한국항해항만학회지 제37권 제3호
J. Navig. Port Res. Vol. 37, No. 3 : 321-327, June 2013 (ISSN:1598-5725(Print)/ISSN:2093-8470(Online))
DOI : http://dx.doi.org/10.5394/KINPR.2013.37.3.321

A Combined Optimization/Simulation Approach to the Reconfiguration of Express Delivery Service Network for Strategic Alliance

Chang-Seong Ko · Hong-Bae Kim** · † Hyun-Jeung Ko*

** ** Department of Industrial & Management Engineering, Kyungsung University, Busan 608-736, Republic of Korea*
† Department of Logistics, Kunsan National University, Gunsan 573-701, Republic. of Korea

Abstract : *As the market of express delivery services expands rapidly, delivery service companies are exposed to severe competition. As a result of the surplus of delivery companies, they are struggling with remaining competitive at a reasonable price with appropriate level of customer satisfaction. To cope with competition pressures, a strategic alliance is suggested as an effective solution to the challenges faced by small and medium enterprises (SMEs) in express delivery services. Therefore, this study suggests a combined optimization and simulation approach to the reconfiguration of an express delivery service network for strategic alliance with respect to strategy partnership of closing/keeping service centers among companies involved and adjustments of their cutoff times. An illustrative numerical example is presented to demonstrate the practicality and efficiency of the approach..*

Key words : *network reconfiguration, express delivery service, strategic alliance, combined optimization/simulation, genetic algorithm*

1. Introduction

As express delivery service market expands rapidly, companies are exposed to fierce competition. To cope with competition pressures, we thus propose strategic alliance as an effective solution to the challenges faced by small and medium enterprises (SMEs) in express delivery services. In the express courier service industry, strategic alliances among SMEs can create economies of scale which leads to the reduction of the total operation cost. Moreover, through efficient cooperation of service centers, participating companies may realize an increase in net profit under a win-win alliance relationship (Chung et al. 2009, 2010; Kim 2011).

Express delivery service network is usually constructed based on the initial investment and operating costs for consolidation terminals and service centers in express delivery services. However, continuous reconfiguration for network design is required according as the service environment is rapidly changing. The productivity and service level-up of the express courier service is highly related to how to operate the consolidation terminals and their corresponded service centers. The consolidation terminal typically acts as a hub where ordered items from a number of service centers are combined, mixed, sorted, and transshipped to nearby service centers for local deliveries. Although a delay at the service center creates a whiplash effect on the succeeding consolidation terminals, the extension of cutoff time can increase sales opportunity of a service center (Ko et al. 2012).

For designing a service network, mainly two approaches can be applied such as optimization and simulation methods. Both approaches have their own shortcomings; optimization approach has difficulty to consider the dynamic nature of service network with the associated levels of performance such as average waiting time, average lateness time, etc. On the contrary, simulation approach considers its dynamic nature and evaluates its throughput in a stochastic environment but it does not guarantee that it provides an optimal solution to the design problem. However, in this study we adopted both optimization and simulation approaches as a recursive procedure to find the best design parameters. This approach takes advantage of the best features of both optimization and simulation (Hwang and Choi 2003; Song et al. 2008).

Therefore, this study suggests a recursive optimization/simulation approach to designing an express delivery service network for strategic alliance with respect

† Corresponding author, hjko@kunsan.ac.kr 063)469-4802
* csko@ks.ac.kr 051)663-4724
** hbkim@ks.ac.kr 051)663-4721

Note) This paper was presented on the subject of "A Combined Optimization/Simulation Approach to the Reconfiguration of Express Delivery Service Network for Strategic Alliance" in 2012 the 13th Pacific Industrial Engineering & Management Systems Conference Proceedings(Patong Beach, Puhket, Dec 2-5, 2012, pp.307-312).

to strategy partnership of closing/keeping service centers among companies and adjustments of their cutoff times based on the study of Ko *et al.* (2012) that only takes into account optimization aspect.

2. Literature review

Cheung et al. (2001) examined a service network design problem encountering express deliveries such as DHL Hong Kong. They proposed a hybrid optimization/ simulation model that aimed to maximize service coverage and service reliability by adjusting cut-off time. However, there have been a few of researches on several types of strategic alliances in logistics. Chopra and Meindl (2004), Min (1996), and Simchi-Levi *et al.* (2003), pointed out that different companies owned and operated independently might benefit from the strategic alliance scheme which was conceptually similar to facility sharing and Cachon and Lariviere (1999) suggested a methodology for optimal capacity allocation.

Recently, Chung *et al.* (2009) proposed a network design model for strategic alliances among express delivery service companies by monopoly of service centers. Chung *et al.* (2010) extended their previous study to the problem of sharing consolidation terminals of each company. An integer programming model and its solution procedure based on a fuzzy set theoretic approach were developed.

Ko *et al.* (2012) suggested an approach to the reconfiguration of an express delivery service network with respect to assignments of service centers to consolidation terminals and adjustments of their cutoff times. They proposed a genetic algorithm-based solution procedure for allowing express couriers to maximize their incremental profit. However, it does not consider the dynamic natures of the main parameters.

Regarding the recursive optimization/simulation approach Nolan and Sovergin (1972), Carlson *et al.* (1979), Rosenblatt *et al.* (1993), Hwang and Choi (2003), Ko *et al.* (2006) adopted the same approach to the design of various types of systems in their studies. Especially, Song *et al.* (2008) applied the approach to the reconfiguration of express courier service network.

3. Model development

3.1 Optimization model

An alliance model of Ko *et al.* (2012) is utilized to develop an optimization model that is designed to maximize the expected profit of each allied company under the following underlying assumptions:

- The operating time of a consolidation terminal is fixed from 8:00 p.m. to 24:00 p.m.
- Once cutoff time is extended, customer orders increase with a constant rate; on the other hand, as cut-off 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.
- There are two groups of service centers in each company; one group consists of candidate service centers for merger due to low volumes; the other is not closed(not for merger).
- 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 :

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

$$\vdots$$

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

subject to

$$\sum Z = Y \qquad (2)$$

$$\sum Y = 1 \qquad (3)$$

$$Z \leq Y \qquad (4)$$

$$\sum d \cdot (1+r \cdot X) \cdot Z \leq Q \qquad (5)$$

$$TST \cdot Z \geq ST \qquad (6)$$

$$TFT \cdot Z \leq FT \qquad (7)$$

Objective function (1) maximizes the profit of each company. Constraint (2) assures that an opened service center is assigned to a consolidation terminal. Constraint (3) means that only a single service center is opened in a merging region. Constraint (4) represents that closed service centers are not assigned to a consolidation terminal. Constraint (5) is for the capacity limitations of consolidation terminals. Constraints (6) and (7) represents the working schedules of consolidation terminals.

3.2 Simulation model

The simulation model is used to evaluate the service network determined in the optimization model based on two performance measures such as average waiting time (AWT) and average lateness time(ALT) for each allied company(Song et al., 2008). Arriving at the terminal, connecting vehicles of service centers may have to wait until the freight unloading begins. AWT represents the average time between the vehicle's arrival and the beginning of freight unloading. On the other hand, ALT is the average delay time when the freight handling at the terminal is not completed by the predetermined time. These performance measures are obtained from a computer simulation model coded with C++.

Operating environments and underlying assumptions of the simulation model are as follows:

- Freight handling is performed one vehicle at a time by the order of arrival at the terminal (*i.e.*, FIFO).
- Daily freight quantity and moving time to consolidation terminal of each service center follows uniform distributions, of which lower and upper bounds are known.
- Vehicles arriving early at a terminal have to wait until the terminal opens.

The simulation model is to be run with various input data including parameters of the optimization model such as reassignments of service centers to terminals, changes in cutoff times, and freight terminal capacities. Functional relationship between performance measures and decision variables are estimated by applying regression model on the results of simulation experiment.

4. Combined optimization/simulation procedure

By applying Song et al.'s procedure (2008) to this study, AWT and ALT may be represented as a function of changes in cutoff times which are denoted by Xi after running a series of simulation experiments, two performance measures for each allied company. Adding the estimated functions of performance measures to the constraints, we solve the optimization model. The updated optimum solution is again fed into the simulation model to test model adequacy by estimating the value of performance measures. The iterations continue until the estimates of performance measures from simulation experiments reach a predetermined level.

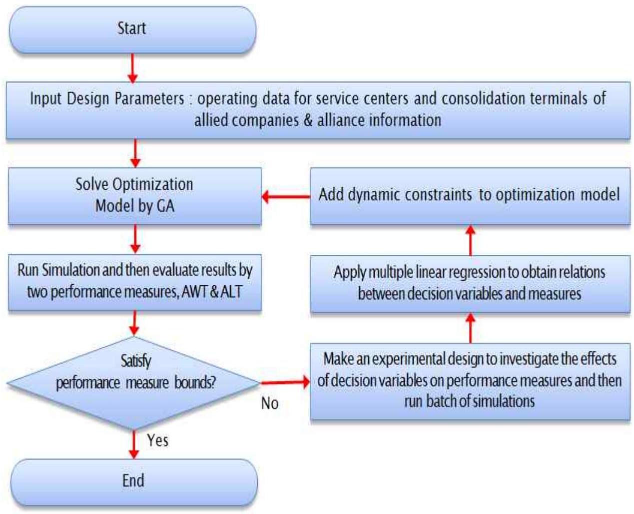

Fig. 1 A recursive optimization/simulation procedure

The solution procedure is further elaborated in the below:

(Step1) Obtain design parameters yielding maximum profit by setting up the optimization model with the input data from service centers and consolidation terminals, and then applying GA to the model. Next, run the simulation model using the results from optimization model. Stop if the values of performance measures for both of the companies satisfy the predetermined levels. Otherwise, continue to Step 2.

(Step2) Design an experiment of which factors are X_i's. Performance measures of the experiment are AWT and ALT. Since there are numerous levels of factors X_i's, an efficient experimental scheme requiring minimal experimental runs is used as follows:

- Applying Taguchi method, set up an experimental design only with factors X_i's to identify factors significantly affecting performance measures.
- Design a two-level experiment with significant X_i's identified in Step 2.1.

(Step3) Run the simulation model at each point of experimental design.

(Step4) Represent AWT and ALT in terms of X_i by applying multiple linear regression to simulation results.

(Step5) Add the constraints for the regression equations obtained in Step 4 to satisfy the predetermined levels of AWT and ALT.

(Step6) Obtain the optimum solution for the model set up in Step 5.

(Step7) Run the simulation using the results from optimization model in Step 6. Stop if the values of performance measures satisfy the predetermined level. Otherwise, go back to Step 2 and continue.

5. Example problem

An illustrative numerical example is developed to evaluate the performance of the proposed exploratory approach. There are two companies such as Company A and Company B. Each company had 30 service centers with a single consolidation terminal, out of which 10 service centers were operated as cost centers which mean that they are not generating profits due to low volumes. 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. However, both of the companies have plans to change the starting time of the terminals to 7:00 p.m. Additional operating data of service centers and terminals of Company A and B in the previous study (Ko et Al., 2010) is also used.

The proposed combined optimization/simulation procedure is applied to this situation. The problem was firstly solved by using the proposed GA that sets parameter values through a series of experiments (Ko *et al.*, 2010). These parameters are: population size = 500; maximum number of generations = 300; cloning = 20%; crossover rate = 80%; mutation rate varies from 1% to 5% as the number of generations increases. The closing/keeping of service centers and changes in cutoff times are obtained by using the GA procedure.

A simulation model is set up to establish the service network and then is run to validate its applicability. Daily fright quantity and travel time follow uniform distribution, of which lower and upper limits are set at 30% lower and 30% higher, respectively, than the value used in the optimization model. The aspiration levels of both AWT and ALT are set to 0.2 hours.

A simulation model is set up to establish the service network and then is run to validate its applicability. Daily fright quantity and travel time follow uniform distribution, of which lower and upper limits are set at 20% lower and 20% higher, respectively, than the value used in the optimization model. The aspiration levels of both AWT and ALT are set to 0.2 hours. The results from 100-day simulations yield 0.028 and 0.023 hours of AWT and 0.371 and 0.375 hours of ALT for each company, respectively. The two values for ALT of each company do not satisfy the aspiration level.

Simulation experiments are conducted at each point of Taguchi experimental design to identify significant factors affecting a performance measure ALT. Only small number of X_i's among 26 X_i's and 24 X_i's for company A and B are identified as significant factors affecting performance measures. X_6, X_{15}, X_{22}, X_{25} and X_{30} for company A and X_{34}, X_{39}, X_{43}, X_{50} and X_{52} for company B are selected as significant factors, respectively. These factors are identified via main effect plots of SN ratios using MINITAB. It is worth noting that only 32 experimental runs for each company are conducted to identify significant factors. Consequently, we need to design a two-level experiment with selected factors to obtain estimated functions of performance measures for each company. Simulation experiments are also conducted at each point of the two-level experimental design. The following estimated linear equations of ALT for two companies are obtained from simulation experiments:

· $ALT_A = 0.0021X_{15} + 0.0504X_{22} - 0.0194X_6 - 0.0172X_{25} - 0.0055X_{30} + 0.362$ ($Correlation\ coefficient = 0.803$)

· $ALT_B = 0.0472X_{43} + 0.0565X_{50} - 0.0535X_{52} - 0.0413X_{34} - 0.0237X_{39} + 0.243$ ($Correlation\ coefficient = 0.993$)

To obtain the solution with ALTs satisfying aspiration levels, the optimization model is updated by adding two constraints $ALT_A \leq 0.2$ and $ALT_B \leq 0.2$.

The solution by GA procedure with additional constraints is obtained in Table 1 and 2, and then fed into the simulation model. The results from the simulation experiments, which yield satisfactory levels of performance measures for two companies with ALT_A of 0.183 hours and ALT_B of 0.191 hours. Compared with the current operation the total freight quantities for company A and B are 43,080 and 42,300 which account for 7.7% and 9.2% increase from Table 3.

Table 1 Results after combined optimization/simulation procedure for company A

Service center	Cutoff time	Terminal arrival time	Terminal start time	Terminal finish time
22	16:30	17:13	19:00	19:10
14	16:30	19:21	19:21	19:26
28	17:30	19:23	19:26	19:31
16	17:30	19:41	19:41	19:47
12	18:00	19:54	19:54	20:02
18	18:00	20:02	20:03	20:10
27	18:00	20:06	20:10	20:19
13	18:00	20:13	20:19	20:28
20	19:30	20:41	20:41	21:01
29	18:30	20:43	21:01	21:16
7	17:30	20:44	21:16	21:22
8	18:30	20:59	21:22	21:32
15	19:30	21:05	21:32	21:43
5	17:00	21:25	21:43	21:49
9	17:30	21:26	21:49	21:59
21	18:30	21:40	21:59	22:05
24	19:00	22:00	22:05	22:22
6	18:00	22:01	22:22	22:37
30	19:00	22:02	22:37	22:55
1	18:00	22:04	22:55	22:59
10	19:00	22:13	22:59	23:06
25	19:30	22:39	23:06	23:22
23	18:00	23:03	23:22	23:29
4	18:30	23:12	23:29	23:36
3	19:00	23:30	23:36	23:47
2	20:00	23:40	23:47	23:58

Table 2 Results after combined optimization/simulation procedure for company B

Service center	Cutoff time	Terminal arrival time	Terminal start time	Terminal finish time
52	17:30	18:08	19:00	19:11
50	18:00	19:14	19:14	19:29
45	18:30	19:52	19:52	20:02
57	18:00	19:56	20:02	20:10
58	18:30	20:16	20:16	20:22
59	18:30	20:33	20:33	20:46
38	18:00	20:36	20:46	20:56
40	17:30	20:46	20:56	21:02
51	17:30	20:46	21:02	21:10
46	19:00	21:08	21:10	21:18
56	18:00	21:22	21:22	21:29
55	18:30	21:24	21:29	21:42
36	17:30	21:38	21:42	21:55
49	18:30	21:46	21:55	22:05
48	20:00	22:04	22:05	22:16
54	19:00	22:10	22:16	22:31
41	19:30	22:29	22:31	22:43
39	18:30	22:42	22:43	22:55
47	19:00	22:44	22:55	23:05
44	19:30	22:45	23:05	23:13
60	20:00	22:58	23:13	23:32
34	18:30	23:22	23:32	23:41
37	20:00	23:39	23:41	23:51
35	19:00	23:41	23:51	23:58

Table 3 Comparisons among current operation, GA procedure, and combined optimization/simulation procedure for company A and company B

		Company A	Company B
Current	Terminal Start Time	20:00	20:00
	Terminal Finish Time	24:00	24:00
	Throughput (units)	40,000	39,100
	Profit ($)	40,000	39,100
GA Procedure	Terminal Start Time	19:21	19:13
	Terminal Finish Time	23:59	24:00
	Throughput (units)	44,818	43,205
	Savings ($)	354	454
	Profit ($)	45,172	43,659
Combined optimization/ simulation procedure	Terminal Start Time	19:00	19:00
	Terminal Finish Time	23:58	23:58
	Throughput (units)	43,080	42,300
	Savings ($)	338	428
	Profit ($)	43,418	42,728

6. 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 to facilitate their responsiveness, and they are under pressure to reduce operating costs as much as possible by highly utilizing their express service network.

For the design of an express courier service network for strategic alliance, this study suggested a solution procedure combining optimization and simulation models, which incorporate the capability of comprehending dynamic characteristics of a service network. The optimization model provided a physical structure of express courier service network by the genetic algorithm, and then it was used as input data for the simulation model such as cutoff time of each service center, the selection of which service centers can be closed, and the assignment of service centers to a consolidation terminal. Based on the parameters, the simulation model was next run using two performance measures such as AWT and ALT until reaching their predetermined levels of stochastic factors(less than 0.2 hours).

After several iterations, the results showed that the levels of performance measures for two companies are ALT_A of 0.183 hours and ALT_B of 0.191 hours, and the throughputs of both companies were increased. As compared with the current operation for company A and B, the throughputs are 43,080 and 42,300 which account for 7.7% and 9.2% increase. Finally, the contributions of the proposed model can be summarized as follows. First, we found that there were some differences in throughputs between the optimization model and the combined optimization/simulation model. This implies the stochastic factors can affect the performance of express service network so that the strategic alliance is carefully analyzed to undermine the impact of uncertainty. Second, if the network structure could not be satisfied in terms of performance levels, it needed to identify which factors were critical for the performance so that experimental design was conducted. In particular, this study adopted Taguchi method that could give minimal experimental runs, and then multiple linear regression equations were generated for the additional constraints in order to update the optimization model. The proposed procedure can be applied to the several types of strategic alliance models as future studies.

However, the strategic alliance in this study has limitations on capturing the mechanisms to govern membership rules and allocate costs and benefits with a fair manner.

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 (2010-0027995).

References

[1] Cachon, G. P. and Lariviere, M. A.(1999), “Capacity Choice and Allocation: Strategic Behavior and Supply Chain Performance”, Management Science, Vol. 45, pp. 1091-1108.

[2] Carlson, R. C. Hershey, J. C. and Kropp, D. D.(1979), “Use of Optimization and Simulation Models to Analyze Outpatient Health Care Settings”, Decision Sciences, Vol. 10, pp. 412-433.

[3] Cheung W., Leung L. C. and Wong, Y. M.(2001), “Strategic Service Network Design for DHL Hong Kong”, Interfaces, Vol. 31, pp. 1-14.

[4] Chopra, S. and Meindl, P.(2004), Supply Chain Management: Strategy, Planning and Operation, NJ: Pearson Prentice Hall.

[5] Chung, K. H., Rho, J. J. and Ko, C. S.(2009), “Strategic Alliance Model with Regional Monopoly of Service Centers in Express Courier Services”, International Journal of Service and Operation Management, Vol. 5, pp. 774-786.

[6] Chung, K. H., Chung, C. S., Ko, Y. M., Hwang and Rho, J. J.(2010), “Network Design for Strategies Alliance in Express Courier Services: a Fuzzy Set Approach”, International Journal of Innovative Computing, Information and Control, Vol. 9, pp. 349-359.

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

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

[9] Hwang, H. and Choi, D. W.(2003), “Economic Design of Multi-Carousel System based on a Recursive Optimization/Simulation Procedure”, International Journal of Industrial Engineering, Vol. 10, pp. 449-454.

[10] Kim, D. Y.(2011), “A Study of Strategic Alliance Research on Culture Factors Affecting for the Focus of Liner Shipping”, International Journal of Navigation and Port Research, Vol. 35(8), pp. 691-699.

[11] Ko C. S., Chung, K. H., and Ko, H. J.(2012), “A Study

on Improving the Efficiency of Logistics Networks in Express Package Deliveries", International Journal of Navigation and Port Research, Vol. 36(4), pp. 305-311.

[12] Ko, H. J., Ko, C. S. and Kim, T.(2006), "A Hybrid Optimization/Simulation Approach for a Distribution Network Design of 3PLs", Computers & Industrial Engineering, Vol. 50, pp. 440-449.

[13] Min, H.(1996), "Consolidation Terminal Location - Allocation and Consolidated Routing Problems", Journal of Business Logistics, Vol. 17, pp. 235-263.

[14] Nolan, R. L. and Sovereign, M. G.(1972), "A Recursive Optimization and Simulation Approach to Analysis with an Application to Transportation Systems", Management Science, Vol. 18, pp. 676-690.

[15] Rosenblatt, M. J., Roll, Y. and Zyser, V.(1993), "A Combined Optimization and Simulation Approach for Designing Automated Storage/Retrieval Systems", IIE Transactions, Vol. 25, pp. 40-50.

[16] Simchi-Levi, D., Kaminsky, P., and Simchi-Levi, E.(2003), Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies, McGraw-Hill.

[17] Song G. H., Lee, H. J., Ko, C. S., and Kim, B. N.(2008), "A Hybrid Optimization/Simulation Approach for Reconfiguration of Express Courier Service Network", Proceedings of The 9th Asia Pacific Industrial Engineering and Management Conference, December, Bali, Indonesia.

Received 13 March 2013
Revised 20 May 2013
Accepted 27 May 2013