Game-theoretic Compromised Network Design in Delivery Services

Young Jun Ko
Department of Industrial & Management Engineering
Kyungsung University, Busan, Korea
Tel: (+82) 51-663-4720, Email: youngjun3812@ks.ac.kr

Ki Ho Chung
Department of Business Administration
Kyungsung University, Busan, Korea
Tel: (+82) 51-663-4451, Email: khchung@ks.ac.kr

Friska Natalia Ferdinad
Department of Information System
University of Nusantara, Banten, Indonesia
Tel: (+62) 21-5422-0808, Email: friska.natalia@umn.ac.id

Chang Seong Ko†
Department of Industrial & Management Engineering
Kyungsung University, Busan, Korea
Tel: (+82) 51-663-4724, Email: csko@ks.ac.kr

Abstract. The delivery service market has grown with double digits on average every year in the last decade. However, some of delivery service companies in small and medium sizes are still suffering with severe competition for low prices, difficult acquisition of delivery vehicles, and lack of country-wide terminals. Strategic alliance is emerging as an effective method to overcome competition pressure with limited resources. This study proposes a compromised network design model in delivery service to maximize the net profit of each participating company. A co-evolutionary algorithm based heuristic is developed for solving the nonlinear programing problem. Also, a weighted Shapley value as a systematic methodology is applied for fair allocation to each company regarding the marginal contribution based on the game theory.

Keywords: delivery service, strategic alliance, compromised network design, co-evolutionary algorithm, game theory, weighted Shapley value

1. INTRODUCTION

In spite of the fact that total amount in Korean delivery service market has been constantly increasing, the market became almost saturated because of massive inflow of companies into the market. In particular, this situation forced small and medium sized companies to focus their attention to the efficient management of their express delivery service network. In this regard, a strategic alliance can be a useful idea, which can lead to the reduction of operational costs in their delivery service networks with the creation of economy of scale. The participating companies can expect a realization of an increase in net profit under a win-win situation as well as an offer of better services to the customers with the cooperation of their existing facilities. Through this method, they can efficiently compete to expand their market share without further investment. This study proposes a compromised decision making model for a strategic alliance aiming to maximize the expected profits from delivery services with the consideration of the survival of multiple service centers in a merging region, the consolidation terminal sharing, and the opening/closing of consolidation terminals integrally. In particular, the survival of multiple service centers and the assignments given to opening service centers to consolidate terminals made the model complex to find out a solution. So, the proposed model is solved using the co-evolutionary algorithm (COEA) to maximize the expected net profit of each company. Also, weighted Shapley value is applied to provide each participating company with equal coalition profit allocation regarding its marginal contribution.

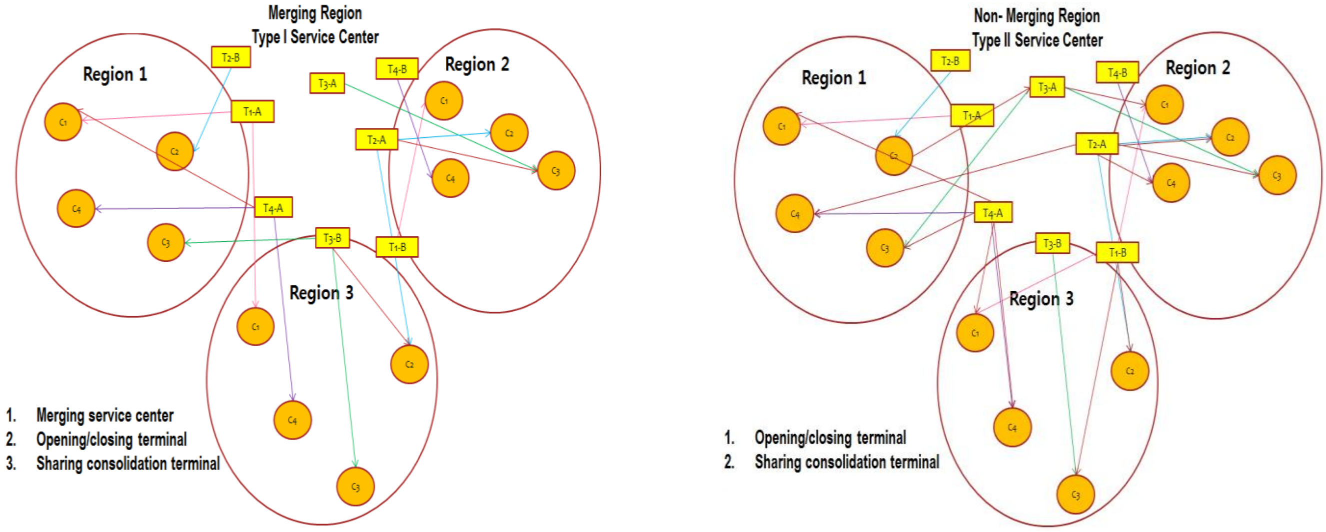
2. LITERATUREREVIEW

A study with the topic of the express delivery service network design reflecting collaboration was performed by Chung et al. (2009). This study proposed a network design model to form collaborations among express courier service companies by monopolizing service centers. Moreover, Chung et al. (2010) developed an integer programming model and its solution procedure is based on a fuzzy set theoretic approach. Chung et al. (2011) also considered the survival of multiple service centers in some merging regions. They extended their previous studies with the consideration of additional assumption of sharing consolidation terminals. Furthermore, another study suggested a nonlinear integer programming model for tactical cooperation among express companies and used a fuzzy set-theoretic solution procedure (Ferdinand et al. 2012(a)). Ferdinand et al. (2012(b)) also developed a multi-objective programming model, maximizing the minimum expected profit of each participating company, to examine the feasibility of merging under-utilized delivery service centers and sharing and closing/opening of consolidation terminals. Ferdinand et al. (2013; 2014(a)) continued the research to provide an optimization model and its solution procedure, which further considered that the expansion of consolidation terminal capacity affects the delivery service network design. Recently, Ferdinand et al. (2014(b)) took account of collaborative pick-up and delivery routing problem of line-haul vehicles as factors to maximize the incremental profits of collaborating companies.

3. PROBLEM DESCRIPTION

This study is divided into two sub-problems: the first case is to construct a strategic alliance model with the objective of maximizing the net profit of each participating company; the second case is to determine how to allocate coalition profits to each respective company. Delivery service companies generally operate a large number of service centers across the nation to collect and deliver service, most of which have sufficient volumes of shipment demand. However, some portion of them is categorized as underutilized facilities, which are unprofitably operated due to small volumes of shipment with high operating costs. In this study, the region that has low volume of daily shipment demand is called as a merging region where the underutilized service centers are valued as Type I service center. The service centers of Type I in a merging region need to be amalgamated for a strategic alliance so that the centers can earn benefit of reducing operating costs without depreciating the current service quality. On the other hand, the service centers which do not belong to any merging regions are called Type II service centers. Figure 1 illustrates two types of service centers. Based on these settings, a multi-objective nonlinear programming model is developed for a win-win situation in the strategic alliance. As a result, this kind of strategic alliance in this study determines that many companies are willing to participate in sharing the capacities of consolidation terminals by collaborating in pick-up operation at the single or multiple opened service center in the merging region, adjusting the opened or closed consolidation terminals, and reassigning all the service centers to the available consolidation terminals. In order to examine the feasibility of strategic alliance, service centers and consolidation terminals are operated according to the following principles:

a) At least one service center should be opened, and all the other service centers are closed within a merging region after alliance.
b) All opened service centers may be able to be reassigned to other company's consolidation terminal while satisfying the processing capacity of the terminal.
c) Every service center should be allocated to only one opened terminal.
d) At least one consolidation terminal of each company should be opened.
e) Only the pick-up and delivery amounts of closed service centers are equally allocated to the opened ones.



(a) In the merging region (b) In the non-merging region

Figure 1: An example of service network for strategic alliance (Chung et al. 2012).

Next, a systematic methodology is established to form a coalition in express delivery services with equitable allocation to each participating company regarding its contribution. The weighted Shapley value allocation methodology is applied to estimate the contribution of each company to the alliance. (Shapley, 1953; Owen, 1968; 1972) According to Tarashev et al. (2009), Shapley proposed a methodology that distributes the overall value among players based on their individual contributions. One of main axioms that characterize the Shapley value is the symmetry. However, this assumption of symmetry seems unrealistic in many applications. (Kalai and Samet, 1987)

4. MODEL DESIGN

Mathematical model can be described as follows based on the above assumptions. Suppose that there are n delivery service companies, and that the locations of consolidation terminals and service centers managed by each company are given. In order to develop the mathematical formulation for this problem some notations are introduced.

I : Set of service regions in which service centers are to be merged, $I = \{1, 2, \ldots, m\}$

J : Set of express courier companies, $J = \{1, 2, \ldots, n\}$

S_i : Set of Type II service centers of company j, $j \in J$

T_j : Set of consolidation terminals for company j, $j \in J$

T : $T_1 + T_2 + \ldots + T_n$

d_i^j : Daily pick-up amount of company j's Type I service center in region i, $i \in I$, $j \in J$

d_j^l : Daily pick-up amount of company j's Type II service center l, $j \in J$, $l \in S_j$

a_i : Indicator constant such that $a_{ijk} = 1$, if daily pick-up amount of company j's Type I service center in region i is assigned to terminal k of company j before alliance, $a_{ijk} = 0$, otherwise, $i \in I$, $j \in J$, $k \in T_j$

b_j : Indicator constant such that $b_{jlk} = 1$, if daily pick-up amount of company j's Type II service center l is assigned to terminal k of company j before alliance, $b_{jlk} = 0$, otherwise, $j \in J$, $l \in S_j$, $k \in T_j$

Q : Capacity for terminal k of company j, $j \in J$, $k \in T_j$

r_{ij} : Net profit contributed by one unit of pick-up amount for company j's Type I service center in region i, $i \in I$, $j \in J$

w : Net profit obtained by terminal k when one unit of pick-up amount is assigned to terminal k of company j, $j \in J$, $k \in T_j$

f_{ij} : Daily fixed cost accruing from operating company j's Type I service center in region i, $i \in I$, $j \in J$

g_j : Daily fixed cost accruing from operating company j's terminal k, $j \in J$, $k \in T_j$

x_i : Binary variable such that $x_{ij} = 1$, if company j's

Type I service center in region i is still opened, $x_{ij} = 0$ otherwise, $i \in I$, $j \in J$

y_i : Binary variable such that $y_{ijpk} = 1$, if company j's Type I service center in region i is open and the merged pick-up amount of company j's Type I service center in region i is assigned to terminal k of company p, $y_{ijk} = 0$, otherwise, $i \in I$, $j \in J$, $p \in J$, $k \in T_i$

v_j : Binary variable such that $v_{jk} = 1$, if terminal k of company j is still opened, $v_{jk} = 0$ otherwise, $j \in J$, $k \in T_i$

z_j : Binary variable such that $z_{jlpk} = 1$, if all pick-up amount of company j's Type II service center l is reassigned to terminal k of company p, $z_{jlpk} = 0$, otherwise, $j \in J$, $l \in S_i$, $p \in J, k \in T_p$

Thus, the problem can be described as the following multi-objective integer programming model (P) with n objective functions:

(p)

$$\text{Max } Z_1(x) = \sum_{i\in I} r_{i1}\left[\frac{\sum_{j\in J} d_{ij}^1(1-x_{ij})}{\sum_{i\in J} x_{ij}} + d_{i1}^1 - f_{i1}\right]x_{i1} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in T_1} w_{1k}\left[\frac{\sum_{j\in J} d_{ij}^1(1-x_{ij})}{\sum_{j\in J} x_{ij}} + d_{ij}^1\right]y_{ij1k}$$

$$-\sum_{k\in T_1} g_{1k}v_{1k} + \sum_{j\in J}\sum_{l\in S_j}\sum_{k\in T_1} w_{1k}\ d_{jl}^2\ z_{jl1k} + C_1$$

$$\vdots$$

$$\text{Max } Z_n(x) = \sum_{i\in I} r_{in}\left[\frac{\sum_{j\in J} d_{ij}^1(1-x_{ij})}{\sum_{i\in J} x_{ij}} + d_{in}^1 - f_{in}\right]x_{in} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in T_n} w_{nk}\left[\frac{\sum_{j\in J} d_{ij}^1(1-x_{ij})}{\sum_{j\in J} x_{ij}} + d_{ij}^1\right]y_{ijnk}$$

$$-\sum_{k\in T_n} g_{nk}v_{nk} + \sum_{j\in J}\sum_{l\in S_j}\sum_{k\in T_n} w_{nk}\ d_{jl}^2\ z_{jlnk} + C_n \qquad (1)$$

s.t.

$$1 \le \sum_{j\in J} x_{ij} \le P, \qquad i \in I \qquad (2)$$

$$\sum_{p\in J}\sum_{k\in T_p} y_{ijpk} \le 1, \qquad i \in I, j \in J \qquad (3)$$

$$y_{ijpk} \le x_{ij}, \qquad i \in I, j \in J, p \in J, k \in T_p \qquad (4)$$

$$y_{ijpk} \le v_{pk}, \qquad i \in I, j \in J, p \in J, k \in T_p \qquad (5)$$

$$\sum_{p\in J}\sum_{k\in T_p} z_{jlpk} = 1, \qquad j \in J, l \in S_j \qquad (6)$$

$$z_{jlpk} \le v_{pk}, \qquad j \in J, l \in S_j, p \in J, k \in T_p \qquad (7)$$

$$\sum_{i\in I}\sum_{j\in J}\left[\frac{\sum_{j\in J} d_{ij}^1(1-x_{ij})}{\sum_{j\in J} x_{ij}} + d_{ij}^1\right]y_{ijpk} + \sum_{j\in J}\sum_{l\in S_j} d_{jl}^2 z_{jlpk} \le Q_{pk}, \qquad pj \in J, k \in T_p \qquad (8)$$

$$x_{ij} \in \{0,1\}, \qquad i \in I,\ j \in J \qquad (9)$$

$$y_{ijpk} \in \{0,1\}, \qquad i \in I,\ j \in J,\ k \in T_j \qquad (10)$$

$$v_{jk} \in \{0,1\}, \qquad j \in J,\ k \in T_j \qquad (11)$$

$$z_{jlpk} \in \{0,1\}, \qquad j \in J,\ l \in S_j,\ p \in J,\ k \in T_p \qquad (12)$$

The objective function (1) consists of n conflicting objectives corresponding to n companies. Each objective function represents the sum of net profit increases through merging Type I service centers and net profit increases by allocating Type II service centers to consolidation terminals. Constraint (2) assures that at most P service centers can be open in each merging region and all the others should be closed. Constraint (3) implies that the open service center in a region should be assigned to only one terminal. Constraint (4) means that the closed service centers in every region cannot be assigned to any terminal. Constraint (5) means that the sum of pick-up amount of all the Type I service centers in region i can be assigned to terminal k of company j only when the terminal k of company j is opened after alliance. Constraint (6) implies that every Type II service centers should be assigned to only one terminal. Constraint (7) means that the pick-up amount of Type II service centers cannot be assigned to any terminal which is closed after alliance. Constraint (8) shows that the sum of daily pick-up amount of Type I and Type II service centers allocated to a terminal cannot exceed more than given processing capacity of terminal. Constraints (9)-(12) represent binary variables.

5. SOLUTION PROCEDURE

A co-evolutionary algorithm (COEA) based heuristic is applied for the design of service network for strategic alliance (Hu et al. 2009). The chromosome representation for each company and calculation of fitness value is illustrated in Figure 2 and 3, respectively. Every developed chromosome is based on a single dimensional array that consists of binary values representing the decision variables associated with the merging of service centers, and reassigning the Type I and Type II service centers to the available terminals. The procedure of COEA is described as follows:

(Step 1) Generate the population randomly for each participating companies.

(Step 2) (a) Calculate the fitness function value of a chromosome (eg: Chromosome of Company A) by calculating the highest profit of all the fitness values of combined chromosomes between the chromosome (Chromosome of Company A) and all the chromosome for the other participating companies (Chromosomes of Company B and C).

(b) Choose a prespecified number of chromosomes with the best fitness values to be used as the next population for each supplier. Generate/Gather the remaining number of chromosomes and add to the next population for each company.

(c) Choose the top-ten best chromosome from each supplier and save all of them into a temporary variable Calculate the fitness function value of a chromosome by calculating the highest profit of all the fitness values of combined chromosomes between the chromosome and the best top ten chromosomes among all the chromosomes for the other suppliers.

(d) Choose the chromosome with the largest average fitness value to be the solution for each participating company

(Step 3) (a) Genetic algorithm (GA) is applied in each generation. A binary tournament selection method for a parent selection is used, which begins by forming two teams of chromosomes. Each team consists of two chromosomes randomly drawn from the current population. The best chromosomes selected from each of two teams are chosen for crossover operations. As such, two off-springs are generated and entered into the new population.

(b) Crossover and mutation are applied. The first step includes random generation of the crossover point which can be in any position in the parent chromosome. The offspring takes the left side of the first parent and the right side of the second parent. Then, swap mutation is adopted as mutation operator.

There are three genetic operators used in the genetic algorithm (GA) process: crossover, mutation, and cloning. The decoded chromosome generates a candidate solution and its fitness value based on the fitness function. The purposes of GA is to generate incremental changes in the opened or closed service centers and also in the opened or closed terminals based on the set of decision variables.

6. MODEL EXPERIMENTS

There are three delivery service companies for a strategic alliance in two types of regions such as merging region (Type I) and non-merging region (Type II). They are described below in more detail. 30 regions are considered, where 10 regions are merging regions and 20 regions are non-merging ones. The sets of terminals for company 1, 2, and 3 are T1= {1, 2}, T2= {3, 4}, and T3= {5, 6}. Their fixed operating costs are assumed to be $1,325, $1,255, $1,474, $1,215, $1,433 and $1,328, respectively. Every service center of company 1, 2, and 3 is already allocated to their own terminals by means of random-number generation. The terminal capacity is equally assigned to 4,000 units for every terminal of two companies. Table 1 and 2 shows the current operation data for three companies, respectively. Table 1 displays the amount of daily pick-up, allocated terminal, and the daily fixed cost of Type I service center for three companies. The daily pick-up amounts of Type II service centers are also shown in Table 2.

Table 1. Data for Type I service centers

Merging region	Pick-up amount			Allocated terminal			Daily fixed cost		
	C1	C2	C3	C1	C2	C3	C1	C2	C3
1	40	13	13	1	3	6	82	57	62
2	50	37	17	1	3	5	58	91	59
3	35	15	42	1	4	5	64	51	95
4	37	42	23	2	4	6	87	64	72
5	34	10	26	2	3	6	71	82	62
6	27	46	17	1	4	5	81	67	69
7	29	30	21	2	4	6	58	76	76
8	28	36	43	1	3	5	82	66	82
9	18	50	50	2	3	6	85	99	81
10	19	27	42	2	4	5	99	99	79

* C1: Company1, C2: Company 2, C3: Company 3

Table 2. Daily pickup amount for Type II service centers

Non-merging region	C1	C2	C3
1	483	447	159
2	478	160	277
3	384	192	410
4	354	219	278
5	107	278	156
6	382	127	389
7	114	298	416
8	257	363	289
9	357	364	203
10	201	267	254
11	432	162	221
12	193	402	396
13	124	381	410
14	436	281	463
15	279	419	175
16	186	384	499
17	500	131	197
18	244	367	315
19	374	171	309
20	428	142	310

Table 3. The COEA results

(a)The survived terminals for each company

Company	Terminal
1	1
2	3
3	5

(b) Type I service centers

Merging region	Opened service centers	Terminal allocation
1	C3	5
2	C1	1
3	C2	4
4	C2	1
5	C1	4
6	C2	4
7	C1	1
8	C1	5
9	C2	5
10	C3	5

(c) Type II service centers

Non-merging region	Terminal allocation		
	C1	C2	C3
1	5	4	5
2	1	4	1
3	5	4	4
4	1	4	1
5	1	4	4
6	5	4	1
7	5	4	4
8	1	1	5
9	5	1	4
10	4	4	5
11	4	4	5
12	5	4	5
13	5	4	4
14	1	1	1
15	5	4	1
16	5	1	5
17	1	1	5
18	5	5	1
19	5	5	1
20	5	5	1

Table 4. Shapley value allocation

Combination for alliance			Marginal contribution		
			A	B	C
No alliance	A, B, C □		0	0	0
Alliance between two Companies	A+B	6,043	6,043	6,043	
	B+C	5,950		5,950	5,950
	A+C	6,300	6,300		6,300
	Average □		6,171.5	5,996.5	6,125
Full alliance	A+B+C□	9,717	3,767	3,417	3,674
Shapley Value	(□+□+□) / 3		3,312.8	3,137.8	3,266.3

The results by the co-evolutionary algorithm are summarized in Table 3. Based on maxsum criterion, the obtained objective function value is $9,717 where the profits for each company are $3,263, $2,945 and $3,509, respectively. Table 4 also shows the Shapley value results by applying maxsum criterion and an allocation method by fairly allocating to each company based on its marginal contribution.

7. CONCLUSION

A compromised model for strategic alliance among delivery service companies was proposed to maximize the expected profit of each allied company by considering the survival of multiple service centers in a merging region, the consolidation terminal sharing, and the opening/closing of consolidation terminals overall. Multi-objective non-linear programming model was developed and a co-evolutionary algorithm approach was also utilized. The applicability and efficiency is demonstrated through a numerical example. In addition, a weighted Shapley value as a systematic methodology was proposed for equitable allocation to each company regarding its marginal contribution. Other problems in a strategic alliance and finding a coordination policies for strategic alliance, will be studied as a future research.

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