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COEVOLUTIONARY ALGORITHM BASED APPROACH TO THE COLLABORATIVE NETWORK DESIGN IN EXPRESS DELIVERY SERVICES USING COALITIONAL GAME THEORY

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Abstract. *Express delivery service companies (EDSCs) are in the middle of fierce competition among each other in order to extend their own market share. This study addresses small and medium-sized EDSCs which are suffering with their low demand and under-utilized service centers and suggests two types of strategic alliance models to overcome their difficulties: merging service centers and sharing of consolidation terminals. Through the cooperation of consolidation terminals in EDSCs, participating companies will be able to improve their accessibilities to complementary resources which belong to other companies and increase efficiency of resource usages in a distribution system of goods. A newly developed coevolutionary algorithm can be implemented under a distributed decision-making scenario assumed in the alliance system. A coalitional game theory can also be applied to forming coalitions in express delivery services with equitable allocation to each participating company. The applicability and efficiency of the proposed models are demonstrated through a numerical example.*
Keywords: Express delivery service, Collaborative network design, Strategic alliance, Coalitional game theory, Coevolutionary algorithm

1. **Introduction.** Express delivery service companies (EDSCs) are normally owned by companies who compete with one another and usually provide services consisting of pick-up, transport and delivery services. Based on the viewpoint of economic growth in Asia and the Pacific and operational efficiency, the current economy had contributed to significant increase of demand in express delivery services. To meet the increasing demand and to improve capacity for delivery, many express delivery service suppliers are establishing additional consolidation terminals. Therefore, we need cooperative strategic alliance in the operation of facilities and also delivery vehicles can create various benefits resulting from the economy of scale, which can lead to reduction of operation cost, especially for small and medium sized companies, and to enhancement of the profitability which is in decline by reducing or eliminating overlapped investments. In strategic alliance, the partners can pool their resources and strengthen them together in order to achieve their respective goals such as sharing risks, gaining knowledge, and gaining access to new markets. In this study, we propose a decision making model for strategic alliance among EDSCs to maximize the expected profit derived from express delivery services by merging the service centers and sharing the capacity of consolidation terminals. The conceptual model can be solved using coevolutionary algorithm. Shapley value allocation is also applied to eqitable profit sharing based on the marginal contribution of each participating

company. There are many studies which are related to this study. Chung et al. [1] firstly proposed the network design model for strategic alliances among express delivery service companies through the monopoly of service centers. In addition, they also developed an integer programming model and its solution procedure based on a fuzzy set theoretic approach [4]. A nonlinear integer programming model for strategic alliance of express companies was also proposed in the consideration of additionally sharing of consolidation terminals [5,6]. Ferdinand et al. [8] also added another option of closing/opening of consolidation terminals, and developed a multi-objective programming model, maximizing the minimum expected profit increase of each participating company to examine the feasibility of merging under-utilized courier service centers and sharing of consolidation terminals. They continued to propose mathematical models for strategic alliance regarding extension of terminal capacity [9,10]. A mathematical model is also presented, regarding transportation cost and service charge as additional parameters and its solution procedure [3]. Ferdinand et al. introduced comparison among three allocation policies for allocating the freight demands of closed service centers to open service centers [7]. Lee et al. proposed a strategic partnership model for pick-up and delivery routing based on Shapley value allocation [11]. A coevolutionary genetic algorithm based heuristic was also suggested for the collaboration model by Ferdinand and Ko [2]. The remainder of the paper is as follows. Section 2 describes the problem. A solution procedure and a numerical example are explained in Sections 3 and 4, respectively. Section 5 proposes conclusions and future researches.

2. **Problem Definition.** This study proposes a decision making model to reflect two types of strategic alliances among EDSCs and develops a solution procedure based on coevolutionary algorithm. A coalitional game theoretic method is also applied to equal allocation of profit. This study is divided into two sub-problems: the first one is to develop a solution procedure for a strategic alliance model with the objective of maximizing the net profit of each participating company; the second one is to determine how to allocate coalition profits to each company who takes part in this coalition. Creating alliances can allow all participating companies to share resources and it can help firms produce services more efficiently or at a higher quality. In this study, the strategic alliance model considers that companies are participating to share the capacity of consolidation terminals by reassigning all the service centers to the terminals, and each participating company is also collaborating in pick-up operation at the open service center in the merging region. Service centers of a company are divided into two types such as Type I and Type II; Type I service centers belong to merging regions and are candidates for merging in strategic alliance, and Type II service centers do not belong to any merging regions. The strategic alliance is operated as follows.

a) Usually only a single service center can be opened in most of candidate merging regions. However, survival of multiple service centers may be possible in some merging regions, and all the other service centers should be closed within a merging region after alliance.
b) The open service center after alliance is also responsible for pickup and delivery of all the amounts of other companies' closed service centers within the same merging region. Table 1 shows an example of allocation rules considering three companies.
c) Even after the alliance, each company should fulfill the processing capacity of each consolidation terminal.
d) All open service centers can be reassigned to other company's consolidation terminal, while satisfying the processing capacity of the terminal.

Also, Shapley value as a coalitional game theoretic approach is applied to forming coalitions in express delivery services with the equitable allocation to each company [12].

TABLE 1. An example of allocation rules for opening/closing service centers

No	SC1	SC2	SC3	SC1	SC2	SC3
1.	√			$OpenSC1 + CloseSC2 + CloseSC3$		
2.		√			$OpenSC2 + CloseSC1 + CloseSC3$	
3.			√			$OpenSC3 + CloseSC1 + CloseSC2$
4.	√	√		$OpenSC1 + \frac{CloseSC3}{2}$	$OpenSC2 + \frac{CloseSC3}{2}$	
5.	√		√	$OpenSC1 + \frac{CloseSC2}{2}$		$OpenSC3 + \frac{CloseSC1}{2}$
6.		√	√		$OpenSC2 + \frac{CloseSC1}{2}$	$OpenSC2 + \frac{CloseSC1}{2}$
7.	√	√	√	$OpenSC1$	$OpenSC2$	$OpenSC3$

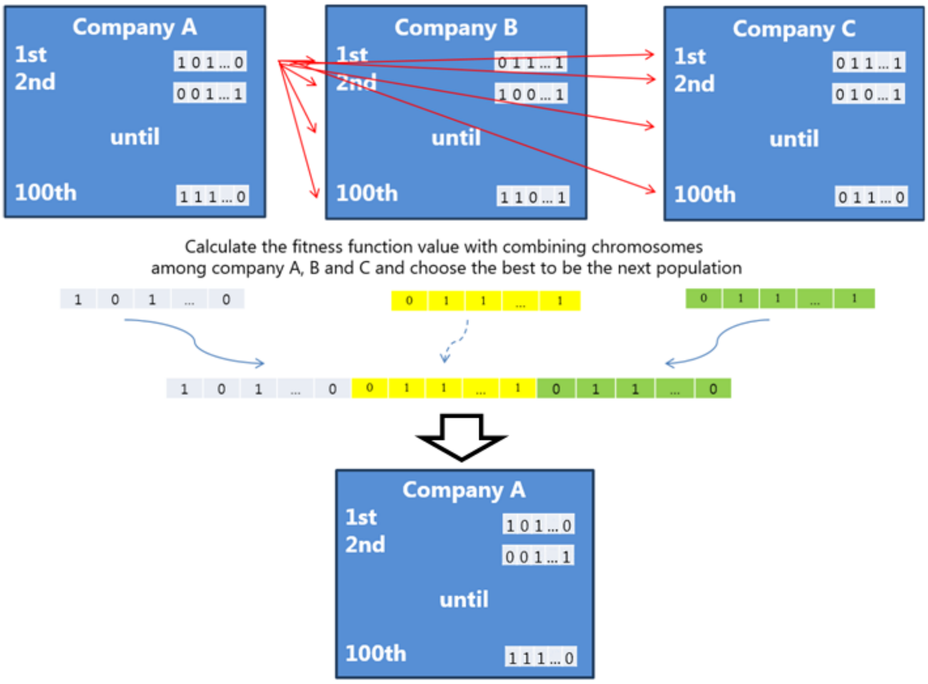

FIGURE 1. Calculating fitness value in coevolutionary algorithm

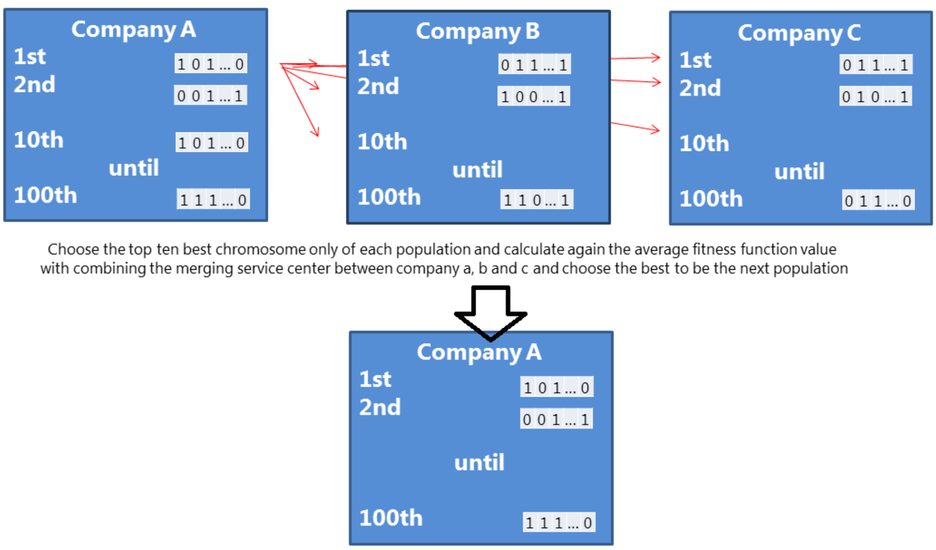

FIGURE 2. Choosing best top ten chromosomes in coevolutionary algorithm

Company A									
R1	R2	R3	R4	R5	AT1	AT2	AT3	AT4	AT5
1	0	0	1	1	0	1	0	0	1

FIGURE 3. Chromosome representation for each company in Type I

Company A																																			...
Open/Close					TA-Merging										TA-Non Merging																				...
R1	R2	R3	R4	R5	R1		R2		R3		R4		R5		R1		R2		R3		R4		R5		R6		R7		R8		R9		R10		...
1	0	0	1	0	0	1	1	0	0	1	0	1	1	0	1	0	1	0	0	1	1	0	0	1	1	1	1	0	0	1	1	0	1	1	...

Company C																																		
Open/Close					TA-Merging										TA-Non Merging																			
R1	R2	R3	R4	R5	R1		R2		R3		R4		R5		R1		R2		R3		R4		R5		R6		R7		R8		R9		R10	
0	0	1	0	0	0	1	1	0	0	1	0	1	1	1	0	1	1	0	1	0	0	1	1	0	0	1	0	1	1	0	0	1	0	1

FIGURE 4. Chromosome representation for calculating fitness value in Type I and II

3. A Coevolutionary Algorithm Based Heuristic.

A coevolutionary algorithm based heuristic is applied to the design of service network for strategic alliance [13]. The coevolutionary process is in detail explained in Figures 1 and 2. Also the chromosome representation for each company and calculation of fitness value are illustrated in Figures 3 and 4, 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 reassign the Type I and II service centers to the available terminals. The chromosome is represented by 40 genes and divided into five parts. The procedure of the coevolutionary algorithm is described as follows.

Step 1: Generate the population randomly for each participating company.

Step 2: (a) Calculate the fitness function value of a chromosome (e.g., 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 Companies 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 chromosomes 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 proposed GA: crossover, mutation, and cloning. The cloning operator copies some of the best chromosomes to the next population. Also, the two point crossover method is used in Figure 5. It uses a special repairing procedure to resolve the illegitimacy caused by the two point crossover. The first point is used to assign service center that can be opened in one region and the second point is used

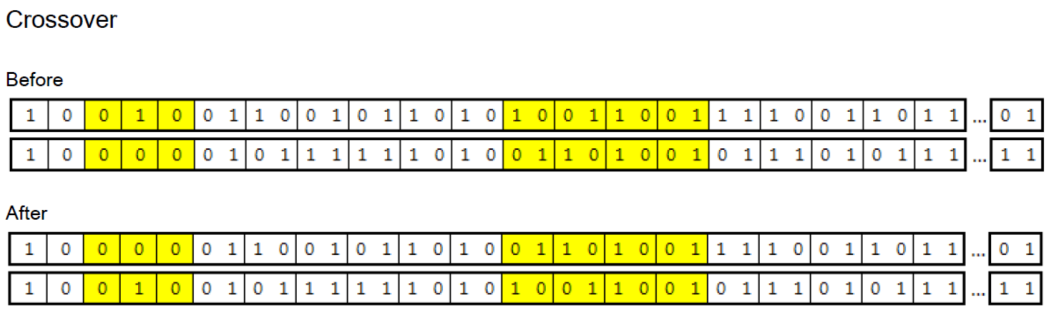

Figure 5. Crossover process

to reallocate the daily pick-up amount to the terminal by considering sharing terminal. Finally, swap mutation is adopted as mutation operator by choosing two random numbers in each part and swap the genes. The decoded chromosome generates a candidate solution and its fitness value based on the fitness function.

4. **A Numerical Example.** There are three express delivery service companies, each of which has one terminal. 15 regions are considered, where 5 regions are in the merging area and 10 regions are in the non-merging area. The daily pick-up amount for each Type I service center is randomly generated in the range between 10 and 100 units, which is shown in Table 2(a). In the similar way, the daily pick-up amount for Type II service centers is shown in Table 2(c). In addition, closing of a service center results in a reduction of the daily fixed costs in Table 2(b) for maintenance and operation. All these data are obtained by generating random-numbers between \$50 and \$100. The handling cost in the service centers for companies 1, 2 and 3 is assumed the same as \$0.5 if they use terminals of other companies.

Table 2. Current operation data

(a) Daily pick-up amount for Type I service centers (merging region)

	Merging Daily Pickup				
	R1	R2	R3	R4	R5
C1	15	38	50	10	43
C2	86	57	62	91	75
C3	53	67	88	94	73

(b) Daily fixed cost for Type I service centers (merging region)

	Daily Fixed Cost(\$)				
	R1	R2	R3	R4	R5
C1	52	88	64	78	75
C2	71	57	92	83	61
C3	82	56	66	54	86

(c) Daily pick-up amount for Type II service centers (non-merging region)

Non-Merging Daily Pickup			
Region	C1	C2	C3
1	265	336	261
2	421	427	407
3	233	218	294
4	214	127	332
5	329	117	304
6	115	467	243
7	444	343	220
8	376	374	445
9	133	159	385
10	228	435	373

The parameter values for GA are: population size of 100, maximum number of generations equal to 100, cloning rate of 2%, and crossover rate and mutation rate of 50% and 10%, respectively. Results of coevolutionary algorithm implementation are shown in Tables 3(a) and 3(b). A strategic alliance is a business arrangement in which two or more firms cooperate for their mutual benefit. Therefore, in this study the advantages of strategic alliance include: allowing each participating company to concentrate on activities that match its capabilities to merge the service centers and competencies to survive in express delivery service area and choose which terminal must be allocated with suitability of the resource by considering the sharing terminal as its resources. The result after coevolutionary algorithm implementation can be seen in Table 3 for Type I and Type II service centers. Total profit for all companies is \$4,556, while the highest profit is \$2,171 for company 1, the second is \$1,710 for company 2 and the lowest is \$675 for company 3. Table 4 shows the entire results for all alliance combinations among participating companies and Shapley value allocation according to the marginal contribution of each company.

TABLE 3. Results after coevolutionary algorithm implementation

(a) Terminal allocation for Type I service centers

Open/Cose				AT		
Region	C1	C2	C3	C1	C2	C3
1	√			1	2	1
2		√		2	2	2
3			√	1	3	1
4	√			1	2	1
5		√		2	2	3

(b) Terminal allocation for Type II service centers

Non-Merging Terminal Allocation (AT)			
Region	C1	C2	C3
1	2	3	1
2	2	1	2
3	1	2	2
4	2	3	1
5	1	1	2
6	3	3	1
7	2	1	1
8	1	1	2
9	2	1	1
10	3	2	1

TABLE 4. Shapley value allocation

Combination for alliance			Marginal contribution		
			A	B	C
No alliance	A, B, C ①		0	0	0
Alliance between two companies	A+B	2,884	2,884	2,884	
	B+C	2,881		2,881	2,881
	A+C	2,663	2,663		2,663
	Average ②		2,773.5	2,882.5	2,772
Full alliance	A+B+C ③	4,556	1,675	1,893	1,672
Shapley Value	(①+②+③) / 3		1,482.8	1,591.8	1,481.3

5. **Conclusions.** As the market size of express delivery industry is growing rapidly, severe competition among express delivery services is inevitable. The adoption of strategic alliance may be one of effective ways to cope with many troubles suffered by small and medium-sized express delivery service companies. This study proposed a model to reflect two types of strategic alliance models among express delivery service companies and developed a solution procedure based on coevolutionary algorithm. Also, a coalitional game

– theoretic method was applied to fair allocation of coalition profit to each participating company. In other network dealing with problems with similar structure, such as logistics network, and communication network, strategic alliance models will be investigated in the future study.

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