transformation of a TSP and PDP tour into an Integrated PDP tour

There are several methods to solve these pickup and delivery problems such as dynamic programming, mathematical methods. Figure 2 shows a simple transformation of pure TSP problem and pickup problem into an integrated PDP tour. In this study we considered a PDP model where orders received in advance and with one or half day services.

The major solution technologies applied to the PDP can be : heuristic method, dynamic programming, mathematical programming, branch and bound method. For the theoretical formulation of PDP, first we consider a single vehicle and a set N of n customers. The vehicle has an origin supply center, represented by +0, and a destination supply center −0. Associated with each customer i is an origin $+i$ and destination $-i$. The objective of PDP is to minimize the total distance traveled by the vehicle in servicing all the customer requests.

For the formulation of this PDP, we define following equations :

$$A_n = (V_n,\ E_n)$$

where, $V_n = (+0, -0) \cup (+i, -i \mid i \in N)$

$$En = ((+0, -0) \cup (+0, -i \mid i \in N) \cup (-0, -i \mid i \in N) \cup E(K_{2n})$$

$E(K_{2n})$ is the edge set of all the customer origins and destinations.

Thus,

$$|V_n| = 2n + 2, \text{ and } |E_n| = 2n^2 + n + 1.$$

In case of two customers, n = 2, the possible route of PDP can be given by :

(+0, +1, -1, +2, -2, -0), (+0, +1, +2, -1, -2, -0) ,
(+0, +1, +2, -2, -1, -0), (+0, +2, -2, +1, -1, -0),
(+0, +2, +1, -2, -1, -0), (+0, +2, +1, -1, -2, -0)

The possible conditions for feasible route of PDP can be given by a collection of edges $R \in E$ satisfying the following conditions :

① $(+0, -0) \in R$,
② $R \cap \delta(v) = 2$, for all $v \in V$
③ $A(R)$, the sub-graph of an induced by R, is bi-connected,

④ $+i$ is on the path from $+0$ to $-i$ in R.

First, we developed a heuristic PDP model and demonstrated the sample result. Then we extended the fundamental facets considering the feasible routes of PDP using AVL system based on GIS. A heuristic model is developed and programmed according to the following 4 steps of fundamental PDP system:

Step 1 : Order and customer responsive data input,
• customer order,
- volume, - origin and destination
• vehicle type
- capability, - possible service time,
• service time data
- time to begin, - route length,

Step 2 : Route scheduling
• determination of the route for vehicle,
• customer response for routing schedule
• computation of the total travel time(or distance)

Step 3 : Output of data
• visual display of input data,
• route information of detail schedule,
• freight information

Table 1. Input Data for Available Vehicle

Type of Vehicle	Available Number	Capability	Operating Time Min.
1. Small truck	1	7 pallets	240:00
2. Medium Size Truck	1	12 pallets	480:00
3.Large Size Truck	1	14 pallets	480:00
4.Small Size Truck-1	1	10 pallets	480:00
Total	4		

Table 2. Sample Output :

VEHICLE = Large Size Truck
START TIME = 800.
DATE = 2002. 3. 15.

Stop	Site	Time	Deliver	Pickup	Order	Stay Time
1	D-4	809		7		3 * Truck
2	C-3	818	7			3 * Truck
3	D-4	834		7		3 * Truck
4	C-3	839	7			3 * Truck
5	D-4	855		7		3 * Truck
6	C-3	900	7			3 * Truck
7	D-4	916		7		3 * Truck
8	C-3	921	7			3 * Truck
9	D-6	937		7		3 * Truck
10	J-17	1000	7			3 * Truck
11	D-6	1026		4		3 * Truck
12	J-17	1031	4			3 * Truck

ROUTE ENDED
LOCATION = S-11
TIME =1045
NO OF PALLETS MOVED = 39

There is a sample output of fundamental PDP system implied in Dongeui Supply Co. with four kinds of vehicle. The input data of vehicle and sample output are shown in Table 1 and 2 respectively.

3. CUSTOMER CENTRIC PDP BASED ON GIS, GIS-PDP

The most basic form of pickup and delivery problem, PDP, consists of a fleet of vehicles and a set of customer requests partly for pickup and partly for delivery. Each request specifies, at least, the origin and destination location, quantity, and time to pickup and deliver. In this study, we consider a customer responsive PDP with customer time constraints based on GIS. Customers can confirm the visual input and output to see their requests in the networks. We used a GIS-distance method to compute the distances between two points on the digital map using Geo-Database. The schematic structure of this study is shown in Figure 3.

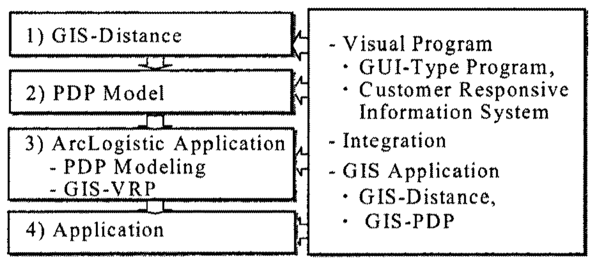

Figure 3. Schematic GIS-PDP Structure

3.1 GIS-Distance

To compute the distance between two points, we used GIS based distance model GIS-distance is very practical method considering geographical factors.

The conventional distance models are :
- Manhattan's Distance,
- Distance-Time,
- *lp*-Distance Model

lp-Distance model is one of the most frequently used models to compute the distance in facility planning. It is given by following equation where A(x, y) and B(a, b) are coordinates of two points and p is a parameter : when p = 1, it is rectilinear distance and when p=2 it is Euclidean distance.

$$d(A, B) = (| x - a_i |^p + | y - b_i |^p)^{1/p}$$

We developed a visual program to compute the distance by *lp*-Distance model. Figure 4 shows a sample output of rectilinear distance.

We applied this *lp*-distance model in vehicle routing problem to demonstrate the effect of the value of parameter p. Table 3 shows the optimal travel distances of VRP for various number of node and p values(Laporte, G. (2001)).

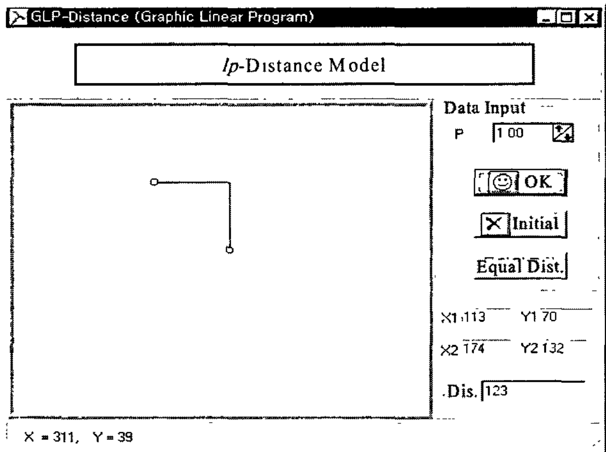

Figure 4. Sample Output of *lp*-Distance Model

Table 3. Total travel distance for various values of p

p No. of Order	P=1.0	P=1.5	P=2.0	P=2.5
10	251.4	217.1	205.7	200.7
20	650.4	548.2	521.4	477.7
50	957.4	928.6	926.0	815.6
100	1,961.4	1,891.2	1,595.5	1,353.8

When p=1.0, and the number of nodes in the problem is given by 20, we found the optimal travel distance is 650.41, while it became 521.4 when p = 2.0.

The distance value computed using *lp*-distance model based on (x, y) coordinate is very uncertain on the digital map. Thus, we used GIS-distance based on Geo-database. We developed a computer program for GIS-distance using heuristic method. To find a shortest route between two locations on the digital map we used three heuristic models; linear model, ellipsoid model, and square model. The sample outputs are shown in Figure 5 and 6.

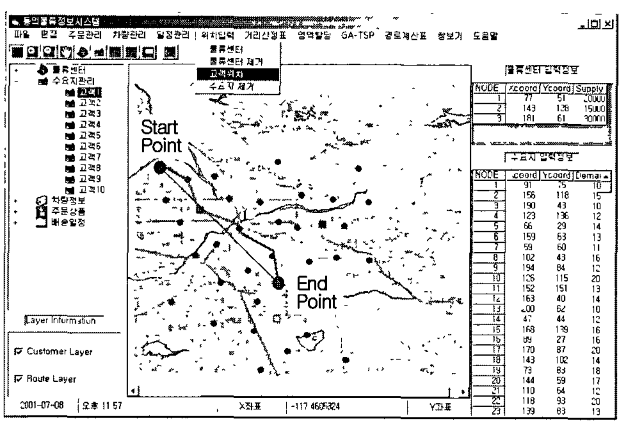

Figure 5. Sample Output of Linear Model

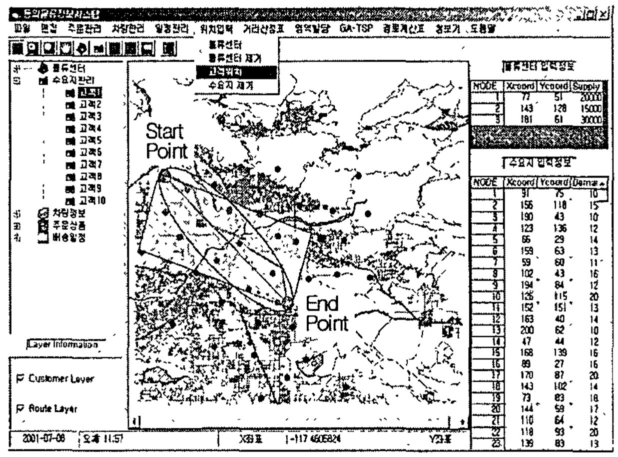

Figure 6. Sample Output of Ellipsoid/Square Model

In this GIS-distance model, we used the address of customers or supply centers as input data instead of x, y coordinates. Because GIS-distance model(Heung-Suk Hwang (2000)) uses Geo-database linked with the digital map and we can include all the road factors (turn, one-way, shape of route, etc), we can compute the realistic distance and also display the position of customers, vehicles and supply centers on the map in real time for the customers.

3.2 AVL-Based Customer Centric PDP

PDP system is a part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers' requirements. AVL is a part of logistics system based on graphical information of vehicle location and freight. It consists of global positioning system (GPS), geographical information system (GIS), and mobile communication system such as truncated radio system (TRS) as shown in Figure 7. In this paper we considered a truck mounted GPS and used GIS packages.

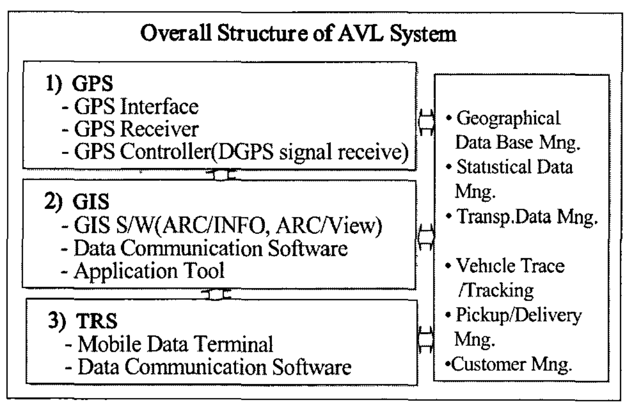

Figure 7. Overall Structure of AVL System

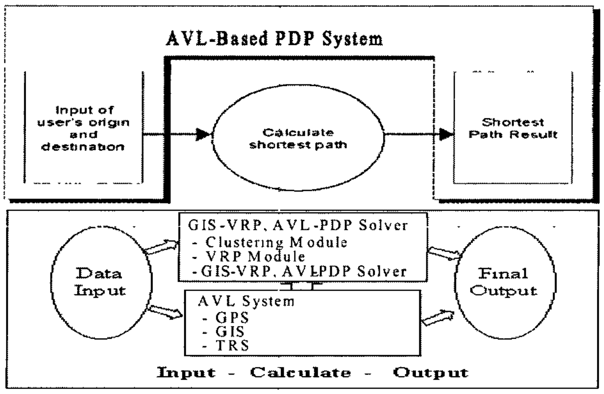

Figure 8. Conceptual Structure of AVL-based PDP System

In developing the structure of AVL-based PDP system, we attempted to simulate the communication that takes place when the mobile service is utilized. Like telephone service interaction, the structure of AVL-based PDP system has three components: input of users' information, calculation of the shortest vehicle route, and graphical display of the results. The "value-addition" of AVL-based PDP system is accurate location and distance (and time) computation using digital geographical information system (GIS). It solves the multi-commodity PDP routing. The combination of vehicle tracking, communication, and optimizing scheduling is regarded as progressive and resulted in a number of key benefits, especially in the areas of customer responsive service. Increased focus on the integrated vehicle routing problem arises from both customer demand and effective information technology. In this study we introduce AVL-based PDP system using GIS-VRP solver as shown in Figure 8.

We developed solution procedures for two parts : 1) AVL system and 2) GIS-PDP solver and TSP. For the solution procedure of GIS-PDP, we used GIS package and ArcLogistics SW with digital map. Figure 9 shows PDP solution procedure using ArcLogistics SW(ESRI Inc. (2000)).

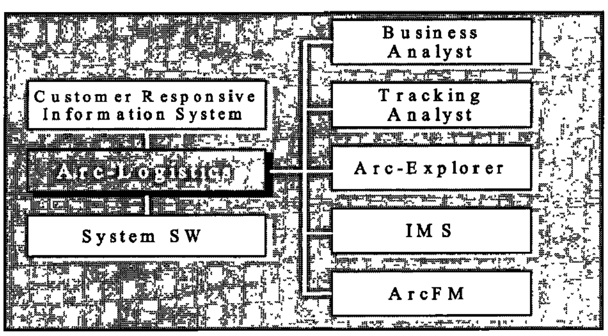

Figure 9. PDP solution procedure using ArcLogistics SW.

Also we developed procedures and programs for both sub-systems and sample examples are implemented and sample outputs are shown as following figures :

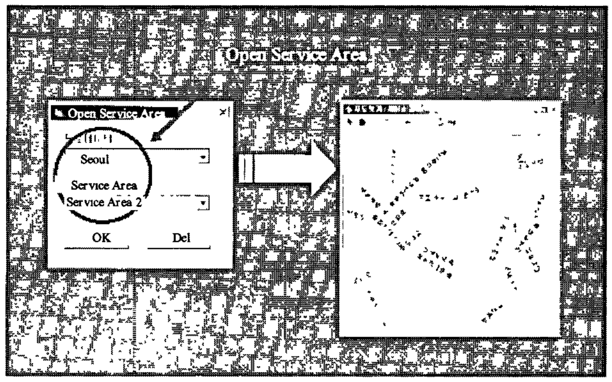

Figure 10. Open Service Area in GIS

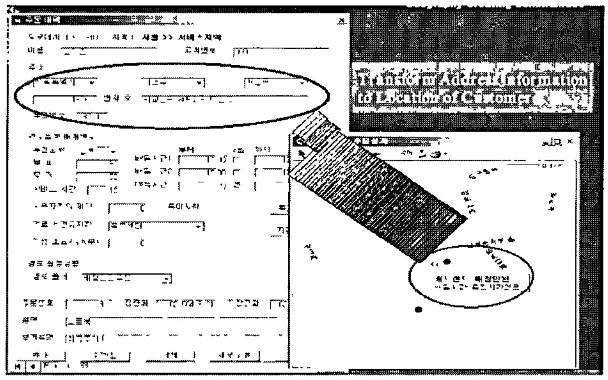

Figure 11. Transform address to Customer Location

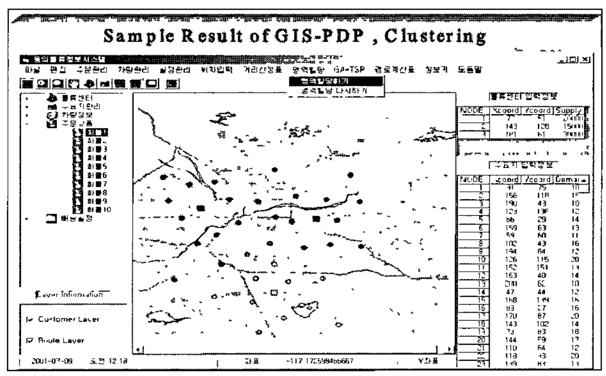

Figure 12. Sample Output of Clustering

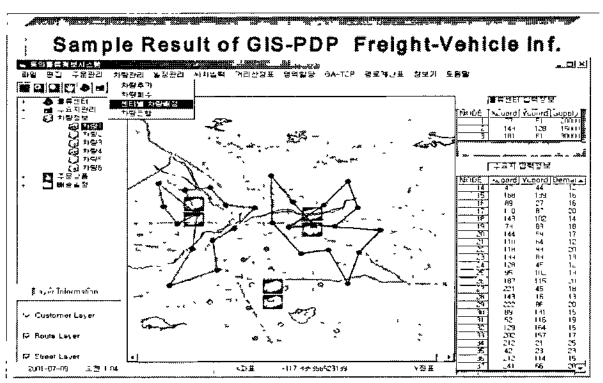

Figure 13. Sample Output of GIS-PDP Freight Vehicle Information

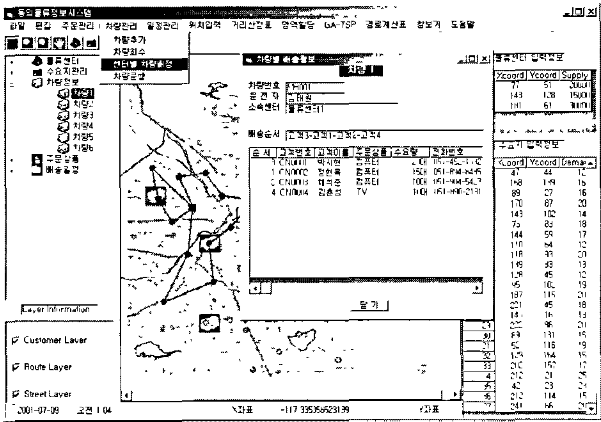

Figure 14. Sample Output of GIS-PDP Freight Information

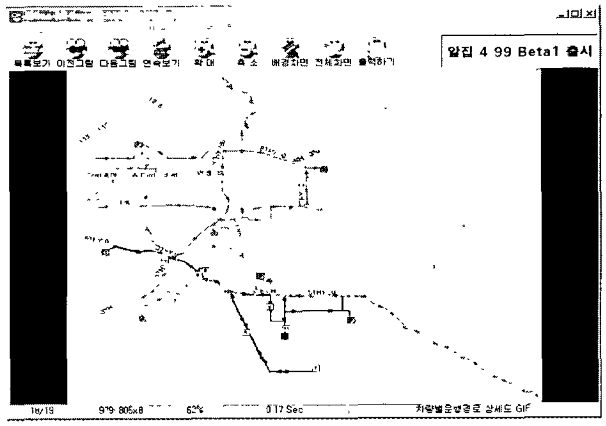

Figure 15. Service Area and Customers Locations

4. COMPUTATIONAL EXPERIMENTS

For computational experiences, we consider a freight delivery company. This company has four kinds of vehicles and each vehicle is operated for 8 hours a day. Table 4 shows vehicle data:

Table 4. Input Data for Available Vehicle

Type Vehicle	Available Number	Capability	Operating Time(Min.)
1. Small truck	1	7 pallets	13:00-17:00
2. Medium Truck	1	12 pallets	09:00-17:00
3. Large Truck	1	14 pallets	09:00-17:00
4. Small Truck-1	1	10 pallets	09:00-17:00
Total	4		

The order data by customer :
- location of origin and destination,
- volume, weight,
- service time required,
- emergency.

In this example 34 orders and a supply center are considered. We used Arc-logistics simulation software and the digital map with Geo-Database to find the optimal route schedule. Figure 15 shows service area, customers, supply centers and road network. Figure 16 shows the route results of each vehicle based on GIS. The information of each route and vehicle are shown in Figure 17 and Table 5 shows text output.

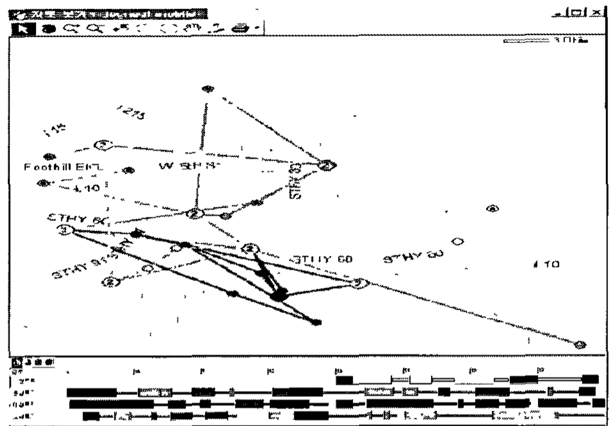

Figure 16. Sample output of Route for Each Vehicle

Table 5. Sample Text Output

Dongeui Delivery Co. Truck Large Size

Arrival Time	Order No	Name	Address	Mail	Time Schedule	Priority	Service Time	Volume	Weight	Customer
09 03 00		Center	gaya street, pu	92557	09 00 00 - 17 00 00		15			
09 18 00	p012431	C4		92557	09 00 00 - 11 00 00	Normal	30	70	50	1
09 48 00	p12425	Center	gaya street, pu	92557	09 00 00 - 17 00 00		30			
10 18 00	p25412	Center	gaya street, pu	92557	09 00 00 - 17 00 00		0			
10 31 00	p09432	B4		92551	10 05 00 - 10 45 00	Normal	15	210	180	1
10 59 00	p12425	Kim	yunsan-dong,	92555	10 00 00 - 11 00 00	Normal	10	100	100	1
11 31 00	p10521	E2		92501	09 00 00 - 11 20 00	High	25	100	140	1
12 02 00	p26541	A5		92509	11 30 00 - 12 00 00	High	5	10	10	1
12 07 00		Lunch					30			
13 00 00	p19042	D1		92518	13 00 00 - 14 00 00	High	15	10	10	1
13 27 00	p09832	B3		92571	13 05 00 - 13 45 00	Normal	60	300	300	1
14 49 00	p09142	D7		92507	13 20 00 - 15 00 00	Normal	5	135	102	1
15 05 00	p12012	C5		92553	14 00 00 - 16 00 00	Normal	21	12	70	1
15 32 00	p98912	D2		92551	15 30 00 - 17 00 00	Normal	21	50	100	1
16 00 00	p25412	Lee	nam street, pus	92507	16 00 00 - 16 10 00	Normal	35	0	500	1
16 48 00		Center	gaya street, pu	92557	09 00 00 - 17 00 00		15			

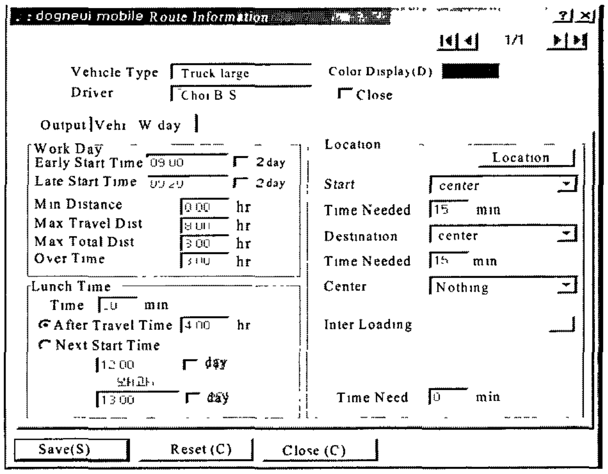

Figure 17. Sample Output of Vehicle Information

5. CONCLUSIONS

The important logistics decisions include inventory allocation pickup and delivery problems. In this paper we have described and evaluated AVL-based PDP system using vehicle routing problems of a multi-depot system. The proposed approach is based on two sub-systems, AVL system and AVL-based PDP solver.

We have developed a procedure for AVL system using GIS, GPS and mobile communication system. For the computational purpose, we developed a GUI-type computer program according to the proposed method using AVL system. It has been found that the proposed model is potentially efficient and useful in solving multi-depot problem. However the proposed model can be used for PDP system decision makers to get the best supply schedule.

ACKNOWLEDGEMENT

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