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A Study on Improving the Efficiency of Logistics Networks in Express Package Deliveries

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Abstract : *The market competition of express package deliveries in Korea is severe because a large number of companies have entered into the market. This study thus suggests an approach to the reconfiguration of express service networks with respect to the strategy partnership of closing/keeping service centers among companies involved and the adjustments of their cutoff times. For this we propose an integer programming model and a genetic algorithm based solution procedure for allowing companies involved to maximize their incremental profit. An illustrative numerical example is presented to demonstrate the practicality and efficiency of the proposed model.*

Key words : *strategic partnership, cutoff time, express package deliveries, reconfiguration of logistics network*

1. Introduction

The market of express package deliveries in Korea has been rapidly expanded according to the progress of TV home shopping and internet buying and selling. Accordingly, various sized domestic express companies have been established, and various foreign companies also have entered into the Korean express market. As a result of the surplus of express companies, they are struggling with remaining competitive at a reasonable price with appropriate level of customer satisfaction.

In Korea, each express company generally operates its own service network which consists of customer zones, service centers, and consolidation terminals. Customer zones refer to geographical districts in which customers either ship or receive packages and are typically covered by a service center. And a service center receives customer shipment requests and picks up parcels from customer zones and then the packages are waited until its cutoff time for transshipment in bulk to a consolidation terminal. In this way, the service center acts as a temporary storage facility connecting customers to a consolidation terminal. At the consolidation terminal, the packages delivered from a number of service centers are combined, screened, sorted, and then loaded onto delivery trucks for their destinations so that it acts as a transshipment hub. Thus, the productivity and service level of an express package service are highly related to how to efficiently manage service centers and consolidation terminals while maintaining appropriate level of customer satisfaction.

A number of express companies, however, are operating under-utilized service centers in certain customer zones for achieving high level service even if they cannot create profits due to low volumes. This challenge can be overcome by the use of strategic partnership with respect to win-win principles. The strategic partnership works in such a way that express companies operating under-utilized service centers in some places agree to operate only single service center in a specific customer zone, but the decision is made by considering the loss-gain tradeoff between closing and keeping service centers of each company while maximizing the overall operating efficiency of express service networks and fairly allocating throughput volumes of companies involved in partnership.

In addition to the partnership, the efficiency of a service center mainly depends on flexibility in setting the cutoff time for the customer's last-minute shipping request. An unnecessarily early cutoff time forces some last-minute customers to give up the next day delivery service and consequently creates inconvenience to customers. On the other hand, an unreasonably late cutoff time leaves service centers little room for handling, sorting, and arranging transportation to the consolidation terminal, and it is likely to delay the succeeding delivery processes.

Therefore, this study suggests an approach to the reconfiguration of express service network with respect to the strategy partnership of closing/keeping service centers among companies involved and the adjustments of their

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cutoff times. For this, we propose an integer programming model and a genetic algorithm based solution procedure for allowing them to maximize their incremental profit. An illustrative numerical example with reduced data sets from an express company is presented to demonstrate the practicality and efficiency of the proposed model.

There are a number of research areas related to the design of service networks for express package delivery. Freight consolidation can be cost-effective especially when substantial freight-rate differentials exist between small and large shipments. Powell&Sheffi(1983) initiated a load planning model linking a number of consolidation terminals. However, they did not consider links between terminals and customers. Schneider et al.(1972) were the first to determine the minimum cost location of urban consolidation terminals, and to extend this study, Min(1994) considered both international and multiple objective aspects of a consolidation terminal location-allocation problem. Another aspect of research topics addressed the issue of determining the length of holding time at the consolidation terminal for ordered items. Jackson(1981) used a simulation model to establish the maximum number of days for which orders can be held to take advantage of consolidation. Other pioneering works dealt with that the question of how long customer orders should be held and/or what quantities should be accumulated before consolidated loads are shipped or released(Buffa, 1987; Higginson&Bookbinder, 1994).

Despite numerous merits, a few consolidation studies consider spatial network design problems linking consolidation terminals to customers and determining the cutoff time for order aggregation simultaneously. Leung et al.(1990) presented a mathematical model and its solution procedure for solving point-to-point delivery problems. The study conducted by Cheung et al.(2001) was the first to examine a service network design problem encountering express couriers such as DHL Hong Kong. They proposed a hybrid optimization/simulation model that aimed to maximize service coverage and service reliability by adjusting cutoff time. Recently, 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 service centers to customers and the capacity of a consolidation terminal.

However, prior studies have dealt with only the cutoff time adjustments so that the current study considers the problem of re-configuring an express package service network with strategy partnership with respect to win-win principles for improving the efficiency of the logistics networks.

2. Model design

This section describes a mixed-integer programming model which maximizes the expected profit of an express service networks by determining the optimal cutoff time subject to the type of service centers and the closing/keeping of under-utilized service centers based on strategic partnership. The cutoff time in this study is time of day before which a customer's order is assured for a next day delivery. The extension of cutoff time for express service centers can provide the company with increase of total sales, but it may also decrease dissatisfying customer needs due to work delay in the consolidation terminal.

Typically, customers' requests of service centers vary according to time of day and the type of their locations such as commercial areas, industrial areas, and residential areas. Demand of express services usually peaks around the daily cutoff time and is high in commercial and industrial areas compared to residential area. Since the demand is concentrated around cutoff times, service centers located in high volume areas want to expand their cutoff time. Underlying assumptions of the proposed model are as follows:

- The operating time of a consolidation terminal is fixed from 6:00 p.m. to 12:00 p.m.
- Once cutoff time is extended, customer orders increase with a constant rate; on the other hand, as cutoff time is set early, express requests decline with a constant rate.
- The current cutoff time of service center is set at 6:00 p.m.; an incremental increase or decrease in cutoff time is 30 minutes; the cutoff time can be shortened to 1.5 hours and extended up to 2 hours.
- The travel time between the service center and the consolidation terminal is constant at any time of a day.
- There is one and only one truck that has a large enough capacity to accommodate shipment loads from a service center to a consolidation terminal.
- The processing time of ordered items at a service center or a consolidation terminal is proportional to the total volume of ordered items.
- The shipments are processed according to the FIFO rule at the consolidation terminal.
- All the outgoing packages from a service center are shipped to the assigned consolidation terminal.

- The customers' orders of closed service centers are assigned to a nearest opened facility.

The conceptual mathematical model can be expressed as follows:

p : profit per unit shipment
d : daily demand of service center
r : incremental accumulated demand
f : fixed operating costs of service center
Q : capacity of consolidation terminal
TST : task starting time of shipments of service center at consolidation terminal
TFT: task completion time of shipments of service center at consolidation terminal
ST : business operating hours of consolidation terminal
FT : business closing hour of consolidation terminal

Decision variables:
X : incremental cutoff time of a service center(from −1.5 hours to +2 hours)
Y = {0. 1} : service center is open or closed
Z = {0, 1} : a service center is allocated to consolidation terminal

Objective function :

$$\text{Max } Z1 = p \cdot \sum\sum (d + r \cdot X) \cdot Z + \sum f(1-Y)$$
$$\vdots$$
$$\text{Max } Zn = p \cdot \sum\sum (d + r \cdot X) \cdot Z + \sum f(1-Y)$$

subject to

$$\sum Z = Y$$
$$\sum Y = 1$$
$$Z \le Y$$
$$\sum d \cdot (1+r \cdot X) \cdot Z \le Q$$
$$TST \cdot Z \ge ST$$
$$TFT \cdot Z \le FT$$

3. Solution Procedure

Considering that the proposed model in this study belongs to a class of NP-complete problems, we develop a heuristic solution procedure based on genetic algorithm(GA), which also first attempt for opening or closing decisions and then adjust cutoff time adjustments simultaneously. 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(Gen & Cheng, 2000; Goldberg, 1989). The subsections will elaborate on the development of GA for the proposed.

3.1 Encoding and genetic operators

The design of a suitable chromosome representation of the candidate solutions is the first step for GA application because it dictates probabilistic transition rules for each chromosome to create a population of chromosomes. Each chromosome developed in this study is based on single dimensional array that consists of binary values, representing decision variables associated with the closing/keeping of under-utilized service centers and the incremental change in cutoff time at service. For example, the representation of a chromosome is illustrated in Figure 1. This chromosome describes that there are 60 service centers, out of which 30 are operated by Company A and the rest 30 belong to Company B. This means that there are two express companies and each company provides express service in 30 customer zones, out of them 10 places are considered for strategic partnership due to low volumes. In the chromosome, the closing or keeping decision is made depending on the value of single gene (0 or 1), and cutoff time is determined by the combination of three genes. The three genes indicate eight possible values from 0 to 7 so that there are eight possible incremental changes in cutoff time ranging from a maximum reduction of an hour and half to an extension of up to two hours: 0-0-0 (=90 minute reduction), 0-0-1(= 1 hour reduction),⋯, 1-1-1 (= 2 hour extension).

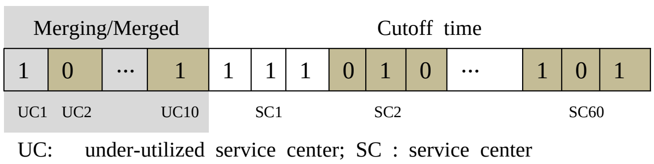

Fig. 1. Chromosome Representation

Four genetic operators are used in the proposed GA such as cloning, parent selection, crossover, and mutation operators. The cloning operator copies 20 percent of the current best chromosomes to a new population; a binary tournament selection method for a parent selection is used, which begins by forming the two teams of chromosomes. Each team consists of two chromosomes randomly drawn from the current population. The two-best chromosomes that are taken from one of the two teams are chosen for crossover operations. As such, two offspring was generated and entered into a new population; the two-point crossover is used for crossover, in which one point is used for a under-utilized service center and another for the cutoff

Table 1 Current operation of Company A

(1)	(2)	(2)	(3)	(4)	(5)	(6	(7)	(8)	(9)	(10)	Current Operation				
											(11)	(12)	(13)	(14)	(15)
24	24	182	2300	3	0	18	4500	0.5	20	0.33	18.83	1.17	20.00	0.23	20.23
22	160	210	2250	2	51.8	18	5500	0.5	34	0.57	19.07	1.16	20.23	0.28	20.50
5	210	22	1050	1	0	18	1500	0.5	58	0.97	19.47	1.03	20.50	0.08	20.58
19	75	169	850	3	82.8	18	3100	0.5	60	1.00	19.50	1.08	20.58	0.16	20.73
6	182	21	2500	3	0	18	1300	0.5	66	1.10	19.60	1.13	20.73	0.07	20.80
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
16	228	225	1550	2	0	18	3800	0.5	209	3.48	21.98	1.30	23.28	0.19	23.47
13	204	188	650	3	74.1	18	5000	0.5	211	3.52	22.02	1.45	23.47	0.25	23.72
12	170	162	750	1	66	18	2100	0.5	238	3.97	22.47	1.25	23.72	0.11	23.83
9	125	16	850	3	0	18	1700	0.5	250	4.17	22.67	1.16	23.83	0.09	23.91
11	145	122	900	3	99.6	18	2200	0.5	250	4.17	22.67	1.24	23.91	0.11	24.00

Columns' descriptions : (1) = service center; (2) = coordinates of the location; (3) = current demand; (4) = 1(residential), 2(industrial), 3(commercial); (5) = fixed cost; (6) = closing time of the service center; (7) = hourly capacity, (8) = processing time in service center; (9) = distances between service center and the consolidation terminal; (10) = travel time between service center and the consolidation terminal; (11) = arrival time of a courier truck at the consolidation terminal; (12) = waiting time of a courier truck at the consolidation terminal; (13) = task starting time of a courier truck at the consolidation terminal; (14) = processing time in terminal; (15) = task completion time of a courier truck at the consolidation terminal

time. The two locations of the crossover points were randomly selected from any genes of a chromosome and then swapped segments of the two parents' strings to produce two children; the mutation operator first randomly selects a bit value of any gene on a chromosome, and then, flips a bit value from 0 to 1, or from 1 to 0 to achieve a good level of diversity in each generation.

3.2 Fitness function

The decoded chromosome generates a candidate solution and its objective value based on the fitness function. The fitness value is a measure of the goodness of a solution with respect to the original objective function and the extent of infeasibility by adding a penalty to the original objective function. To elaborate, the original objective function is comprised of the goals of maximizing expected incremental profit of overall service network for all companies involved by balancing opening/keeping under-utilized facilities and cutoff time extensions. In particular, the proposed GA first select possible closing service centers and generate incremental changes in the cutoff times at service centers. Then, based on a set of decision variables, a fitness value of chromosome were obtained by applying solution. The detailed overall procedure is described as follows:

Step 1: Given the partnership based closing and keeping decisions, the shipment requests of a closed service center are assigned to the nearest opened facility. Then, the incremental changes of cutoff times of the opened service centers are made. Based the these settings, sorting operations in accordance with the arrival times of delivery trucks originated from the service centers at the consolidation terminal using the FIFO rule are conducted.

Step 2: Re-calculate the task starting and completing time of each service center by reversing orders according to the capacity of a consolidation terminal. As such, the completion time of the last job equals to the closing time of the consolidation terminal. Afterward, if the re-calculated total time of delivery and documentation is infeasible, the cutoff time is adjusted to make the completion time of a current job smaller than the starting time of an immediately succeeding job. If the modification process fails, a penalty value is incurred.

Step 3: If the total incremental cutoff time surpasses the total processing time of the consolidation terminal, a penalty is added to the original objective function so that this chromosome is identified as one of infeasible solutions.

4. Model experiments

4.1 An example problem

An example problem was solved for model application for which its data set is summarized in Table 1 and Table 2. There were two companies such as Company A and Company B. Each company had 30 service centers with single consolidation terminal, out of which 10 service centers were operated as cost centers. Currently, the cutoff time was set uniformly at 6:00 p.m. for all the service centers. These service centerswere classified into three

Table 2 Current operation of Company B

(1)	(2)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	Current Operation				
											(11)	(12)	(13)	(14)	(15)
54	24	182	2100	3	0	18	4200	0.5	10	0.17	18.67	1.33	20.00	0.21	20.21
52	160	210	2100	2	0	18	5000	0.5	44	0.73	19.23	0.98	20.21	0.26	20.47
49	75	169	600	3	70	18	3200	0.5	50	0.83	19.33	1.14	20.47	0.16	20.63
35	210	22	1100	1	0	18	1300	0.5	68	1.13	19.63	1.00	20.63	0.07	20.70
58	165	269	1100	1	0	18	2200	0.5	74	1.23	19.73	0.97	20.70	0.11	20.81
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
46	228	225	1250	2	0	18	3400	0.5	219	3.65	22.15	1.13	23.28	0.17	23.46
43	204	188	800	3	52.9	18	4800	0.5	221	3.68	22.18	1.27	23.46	0.25	23.70
42	170	162	650	1	54	18	2200	0.5	248	4.13	22.63	1.07	23.70	0.11	23.82
39	125	16	1700	3	0	18	1000	0.5	260	4.33	22.83	0.98	23.82	0.05	23.87
41	145	122	750	3	81.8	18	2600	0.5	260	4.33	22.83	1.03	23.87	0.13	24.00

categories with respect to their shipping volume of express services. For instance, service centers located in residential areas were categorized as “1” where customer demand for express courier service is relatively low; service centers located in industrial areas were categorized as “2” where demand is at the medium level; service centers located in high-demand commercial areas were categorized as “3”. A consolidation terminal of each company started operating at 6:00 p.m. for the shipments of trucks based on first come-first served rule.

Company A currently processes the total of 40,000 units per the day in the consolidation terminals from 8:00 p.m to 12:00 p.m., and Company B processes the total 39,100 units per the day from 8:00 p.m. to 12:00 p.m.. Under this setting, the problem was solved by using the proposed GA that sets parameter values through a series of experiments. These parameters are: population size = 300∼500; maximum number of generations = 150∼300; cloning = 20%; crossover rate = 80%; mutation rate varies from 1% to 5% as the number of generations increases.

4.2 Test results

For the Company A, the results showed that five under-utilization facilities were closed such as SC2, SC3, SC11, SC17, and 19 reflecting \$418 savings and total throughput was 39,963 units at the consolidation terminal from 8:00 p.m. to 24:00 p.m. summarized in Table 3. As such, the total shipments were decreased by 0.09% (from 40,000 to 39,963), but the profit were increased from \$40,000 to 40,399 with \$436 saving. In addition, average driver-waiting time at consolidation terminal was reduced from 1.29 hour to 0.84 hour.

For the Company B, the results indicated that five under-utilization facilities were closed such as SC31, SC42, SC43, SC53, and SC56, leading to \$372 savings and total throughput was 39,990 units at the consolidation terminal from 8:00 p.m. to 24:00 p.m. summarized in Table 4.

Table 3 GA test results for Company A after applied strategic partnership

(1)	(2)	(3)	(4)	(5)	(6)
i	CT	LT	T_AT	T_ST	T_FT
28	16.50	16.93	18.33	20.00	20.08
18	17.00	17.40	18.93	20.08	20.18
22	18.50	19.04	19.37	20.18	20.42
13	17.50	18.50	19.60	20.42	20.55
16	17.50	17.96	19.68	20.55	20.67
30	17.00	17.40	19.83	20.67	20.87
14	17.00	17.43	19.89	20.87	20.95
12	18.00	18.93	19.90	20.95	21.09
10	17.00	17.43	20.06	21.09	21.17
29	18.00	18.50	20.17	21.17	21.40
8	18.00	18.50	20.43	21.40	21.55
6	17.00	17.40	20.92	21.55	21.75
4	16.50	16.89	21.05	21.75	21.84
20	20.00	20.65	21.22	21.84	22.20
25	18.50	19.04	21.57	22.20	22.43
15	20.00	20.60	21.60	22.43	22.62
7	18.50	19.05	21.83	22.62	22.74
5	17.50	17.98	21.94	22.74	22.84
24	19.00	19.60	22.00	22.84	23.12
27	20.00	20.60	22.20	23.12	23.30
21	19.00	19.58	22.21	23.30	23.42
9	19.00	19.60	23.08	23.42	23.65
1	19.00	20.23	23.23	23.65	23.73
26	19.50	20.81	23.44	23.73	23.88
23	18.50	19.43	23.60	23.88	24.00

Columns' descriptions: (1) = service center; (2) = closing time of the service center; (3) = leaving time of a truck from the service center (4) = arrival time of a truck at the consolidation terminal, (5) = task starting time of a truck at the consolidation terminal, (6) = task completion time of a truck at the consolidation terminal

As such, the total shipments were increased by 2.23% (from 39,100 to 39,990) and average driver-waiting time at consolidation terminal was reduced from 1.22 hour to 0.92 hour.

Table 4 GA test results for Company B after applied strategic partnership

(1)	(2)	(3)	(4)	(5)	(6)
i	CT	LT	T_AT	T_ST	T_FT
33	18.50	17.96	18.13	20.00	20.19
47	19.50	16.85	18.22	20.19	20.29
36	19.50	16.85	18.35	20.29	20.42
32	18.50	17.96	18.70	20.42	20.65
35	18.50	17.98	19.21	20.65	20.75
37	19.50	16.89	19.25	20.75	20.91
34	19.50	17.35	19.28	20.91	21.01
46	18.00	18.50	19.93	21.01	21.15
54	18.50	17.95	20.05	21.15	21.30
39	18.50	17.95	20.22	21.30	21.51
51	17.00	19.55	20.38	21.51	21.69
41	18.50	17.96	20.60	21.69	21.78
40	18.50	17.96	20.76	21.78	21.89
44	17.50	19.71	21.26	21.89	22.07
45	17.50	19.04	21.84	22.07	22.21
60	18.00	18.50	22.15	22.21	22.38
38	17.00	19.60	22.17	22.38	22.63
57	16.00	20.65	22.20	22.63	22.80
49	18.50	17.96	22.30	22.80	22.92
55	17.00	19.60	22.55	22.92	23.06
58	18.00	18.50	22.63	23.06	23.17
50	17.00	20.19	22.78	23.17	23.33
59	17.00	19.60	23.28	23.33	23.61
48	16.50	20.81	23.31	23.61	23.81
52	17.00	20.12	23.60	23.81	24.00

We also noticed that even though each company closed up some of their service centers, the total throughput was increased from 79,100 to 79,953 units, and the profits gained from a change in cutoff time at the service center varied depending on the type and location of service centers. The profit of the company was better off, when the cutoff time at the commercial type of service centers was extended. The reason is from that the company could increase sales opportunities and consequently increase profit by accommodating the surging customer demand around the cutoff time. Table 5 showed the summary of the test results by applying the proposed model.

Table 5 Summary of test results

		Company A	Company B
Current	Start	20:00	20:00
	Finish	24:00	24:00
	Throughput	40,000	39,100
	Waiting time	1.29 hour	1.22 hour
	Savings	0	0
	Total profit	$79,100	
After	Start:	20:00	20:00
	Finish:	24:00	24:00
	Throughput	39,963 units	39,990 units
	Waiting time	0.84	0.92
	Savings	$436	$372
	Total profit	$80,791	

5. Conclusions

In the high competitive business environment, express companies need to capture the last-minute customers who are willing to pay price for delivery services by facilitating their responsiveness, and they are under pressure to reduce operating costs as much as possible by highly utilizing their express service networks. However, a number of express companies are operating under-utilized service centers in certain customer zones for achieving the high level of delivery service even if they cannot create profits due to low volumes. This challenge can be overcome by the use of strategic partnership and the cutoff time adjustments of service centers.

Therefore, this paper developed a mathematical model and its efficient solution procedure based on a genetic algorithm.

The proposed model aimed to maximize the expected profits of participating companies in strategic partnership by the consideration of not only closing or keeping some of under-utilized service centers with respect to win-win principle among partners but also determining the exact length of holding time for collection at a service center and the detailed working schedule at the consolidation terminal.

According to the results of this study, the partnership based express service network design approach could provide express companies a number of benefits, resulting in not only the increase of throughput volume despite of closing some service centers but also the reduction of operating costs without hurting the customer service level. In particular, the strategic partnership was proved as a useful weapon for remaining competitive in small and medium sized express companies which are generally weak to price competition compared to large companies. In addition, the waiting times of truck drivers at consolidation terminal were reduced so that we can expect to enhance the utilization of logistics equipments. As a further study, the authors are planning to conduct capacity variations of consolidation terminals as an alternative approach for improving the profits in all partners.

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