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A GAME-THEORETIC COLLABORATION MODEL FOR EXPANDING PARCEL DELIVERY SERVICE MARKET

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Abstract. *While the demand for parcel service has gradually increased over the past decade, the delivery service price has dropped due to the more intense competition between parcel services. The parcel service providers with low market share are making a lot of efforts to survive in competitive market. Cooperation through the sharing economy can allow parcel service companies to expand their service network and increase market share. A network of terminals, service centers and customers is defined as a parcel service system. This study considers a collaboration model to strengthen the competitiveness among participating parcel companies through a monopoly of service centers. Moreover, based on a cooperative game theory a nucleolus-based profit allocation methodology is proposed for fair allocation of the profits to each allied company. The applicability and efficiency of the proposed model are illustrated by an example problem.*

Keywords: Parcel service, Game theory, Collaboration, Nucleolus-based allocation

1. **Introduction.** In recent years, the concept of sharing economy has been applied in different industrial areas in order to meet the need for more efficient use of physical assets. It could develop an innovation-based community and contribute changes in business relationships to the ecosystem. The consumer-driven sharing economy based on experience and trust, such as Uber and Airbnb, is gradually shifting to the business-to-business (B2B) shared economic support to prevent duplicate asset loss. The logistics and transportation sectors are leading the sharing economy in comparison with other industries.

Especially, it has been active in the field of air and maritime transport and has been extended to several areas of land transport. Currently, the rapid growth of business-to-client (B2C) as a result of indirect purchases accelerates the sharp growth in the parcel services market. The recent trend for the parcel market in Korea is shown in Figure 1. It is observed that the courier amount has continuously been growing year by year. On the other hand, the price per unit is reducing due to the increasingly fierce competition among providers of parcel services. After all, courier companies with a low market share are unlikely to survive in a competitive market and they need to collaborate with other companies in order to expand their market share [1].

The elements of parcel service include service centers, consolidation terminals and customers, and this service is carried out using last-mile delivery and line-haul transport by

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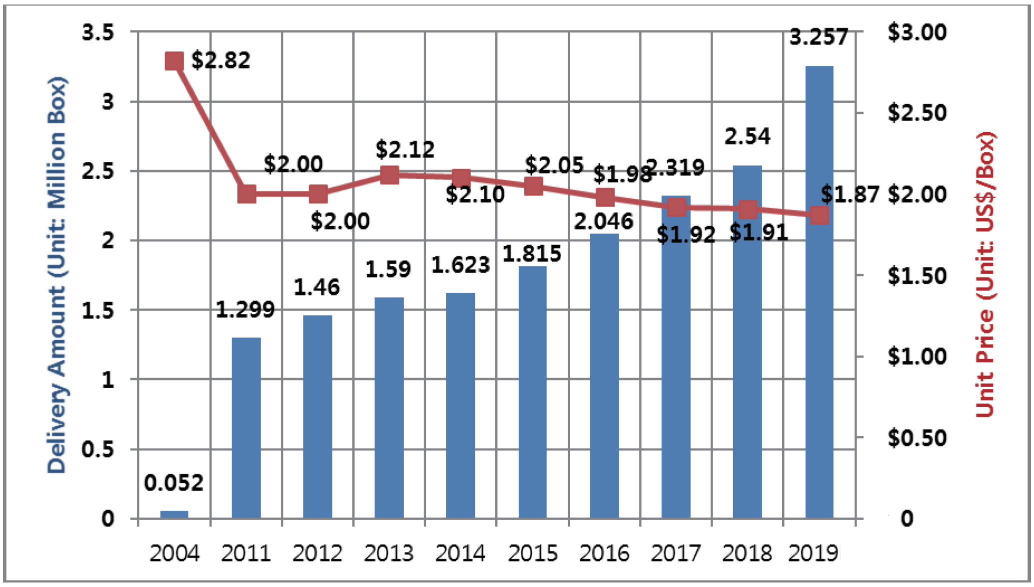

Figure 1. Parcel service market trend in Korea

linking customers by means of economies of scale. The objective of this study is to use sharing economy in parcel service in order to create win-win business model and build healthy ecosystem. Furthermore, in order for business model to be sustainable, relying on the co-operative game theory the equitable method of allocating alliance profits is proposed [11].

During the last decade, some studies have been conducted on strategic alliance in the research area of designing network of parcel service. For the first time, Chung et al. did research on collaboration in designing network of parcel service [2]. Afterward several decision-making models that reflect different types of collaborations were created [4-10]. Moreover, Ko et al. conducted research on parcel service network reconfiguration problem which is based on collaboration and which is with cut-off time adjustments [13]. Another study that was done by Ferdinand et al. considered line-haul vehicles' collaborative pick-up and courier routing problem in order to maximize profits of companies-participants [9]. Chung et al. [3] recently proposed a model of sustainable cooperation with the monopoly of service centers using the Shapley value distribution. Their study has also been extended to the sharing of each company's consolidation terminals [11]. For reflecting two types of collaboration issues such as terminal sharing and survival of service centers simultaneously a multi-objective non-linear integer programming model was developed. In this study, we constructed a strategic alliance model with the objective of expanding service market of each participating company even if they have no service center in some regions. The fair allocation of the revenue has a critical importance for the long-term stability of the alliance. Therefore, we propose to use a revenue proration scheme based on the concepts of the maxmin, maxsum, Shapley value and the Nucleolus-based allocation. In particular, the Nucleolus solution is strictly superior to all the others, achieving higher throughputs and fairness. Shapley value may not satisfy core conditions. Thus, the nucleolus-based allocation is proposed to overcome the problem of Shapley value. It tries to maximize excess vector under the core conditions. To find a nucleolus-based allocation for combinations of three companies with three consolidation terminals the linear programming is developed. The remainder of the paper is as follows. In Section 2 a mathematical model for collaborative network design is developed. Nucleolus-based allocation procedure is introduced in Section 3. A numerical example is explained in Section 4. Section 5 proposes conclusions and future researches.

2. **Model Design.** This section constructs a strategic alliance model with the objective of maximizing the net profit of each participating company using Chung et al.'s model [1]. We assume that there are m parcel courier companies and the locations of each company's operated terminals and service centers are known in advance. And there are expected to be n merging regions where companies have a relatively small amount of distribution. Additionally, we assume that the daily delivery amount of each company in each region and the terminal processing capacity per day are given in advance. The underlying premise of this study is that in n merging regions, all the companies do not have a service center. In each merging region, some companies have their service center and other companies do not have a service center. A company without a service center in a region can deliver its own shipment by using other company's service center at a higher delivery cost. In every merging region only a single service center can be open and all the other service centers are closed after alliance. The delivery amounts of the closed service centers within the same merging region are delivered by the open service center after alliance. The processing capacity of the terminal for each company should be satisfied after alliance. Under these conditions, we suggest maximizing the profit of each company by selecting a single service center among candidate service centers within each region subject to the processing capacity of all the terminals. From this, it is assumed that all the terminals operated by a company can also be available to other companies after alliance.

In order to develop a mathematical formulation the following notations are introduced [1]:

I: Set of express courier companies, $I = \{1, 2, 3, \dots, m\}$

J: Set of service regions in which service centers are to be merged, $J = \{1, 2, 3, \dots, n\}$

T_i: Set of consolidation terminals for company i, $i \in I$

J_{ik}: Set of merging regions allocated to company i's terminal k, $i \in I$, $k \in T_i$

d_{ij}: Daily delivery amount of company i within the merging region j, $i \in I$, $j \in J$

D_j: Sum of daily delivery amount of all the service centers within the merging region j, $j \in J$

r_{ij}: Revenue that company i obtains by delivering one unit within the merging region j, $i \in I$, $j \in J$

c^1_{ij}: Unit delivery cost when company i's service center exists in the merging region j, $i \in I$, $j \in J$

c^2_{ij}: Unit delivery cost when company i's service center does not exist in the merging region j, $i \in I$, $j \in J$

a_{ij}: Indicator constant such that $a_{ij} = 1$, if company i's service center exists in the merging region j before alliance, $a_{ij} = 0$, otherwise, $i \in I$, $j \in J$

Q_{ik}: Delivery process capacity remaining at terminal k of company i, $i \in I$, $k \in T_i$

f_{ij}: Daily fixed cost for operating the service center when company i's service center exists in the merging region j, $i \in I$, $j \in J$

x_{ij}: Binary variable such that $x_{ij} = 1$, if company i's service center in the region j is still open after alliance, $x_{ij} = 0$, otherwise, $i \in I$, $j \in J$

After alliance, the net profit that company i obtains can be calculated by dividing into two cases. If company i does not have a service center in the merging region j, then the net profit of company i is $\left(c^2_{ij} - r_{ij}\right) d_{ij}$. On the other hand, if company i has a service center in the merging region j and the service center is closed and consolidated into other company's open service center after alliance, that is $a_{ij} = 1$, $x_{ij} = 0$, then the net profit of company i is $-\left(r_{ij} - c^1_{ij}\right) d_{ij} + f_{ij}$. If company i has a service center in the merging region j and the service center is still open after alliance, that is $a_{ij} = 1$, $x_{ij} = 1$, then the net profit of company i is $\left(r_{ij} - c^1_{ij}\right)(D_j - d_{ij})$. Therefore, when company i has a service center in the merging region j before alliance, the net profit of company i after alliance can be expressed as $\left(r_{ij} - c^1_{ij}\right)(D_j x_{ij} - d_{ij}) + f_{ij}(1 - x_{ij})$. Considering all the merging regions, the company i's total net profit reflecting above two cases simultaneously is

$$\sum_{j\in J}\left(r_{ij} - c^1_{ij}\right) a_{ij}(D_j x_{ij} - d_{ij}) + \sum_{j\in J} f_{ij} a_{ij}(1 - x_{ij}) + \sum_{j\in J}\left(c^2_{ij} - r_{ij}\right) d_{ij}(1 - a_{ij})$$

The problem can be formulated as the following multi-objective integer programming model (P) with m objective functions:

(P)

$$\begin{aligned} \text{Max } Z_1 = &\sum_{j\in J}\left(r_{1j} - c^1_{1j}\right) a_{1j}(D_j x_{1j} - d_{1j}) + \sum_{j\in J} f_{1j} a_{1j}(1 - x_{1j}) \\ &+ \sum_{j\in J}\left(c^2_{1j} - r_{1j}\right) d_{1j}(1 - a_{1j}) \\ &\vdots \\ \text{Max } Z_m = &\sum_{j\in J}\left(r_{mj} - c^1_{mj}\right) a_{mj}(D_j x_{mj} - d_{mj}) + \sum_{j\in J} f_{mj} a_{mj}(1 - x_{mj}) \\ &+ \sum_{j\in J}\left(c^2_{mj} - r_{mj}\right) d_{mj}(1 - a_{mj}) \end{aligned} \tag{1}$$

Subject to

$$\sum_{i\in I} x_{ij} = 1, \quad j \in J \tag{2}$$

$$x_{ij} \le a_{ij}, \quad i \in I,\ j \in J \tag{3}$$

$$\sum_{j\in J_{ik}} (D_j x_{ij} - d_{ij}) \le Q_{ik}, \quad i \in I,\ k \in T_i \tag{4}$$

$$x_{ij} \in \{0, 1\}, \quad i \in I,\ j \in J \tag{5}$$

The objective Function (1) has m conflicting objectives corresponding to m companies. Every objective function reflects the sum of net profit increases obtained by alliance. Only one service center can be open in each merging region and all the others should be closed in Constraint (2). Constraint (3) means that an open service center is chosen as one of the existing service centers in the merging region. Constraint (4) implies that the sum of the daily amount of pick-up and deliveries of the merging regions allocated to the terminal by considering the processing capacity of each terminal. Constraint (5) represents decisions variables as the binary number [1].

3. **Nucleolus-Based Profit Allocation Procedure.** To maintain long-term cooperation, a fair distribution of coalition profits is very important. In the theory of cooperative games, there is a core for any coalition if the conditions of completeness, rationality and marginality are fulfilled. Completeness means that the profit is completely divided into the participating classes of the company. And rationality means that entering a large coalition, classes of companies cannot receive less than they would if they decided to become part of any smaller coalition of classes of companies. Margin means that the classes of companies are provided in most cases with their marginal profit. The need for a coalition is emphasized by the presence of a core. Since there are no cores or too many cores for some coalitions, the Shapley value and nucleolus-based distribution are proposed as a single solution [12]. The value of Shapley is well known as the fairest method of profit distribution in the theory of cooperative games, which reflects the concept of the distribution of synergies obtained through the coalition, in accordance with the marginal contribution of the participants [14]. However, his weakness lies in the fact that he may not satisfy the basic conditions. In contrast, a nucleolus-based distribution is proposed to overcome the

Shapley cost problem. He is trying to maximize the excess vector under basic conditions. To find the distribution based on the nucleolus for combinations of coalitions of the three companies, linear programming is developed as follows:

$$\text{Maximize} \quad e \tag{6}$$

Subject to

$$y_1 \geq Z_1^* + e \tag{7}$$
$$y_2 \geq Z_2^* + e \tag{8}$$
$$y_3 \geq Z_3^* + e \tag{9}$$
$$y_1 + y_2 \geq Z_{12}^* + e \tag{10}$$
$$y_1 + y_3 \geq Z_{13}^* + e \tag{11}$$
$$y_2 + y_3 \geq Z_{23}^* + e \tag{12}$$
$$y_1 + y_2 + y_3 = Z_{123}^* \tag{13}$$
$$y_1, y_2, y_3, e \geq 0 \tag{14}$$

where e is excess vector, y_i is profit allocation for company i, Z_i^*, Z_{ij}^*, Z_{ijk}^* indicate coalition profit for only company i, companies i and j, companies i, j, and k, respectively.

The objective Function (6) implies the maximum vector excess. Satisfaction of rationality and marginality conditions of the core are given in Constraints (7)-(12). Core's completeness is shown in Constraint (13). Constraint (14) means non-negativity.

4. **Numerical Example.** An example is given to illustrate how appropriate is collaboration model and to provide evaluation of nucleolus-based allocation. An assumption is made in which three courier companies are given with ten merging regions and three consolidation terminals. By generating random numbers within range from 10 to 50 every service center's delivery amount is ascertained. Moreover, because closedown of service center results in decrease in operation cost and recovery of capital out of fixed assets, such changes are turned into NPV (net present value) using random number generation within range from 50,000 until 100,000. Amount of delivery, allocated terminal, recovery of capital out of fixed assets based on closedown of service center for three parcel service companies are shown in Table 1. The terminal's present remaining processing capacity for every company is determined likewise using random generation as is depicted in Table 2.

The optimal solution for maxmin criterion can be obtained using Excel Solver in Table 3.

Table 1. Input data for companies A, B, and C

Regions	Delivery amount			Terminal allocation			Daily fixed cost ($)		
	A	B	C	A	B	C	A	B	C
1	31	47	39	1	1	2	77	93	91
2	24	19	31	1	2	2	97	79	81
3	48	32	42	1	2	2	89	69	85
4	12	28	29	2	2	2	81	88	63
5	50	44	21	2	1	1	66	56	–
6	49	44	37	1	2	1	64	64	–
7	31	18	39	2	2	2	67	–	96
8	27	20	25	1	1	2	82	–	65
9	22	38	31	2	1	1	–	79	92
10	25	52	44	2	2	1	–	82	54

Table 2. Remaining processing capacity for three companies

Q^1_{A1}	Q^1_{A2}	Q^1_{B1}	Q^1_{B2}	Q^1_{C1}	Q^1_{C2}
147	139	114	164	131	108

Table 3. Solution based on maxmin criterion

	1	2	3	4	5	6	7	8	9	10
x_{Aj}	1	1	0	0	1	0	1	0	0	0
x_{Bj}	0	0	1	0	0	1	0	0	1	0
x_{Cj}	0	0	0	1	0	0	0	1	0	1

Table 4. Solution based on maxsum criterion

	1	2	3	4	5	6	7	8	9	10
x_{Aj}	1	0	0	0	0	0	1	0	0	0
x_{Bj}	0	1	1	0	1	1	0	0	1	0
x_{Cj}	0	0	0	1	0	0	0	1	0	1

Table 5. Shapley value versus nucleolus-based allocation

Subgroup		Subgroup output	Marginal contribution		
			A	B	C
No collaboration	A	0	0		
	B	0		0	
	C	0			0
	Column Average (①)		0	0	0
Collaboration between two companies	A, B	630	630	630	
	B, C	702		702	702
	A, C	662	662		662
	Column Average (②)		646	666	682
Full collaboration	A, B, C (③)	1,411	446	509	456
Shapley Value			468	455	456
Nucleolus			**473**	**433**	**505**

The service centers of company A are chosen to be open in region 1, region 2, region 5 and region 7, while service centers of companies B and C are chosen to be closed in these regions. Company B's service centers are chosen to be kept open in region 3, region 6 and region 9, whereas company C's service centers are selected to be open in region 4 and regions 8 and 10. All companies' objective functions (of A, B and C) show the following values: $Z_A = 468$ dollars, $Z_B = 455$ dollars and $Z_C = 456$ dollars accordingly. The profit in total resulting from strategic alliance by the use of service centers consolidation equals $1,379. On the contrary, optimal solution obtained using the criterion of maxsum is illustrated in Table 4: total profit in it equals $1,405, this figure is bigger that total profit acquired using maxmin criterion. Furthermore, Table 5 gives Shapley value results using criterion of maxsum and the method of allocation by ensuring fair distribution to every company depending on their marginal contribution. Tarashev et al. [15] stated that marginal contribution into a subgroup made by company equals the result of subtraction from subgroup's output of the same group's output without individual participant. Every company's Shapley value then equals this company's marginal contributions' average in all subgroups of different sizes. On the other hand, the solution to linear programming was found with parameter values; C_1, C_2 and C_3 all equaling to zero, C_{12} equals 630,

C_{13} equals 702, C_{23} equals 662 and C_{123} equals 1,411 to figure out for three companies nucleolus-based allocation. The availability of nucleolus-based solution implies that it is able to satisfy the need for three companies' coalition, and is able to produce greater profit in comparison with maxmin criterion.

5. **Conclusions.** The majority of small and medium-sized companies providing parcel service in Korea are in difficult situation because of fierce competition in this market. A new strategy to get a larger share of the market with limited resources in several fields of industry is the coalition. Furthermore, one of the difficulties of implementing collaboration is to decide how to share profits and costs to every company-participant. This study suggested a decision-making model for alliance in the field of parcel services. As a systematic approach of allocation for sharing their profits fairly to each allied company, the nucleolus-based allocation was also suggested. This study is able to enhance collaboration in various areas through the provision of technology for the purpose of coalition, and of fair allocation for the purpose of its sustainability. Moreover, in future research different types of models of collaboration concerned with the overall design of the network in the field of parcel delivery services will be also considered.

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