A GENETIC ALGORITHM-BASED HEURISTIC FOR NETWORK DESIGN OF SERVICE CENTERS WITH PICK-UP AND DELIVERY VISITS OF MANDATED VEHICLES IN EXPRESS DELIVERY SERVICE INDUSTRY

by

Friska Natalia Ferdinand[1], Hae Kyung Lee[2], Hee Jeong Lee[2], and Chang SeongKo[2]
[1]Department of Industrial Engineering,
Pusan National University, Busandaehak-ro,
Geumjeong-gu, Busan, 609-735, Korea
E-mail: freezk_83@yahoo.com

[2]Department of Industrial and Management Engineering,
Kyungsung University 309, Suyeong-ro, Nam-gu,
Busan, 608-736, Korea
E-mail: hshklee@naver.com, heejeong@ks.ac.kr, csko@ks.ac.kr

ABSTRACT

In Korean express delivery service market, many domestic companies have been competing fiercely to extend their own market share. The line-haul vehicles operated by the express delivery service companies in Korea in general can be classified into three types depending on the ways their expenses occur; company-owned vehicle, mandated vehicle which is owned by outsider who entrust the company with its operation, and rented vehicle (outsourcing). Actually, most of the line-haul vehicles in express delivery services belong to the mandated vehicle class. Hence, this study suggests an approach to the design of a service network with pick-up and delivery visits for mandated line-haul vehicles with the objective of maximizing the incremental profits of the drivers of the vehicles under the assumption that express delivery service companies operate mandated vehicles only. A genetic algorithm-based heuristic is developed and tested through an example problem.

KEYWORDS
Express Delivery Services, Pick-Up and Delivery, Mandated Line-Haul Vehicle, Genetic Algorithm

INTRODUCTION

Although most service centers in an express courier service network are directly linked to a consolidation terminal, some of them with geographical disadvantages are operated as milk run types (from/to the consolidation terminal), which can be represented as a traditional Pick-up and Delivery Problem (PDP). The pick-up and delivery activities in PDP are performed using a fleet of vehicles and a set of customer requests. In this case, both the collection and delivery of goods should be carried out within the routes and the goods collected from the pick-up location must be delivered to the corresponding customers by the vehicles (Lee *et al.* 2010, Kim *et al*. 2011; 2012, Ferdinand *et al*. 2013). Usually, the line-haul vehicles operated by the express delivery service companies in Korea can be classified into three types depending on how their expenses occur; company-owned vehicle, mandated vehicle which is owned by outsiders who entrust the company with its operation, and rented vehicle (outsourcing). From the operational point of view, mandated vehicles are essentially identical to company-owned vehicles. The only difference is how the drivers are paid, and a mandated vehicle is paid by the amount which is proportional to its workload. For a given set of delivery orders, the manager of the express delivery service company has to allocate the orders to three types of vehicles considering vehicle routing and dispatching (Ko *et al.* 2002, Chung *et al.* 2007). The objective of this study is to construct a network design for the profitable tour problem with pick-up and delivery visits with the goal of maximizing the incremental profits of the drivers of mandated line-haul vehicles.

LITERATURE REVIEW

A number of studies have been carried out related to the design of service networks for express delivery service. Cheung *et al.* (2001) was the first to examine a service network design problem encountered by express couriers such as DHL Hong Kong. They proposed a hybrid optimization/simulation model that aims to maximize service coverage and service reliability by adjusting the cutoff time. Their study revealed that the extension of the cutoff time led to a higher level of service coverage but decreased the service reliability. Also, Ko *et al.* (2007) developed an integer programming model and a genetic algorithm to determine the cutoff time at each service center according to the spatial proximity of the service centers to the customers and the consolidation terminal capacity. Lee *et al.* (2010) configured an express delivery service network that maximizes revenue for PDP. An optimization model for a profitable tour design with pick-up and delivery based on a multi-objective formulation involving single and multiple companies allied for resource sharing was developed by Kim *et al.* (2011, 2012). Recently, Ferdinand *et al.* (2013) proposed an approach to a pick-up and delivery service network design problem with the objective of maximizing profits of the companies.

Problem Definition

First consider the cost structures of operating three types of vehicles. The cost of a company-owned vehicle is the sum of the fixed cost and the variable cost and 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 shipping amount is high, while in the opposite case mandated and rented vehicles are more economical (Ko *et al.* 2002). According to the classification by Bodin *et al.* (1983), the problem considered here can be represented as a typical PDP. The difference in this study is that the objective function is formulated to maximize the revenue instead of minimizing the cost of delivery. However, a PDP with sales (PDPs) may be also interpreted as a travelling salesman problem with sales (TSPs). The approach used in this study has a similar concept to the previous studies such as Lee *et al*. 2010, Kim *et al*. 2011; 2012, Ferdinand *et al*. 2013). The first step of the proposed procedure is to divide all nodes into pick-up and delivery nodes. Route generation is intended to link all nodes for each vehicle starting from and ending at the same depot. The second step is to build the m-TSP (Multiple Traveling Salesman Problem) by converting the profitable tour problem with pick-up and delivery nodes. For example, consider that a line-haul vehicle travels among five service centers for pick-up and delivery at early times, and packages are picked up and delivered along the travel route followed; there are two vehicles and each vehicle is assigned to one tour. Each service center has two different nodes, delivery and pick-up, and thus there are ten nodes for five service centers. The difference in this study is that the delivery and pick-up processes are not performed by the same vehicle. The converted model is regarded as a type of m-TSP with the objective of maximizing the incremental profit. Many studies have been performed regarding the m-TSP with applications in several areas including logistics. Because this problem belongs to the NP class, most studies suggest heuristic algorithms due to the problem characteristics. Given the tour route, the total revenue and operating costs are easily obtained based on the travel times among the depot and the service centers and the operating times for each service center. The objective function in this study is to maximize the net profit, which is calculated by subtracting the incremental cost from the incremental revenue instead of assessing the total revenue for m-TSPs with multiple service centers.The constraints are equivalent to those of an m-TSP with two nodes for each service center. Thus, the objective function is defined as follows:

$$\begin{aligned} &\text{Maximize } W_1 = \{\alpha Z_1 - \beta(\Delta T_1)^{\gamma}\} \\ &\quad\vdots \\ &\text{Maximize } W_m = \{\alpha Z_m - \beta(\Delta T_m)^{\gamma}\} \end{aligned} \qquad (1)$$

where

$$Z_i = \begin{cases} \sum_{j=1}^{n_i} D_{ij}(a_{ij})(\Delta dt_{ij}) & \text{if } j \text{ is a delivery mode} \\ \sum_{j=1}^{n_i} P_{ij} b_{ij}(\Delta pt_{ij}) & \text{if } j \text{ is a pick}-\text{up mode} \end{cases}$$

In Expression (1), incremental revenue is produced via an increase in collected profits resulting from adjustment of the tour route and the delivery and pick-up times. An incremental operating cost is incurred due to an increase in the travel times. When calculating the operating cost, instead of *(ΔT)*, ($\Delta T)^{\gamma}$ is used to prevent an excessive time increase that may affect the operating times in the consolidation terminal where γ is larger than or equal to one. The notation used in this study is defined as follows:

i	index for a vehicle from an express delivery service company, $i = 1, 2, \ldots, m$
j	index for a node corresponding to a service center serviced by vehicle i, $j = 1, 2, \ldots, n_i$
W_i	incremental of revenue of vehicle i
α	incremental revenue per unit
D_{ij}	delivery amount per hour of service center$j$ for vehicle i
a_{ij}	delivery type for service center j for vehicle i which reflects order characteristics such as residential, industrial, and commercial areas
Δdt_{ij}	incremental increase in time required for delivery order for vehicle i in an updated tour as compared to the current tour of service center j (unit: hour)
P_{ij}	pick-up amount per hour of service center j for vehicle i
b_{ij}	pick-up type of service center j for vehicle i which reflects order characteristics
Δpt_{ij}	incremental increase in time required for pick-up order for vehicle i in an updated tour compared to the current tour of service center j (unit: hour)
β	incremental cost per hour according to increase of total tour time
ΔT_i	incremental increase in total tour time for an updated tour of vehicle i compared to the current tour (unit: hour)
γ	index reflecting the effect of tour time on tour cost

Since the above problem belongs to NP-hard class, a genetic algorithm-based heuristic is developed to solve it.

Solution Procedure

A genetic algorithm (GA) is generally referred to as a stochastic solution search procedure that is proven to be useful for solving combinatorial problems using the concept of evolutionary computation imitating the natural selection and biological reproduction of animal species (Goldberg, 1989; Gen and Cheng, 2000). The chromosome representation contains 51 genes, as shown in Figure 1. The first three genes represent the number of service centers supported by three vehicles, respectively. We assume that each vehicle should support at least 10 nodes. The remaining 48 genes denote the routes that will be taken by each vehicle. Four genetic operators are used in the proposed GA: cloning, crossover, mutation and selection operators. The cloning operator copies a subset of the best current chromosomes to the new population. A partial-mapped crossover (PMX) is applied, which is viewed as an extension of the two point crossover operation for a binary string to a permutation representation. Next, a reciprocal exchange mutation is adopted for the mutation operation, and roulette wheel selection is used to select the new population. The decoded chromosome generates a candidate solution and its fitness value based on the fitness function. The objective function in the proposed model given in Expression (1) is used as the fitness function.

FIGURE 1
AN EXAMPLE OF CHROMOSOME REPRESENTATION

No of SC			Truck 1															Truck 2																	Truck 3															
15	17	16	P8	P14	P3	P15	P19	P6	P7	P10	D15	D8	P21	P11	P12	D10	P23	P24	D11	P20	P2	P9	D12	P1	P18	P22	D2	D1	P4	D19	D21	D7	D18	P17	P5	D24	P16	P13	D23	D3	D20	D4	D9	D16	D6	D13	D22	D5	D14	D17

(a) Overview of chromosome

15	17	16

(b) Number of nodes supported by each vehicle

P8	P14	P3	P15	P19	P6	P7	P10	D15	D8	P21	P11	P12	D10	P23

(c) Vehicle 1

P24	D11	P20	P2	P9	D12	P1	P18	P22	D2	D1	P4	D19	D21	D7	D18	P17

(d) Vehicle 2

P5	D24	P16	P13	D23	D3	D20	D4	D9	D16	D6	D13	D22	D5	D14	D17

(e) Vehicle 3

The partial mapped crossover is used in the crossover process, which passes ordering and value information from the parent tours to the offspring toursin which the chromosome cannot contain duplicate values. The process is mapped from a portion of one parent string onto a portion of the other parent string while the remaining string values are exchanged. Next, the reciprocal exchange mutation is adopted as a mutation operator. The decoded chromosome generates a candidate solution and its fitness value based on the fitness function. The objective function in the proposed modelis used as the fitness function. The values of dt_{ij}, pt_{ij}, ΔT_i can be easily calculated from the tour sequence corresponding to a chromosome. Since the proposed model belongs to a class of multi-objective decision making problems, the maxmin operator is employed to obtain a compromised solution. The overall procedures are coded in Matlab.

AN EXAMPLE PROBLEM

An illustrative numerical example is carried out with a data set similar to the previous studies (Lee *et al.* 2010, Kim *et al.* 2011; 2012, Ferdinand *et al.* 2013). The example problem considers a single consolidation terminal, 24 service centers and three mandated line-haul vehicles. Table 1 shows the current operation data of each service center. It is also assumed that 5 minutes are required for preparing the package loading/unloading tasks in the service center, and 0.03 minutes of package handling is required for each package. The upper bound of trip time is 12 hours, and the capacity for each vehicle is 3000 units. The GA parameter values are as follows: population size is set to 500, maximum number of generations is 300, and cloning, crossover and mutation rates are 2%, 70% and 6%, respectively. After a GA-based heuristic is applied to the example problem based on the maxmin criterion, it is obtained that the incremental profits and travel times for each vehicle are: 9.03 hours and $166.80 for vehicle 1, 12.30 hours and $68.37 for vehicle 2, and 12.53 hours and $39.43 for vehicle 3, respectively. We observe that although the travel time for each vehicle is longer, more incremental profits of $39.427 are realized. Figure 2 shows the tour sequences for each vehicle after GA implementation.

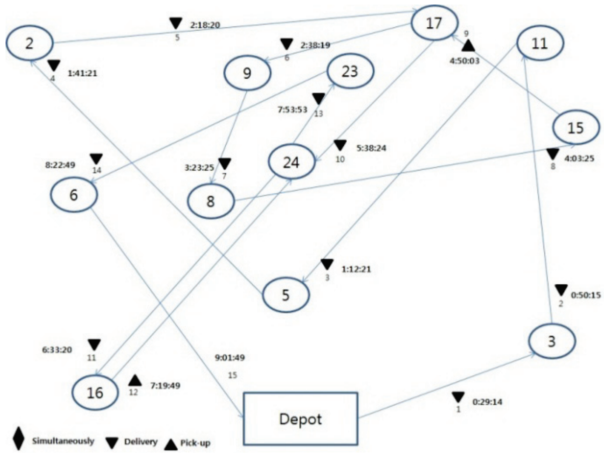
CONCLUSION

This study suggests a GA-based heuristic for the service network design for the pick-up and delivery among a single depot and multiple service centers with the objective of maximizing the incremental profits of the drivers of mandated line-haul vehicles. While most of the express delivery service companies in Korea operate mandated vehicles, the proposed approach considers the balance of the profits of drivers based on maxmin criterion. As a further research, a service network design problem compromising profits of the company and drivers is suggested based on maxsum and maxmin criteria.

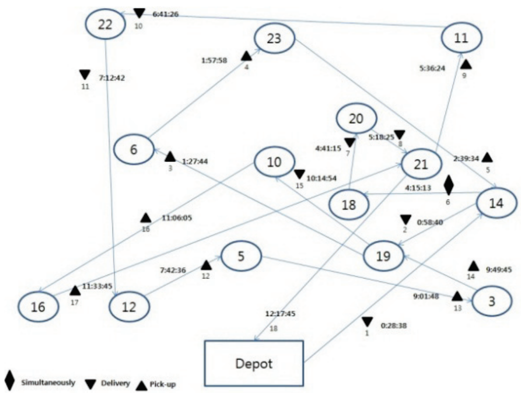
TABLE 1
CURRENT OPERATION DATA FOR SERVICE CENTERS

Service Centers	Delivery	Pick-up	a_i	b_j	Service Centers	Delivery	Pick-up	a_i	b_j
1	160	200	0.2	0.02	**13**	40	20	0.1	0.01
2	20	40	0.1	0.01	**14**	50	60	0.1	0.01
3	120	100	0.2	0.02	**15**	380	450	0.3	0.03
4	20	20	0.1	0.01	**16**	170	220	0.2	0.02
5	60	80	0.1	0.01	**17**	20	40	0.1	0.01
6	40	20	0.1	0.01	**18**	120	100	0.2	0.02
7	400	500	0.3	0.03	**19**	20	20	0.1	0.01
8	150	180	0.2	0.02	**20**	40	40	0.1	0.01
9	20	40	0.1	0.01	**21**	60	80	0.1	0.01
10	100	180	0.2	0.02	**22**	40	20	0.1	0.01
11	20	20	0.1	0.01	**23**	60	80	0.1	0.01
12	60	80	0.1	0.01	**24**	350	420	0.3	0.03

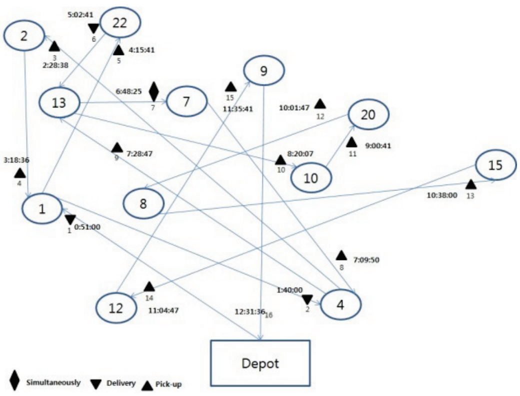
FIGURE 2
THE TOUR SEQUENCES BASED ON GA



(a) Mandated vehicle 1



(b) Mandated vehicle 2



(c) Mandated vehicle 3

ACKNOWLEDGEMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (2012-007468).

REFERENCES

Bodin, L. D., Golden, B. L., Assad, A. A. and Ball, M. O. (1983). "Routing and scheduling of vehicles and crews: The state of the art," *Computers and Operations Research,* Vol.10, pp.63-211.

Cheung, W., Leung, L. C. and Wong, Y. M., (2001), "Strategic service network design for DHL Hong Kong," *Interfaces,* Vol.31, pp.1-14.

Chung, K.H., Ko, C.S., Shin, J.Y., Hwang, H., and Kim, K.H. (2007), "Development of mathematical models for the container road transportation in Korean trucking companies,"*Computers and Industrial Engineering*, Vo.53, No.2, pp.252-262.

Ferdinand, F.N., Moon, I., and Ko, C.S. (2013), "A pick-up and delivery service network design among service centers for low demands in express delivery services," *ICIC Express Letters: International Journal of Research and Surveys,* Vol.5, No.21, pp.3625-3630.

Gen, M. and Cheng, R. (2000). *Genetic Algorithms and Engineering Optimization,* New York: Wiley.

Goldberg, D. E. (1989). *Genetic Algorithms in Search*, Optimization and Machine Learning, Reading, MA: Addison Wesley.

Kim, Y. J., Ferdinand, F. N., Lee, H. K. and Ko, C.S. (2011). "Collaboration-Based Profitable Tour Design with Pick-up and Delivery in Express Courier Services," *ICIC Express Letters: International Journal of Research and Surveys,* Vol.5, No.21, pp.3625-3630.

Kim, Y. J., Ferdinand, F. N., Lee, H. K. and Ko, C. S. (2012). "Multi-objective Profitable Tour Design with Strategic Alliance Scheme in Express Courier Services," *ICIC Express Letters: International Journal of Research and Surveys,* Vol.6, No.24, pp.923-928.

Ko, C.S., Chung, K.H., and Shin, J.Y. (2002), "Determination of fleet size for the LTL transportation with dynamic demand," *International Journal of Management Science*, Vol.8, No.2, pp.33-45.

Ko, C.S., Min, H. and Ko, H.J. (2007), "Determination of cutoff time for express courier services: A genetic algorithm approach," *International Transactions in Operational Research*, Vol.14, pp.159-177.

Lee, H.K., Ferdinand, F.N., Kim, T. and Ko, C.S. (2010), "A Genetic Algorithm Based Approach to the Profitable Tour Problem with Pick-up and Delivery," *International Journal of Industrial Engineering and Management Systems,* Vol.9, No.22, pp.80-87.