ICIC Express Letters
Volume **15**, Number **8**, August **2021**
ICIC International ©2021 ISSN 1881-803X
pp. **861–868**

NETWORK DESIGN FOR TIME-PHASED COLLABORATION IN DELIVERY SERVICE

Muzaffar Makhmudov[1], Young Tae Park[2], Young Hwan Sohn[3] and Chang Seong Ko[1,*]

[1]Department of Industrial and Management Engineering
Kyungsung University
309 Suyeong-ro, Namgu, Busan 48434, Korea
muzaffar1@ks.ac.kr; *Corresponding author: csko@ks.ac.kr

[2]Division of International Trade and Distribution
Dong-Eui University
176 Eomgwangno, Busanjin-gu, Busan 48434, Korea
gregory@deu.ac.kr

[3]Department of Logistics System Engineering
Seokyeong University
124 Seogyeong-ro, Seongbuk-gu, Seoul 02173, Korea
yhsohn59@naver.com

Received December 2020; accepted February 2021

Abstract. *Recently, the e-commerce market has been rapidly increasing due to the influence of the Corona Pandemic. Accordingly, many distribution companies are consigning themselves or courier companies to satisfy delivery demand. In particular, cold chain products are delivered in various time zones such as dawn, day and night. This study proposes a network design model for time-phased collaboration in delivery service to overcome the fierce delivery competition. It proposes a mathematical model for network design to maximize the profits of each affiliate, and also proposes solution procedures to find compromised solutions between companies participating in the collaboration strategy. In addition, we intend to apply the cooperative game theoretic approach for fair profit allocation that can increase the sustainability of collaboration. For the proposed methodology, the validity and applicability are verified through example problems.*
Keywords: Network design, Delivery service, Time-phased collaboration, Cooperative game theory, Sustainability

1. **Introduction.** With more people spending more time indoors due to the COVID-19 pandemic, there has been a surge in demand for product delivery services and online shopping. One example is food or grocery delivery. According to a survey conducted by Rakuten Insight, around 44.6 percent of respondents stated that their use of food delivery apps during the COVID-19 pandemic increased. Globally, B2C e-commerce is a fast-growing industry and this online market was worth more than €2.5 billion worldwide in 2018 [1]. Compared to the offline market, B2C e-commerce opens up new obstacles for companies that have to manage additional issues. Some of the obstacles have high complexity of logistics operations, the small quantity with various items (i.e., 'mass customization' issues), the intangibility of electronic transactions, and quick delivery service. The giant delivery companies as Amazon in America, Alibaba in China and Coupang in Korea focus more on speed, cost, and accuracy. However, a fierce competition between small and medium-sized express companies makes them face serious survival challenges in the rapid delivery market. Therefore, such companies are forced to restructure their delivery or service network to overcome the cost and delivery speed problems [2].

DOI: 10.24507/icicel.15.08.861

Collaboration among the small and medium-sized companies can create economies of scale which leads to the reduction of the total operation cost. Moreover, participating companies may realize an increase in net profit under a win-win alliance relationship through efficient cooperation of delivery hubs or consolidation terminals. This study proposes a time-phased collaboration model in delivery service and provides new perspectives to respond to survive in competitive market environments. The key idea behind this model is to operate only one service center shared by various delivery service companies in each merging region and deliver orders according to specified time windows (morning and daytime). A mathematical model is formulated as a multi-objective programming problem for collaboration model to maximize the incremental profit of each participating company. Sustainability can be achieved by fair allocation of profit gained from the collaboration based on cooperative game theory approaches such as Shapley value and Nucleolus allocation.

This paper is organized as follows. Section 2 provides the literature review related to this topic. Section 3 includes the problem statement and time-phased collaboration model concept in delivery service. Section 4 creates a mathematical model for multi-objective programming problem and provides some approaches to solve the problem. Applicability of the proposed collaboration model is demonstrated through a numerical example in Section 5. Lastly, the study report is finalized with conclusions including future study area in Section 6.

2. **Literature Review.** Express and last mile delivery services are broad research topics, especially given that this industry is continuously and rapidly growing. Olsson et al. identified the reasons for rapid growth of last mile logistics as increasing urbanization and population growth, e-commerce development, changing consumer behavior, innovation and growing attention to sustainability [3]. Also, in their study they provide statistics that there were only one to three annual publications on this topic between 2001 and 2012; however, in the following years (2013-2019), the publication rate grew significantly – there were 50 publications in 2018, and approximately 3/4 of articles had been published over the period of 2015-2019. Duin et al. [4] suggested to improve the efficiency of the last mile delivery in B2C markets by including into the system different factors such as route, location, time and consumer behavior. Agatz et al. [5] introduced concept of demand clustering and flexible pricing within the last mile delivery system. Belgin et al. [6] studied vehicle routing problem with simultaneous pickup and delivery. Chung et al. [7-9] proposed various types of collaboration models in the delivery service. Ferdinand et al. developed a decision making model for collaboration in delivery services using genetic algorithm-based approach for multi-objective problem [10]. Shapley value allocation from cooperative game theory was used by Ferdinand and Ko [11] to determine fair and reasonable profit allocation among the alliance of delivery service companies. Optimal profit allocation was also reviewed by Dai and Chen [12], Cachon and Lariviere [13], and Frisk et al. [14].

The contribution of this study is summarized as compared to the previous studies: a new time-phased collaboration model is developed in consideration of additional constraints such as delivery schedule (morning and daytime), and various profit allocation approaches (max-min, max-sum, Shapley value allocation, nucleolus based allocation) are applied to securing fair and proper profit allocation between the delivery companies, who participate in the collaboration system.

3. **Problem Statement.** Express delivery service companies work with various types of products, time schedules and deadlines. Express delivery service in the modern world requires the logistic system to operate 24/7. However, there can be different patterns for delivery depending on the product range and service type. For example, there can be

specific products that are usually delivered or required to be delivered in the morning (meat, vegetables, etc.), or there can be companies that offer "order today, deliver next day" services. Here, companies tend to ship out and deliver the ordered products next morning. In such case, in order to increase their efficiency and achieve the maximum profit, these companies may choose to collaborate between each other by swapping the delivery volumes between each other depending on the time. The objective of this study is to develop a time-phased-collaboration model, where participant companies agree to share their infrastructure and service regions between each other with condition that each company shall operate in specific service regions in the pre-determined time period such as in the morning or during the day.

Figure 1 shows an example with two delivery service companies (A and B), which operate in service region 1 to N, and each company operates throughout the day without differentiating morning and the day. Here, both companies have different rates of load in their logistic systems during the whole day depending on amount of orders, distribution in service regions, capacity restrictions, etc.

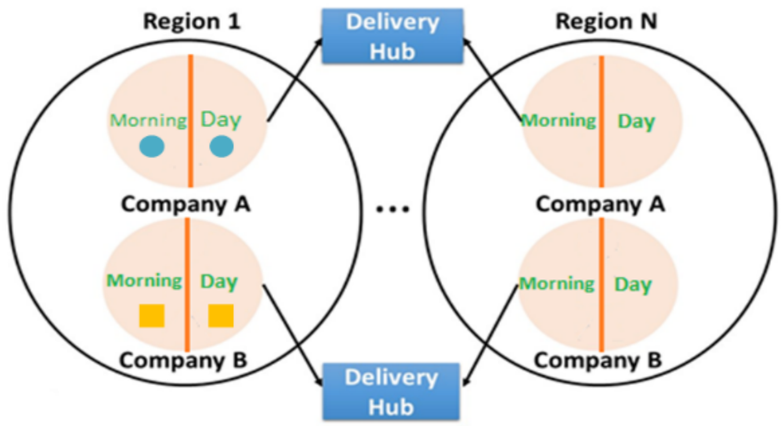

FIGURE 1. Before time phased collaboration model

However, this study proposes collaboration for these companies in Figure 2, where both companies agree to divide their operating schedule in each region and deliver each other's orders within the agreed time period. For example, in region 1, company A operates in the morning and company B during the daytime. The primary goal of this collaboration model is to maximize the incremental profit of each participating company.

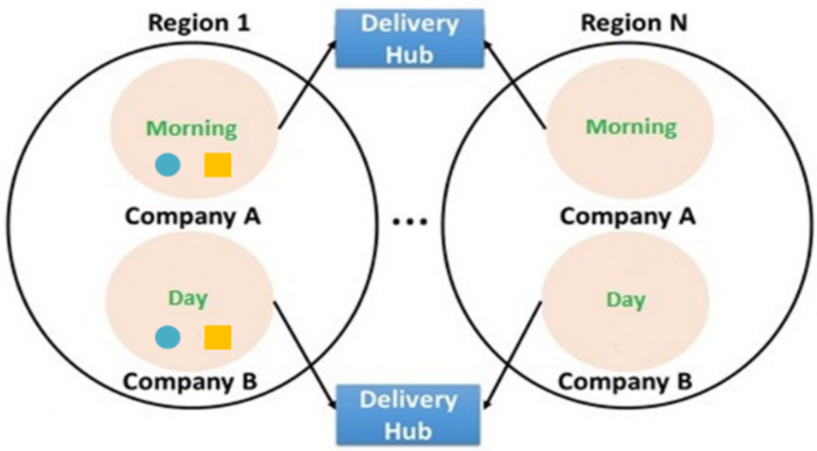

FIGURE 2. After time phased collaboration model

4. **Model Design.** This section forms time-phased-collaboration model, which is basically an extension of Chung et al. [8], but considers different environment, where the delivery companies collaborate using the delivery schedule. The model is built using mathematical formulation of multi-objective programming problem, which is solved using max-min and max-sum criteria.

The following notations are defined to formulate mathematical model

I: set of delivery service companies, $I = \{1, 2, \ldots, m\}$
J: set of merging regions, $J = \{1, 2, \ldots, n\}$
K: set of working periods, $K = \{1, 2, \ldots, p\}$
f_{ijk}: fixed cost accruing from operating the service in region j by company i during working period k, $i \in I$, $j \in J$, $k \in K$
Q^1_{ik}: remaining capacity for processing pick-up amount of the delivery hub of company i during working period k, $p \in T_i$, $i \in I$, $k \in K$
Q^2_{ik}: remaining capacity for processing delivery amount of the delivery hub of company i during working period k, $p \in T_i$, $i \in I$, $k \in K$
d^1_{ijk}: daily delivery amount of the company i in region j during working period k, $i \in I$, $j \in J$, $k \in K$
d^2_{ijk}: daily delivery amount of the company i in region j during working period k, $i \in I$, $j \in J$, $k \in K$
D^1_{jk}: daily pick-up amount within region j during working period k, $j \in J$, $k \in K$, i.e., $D^1_{jk} = \sum_{i \in I} d^1_{ijk}$
D^2_{jk}: daily delivery amount within region j during working period k, $j \in J$, $k \in K$, i.e., $D^2_{jk} = \sum_{i \in I} d^2_{ijk}$
w^1_k: weight for revenue per item during working period k, in delivery hub
w^2_k: weight for handling item during working period k, in delivery hub
r^1_{ijk}: net profit contributed by one unit of pick-up amount of company i within region j during working period k, $i \in I$, $j \in J$, $k \in K$
r^2_{ijk}: net profit contributed by one unit of delivery amount of company i within region j during working period k, $i \in I$, $j \in J$, $k \in K$

Decision variable:

x_{ijk}: binary variables such that $x_{ijk} = 1$, if company i in region j during working period k, is selected, otherwise, $x_{ijk} = 0$, $i \in I$, $j \in J$, $k \in K$

The objective function of this study is to maximize the profit for each company. The problem in this study can be explained through the following mathematical model (P) which consists of m objective functions:

$$
\begin{aligned}
Max Z_1(x) &= \sum_{j \in J} \sum_{k \in K} \left(w^1_k r^1_{1jk} D^1_{jk} + w^1_k r^2_{1jk} D^2_{jk} - f_{1jk} \right) x_{1jk} \\
&\quad + \sum_{j \in J} \sum_{k \in K} \left(f_{1jk} - w^1_k r^1_{1jk} d^1_{1jk} + w^1_k r^2_{1jk} d^2_{1jk} \right) \\
&\ \ \vdots \\
Max Z_m(x) &= \sum_{j \in J} \sum_{k \in K} \left(w^1_k r^1_{mjk} D^1_{jk} + w^1_k r^2_{mjk} D^2_{jk} - f_{mjk} \right) x_{mjk} \\
&\quad + \sum_{j \in J} \sum_{k \in K} \left(f_{mjk} - w^1_k r^1_{mjk} d^1_{mjk} + w^1_k r^2_{mjk} d^2_{mjk} \right)
\end{aligned} \tag{1}
$$

$$
\text{s.t.} \quad \sum_{i \in I} x_{ijk} = 1, \quad j \in J,\ k \in K \tag{2}
$$

$$\sum_{j \in J} w_k^2 \left(D_{jk}^1 x_{ijk} - d_{ijk}^1 \right) \leq Q_{ik}^1, \quad i \in I,\ k \in K \tag{3}$$

$$\sum_{j \in J} w_k^2 \left(D_{jk}^2 x_{ijk} - d_{ijk}^2 \right) \leq Q_{ik}^2, \quad i \in I,\ k \in K \tag{4}$$

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

The objective function (1) represents the net profit increase of each company. Constraint (2) provides that only one service center is opened in each region. Constraints (3) and (4) mean that the daily pick-up and delivery amounts should satisfy the processing capacity of each delivery hub considering the weight for handling item during each working period. Constraint (5) includes decisions variables as the binary number.

5. **Numerical Example.** This section presents a numerical example of use of time-phased-collaboration model and withdraws the results based on max-min, max-sum and cooperative game theory solution methods. We assume that there are 3 express delivery companies (A, B, C) operating in 10 merging regions. They operate in the same delivery hub and their delivery schedule is divided into two time periods, that is, morning and daytime.

The data for delivery amount, terminal capacity, weight on capacity during each time period (morning and daytime) and revenue are shown in Tables 1, 2 and 3.

First, a solution based on min-sum criterion in Table 4 shows that in the morning delivery period, companies A and B took over the deliveries in 3 regions whereas the company C in 4 regions. On the other hand, for the daytime delivery period, company A dominates in 5 regions, company B in 4 regions and company C in only 1 region.

Table 1. Data for delivery amount

Merging region	Total for day			Morning			Daytime		
	A	B	C	A	B	C	A	B	C
1	224	171	120	133	113	60	91	58	60
2	95	144	160	61	100	108	34	44	52
3	118	87	179	41	43	79	77	44	100
4	88	63	102	63	33	72	25	30	30
5	175	177	124	92	87	58	83	90	66
6	138	166	122	102	137	77	36	29	45
7	158	117	210	113	68	118	45	49	92
8	170	106	113	139	86	34	31	20	79
9	134	127	130	53	77	60	81	50	70
10	76	114	207	33	49	114	43	65	93

Table 2. Remaining capacity of terminal

Terminal	Capacity
1	1,256
2	1,330
3	1,315

Table 3. Weight and revenue

	Capacity	
	Morning	Daytime
Weight	1.5	1
Revenue	3	2

Table 4. Optimal solution for the max-sum criterion

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

The maximum profit achievable using this method by all companies is \$3,877.20, which is distributed among companies as follows: $Z_A = \$1{,}243.70$, $Z_B = \$1{,}328.90$, $Z_C = \$1{,}304.60$.

Second, a solution based on max-min criterion in Table 5 shows that in the morning delivery, company C took over the delivery in 5 regions (1, 3, 4, 5, 6), while company A in 3 regions (2, 9, 10) and B in 2 regions (7, 8). At the same time, only companies A and B were involved in the daytime delivery (A in 5 regions and B in 5 regions). The maximum profit achievable using this method by all companies is \$3,779.70, which is distributed among companies as follows: $Z_A = \$1{,}244.90$, $Z_B = \$1{,}271.90$; $Z_C = \$1{,}262.90$. Compared to max-sum method, profit of company A remains in similar level, but companies B and C lose \$57.00 and \$41.70, respectively.

Table 5. Optimal solution for the max-min criterion

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

Third, profit allocation using Shapley value between the companies is calculated, results of which are \$1,275.66, \$1,249.43, and \$1,352.17, respectively. Here, company C receives the highest allocation in profit. Fourth, Nucleolus-based profit allocation gives us the following distributions for companies A, B and C: \$1,258.90, \$1,206.44 and \$1,411.92. Company C is better off with the highest allocation of profit.

Finally, we compare the profits of each company under collaboration, derived using max-min, max-sum, Shapley value and nucleolus-based allocation methods as shown in Table

Table 6. The comparison results of max-min, max-sum, Shapley value and nucleolus-based allocation

	Company A	**Company B**	**Company C**	**Total**
Max-sum	\$1,243.70	\$1,328.90	\$1,304.60	\$3,877.20
Max-min	\$1,244.90	\$1,271.90	\$1,262.90	\$3,779.70
Shapley value allocation	\$1,275.66	\$1,249.43	\$1,352.17	\$3,877.26
Nucleolus	\$1,258.90	\$1,206.44	\$1,411.92	\$3,877.26

6. Applying the max-sum criterion improves the total benefit by coalition compared to the max-min criterion, but it may provide imbalance among the profit of each participating company. The Shapley value and Nucleolus are widely recognized and used as a fair way of distributing the gain in a coalition. Shapley value allocation emphasizes that the distribution of profit allocation is fair to each company based on its marginal contribution. The Nucleolus is a solution concept that allows coalitions' largest unhappiness as minimum as possible or, equally, minimizes the worst inequity.

6. **Conclusion.** E-commerce's growth is much accelerated as of effect of COVID-19. According to Edge by Ascential (USA), COVID-19 pandemic has almost certainly had a lasting impact on the retail sector, reshaping consumer shopping habits, and the priorities for retailers and brands. In this study, we built time-phased collaboration model in delivery service, where participant companies form an alliance and deliver products in their respective service areas using the existing network of each other but in pre-agreed time schedule: morning or daytime. Mathematical model in form of multi-objective programming problem was formulated and used for finding maximum profit for participants of collaboration system. Furthermore, we considered the most popular profit allocation solution concepts: Shapley value and Nucleolus. Finally, the numerical example demonstrated the applicability of the proposed time-phased collaboration model. We believe that there are yet many topics that can be covered and we recommend following areas for further research: extension of existing collaboration models by adding other constraints from the real world such as customer satisfaction, various operational risks that may affect the work of collaboration system, etc. Also, one can propose development of coordinating policies for such systems, and check the reliability and accessibility of each participant.

Acknowledgment. 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 (NRF-2019S1A5A2A03052217).

REFERENCES

[1] S. Y. Ko, P. S. Ratna and M. M. Makhmudov, Collaboration model for service clustering in last-mile delivery, *Sustainability*, vol.12, DOI: 10.3390/su12145844, 2020.

[2] S. Y. Ko, S. W. Cho and C. Lee, Pricing and collaboration in last mile delivery services, *Sustainability*, vol.10, 2018.

[3] J. Olsson, D. Hellström and H. Pålsson, Framework of last mile logistics research: A systematic review of the literature, *Sustainability*, vol.11, DOI: 10.3390/su11247131, 2019.

[4] J. H. R. Duin, W. Goffau and B. Wiegmans, Improving home delivery efficiency by using principles of address intelligence for B2C deliveries, *Transportation Research Procedia*, vol.12, pp.14-25, 2016.

[5] N. A. H. Agatz, M. Fleischmann and J. A. E. E. Nunen, E-fulfillment and multi-channel distribution – A review, *European Journal of Operational Research*, vol.187, pp.339-356, 2008.

[6] O. Belgin, I. Karaoglan and F. Altiparmak, Two-echelon vehicle routing problem with simultaneous pickup and delivery: Mathematical model and heuristic approach, *Computers & Industrial Engineering*, vol.115, pp.1-16, 2018.

[7] K. H. Chung, J. J. Rho and C. S. Ko, A strategic alliance model with regional monopoly of service centres in express courier services, *International Journal of Services and Operations Management*, vol.5, pp.774-786, 2009.

[8] K. H. Chung, S. Y. Ko and C. U. Lee, Sustainable collaboration model with monopoly of service centers in express delivery services based on Shapley value allocation, *The International Journal of Industrial Engineering: Theory, Applications and Practice*, vol.23, pp.166-173, 2016.

[9] K. H. Chung, S. Y. Ko and C. S. Ko, A cooperative game theoretic network design for collaborative operation of service centers and consolidation terminals in delivery services, *The International Journal of Industrial Engineering: Theory, Applications and Practice*, vol.25, pp.18-28, 2018.

[10] F. N. Ferdinand, K. H. Chung, H. J. Ko and C. S. Ko, Genetic algorithm-based approach to multi-objective decision making model for strategic alliances in express courier services, *ICIC Express Letters*, vol.6, no.4, pp.929-934, 2012.

[11] F. N. Ferdinand and C. S. Ko, Coevolutionary algorithm based approach to the collaborative network design in express delivery services using coalitional game theory, *ICIC Express Letters*, vol.10, no.11, pp.2711-2717, 2016.
[12] B. Dai and H. Chen, Profit allocation mechanisms for carrier collaboration in pickup and delivery service, *Computers and Industrial Engineering*, vol.62, pp.633-643, 2012.
[13] G. P. Cachon and M. A. Lariviere, Capacity choice and allocation: Strategic behavior and supply chain performance, *Management Science*, vol.45, pp.1091-1108, 1999.
[14] M. Frisk, M. G. Lundgren and K. Jomsten, Cost allocation in collaborative forest transportation, *European Journal of Operational Research*, vol.205, pp.448-458, 2010.