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A COOPERATIVE GAME-THEORETIC METHOD FOR DESIGN OF SUSTAINABLE ALLIANCE NETWORK IN EXPRESS DELIVERY SERVICES

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Abstract. *While express delivery service market in Korea expands rapidly despite global economic downturn, many domestic delivery service companies are suffering from the decline in unit price of delivery service due to excessive competition. They are striving for providing superior service at a cheaper price in order to remain competitive. Alliance enables economies of scale to reduce operational cost as well as to increase net profit under a win-win situation. This study proposes a sustainable alliance model, which deals with selecting service centers in each merging region with low demand in express delivery services. In particular, a co-evolutionary genetic algorithm is developed, which may be implemented under a distributed decision-making scenario assumed in collaboration system. A Shapley value as a methodology for cooperative game theory is also applied in forming coalitions in express delivery services with the equitable allocation to each company. An example problem is performed to verify the appropriateness of the suggested collaboration model.*

Keywords: Express delivery service, Sustainable alliance, A co-evolutionary genetic algorithm, Cooperative game theory, Shapley value

1. **Introduction.** Express delivery service provides delivery services at scheduled times to customers and also makes pick-ups during a day when requested by customers. The express delivery market has grown with average double digits every year in the last decade. Recently, the total sales of the express delivery market in Korea increased around 9.3% compared to 2014 [1]. Most of express delivery service companies are striving for an increment in their delivery amounts with rapid and on-time delivery, under a well-built infrastructure. However, some of express delivery service companies in small and medium sizes are suffering with competition for low prices, difficult acquisition of delivery vehicles, and lack of country-wide terminals [2]. Alliance enables small and medium sized companies to expect reduction of the operational cost by eliminating overlapped investments. In addition, through efficient cooperation of service centers, participating companies can expect net profit increase under the win-win situation [3].

Chung et al. [2] firstly proposed the network design model for strategic alliances among express courier 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 additional sharing of consolidational terminals [5,6]. Ferdinand et al. 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 [7]. They continued to propose mathematical models for strategic alliance regarding extension of terminal capacity [8,9]. A mathematical model is also developed, which considers transportation cost and service charge as additional parameters and its solution procedure [3].

This study suggests a sustainable alliance model for increasing the competitiveness of each participating company through monopoly of demand as well as equitable allocation of alliance profits. A co-evolutionary genetic algorithm based heuristic is developed for network design, which may be implemented under a distributed decision-making scenario assumed in collaboration system. The difference from the previous alliance models can be summarized as follows: first, this study proposes a co-evolutionary genetic algorithm based heuristic, confirming that only the pick-up and delivery amounts of closed service centers are equally allocated to the survived service centers in the collaboration model; second, this study also suggests a systematic fair allocation method of coalition profit.

The remainder of the paper is organized as follows. Section 1 introduces the previous studies related to the problem considered. Sections 2 and 3 respectively define the problem and a solution procedure. Section 4 shows a numerical example. Section 5 explains the conclusions and further research areas.

2. **Problem Statement and Preliminaries.** This study is divided into two sub-problems: the first concern is to develop a solution procedure for a strategic alliance model with the objective of maximizing the net profit of each participating company, and the second is to determine how to allocate coalition profits to each company. The strategic alliance model investigated in this study is considered as a service center level collaboration model. In this model, all the companies participating in the alliance collaborate in pick-up/delivery together at the merged service center. The 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 pick-up and delivery of all the amounts of other companies' closed service centers within the same merging region.

c) Even after the alliance, the current existing consolidation terminals are still used as usual.

d) All open service centers cannot be reassigned to other company's consolidation terminal, while satisfying the processing capacity of the terminal.

Next, a Shapley value as a methodology for cooperative game theory is also used to form coalitions in express delivery services with the equitable allocation to each company [10].

3. **Solution Procedure.** A co-evolutionary genetic algorithm based heuristic is proposed for the collaboration model, which is regarded as further upload of traditional evolutionary algorithms and this also behaves in a complicated and counterintuitive way in some complex problem [11]. The heuristic algorithm applies a probabilistic transition rule on each chromosome to create a new population and represent a good candidate generation [3,9,12]. Tables 1 and 2 show an example of chromosome representation for opening/closing of service centers and an example of chromosome representation to calculate fitness function value, respectively. If the service center is still open in each merging region after alliance each gene has a value of 1. On the contrary, it has a value of "0" in

TABLE 1. An example of chromosome for each company

Company A				
R1	R2	R3	R4	R5
1	1	1	0	0

TABLE 2. An example of chromosome representation to calculate fitness function value

Service centers														
Company A					Company B					Company C				
R1	R2	R1	R4	R5	R1	R2	R3	R4	R5	R1	R2	R3	R4	R5
1	1	1	0	0	0	0	0	1	1	1	1	1	1	1

the tables. The objective function used as fitness function is to maximize the total profit consisting of fixed cost of service centers, handling cost at service centers, and service charge paid to (received by) service centers. In this study, the revenue from customer for company A, B and C is assumed to be $10 per unit. To evaluate the fitness values for the companies, the co-evolutionary process is performed, where genetic algorithm is also applied.

Three genetic operators are used in the proposed GA: crossover, mutation, and cloning. The cloning operator copies some of the best chromosomes to the next population. The single point crossover is used: The first point is used to determine service centers to open within each region and the second one is used for terminal sharing. The procedure of the co-evolution algorithm [8] is summarized as follows:

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

(Step 2) Calculate the fitness function value for each participating company by matching each chromosome from the other companies.

(Step 3) Re-calculate the fitness function value for each chromosome by averaging all the fitness values of combined chromosomes and choose the best top ten chromosomes among all the chromosomes for the other companies.

(Step 4) Choose a pre-specified number of chromosomes with the best fitness values, which is considered to be the next population for each company. Generate the remaining number of chromosomes and add to the next population for each company. If stopping condition is not satisfying, then go to Step 3.

(Step 5) Choose the best chromosome with the largest average fitness value as the solution for each participating company.

4. **A Numerical Example.**

An illustrative example is provided to verify the appropriateness of the proposed heuristic solution for alliance model, as well as to explain how to use the Shapley value allocation. Assume that there are three express delivery service companies with five merging regions and that each company has two consolidation terminals. Tables 3 and 4 show current operation data and remaining terminal capacity for company A, B and C, respectively. Here, Q_{ij} means a remaining terminal capacity of terminal j of company i.

The result using co-evolutionary genetic algorithm is shown in Table 5, based on max-sum criterion, which considers collaboration of three companies. It presents that multiple service centers will be open in each region. Here, x_{ij} means a binary variable such that $x_{ij} = 1$, if the service center of company i in the merging region j is still open, $x_{ij} = 0$, otherwise. In region 1 and 4, service centers of company A and B will be open while company C's service center will be closed. In region 3 and 5, service centers of company A and C will be open. Only the service center of company A will be closed in region 2.

TABLE 3. Data for company A, B, and C

Region	Pick-up amount			Allocated terminal			Daily fixed cost ($)		
	A	B	C	A	B	C	A	B	C
1	53	58	86	1	3	6	52	71	56
2	67	74	57	1	4	6	88	57	87
3	88	80	62	2	4	5	64	91	93
4	94	66	91	1	3	6	78	83	98
5	73	92	75	2	3	5	75	61	90

TABLE 4. Data for each company's remaining terminal processing capacity

Q_{A1}	Q_{A2}	Q_{B1}	Q_{B2}	Q_{C1}	Q_{C2}
145	137	112	162	129	106

TABLE 5. Optimal solution for maxsum criterion

	R1	R2	R3	R4	R5
x_{Aj}	1	0	1	1	1
x_{Bj}	1	1	0	1	0
x_{Cj}	0	1	1	0	1

TABLE 6. Shapley value allocation

Combination for alliance			Marginal contribution		
			A	B	C
No alliance	A, B, C ①		605.5	856	564.5
Alliance between two companies	A+B	1,717.5	861.5	1,112.5	
	B+C	1,752.5		1,188	896.5
	A+C	1,424.5	860		819.5
	Average ②		860.8	1,150.3	858
Full alliance	A+B+C ③	2,499.5	747	1,075	782
Shapley value	(①+②+③)/3		737.6	1,027.1	734.8

Table 6 shows the entire results for all alliance combinations among participating companies and calculated Shapley value allocation, regarding the marginal contribution of each company.

5. **Conclusions.** Alliance recently emerges as a hot issue in most industry fields, while searching for a strategy to overcome critical survival problems. Most express courier service companies of small and medium size in Korea are still suffering many difficulties due to severe competition in the market. This study develops a co-evolutionary genetic algorithm based heuristic for a sustainable alliance model to increase the competiveness of each participating company through monopoly of demand as well as equitable allocation of alliance profits. As a result, the alliance model and the developed heuristic enable most of express delivery service companies to expect increase of profit in saturated market. Application of various types of the alliance models will be included as future research areas.

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