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DYNAMIC DESIGN FOR COLLABORATIVE DELIVERY SERVICES

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Abstract. *Over the last years, e-commerce has been surging rapidly due to rapid spread of the coronavirus pandemic (COVID-19). Customers' demands and requirements are increasing as the importance of e-commerce grows globally, and finding optimal solutions to fully satisfy their wants is regarded an urgent issue of the global world. As a result of increased global output and the development of new technologies, the demand for delivery services has grown at an exponential rate. This study involves a dynamic design collaboration model in delivery service to overcome the intense competition under such market conditions. Also, a strategic decision-making model is designed as collaboration of delivery companies for the number of equal periods, during which the participant companies are forced to have their facilities/service open or closed (while their participation in collaboration system is not discontinued) in order to increase the efficiency and profitability of the collaboration system. A mathematical model is developed as multi-objective programming problem with profit maximization of the overall collaboration and incremental profit of each participating company. A numerical example is developed to demonstrate the model's applicability.*
Keywords: e-commerce, Delivery service, Dynamic collaboration, Network design

1. **Introduction.** COVID-19 has had an impact on people's daily lives and has affected the global economy. This pandemic had an impact on people's social lives all around the world; 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 are also changing their business structures and investment plans to respond to the rising e-commerce market.

The lockdowns set up across many countries globally due to the pandemic have significantly accelerated the adoption of retail e-commerce and growth of worldwide sales. The latter grew 46% between 2019 and 2021 estimates (Figure 1). According to the eMarketer research data, the annual growth of retail e-commerce sales in top 10 countries was from 2% to 22% in 2021 (Figure 2). China and India stood out with staggering 21% and 22% sales growth respectively whereas the sales in South Korea grew 9% from $110.60 billion to $120.56 billion making up 2.5% of total worldwide retail e-commerce.

Everyone had to change their shopping habits after the COVID-19 outbreak and demand for the delivery has boomed with the high emphasis on the speed and quality of the

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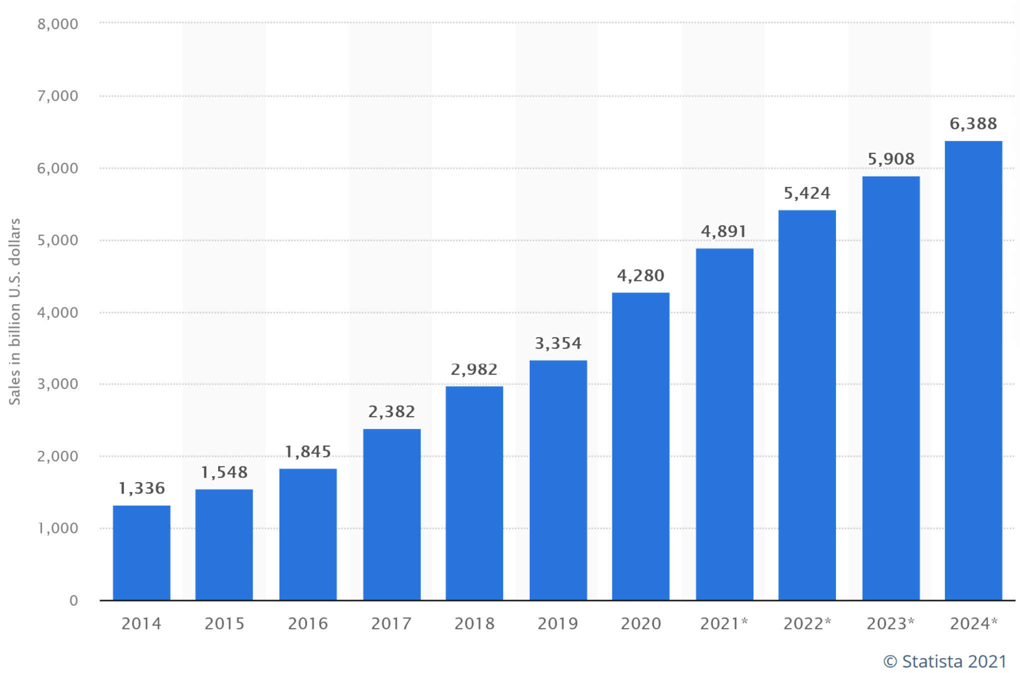

FIGURE 1. Retail e-commerce sales worldwide from 2014 to 2024 (in billion U.S. dollars)

Top 10 Countries, Ranked by Retail Ecommerce Sales, 2020 & 2021
billions and % change

	2020	2021	% change
1. China*	$2,296.95	$2,779.31	21.0%
2. US	$794.50	$843.15	6.1%
3. UK	$180.39	$169.02	-6.3%
4. Japan	$141.26	$144.08	2.0%
5. South Korea	$110.60	$120.56	9.0%
6. Germany	$96.86	$101.51	4.8%
7. France	$73.80	$80.00	8.4%
8. India	$55.35	$67.53	22.0%
9. Canada	$39.22	$44.12	12.5%
10. Spain	$36.40	$37.12	2.0%

*Note: includes products or services ordered using the internet, regardless of the method of payment or fulfillment; excludes travel and event tickets, payments such as bill pay, taxes or money transfers, food services and drinking place sales, gambling and other vice goods sales; *excludes Hong Kong*
Source: eMarketer, Dec 2020

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FIGURE 2. Top 10 countries, ranked by retail e-commerce sales (in billions), 2020 & 2021 Source: eMarket, 2021 [1]

products being delivered. While the number of small delivery companies has increased, competition from huge global companies such as Coupang, Amazon, and Alibaba has resulted in them losing market share. Such large companies with financial, infrastructural, and R&D investment power can move fast in a dynamic business environment by continuously optimizing their logistic systems and increasing their order delivery activities. On the other hand, small and medium-sized businesses struggle to respond quickly enough to market changes and may face bankruptcy. To stay competitive in the delivery business in the COVID-19 environment requires to create a variety of collaborative strategies among small and medium-sized businesses. They can establish mutual partnerships across the value chain to minimize service costs, improve service quality and satisfy customers.

The goal of this study is to incorporate a dynamic design for collaborative delivery services, in which delivery companies collaborate by sharing delivery hubs, facilities, and servicing pre-agreed merging delivery regions. The collaboration is scheduled for an equal number of periods, where the collaboration system's effectiveness and profitability are expected to be at their maximum during coalition period. Sometimes this may require the coalition to close the inefficient facilities/service of the collaboration system for certain period to achieve most desirable result. A multi-objective programming problem is used to formulate a mathematical model for collaboration in order to maximize the incremental profit of each participating company.

2. **Literature Review.** Pandemic caused a strong acceleration in development of e-commerce compared to pre-crisis period [2]. The pandemic compelled consumers to turn to Internet and created a habit to purchase products and services online in their daily routine [3]. There is expectation that digitalization of the marketplace that took place during COVID-19 and consumer habits and behavior acquired will bring significant changes for product and service consumption among people even after the crisis times [2,4]. The pandemic crisis has made a significant impact on the logistics systems globally [5].

Chung et al. [6] proposed a network design with a strategic alliance structure for express delivery companies. There were several extensions for this work (Chung et al. [7-9]). Ferdinand et al. [10] incorporated a genetic algorithm to determine efficient operations in terminals under the strategic alliance and concept for decision-making on decreasing or increasing the number of service centers. Makhmudov et al. [11] proposed time-phased collaboration model, which considers collaboration in pre-agreed timeframes: morning and daytime. According to [12], transportation industry is being transformed by new business models such as collaborative transportation planning and resource sharing in order to reduce costs, and improve operational efficiency, which are the key requirements to stay competitive in the market. Here, the authors presented a survey of collaborative logistics research, which incorporated separable and non-separable costs of delivery companies in coalition, profit and cost sharing mechanism, Shapley method as well as equal sharing of the profit. The last topic was also analyzed by [13], where the authors attempted to find a sustainable allocation of profit by minimizing the difference between relative savings of any two logistic carriers. [14,15] used the Shapley value method from cooperative game theory to fairly allocate the profit margins between carriers involved in collaboration.

3. **Problem Statement.** Given rapid changes in the delivery service sector, it is important for the delivery companies to form a long-term coalition in order to keep their market share and not to lose their position to existing large corporates. For this purpose, the coalition or collaboration system shall come with the rightful strategic decisions to maximize the efficiency of the service in the serviced regions, where the main goal is to optimize the processes and maximize the profitability. Sometimes, this may require the coalition to close the inefficient facilities/service of the collaboration system for certain period to achieve most desirable result. Here, the delivery company with closing facility continues to benefit from the collaboration as such decision increases the overall profitability of the system and the related profit share between the companies. In this research, we consider n delivery companies, who agree to form a collaboration for a number of equal periods (multiple years, quarters or months). These companies agree that they will serve the pre-agreed merging regions, use common delivery hubs and facilitate in use of their infrastructure for the benefit of the coalition. There is also understanding between the companies that the cost and capacity (for example, capacity of terminal) of each company is different and in order to achieve the most desired result for the collaboration system, the inefficient facilities with highest costs or limited capacity may be forced to close temporarity for some period (see Figure 2).

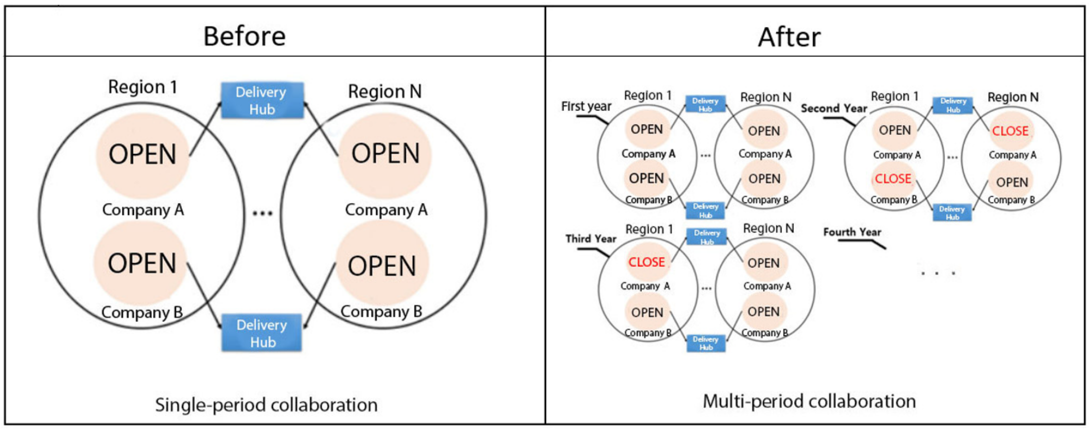

FIGURE 3. Before and after dynamic collaboration

This research's collaborative model with dynamic design shall find an optimum solution for the coalition in terms of (i) profit maximization and (ii) keeping the collaboration system efficient, which requires decisions on opening or closing the facilities/services of companies in certain periods.

4. **Model Design.** This study constructs a multi-objective programming model on the basis of the collaboration model introduced by Makhmudov et al. [16]. The study intends to extend Makhmudov et al.'s model to consider dynamic collaboration between delivery companies over number of periods and strategic decisions to open or close the facilities of the participating companies to achieve the highest efficiency. To consider the last, we construct first non-linear problem, which will be then linearized by introduction of the new variables (y and z). The problem is solved using the max-min and max-sum criterions, where the objective function is the maximization of the profit of overall collaboration system and profit of each company.

Mathematical model is formulated as per below using the notations described.

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 planning periods, $T = \{1, 2, \ldots, l\}$

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

Q_{it}: remaining capacity of the terminal for processing demand amount of company i at period t, $i \in I$, $t \in T$

d_{ijt}: yearly demand of the company i in region j during planning period t, $i \in I$, $j \in J$, $t \in T$

D_{jt}: yearly demand within region j during planning period t, $j \in J$, $t \in T$, i.e., $D_{jt} = \sum_{i=1}^{m} d_{ijt}$

r_{ijt}: net profit contributed by one unit of demand of company i within region j during planning period t, $i \in I$, $j \in J$, $t \in T$

v_{ij}: set-up cost for service region j of company i, $i \in I$, $j \in J$

Decision variable:

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

Non-linear model formulation (P1):

$$Max\phi_1(x) = \sum_{t \in T} \sum_{j \in J} (r_{1jt} D_{jt} - f_{1jt}) \, x_{1jt} + \sum_{j \in J} \sum_{t \in T} (f_{1jt} - r_{1jt} d_{1jt})$$

$$- \sum_{t\in T-\{l\}} \sum_{j\in J} \{v_{1j} \cdot (1 - x_{1jt}) \cdot x_{1j,t+1}\} \tag{1}$$

$$\vdots$$

$$Max \phi_m(x) = \sum_{t\in T} \sum_{j\in J} (r_{mjt} D_{jkt} - f_{mjt})\, x_{mjt} + \sum_{j\in J} \sum_{t\in T} (f_{mjt} - r_{mjt} d_{mjt})$$
$$- \sum_{t\in T-\{l\}} \sum_{j\in J} \{v_{mj} \cdot (1 - x_{mjt}) \cdot x_{mj,t+1}\}$$

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

$$\sum_{j\in J} \sum_{t\in T} (D_{jt} x_{ijt} - d_{ijt}) \le Q_{it} \quad i \in I,\, t \in T \tag{3}$$

$$x_{ijt} \in \{0, 1\} \quad i \in I,\, j \in J,\, t \in T \tag{4}$$

The objective function (1) represents the net profit increase of each company. It includes the gain or loss of each company in profit from a change in the yearly demand amount, and its reduction of fixed cost. Constraint (2) provides only one service center in which each company is opened. Constraint (3) includes the information on weight multiplication by summing the amount of demand and considering each delivery hub's processing capacity. Constraint (4) includes decision variables as the binary number.

Linear model formulation (P2):

Binary decision variable $z_{ijt,t+1}$ is introduced to linearize the above problem as follows:

$$z_{ijt,t+1} = (1 - x_{ijt}) \cdot x_{ij,t+1}$$

Decision variables can be applied in our study in following way

$$z_{ijt,t+1} \le \frac{1 - x_{ijt} + x_{ij,t+1}}{2}$$

Formula above provides us the possible variants of decisions shown in Table 1.

Table 1. Matrix for possible variants for $z_{ijt,t+1}$

x_{ijt}	$x_{ij,t+1}$	$z_{ijt,t+1}$
1	1	0
1	0	0
0	1	1
0	0	0

With above variables, our model can be reformulated as follows:

$$Max \phi_1(x, y, z) = \sum_{t\in T} \sum_{j\in J} (r_{1jt} D_{jt} - f_{1jt})\, x_{1jt} + \sum_{t\in T} \sum_{j\in J} (f_{1jt} - r_{1jt} d_{1jt})$$
$$- \sum_{t\in T-\{l\}} \sum_{j\in J} (v_{1j} z_{1jt,t+1}) \tag{5}$$

$$\vdots$$

$$Max \phi_m(x, y, z) = \sum_{t\in T} \sum_{j\in J} (r_{mjt} D_{jt} - f_{mjt})\, x_{mjt} + \sum_{t\in T} \sum_{j\in J} (f_{mjt} - r_{mjt} d_{mjt})$$
$$- \sum_{t\in T-\{l\}} \sum_{j\in J} (v_{mj} z_{mjt,t+1})$$

$$\text{s.t.} \quad \sum_{i\in I} x_{ijt} = 1 \qquad j \in J,\, t \in T \tag{6}$$

$$\sum_{j\in J}\sum_{t\in T}(D_{jt}x_{ij} - d_{ijt}) \leq Q_{it} \qquad i \in I,\ t \in T \tag{7}$$

$$z_{ijt,t+1} \leq \frac{1 - x_{ijt} + x_{ij,t+1}}{2} \qquad i \in I,\ j \in J,\ t \in T \tag{8}$$

$$x_{ijt} \in \{0,1\}, z_{ijt,t+1} \in \{0,1\} \qquad i \in I,\ j \in J,\ t \in T \tag{9}$$

The objective function (5) represents the net profit increase of each company. It includes the gain or loss of each company in profit from a change in the yearly demand amount, and its reduction of fixed cost. Constraint (6) provides only one service center in which each company is opened. Constraint (7) includes the information on weight multiplication by summing the amount of demand and considering each delivery hub's processing capacity. Constraint (8) is new decision variable z, which linearizes our model and is responsible for opening or closing for the next period of the time. Constraint (9) includes decision variables as the binary number.

5. **Numerical Example.** In this section, the study examines the applicability of the constructed dynamic model in the example of three delivery companies (A, B and C), who enter into collaboration, which allows them to service four merging regions (1, 2, 3 and 4) by using the infrastructure of each other. These companies agree to form a coalition for 3 years. Data for delivery demand, daily fixed cost and capacity of the delivery hub/terminals are given in Tables 2-4.

Table 2. Data for delivery demand

Merging region	1st year			2nd year			3rd year		
	A	B	C	A	B	C	A	B	C
1	51	15	19	85	25	26	72	43	75
2	85	63	87	22	93	62	36	64	22
3	58	34	72	96	45	36	54	74	88
4	20	85	57	26	26	85	75	35	76

Table 3. Data for daily fixed cost

Merging region	1st year			2nd year			3rd year		
	A	B	C	A	B	C	A	B	C
1	83	130	136	196	127	132	83	236	89
2	68	168	121	201	86	69	225	50	140
3	52	272	64	261	185	298	271	67	175
4	214	111	79	259	275	227	293	104	258

Table 4. Capacity of terminals/hubs

Terminal	Capacity
1	480
2	430
3	525

(1) Solution based on max-min criterion.

First, a solution based on max-min criterion in Table 5 compares amounts of deliveries companies A, B and C should make during the 1st year, the 2nd year and the 3rd year, respectively to the 4 regions. To be more exact, for the 1st year, company A dominates in regions 1 and 3, and company C in regions 2 and 4. In the 2nd year company B is in charge of delivering only to region 3 while company C is in charge of regions 1, 2 and 4. In the 3rd year company A takes responsibility for delivering to region 1 while company B is in charge of regions 2, 3 and 4. To sum up, according to the max-min criterion method, the highest volume of profit that can be achieved by companies A, B and C in 3 years equals \$4,487. Each company makes the following profit: ϕ_A = \$1,494; ϕ_B = \$1,560 and ϕ_C = \$1,433.

TABLE 5. Optimal solution for the max-min criterion

	1st year				2nd year				3rd year			
Region	1	2	3	4	1	2	3	4	1	2	3	4
x_{At}	1	0	1	0	0	0	0	0	1	0	0	0
x_{Bt}	0	0	0	0	0	0	1	0	0	1	1	1
x_{Ct}	0	1	0	1	1	1	0	1	0	0	0	0

(2) Solution based on max-sum criterion.

Second, a solution based on max-sum criterion in Table 6 shows the number of deliveries for which companies A, B and C are responsible in 4 regions during 3 years. In year 1 company A is to carry out deliveries for regions 1, 2 and 3. Meanwhile, region 4 is served by company C. In the 2nd year delivery services are undertaken by company B and company C (region 3 and regions 1, 2, 4, respectively). Finally, in year 3 again delivery services are shared by company B in regions 2, 3, 4 and company C in region 1. In conclusion, according to the max-sum criterion method, the highest volume of profit that can be achieved by companies A, B and C equals \$4,535. Each company makes the following profit: ϕ_A = \$1,611; ϕ_B = \$1,560 and ϕ_C = \$1,364.

TABLE 6. Optimal solution for the max-sum criterion

	1st year				2nd year				3rd year			
Region	1	2	3	4	1	2	3	4	1	2	3	4
x_{At}	1	1	1	0	0	0	0	0	0	0	0	0
x_{Bt}	0	0	0	0	0	0	1	0	0	1	1	1
x_{Ct}	0	0	0	1	1	1	0	1	1	0	0	0

6. **Conclusions.**

The COVID-19 problem has pushed expansion e-commerce's 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. Delivery service sector is booming as demand for such service has reached historical highs. Given the severe competition between the large and small, traditional old and new companies, the needs for forming coalition between the delivery companies. Collaboration between companies can be a smart tool to protect the market and increase competitiveness.

This study introduced a dynamic design for a collaboration model in delivery service, where companies agree to cooperate for longer term or specific periods with the key aim to (i) maximize the total profit and profit share, and (ii) increase efficiency of the collaboration system by making common strategic decisions such as close or open the facilities/service of the participating companies for a temporary period. A mathematical model for such collaboration is formulated as a multi-objective programming problem to maximize the total profit of the collaboration system and profit of each participating company. Applicability of the model in realistic world is checked through the numerical example, results of which were satisfactory and met our expectations.

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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