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TEMPORAL COLLABORATION IN DELIVERY SERVICE CONSIDERING DEFECTIVE RATE

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Abstract. *In recent years, the COVID-19 problem has accelerated the growth of e-commerce to new enterprises, product categories, and customer segments. The e-commerce industry's rapid expansion has resulted in an increase in parcel quantities. As a result of this growth, delivery companies are becoming more competitive, capturing market growth. This study proposes a temporal-collaboration model to overcome the intense competition. Moreover, there are cases of unforeseen accidents during the delivery processes such as loss, physical damage, or delay of delivery due to retainment of shipment in customs, which in turn may quickly reflect the delivery company reputation and reliability of its services. In order to maximize profit for each allied company, a mathematical model for network design is developed. Based on a co-operative game theory, a fair allocation method of coalition profit is also proposed. An example problem is used to demonstrate the applicability of the collaboration model.*
Keywords: E-commerce, Delivery service, Temporal-collaboration, Network design, Defective rate, Profit allocation

1. Introduction.

The COVID-19 pandemic has changed the modern world with its enormous health, social and economic effects; however at the same time, it brought critical changes such as acceleration of technology development, digitalization and automation. People's lifestyle and spending habits changed forever, which includes increase of use of online shopping platforms, contactless modes of delivery, dining, etc. Retailers also keep modifying their business models and investment plans to adapt their businesses for growing e-commerce.

Market players understand well that success of e-commerce is greatly dependent on the last mile, where the consumers mainly look at factors such as accessibility, affordability, and convenience. According to Euromonitor [1], an independent global market research company, South Korea has the highest online retail penetration in the world and Korean e-commerce market grew at an unprecedented rate of 26% in the first year of pandemic. Growth rate in online shopping in the country in 2021 is expected to reach 10.70% (Figure 1).

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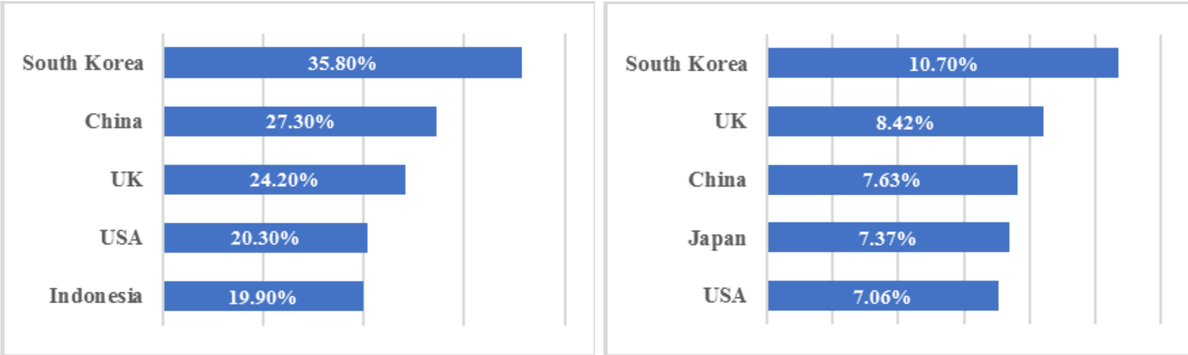

FIGURE 1. Countries with the highest percentage of online purchases (left) and estimated growth rate in online shopping for 2021 (right) [1]

In Korea, it is obvious that large companies such as Coupang dominate the delivery industry given that they have all financial, infrastructural and R&D advantage over the smaller companies. However, there are many small and medium companies that offer innovative and more convenient ways of delivery that makes consumers choose them over large brand name companies. At today's digital era, it is important for the companies of various sizes not to underestimate the competition that may emerge at any time. In current cross-border e-commerce environment, i.e., when the business activities are not limited by the boundary of one country, the competition is considered to be even tighter [2]. To be more efficient in competition, the smaller companies may choose cooperation and collaboration between each other to create a market presence and compete against large and established companies. There may be different ways of collaboration in the market including sharing common infrastructure, segmenting the market by type of delivery products and splitting the service regions, as well as pre-agreeing service schedule between each other. Collaboration may be long term or temporal (e.g., for specific period such as pandemic or post pandemic).

This study proposes temporal collaboration model in delivery service considering quality level, where the quality level includes the factor of defect in the delivery. In this model, the cooperating delivery companies have common delivery hub and agree among themselves to operate within the merging regions in specified time windows (morning, daytime and night). A mathematical model for such collaboration is formulated as a multi-objective programming problem to maximize the incremental profit of each participating company, where the model incorporates also defect rates in the delivery. Fairness and sustainability of profit allocation between the participants are checked using cooperative game theory approaches such as nucleolus and Shapley value.

This study is organized in the following way: Section 2 describes the previous literature; Section 3 provides the problem statement; Section 4 creates mathematical model for multi-objective programming problem and provides the solution concepts to address such problem; numerical example is given in Section 5 and applicability of the proposed collaboration model is discussed; lastly, Section 6 defines the conclusions derived from the research and illustrates potential directions for future study.

2. **Literature Review.** Parcel delivery and last mile delivery were broad topics for research in past 20-25 years, owing to fast growth of e-commerce (in 1979, Michael Aldrich invented the first teleshopping system; WWW server and browser were created in 1990; Amazon and E-bay were established in 1995), development and rise of giant logistic companies such as Amazon. Optimization of parcel delivery and last mile delivery process is essential for all delivery companies. Gevaers et al. [3] stated that the last mile delivery services are expensive and the most inefficient part of logistic supply chain. Olsson

et al. [4] identified the reasons for rapid growth of last mile logistics as increasing urbanization and population growth, changing consumer behavior, innovation and growing attention to sustainability. Efficiency of last mile delivery depends on multiple factors such as consumer density (Gevaers et al. [3]), congestion (Muñuzuri et al. [5]), and fragmentation of deliveries (Leung et al. [6]). Optimization of last mile delivery system was addressed in work of Agatz et al. [7], where demand clustering and flexible pricing were proposed; Belgin et al. [8] studied simultaneous delivery service and pickup as the one kind of vehicle routing problem.

Concept of collaboration was introduced with advancing of competition in the marketplace over time and need of smaller companies to protect their market share against large corporations. Different kinds of collaboration models have been introduced by Chung et al. [9-11] in the delivery service. Ko et al. constructed a collaborating model by considering the market density and price by developing a pricing and collaboration model [12,13]. By utilizing genetic algorithm-based approach for multi-objective problem, Ferdinand et al. [14] evolved decision-making model for collaboration in delivery services. With aim of indicating fair and appropriate profit allocation between the alliance of logistic companies in express delivery service, Shapley value allocation from cooperative game theory has been utilized by Ferdinand and Ko [15] in their study. Several researchers such as Dai and Chen [16] Cachon and Lariviere [17], and Frisk et al. [18] have examined the best profit allocation.

Consistency of business collaboration and cases of temporal collaboration is observed by Sun et al. [19]. According to this research, business collaboration is time critical and advantage of temporal collaboration is that participant companies can restrict start and end of services in the participating processes, easier to control and possible to adjust or improve the next collaboration based on results of temporal collaboration. Also, companies always emphasize the customer satisfaction and quality as a means to achieve success. One of the methods to quantify the quality level is to apply defective rates in the optimization system. Franca et al. [20] studied forward logistic network that uses six sigma concept to evaluate the quality of raw materials supplied – the study proposed multi-objective model, where objectives of the problem are to maximize the profit of supply chain and minimize the total number of defective raw material parts. Inspired by previous research works, this study aims to build temporal collaboration model in delivery service in consideration of new constraints such as quality level and delivery schedule, and use profit allocation approaches such as max-min, max-sum, Shapley value and nucleolus-based allocation to ensure a fair and equitable profit distribution among the delivery companies participating in the collaboration system.

3. **Problem Statement.** In modern world, delivery industry is becoming more popular because of its convenience, speed of delivery and low cost. We live in the era, where the customers may purchase a product in the evening and receive the product the next morning. It may look easy in the first sight, but a lot of procedures and complex processes are involved, where the delivery system works 24 hours. In order to achieve maximum efficiency, the n companies may decide to enter into collaboration system, where they agree to split the work while delivering products in pre-agreed time schedule. For example, company A may deliver products that require urgent handling at night in order to make the product available for the last mile consumer in the morning. Or company B may deliver products that do not require urgency in the daytime. The same way, company C may operate only in mornings (Figure 2). Such collaboration may optimize the use of resources and decrease cost.

The primary objective of this study is to create a temporal collaboration model, where the cooperating companies decide to work together in the merging regions by sharing each other's infrastructure and that each company follows the pre-agreed schedule for

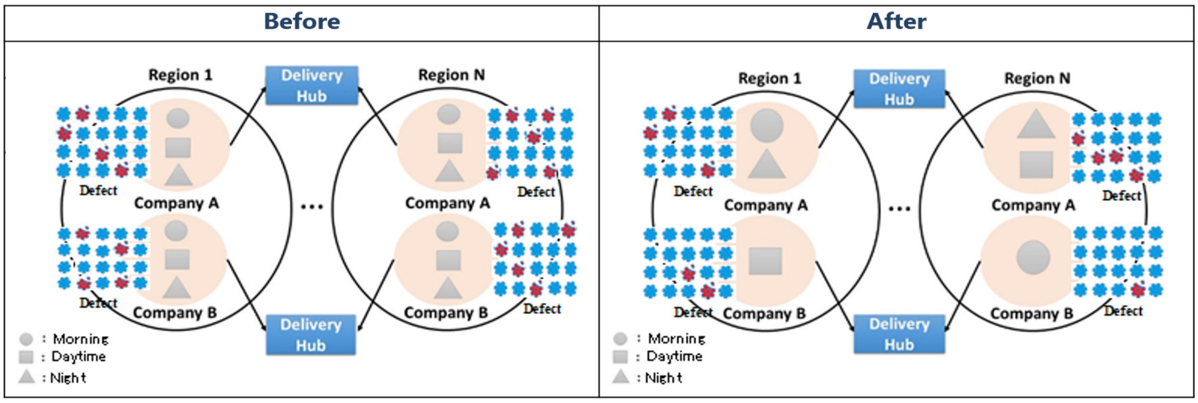

FIGURE 2. Before and after temporal collaboration

operation: morning, daytime and night. It is obvious that each company will have different levels of involvement in the system depending on their size, number of orders, number of service regions and resources, but the key aim here is to maximize the profit of the system and incremental profit of each participating company regardless of these factors. In order to consider realistic situations that not all deliveries are performed ideally and there can be defective cases (damage to product, delay, lost, etc.), we incorporate defective rate for each company considering the experience of the company with such defect.

4. **Model Design.** In this section, we build temporal collaboration model. The model is an extension of the Makhmudov et al. [21], where new parameters such as temporal schedule and defective rates are incorporated. The model is formulated mathematically as multi-objective programming problem and solution is obtained using max-min and max-sum criterions. 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.

Notations for collaboration model:

I: set of delivery service companies, $I = \{1, 2, \ldots, m\}$

J: set of merging regions, $J = \{1, 2, \ldots, n\}$

T: set of working periods, $T = \{1, 2, \ldots, t\}$

f_{ijt}: fixed cost accruing from operating the service in region j by company i during working period t, $i \in I$, $j \in J$, $t \in T$

Q^1_{it}: remaining capacity for processing pick-up amount of the terminal p of company i, $p \in T_i$, $i \in I$

Q^2_{it}: remaining capacity for processing delivery amount of the terminal p of company i, $p \in T_i$, $i \in I$

d^1_{ijt}: daily pick-up amount of the company i in region j during working period t, $i \in I$, $j \in J$, $t \in T$

d^2_{ijt}: daily delivery amount of the company i in region j during working period t, $i \in I$, $j \in J$, $t \in T$

D^1_{ijt}: daily pick-up amount of company within region j during working period t, $j \in J$, $t \in T$, i.e., $D^1_{ijt} = \begin{cases} d^1_{ijt} + \frac{\sum_{i\in I} d^1_{ijt}(1-x_{ijt})}{\sum_{i\in I} x_{ijt}} & \text{if } x_{ijt} = 1 \\ 0 & \text{if } x_{ijt} = 0 \end{cases}$

D^2_{ijt}: daily delivery amount of company within region j during working period t, $j \in J$, $t \in T$, i.e., $D^2_{ijt} = \begin{cases} d^2_{ijt} + \frac{\sum_{i\in I} d^2_{ijt}(1-x_{ijt})}{\sum_{i\in I} x_{ijt}} & \text{if } x_{ijt} = 1 \\ 0 & \text{if } x_{ijt} = 0 \end{cases}$

w^1_t: weight for revenue per item during working period t, in delivery hub

w_t^2: weight for handling item during working period t, in delivery hub

r_{ijt}^1: net profit contributed by one unit of pick-up amount of company i within region j during working period t, $i \in I$, $j \in J$, $t \in T$

r_{ijt}^2: net profit contributed by one unit of pick-up amount of company i within region j during working period t, $i \in I$, $j \in J$, $t \in T$

p_{ijt}^1: expected defective rate for one unit of pick-up amount of company i within region j during working period t, $i \in I$, $j \in J$, $t \in T$

p_{ijt}^2: expected defective rate for one unit of delivery amount of company i within region j during working period t, $i \in I$, $j \in J$, $t \in T$

s_{ijt}: Average penalty for unit defective of company i within region j during working period t, $i \in I$, $j \in J$, $t \in T$

Decision variable:

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

Model formulation:

$$\begin{aligned}
\text{Max } \mathrm{Z}_1(x) = & \sum_{j \in J} \sum_{t \in T} \left(r_{1jt}^1 D_{1jt}^1 + r_{1jt}^2 D_{1jt}^2 - r_{1jt}\right) x_{1jt} \\
& + \sum_{\substack{j \in J \\ i \neq 1}} \sum_{j \in J} \sum_{t \in T} s_{1jt} \left\{ \left(p_{1jt}^1 - p_{ijt}^1\right) d_{1jt}^1 + \left(p_{1jt}^2 - p_{ijt}^2\right) d_{1jt}^2 \right\} x_{ijt} \\
& + \sum_{j \in J} \sum_{t \in T} \left(f_{1jt} - r_{1jt}^1 d_{1jt}^1 - r_{1jt}^2 d_{1jt}^2\right) \\
\text{Max } \mathrm{Z}_m(x) = & \sum_{j \in J} \sum_{t \in T} \left(r_{mjt}^1 D_{mjt}^1 + r_{mjt}^2 D_{mjt}^2 - r_{mjt}\right) x_{mjt} \\
& + \sum_{\substack{j \in J \\ i \neq m}} \sum_{j \in J} \sum_{t \in T} s_{mjt} \left\{ \left(p_{mjt}^1 - p_{ijt}^1\right) d_{mjt}^1 + \left(p_{mjt}^2 - p_{ijt}^2\right) d_{mjt}^2 \right\} x_{ijt} \\
& + \sum_{j \in J} \sum_{t \in T} \left(f_{mjt} - r_{mjt}^1 d_{mjt}^1 - r_{mjt}^2 d_{mjt}^2\right)
\end{aligned} \quad (1)$$

$$\text{s.t. } \sum_{i \in I} x_{ijt} \geq 1 \quad j \in J,\ t \in T \quad (2)$$

$$D_{ijt}^1 = \left[d_{ijt}^1 + \frac{\sum_{i \in I} d_{ijt}^1 (1 - x_{ijt})}{\sum_{i \in I} x_{ijt}} \right] x_{ijt} \quad i \in I,\ j \in J,\ t \in T \quad (3)$$

$$D_{ijt}^2 = \left[d_{ijt}^2 + \frac{\sum_{i \in I} d_{ijt}^2 (1 - x_{ijt})}{\sum_{i \in I} x_{ijt}} \right] x_{ijt} \quad i \in I,\ j \in J,\ t \in T \quad (4)$$

$$\sum_{j \in J} \sum_{t \in T} w_t \left(D_{ijt}^1 x_{ijt} - d_{ijt}^1\right) \leq Q_i^1 \quad i \in I \quad (5)$$

$$\sum_{j \in J} \sum_{t \in T} w_t \left(D_{ijt}^2 x_{ijt} - d_{ijt}^2\right) \leq Q_i^2 \quad i \in I \quad (6)$$

$$x_{ijt} \in \{0, 1\} \quad i \in I,\ j \in J,\ t \in T \quad (7)$$

The objective function (1) represents the net profit increase of each company. Constraint (2) provides at least one service center opened in each region. Constraints (3) and (4) mean that the sum of the pick-up and delivery amount of closed service centers is divided by the number of open service centers in the region and is assigned equality to each open service center. Constraints (5) and (6) show the information on weight multiplication by summing the amount of pick-up and delivery amounts and by considering the processing capacity of each delivery hub. Constraint (7) includes decisions variables as the binary number.

5. **Numerical Example.** This section contains a numerical example of temporal-collaboration model with quality level, as well as findings obtained using approaches such as max-sum, max-min and cooperative game theory. We assume that in three merging regions, there are three express delivery companies (A, B, and C). The delivery companies share a distribution hub, and their delivery schedule is split into three parts: morning, daytime and night. The section involves delivery defect rates as well as the penalty rate for defective cases to add realistic parameters. Also, there is a penalty charge for the defective rate of $75 in the morning, $25 for daytime and $50 at night. Table 1 shows the data for delivery amount by each company in service regions 1-3 during different timeframes (morning, daytime and night). Defective rates for each company by regions and by time are illustrated in Table 2. Tables 3 and 4 provide capacity of terminals and weight for capacity and revenue by timeframe.

TABLE 1. Data for delivery amount

Merging	Morning			Daytime			Night		
region	A	B	C	A	B	C	A	B	C
1	124	100	107	78	45	60	30	25	15
2	109	117	144	45	58	68	22	30	20
3	131	104	100	78	60	75	38	20	17

TABLE 2. Data for defective rate

Merging	Morning			Daytime			Night		
region	A	B	C	A	B	C	A	B	C
1	0.002	0.003	0.001	0.006	0.005	0.004	0.008	0.01	0.009
2	0.002	0.003	0.001	0.006	0.005	0.004	0.008	0.01	0.009
3	0.002	0.003	0.00	0.006	0.005	0.004	0.008	0.01	0.009

TABLE 3. Capacity of terminals/hubs

Terminal	Capacity
1	1,410
2	1,619
3	1,791

TABLE 4. Weight for capacity and revenue

	Time-period (t)		
	Morning	Daytime	Night
Weight	1	1.5	2
Revenue	2	3	5

5.1. **Solution based on max-min criterion.** The supplied Table 5 represents optimal solution based on max-min criterion. Overall, three various companies handle their deliveries to three different regions by sharing tasks with each other. For instance, company A is responsible for delivering goods to the region 3 in the morning while company B is in charge of handling products to region 1 and company C for region 2. On the flip side, company A heads up for handling goods to the regions 2, 3 in the daytime and at the same time company C is going to deliver to region 1. With respect to the nigh time delivery, company B dominates in regions 2, 3 and company C in region 1. To conclude, the

TABLE 5. Optimal solution for the max-min criterion

	Morning			Daytime			Night		
Region	1	2	3	1	2	3	1	2	3
x_{At}	0	0	1	0	1	1	0	0	0
x_{Bt}	1	0	0	0	0	0	0	1	1
x_{Ct}	0	1	0	1	0	0	1	0	0

maximum profit achievable by companies using max-min calculation method is \$1,771.80, allocated as follows Z_A = \$565.30; Z_B = \$583.50; Z_C = \$623.00.

5.2. **Solution based on max-sum criterion.** Table 6 depicts optimal solution based on max-sum criterion. In general, the table outlines three companies delivering products to three different regions according to their schedules. It can be clearly seen that company B handles products to the region 1 while company C to the regions 2 and 3 in the morning. Furthermore, in Region 1, only Company A is involved in the daytime distribution. Besides that, company A decided to handle deliveries to the regions 1, 3 whilst company B to the region 2 in the night time. In sum, the maximum profit achievable by companies using max-sum where quality level including the factor of the delivery defect calculation method is \$1,855.73, allocated as follows Z_A = \$1,290.40; Z_B = \$203.25; Z_C = \$362.08. As it is observed that the total profit of company A is two-times as large as company A in max-min whereas companies B and C's maximum profit is double less than B and C in max-min.

TABLE 6. Optimal solution for the max-sum criterion

	Morning			Daytime			Night		
Region	1	2	3	1	2	3	1	2	3
x_{At}	0	0	0	1	1	1	1	0	1
x_{Bt}	1	0	0	0	0	0	0	1	0
x_{Ct}	0	1	1	0	0	0	0	0	0

5.3. **Shapley value allocation.** Profit allocation using Shapley value between the companies is calculated, results of which are \$619.00, \$628.00, and \$608.00, respectively. Here, company B receives the highest allocation in profit.

5.4. **Nucleolus-based allocation.** Nucleolus-based profit allocation gives us the following distribution for companies A, B and C: \$607.00, \$624.00 and \$624.00. Companies B and C are equal profits and 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 in Table 7.

The nucleolus allocation methodology appears that profits between the companies A, B and C is distributed in a fair and similar basis. Furthermore, when compared to the

TABLE 7. Result comparison of max-min, max-sum, Shapley value and nucleolus-based allocation

	Company A	Company B	Company C	Total
Max-sum	\$1,290.40	\$203.25	\$362.08	\$1,855.73
Max-min	\$565.30	\$583.50	\$623.00	\$1,771.80
Shapley value allocation	\$619.00	\$628.00	\$608.00	\$1,855.00
Nucleolus	\$607.00	\$624.00	\$624.00	\$1,855.00

max-min criterion, we can see that using the max-sum criterion improves the total profit in the collaborative system.

6. **Conclusions.** The COVID-19 problem has pushed expansion of e-commerce to new firms, customers, and product categories. It has given customers access to a wide range of products from the comfort and safety of their own homes, and it has allowed businesses to continue operating despite contact limits and other prohibitions.

This study provides a temporal collaboration model in delivery service that takes consideration of defective rate in delivery. In this model, the collaborating delivery companies form an alliance and deliver products in their respective service areas, using each other's existing network, but on a pre-agreed schedule (morning, daytime and night). A mathematical model for such collaboration is formulated as a multi-objective programming problem to maximize each participating company's incremental profit, with the model considering the effect defect rates in delivery.

From our point of view, it is yet possible to cover a number of topics and we suggest that research can be done in the following fields: given collaboration models can be extended by means of adding some other real-world constraints (e.g., different operational risks that can influence the collaboration system's work, and customer satisfaction).

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