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RESEARCH ARTICLE

Optimization of OmniChannel Distribution Network Using Micro Fulfillment Center Under Demand Uncertainty

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ABSTRACT Quick commerce has recently become the most important issue in the logistics industry due to intensifying competition for a faster delivery. A fulfillment service that integrates various logistics processes has emerged to conduct delivery service as quickly as possible. With a need for facilities that can serve a fulfillment service near the customer, a Micro Fulfillment Center (MFC) is suggested as a solution. MFC refers to a small fulfillment center located in the city center and functions as an advanced base for quick commerce services. However, quick commerce services, including the operation of MFC, are suffering from high costs and operational inefficiency. In this situation, the integration of online and offline distribution networks in the omnichannel logistics system is showing a new possibility for Quick commerce service. for instance, the waste cost resulting from the failures of demand forecasting can be alleviated by the integration of both networks, especially for perishable goods. Accordingly, this study aims to determine the optimal MFC location for Quick commerce service to serve an online order in an omnichannel system that deals with perishable goods, and to identify operational benefits that can be led by the connection between MFCs and Retail stores. This study has introduced a two-stage stochastic optimization model to deal with demand uncertainty. we developed two optimization models to explain the integration between MFCs and offline stores. In addition, we conduct a numerical analysis based on real-world data including actual retail stores and modifications of online demand to verify the models we introduce. The case study is executed in Gangdong-gu, Songpa-gu in Seoul, Korea. Rep of. The results say that the connection of the different channels can be significantly beneficial in operating costs.

INDEX TERMS Quick commerce, omnichannel, stochastic programming, demand uncertainty, MFC, micro fulfillment center, urban logistics.

I. INTRODUCTION

e-commerce industry has been shown for continuous growth as infrastructure for internet and smart devices advanced. The global e-commerce market is expected to be \$6.3 trillion in 2023 and will be over \$8.1 trillion in 2026 [1] It is also can be applicable for Korean domestic e-commerce market. Particularly, with the COVID-19 pandemic, the total transaction volume of domestic e-commerce reached \210 trillion in 2022 [2] In this circumstance, various services are offered to fulfill diverse customers' needs and, consequently, on-demand service which is a customer-oriented service differs from the existing logistics service is highlighted [3] Competition for delivery speed such as early morning delivery or same-day delivery and a Cold-chain service for perishable goods are offered in this context.

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Especially, the competition for faster delivery is extended to the area of Quick commerce. Quick commerce refers to a service that completes delivery as soon as possible [4] For instance, Baemin provides instant delivery services within 30 minutes to 1 hour through B-Mart service, and several companies are competitively planning and operating services. 'Yo-Convenience Store' service by Yogiyo with GS Retail and daily delivery services by Lotte Mart and E-mart is also in implementation or in planning.

A faster delivery service needs a faster response to the order from the customer. In turn, the concept of a warehouse is also transformed into a fulfillment center that provides a fulfillment service that integrates overall delivery processes including packaging, picking and shipping [5]

In the meaning of Quick commerce with fulfillment service, MFC, a small size fulfillment center located in the urban area, is now on the spotlight. It can respond quickly by minimizing the last mile delivery distance [6] Currently, various type of MFCs are operated by multiple companies in Korean domestic logistics industry. This study focuses on dark store type MFC. This type of MFC is characterized by its location, small size in office or retail properties, with manual picking, and operating with instant delivery services within 30 minutes to 1 hour [7] However, Operating Quick commerce services including utilizing MFC requires a huge investment for the infrastructure such as estate rental cost, Increasing network capacity, and accurate demand forecasting, which is an obstacle to the execution of the services [8]

In contrast with this situation, Oasis Market, an omnichannel fresh food retail company operates in the black for early morning delivery by using their integrated distribution network online and offline. They use MFC to serve an online customer and if share the inventory for MFCs and retail stores. And they move the unsold goods which is near the expiration date to the retail market with the selling promotion [9]

Accordingly, this study focuses on the successful cases of Oasis market, determines the optimal location of MFC depending on whether the distribution networks – online and offline - are connected to each other. We introduce Two-stage stochastic optimization models describing each case and by comparing the operational cost, demonstrate the effect of the network connection. In the independent operation, MFCs take care of online orders and offline purchases take place at the retail store. Also, the inventory process is upon each network independently. We depict this case on Model1. On the other hand, in a network connection case, a retail store uses MFCs' inventory to fulfill the offline demands if it is needed. Furthermore, MFCs can reduce their operational inefficiency by sending the useless inventories off to the retail store. Model2 define this case. Since the problem state is under the demand uncertainty, both models take the form of the Two-stage Stochastic Optimization (TSO) model.

Numerical experiments were conducted on part of Seoul, Korea to evaluate the performance and effectiveness of the defined model. To reflect the actual situation, the contents of real estate information and actual online purchasing data were reflected. As a result, it was shown that the connection of the distribution network could lead to significant benefit for implementation of the service. The installation of MFC is differ from the timespan and the number of customers or orders. To be specific, the effect of the connection gives the largest difference between models in terms of delivery cost. In addition, a relative EVPI index was presented to measuring the relevance of using a stochastic methodology, and through this, it was concluded that the distribution network connection alleviates the difficulty of the demand uncertainty problem.

In Chapter II, we review previous studies conducted on logistics network optimization methodologies, including omnichannel distribution networks, and highlight the contribution of this study. Chapter III defines the problem situation in this study, and Chapter IV introduces the mathematical optimization model for each model based on the problem situation. Chapter V describes the EVPI indicators used to measure the relevance of using stochastic methodology for the uncertainty adopted in this study. In Chapter VI, we explain the results of solving the methodology presented in this study by substituting it into the actual situation and examine the effectiveness of distribution network connection by identifying various factors that make up the results. In addition, we check the results of relative EVPI introduced in Chapter V and examine its significance. Chapter VII introduces the meaning and limitations of this study and presents future research and research development.

II. LITERATURE REVIEW

Several research based on demand uncertainty has been studied constantly for a long time. Aghezzaf [10] presented a methodology that defines demand uncertainty in the location problem with the size of warehouses. The Robust Optimization model was suggested to respond to uncertainty, and it was approached through an algorithm based on Lagrange relaxation. Correa et al. [11] applied stochastic programming to solve the multi-cycle hub capacity allocation problem under demand uncertainty. The TSO model was proposed, and accordingly, decisions on deterministic variables are made in the first stage, and decisions related to demand uncertainty defined by scenarios are made in the lower stage. In this process, the structure of the distribution network is determined at the first stage, and the hub capacity and logistics flow according to demand are determined at the second stage. Li et al. [12] applied the TSO model to the refined oil supply chain under demand uncertainty. Uncertain demand was defined as a probabilistic scenario, and accordingly, the transport schedule and quantity supplied for each gas station were determined. Here, the stochastic mathematical model is converted into a deterministic model with an equal meaning, and this is solved through a commercial Solver. The derived solution was verified through an evaluation scale, and accordingly, it was shown that the presented model can find the optimal solution. Lu and Cheng [13] considered

TABLE 1. Literature review.

No.	Research Article	Location	Inventory	Perishable	Method	Multi Period	Omnichannel	Objective
1	E. Aghezzaf (2005)	○		○	Ro	○		Min. Cost
2	I. Correira et al. (2018)	○			St	○		Min. Cost
3	M. Millstein et al. (2018)	○			Det			Max. Profit
4	Z. Li et al. (2020)		○		St		○	Min. Cost
5	X.Lu et al. (2021)	○			Ro			Min. Cost
6	M.Millstein et al. (2022)	○			Det		○	Max. Profit
7	P. Hooshangi-Tabrizi et al. (2022)		○	○	Ro	○		Min. Cost
8	Y. H. Lin et al. (2022)	○		○	Det		○	Min. Cost
9	J. Lee et al. (2022)		○		St	○		Min. Cost
	This Study	○	○	○	St	○	○	Min. Cost

Ro: Robust Optimization, St: Stochastic Optimization, Det: Deterministic Optimization

changes in customer demand due to suspension of operation in determining the location of facilities, and approached the resulting demand uncertainty through the Two-Stage Robust Optimization (TRO) model. The study reflected the distribution of demand to define demand uncertainty. Demand was regulated by reflecting the uncertainty budget in the variance of demand based on average demand. They compared the proposed model with the TSO model and confirmed that the TSO model produced better results in general cases for the defined scenario, but in the worst-case scenario, the TRO model showed better results. Hooshangi-Tabrizi et al. [14] introduce a TRO model for the ordering and inventory problem in a management of medical blood under demand uncertainty. In this process, the purchase quantity according to the initial order is supplied in the first stage, and in the second stage, additional orders, carryover inventory, and waste volume are determined according to uncertain demand. As a result, numerical experiments have shown that it is more advantageous to manage inventory to revise orders and consider additional orders at a time when demand is uncertain for goods with high risk of corruption such as blood. Lee et al. [15] addressed the issue of e-commerce supply chain network design based on a logistics warehouse system to meet on-demand services. To solve the problem, a TSO model was presented, and several types of logistics warehouses were defined in the context of on-demand services and used in the problem, which showed significant cost savings in supply chain design.

Research about the Omnichannel retail distribution system has been actively conducted recently. Millstein and Campbell [16] deal with the warehouse location problem for the omnichannel distribution system of sporting goods retailers. Non-linear inventory costs were built based on the definition of warehouse size and unit cost, and a MILP model was invented in consideration of inventory in the facility in terms of location problems. Millstein et al. [17] define the relationship between warehouses and offline retail stores in the omnichannel distribution system in various aspects and present an advantageous operation pattern based on the ratio of online and offline demand and the characteristics of products handled. As a result, it was more beneficial to handle online demand in warehouses than to be shipped from offline stores and delivered, and in the case of fresh food, profitability can be improved through the connection between facilities. Lin et al. [18] conducted an approach that comprehensively considered the location and operation strategy of offline stores of e-commerce companies. The study estimated customers' choice of online/offline channels using a discrete selection model, and based on this, it also showed that offline store operation can lead to a decrease in transportation costs and an increase in profits for e-commerce companies.

As we have seen, the location and inventory problems based on demand uncertainty has been carried out in a various methodology in many studies. This study designs an omnichannel logistics network based on an approach under demand uncertainty and show the effect of a connection between the networks. We present a TSO model to optimize the distribution network for scenarios that define uncertain demand, and with this, we intend to determine the optimal location of MFC considering offline stores in operation. In addition, we compare the costs of independent networks operation and the connected networks to serve online and offline orders. It deals with perishable goods during multiple periods, which can be presented as a difference from existing omnichannel-related studies. <Table 1> summarizes the characteristics and contributions of the existing studies and this study.

III. PROBLEM DESCRIPTION

In this chapter, the problem situation is presented. The demand consists of online and offline demand. The MFC is

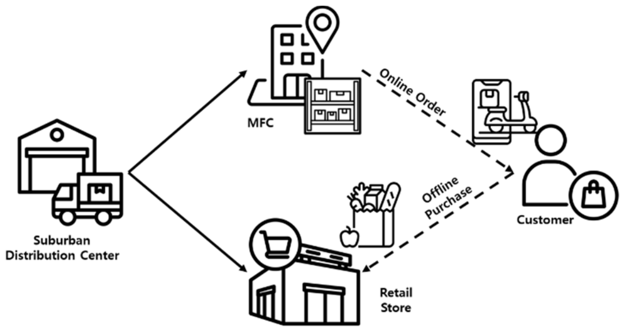

FIGURE 1. Connected network operation description.

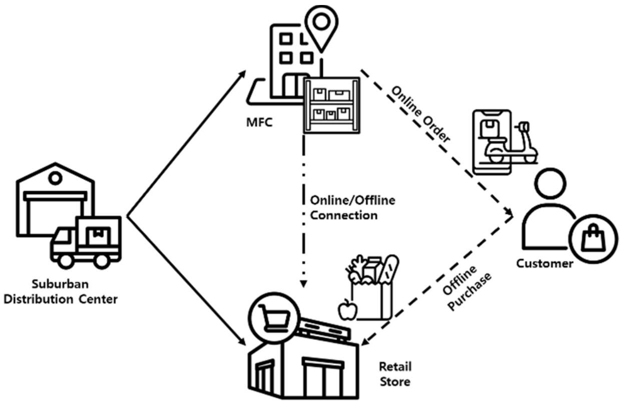

FIGURE 2. Independent network operation description.

dedicated to serving online demand. parcels amount needed for each facility will be promoted at the distribution center (DC) located in suburban area. In the case of online demand, 24-hour services are provided, and in the case of offline demand, offline stores are open for 12 hours from 10:00 to 22:00. In the case of online orders, it is considered that the delivery proceeds immediately when the order take place, and delivery services are provided for a single order regardless of the quantity. This is to reflect the situation in which purchase decisions are freer from time constraints in the case of actual online instant delivery services.

<Figure 1> and <Figure 2> show the problem situation covered by this study.

Each facility replenishes the quantity required by the suburban DC at nighttime when customers cannot access to offline stores. In this process, there is a limit to the quantity that can be satisfied with a single delivery schedule, hence, the additional quantity required is satisfied in different ways depending on the operation of the distribution network. For additional order quantities, we define situations that take place regardless of the time of occurrence, considering what happens to meet demand appropriately.

In the case of products covered, perishable goods with expiration dates are considered. inventories that have passed the expiration date will be discarded, the difference in the expiration date in the online and offline distribution networks and the point of generation of the disposal quantity will differ depending on whether the distribution network is connected.

In the case of independent distribution network operation, it corresponds to <Figure 1>. Retail stores and MFCs operate independently and provide services for offline and online order each. The expiration date of inventories in the online and offline distribution networks is the same. According to independent operation, MFC and retail stores will handle their own disposal quantity.

In the case of the distribution network connection situation, it corresponds to <Figure 2>. The networks connection means the quantity movement from MFC to retail stores. In this situation, the storage period of the inventories for MFC has a shorter storage period than that of the inventories in the retail store. In MFC, all items that have passed the storage period are moved to offline stores and utilized to meet offline demand. This is to alleviate the inefficiency of the distribution network by selling inventories that may occur as waste volume in MFC at retail stores. In addition, retail stores can receive volume promotion from MFC if necessary.

IV. MATHEMATICAL OPTIMIZATION MODEL

A. NOMENCLATURE

1) SETS

I	: Set of online demand node
R	: Set of retail store node
J	: Set of MFC candidate location
N	: Set of all facility node ($N = R \cup J$)
Day	: Planning Horizon (Day)
T	: Planning Horizon (12 hours: $\lvert T \rvert = 2 \cdot \lvert Day \rvert$
D	: Expiration time
D_{mfc}	: Expiration time in MFC (Model 2)
S	: Set of Scenarios

2) INDICES

i	: index for online demand node
r	: index for retail store node
j	: index for MFC candidate location
n	: index for all facility node ($N = R \cup J$)
day	: index for Planning Horizon (Day)
t	: index for Planning Horizon (12 hours)
d	: index for Expiration time
s	: index for Expiration time in MFC (Model 2)
i	: index for Scenarios

3) PARAMETERS

Dr_r^t	: Offline demand at time t in retail store r (ea)
Do_i^t	: Online demand at time t from customer node i (ea)
c_n	: Unit delivery cost from suburban DC to each facility (won)
cb_n	: Backorder delivery cost from suburban DC to each facility per unit (won)
c_{ij}	: Last mile delivery cost from MFC j to customer node i per unit (won)

c_{jr} : Delivery cost from MFC j to retail store r per unit (won)
h_n : Handling cost for goods at each facility (won)
f_j : Location cost for MFC j (won)j
Cap_n : Capacity for each facility (ea)
Q_{max} : Maximum quantity for promotion from suburban DC (ea)
Q_{min} : Minimum quantity for promotion from suburban DC (ea)
cl_n : Waste handling cost at each facility (won)
p_{um} : Penalty for unmet demand (won)
M : Very large number
p_s : Probability for scenario s

4) DECISION VARIABLES

x_j : 1 if MFC located on candidate j, 0 otherwise
y_n^t : 1 if promotion from the suburban DC is on time t to facility n, 0 otherwise
$inv_n^{t,d}$: Inventory quantity in facility n at time t with expiration day a passed
$q_n^{t,d}$: Quantity sold in facility n at time t with expiration day a passed
Q_n^t : Quantity sold in facility n at time t
Q_{ij}^t : Quantity delivered from MFC j to customer node i
Q_{jr}^t : Quantity moved from MFC j to retail store r
Ql_n^t : Quantity passed the expiration date at time t in each facility
um_i^t : Unmet demand quantity at time t at customer node i
um_r^t : Unmet demand quantity at time t at retail store r

B. MATHEMATICAL OPTIMIZATION MODEL

In general, inefficiency can occur in the operation of the distribution network since it is difficult to predict future demand accurately. We design TSO model to demonstrate such problem properly.

The TSO model is consisted of two stages. For the first stage, deterministic decision variables are calculated. And for the second stage, stochastic decision variables correlated with the uncertainty are decided. Uncertain demand is defined by the scenario with the probability. In the second stage, the variables are decided scenario-wise, in contrast with the first stage which is for all scenarios. The objective function consists of the first stage's objective function and the expectation value of the second stage's objective function in each scenario.

Bring it to our case, the location of MFC, the amount, and the schedule for the regular delivery from the suburban DC to each facility are made at the first stage. And the stochastic variables, backorder quantity, amount sold with expiration date passed, and inventories, waste, or unmet demand are decided in the second stage. In addition, the amount move between the facilities is made in the network connection case.

1) MODEL1: INDEPENDENT OPERATION

Model1 represents the independent operation of networks online and offline. The objective function is a minimization of the entire costs with the expectation of the second stage objective under the uncertainty scenarios.

Following is the first stage model.

$$\min TC_1 = \sum_j f_j \cdot x_j + \sum_t \sum_n Q_n^t \cdot c_n + \mathbb{E}\left[Q_1(x, y, \xi)\right] \tag{1}$$

Objective function (1) is the objective function for Model1. It is a sum of the Construction cost for MFC, regular delivery cost and the expectation of the second stage's objective.

$$\mathbb{E}\left[Q_1(x, y, \xi)\right] = \sum\nolimits_s p_s \cdot Q_1(x, y, \xi) \tag{1-1}$$

Equation (1-1) explains the expectation of the objective for the second stage. Consequently, the entire objective function can be reformulated to objective function (1-2).

$$\min TC_1 = \sum_j f_j \cdot x_j + \sum_t \sum_n Q_n^t \cdot c_n + \sum_s p_s \cdot Q_1(x, y, \xi) \tag{1-2}$$

Following are the constraints for the first stage.

Subject to

$$y_r^{2day-a} = a \quad \forall r \in R, \forall day \in Day, a \in \{0, 1\} \tag{2}$$
$$y_j^{2day-1} = x_j \quad \forall j \in J, \forall day \in Day \tag{3}$$
$$Q_{min} \cdot y_n^t \le Q_n^t \le Q_{max} \cdot y_n^t \quad \forall n \in N, \forall t \in T \tag{4}$$
$$x_j, y_n^t \in \{0, 1\} \quad \forall j \in J, \forall n \in N, \forall t \in T \tag{5}$$
$$Q_n^t \ge 0 \quad \forall n \in N, \forall t \in T \tag{6}$$

constraints (2)-(3) explain the regular delivery schedule from the suburban DC to MFCs and retail stores. An appropriate schedule is made with these constraints. The time unit for this study is 12-hour intervals and the constraints reflect it to describe a promotion during night times. constraint (4) regulates the quantity for a regular promotion in a limitation. constraint (5) is a binary constraint for certain variables, and constraint (6) ensures decision variables are having non-negative values.

Next is a definition for the second stage. The stochastic variables are decided in the second stage. Objective function (7) is the objective for the second stage. ξ is a variable represents an uncertain situation.

$$\begin{aligned} Q_1(x, y, \xi) &= min\Bigg(\sum_t \sum_i \sum_j Q_{ij}^t(\xi) \cdot c_{ij} \\ &\quad + \sum_t \sum_d \sum_n Inv_n^{t,d}(\xi) \cdot h_n \\ &\quad + \sum_t \sum_n \left(Ql_n^t(\xi) \cdot cl_n + B_n^t(\xi) \cdot c_n\right) \\ &\quad + p_{um}\left(\sum_t \sum_i um_i^t(\xi) + \sum_t \sum_r um_r^t(\xi)\right)\Bigg) \end{aligned} \tag{7}$$

The objective consists of the cost for last-mile delivery, inventory cost, waste cost, the penalty for the unmet demand, and backorder costs. Those are decided under the demand uncertainty and the following constraints.

Subject to

$$\sum_j Q_{ij}^t(\xi) \le Do_i^t(\xi) \quad \forall j \in J, \forall t \in T \tag{8}$$

$$\sum_D q_r^{t,d}(\xi) \le Dr_r^t(\xi) \quad \forall r \in R, \forall t \in T \tag{9}$$

$$\sum_d Inv_n^{0,d}(\xi) = 0 \quad \forall n \in N \tag{10}$$

$$Inv_n^{t,d}(\xi) = Inv_n^{t-1,d-1}(\xi) - q_n^{t,d}(\xi) \quad \forall n \in N, \forall t \in T, \forall d \in D \tag{11}$$

$$Inv_n^{t,0}(\xi) = Q_n^t + B_n^t(\xi) - q_n^{t,0}(\xi) \quad \forall n \in N, \forall t \in T, \forall d \in D \tag{12}$$

$$\sum_d Inv_n^{t,d}(\xi) + Q_n^t + B_n^t(\xi) \le Cap_n \quad \forall n \in N, \forall t \in T \tag{13}$$

$$Inv_n^{t,D}(\xi) = Ql_n^{t+1}(\xi) \quad \forall n \in N, \forall t \in T \tag{14}$$

$$\sum_d q_j^{t,d}(\xi) = \sum_i Q_{ij}^t(\xi) \quad \forall j \in J, \forall t \in T \tag{15}$$

$$um_i^t(\xi) = Do_i^t(\xi) - \sum_j Q_{ij}^t(\xi) \quad \forall i \in I, \forall t \in T \tag{16}$$

$$um_r^t(\xi) = Dr_r^t(\xi) - \sum_d q_r^{t,d}(\xi) \quad \forall r \in R, \forall t \in T \tag{17}$$

$$Q_{min} \le B_n^t(\xi) \le Q_{max} \quad \forall n \in N, \forall t \in T \tag{18}$$

$$Inv_n^{t,d}(\xi), q_n^{t,d}(\xi) \ge 0 \quad \forall n \in N, \forall t \in T, \forall d \in D \tag{19}$$

$$Ql_n^t(\xi), B_n^t(\xi) \ge 0 \quad \forall n \in N, \forall t \in T \tag{20}$$

$$um_r^t(\xi) \ge 0 \quad \forall r \in R, \forall t \in T \tag{21}$$

$$um_i^t(\xi) \ge 0 \quad \forall i \in I, \forall t \in T \tag{22}$$

Constraints (8) and (9) represent the definition of the quantity sold. They cannot exceed the online/offline demand of the period. Constraints (10) - (14) are the definitions of inventory and logistics flows within each facility. Constraint (10) is the definition of initial inventory. Constraints (11) and (12) correspond to inventory balance constraints. Constraint (13) is a constraint on the capacity of each facility, and constraint (14) is a constraint that defines the amount of waste. The amount of inventory stored by the defined maximum storage time is determined by the amount of disposal at the next period. Constraint (15) is a constraint indicating the sales volume and total sales volume according to the storage period. Constraints (16) and (17) represent the definition of unmet demand each time. Constraint (18) is a constraint on additional promotion volume from suburban DC, in a similar sense to Constraint (4). Constraints (19) to (22) regulate the variables to non-negative.

2) MODEL 2: CONNECTED OPERATION

Model 2 represents the situation under the connection between distribution networks. The objective function (23) is similar with Model 11.

$$\min TC_2 = \sum_j f_j \cdot x_j + \sum_t \sum_n Q_n^t \cdot c_n + \mathbb{E}[Q_2(x, y, \xi)] \tag{23}$$

The expected value of the objective function of the sub-problem is equation (23-1), and thus the objective function is reformulated as objective function (23-2).

$$\mathbb{E}[Q_1(x, y, \xi)] = \sum_s p_s \cdot Q_1(x, y, \xi) \tag{23-1}$$

$$\min TC_2 = \sum_j f_j \cdot x_j + \sum_t \sum_n Q_n^t \cdot c_n + \sum_s p_s \cdot Q_2(x, y, \xi) \tag{23-2}$$

The first stage situation defined in Model 2 is the same as Model 1, and accordingly, the contents of the constraints are the same.

***Subject to* (2)–(6)**

The objective function of the second stage sub-problem of Model2 is defined as shown in (24). It is similar with (7), but there is a difference in that the cost according to the amount of shipment between mfc and offline retail stores is added.

$$\begin{aligned} Q_2(x, y, \xi) = min \Bigg(& \sum_t \sum_i \sum_j Q_{ij}^t(\xi) \cdot c_{ij} \\ & + \sum_d \sum_t \sum_i \sum_j \boldsymbol{Q_{jr}^{t,d}(\xi) \cdot c_{jr}} \\ & + \sum_t \sum_d \sum_n Inv_n^{t,d}(\xi) \cdot h_n \\ & + \sum_t \sum_n (Ql_n^t(\xi) \cdot cl_n + B_n^t(\xi) \cdot c_n) \\ & + p_{um} \left(\sum_t \sum_i um_i^t(\xi) + \sum_t \sum_r um_r^t(\xi) \right) \Bigg) \end{aligned} \tag{24}$$

Model2's constraints for second stage subproblem are defined as follows.

subject to

(8)-(10), (15)-(22)

$$Inv_r^{t,d}(\xi) = Inv_r^{t-1,d-1}(\xi) + \sum_j Q_{jr}^{t,d}(\xi) - q_n^{t,d}(\xi) \quad \forall r \in R, \forall t \in T, \quad \forall d \in D \tag{25}$$

$$Inv_j^{t,d}(\xi) = Inv_j^{t-1,d-1}(\xi) - \sum_r Q_{jr}^{t,d}(\xi) - q_j^{t,d}(\xi) \quad \forall j \in J, \forall t \in T, \forall d \in D \tag{26}$$

$$Inv_r^{t,0}(\xi) = Q_r^t + B_r^t(\xi) + \sum_j Q_{jr}^{t,0}(\xi) - q_r^{t,0}(\xi) \quad \forall n \in N, \forall t \in T \tag{27}$$

$$Inv_j^{t,0}(\xi) = Q_j^t + B_j^t(\xi) - \sum_r Q_{jr}^{t,0}(\xi) - q_j^{t,0}(\xi) \quad \forall n \in N, \forall t \in T \tag{28}$$

$$\sum_{d} Inv_{r}^{t,d}(\xi) + Q_{r}^{t} + B_{r}^{t}(\xi) + \sum_{j} Q_{jr}^{t,d}(\xi) \le Cap_{r} \quad \forall r \in R, \forall t \in T \tag{29}$$

$$\sum_{d} Inv_{j}^{t,d}(\xi) + Q_{j}^{t} + B_{j}^{t}(\xi) \le Cap_{j} \quad \forall j \in J, \forall t \in T \tag{30}$$

$$Inv_{r}^{t,D}(\xi) = Ql_{r}^{t+1}(\xi) \quad \forall r \in R, \forall t \in T \tag{31}$$

$$Inv_{j}^{t,Dmfc}(\xi) = \sum_{r} Q_{jr}^{t+1,Dmfc+1}(\xi) \quad \forall j \in J, \forall t \in T \tag{32}$$

$$Q_{jr}^{t,d}(\xi) \ge 0 \quad \forall r \in R, \forall j \in J, \forall t \in T, \forall d \in D \tag{33}$$

Since the problem situation being dealt with is similar with Model 1, constraints (8)-(10) and constraints (15)-(22) are defined as the same content in Model 2. Constraints (25)-(32) are constraints that define inventory and logistics flows. Constraints (25)-(28) define inventory balance constraints. Constraints (25) and (27) correspond to retail stores, and constraints (26) and (28) correspond to MFC. In Model 2, the delivery cost between facilities is incurred, so it can be confirmed that the corresponding cost has been added. Constraints (29) and (30) are constraints on the capacity of each facility. Constraint (31) is a constraint on the amount of waste. Since the amount of waste in Model 2 occurs only in offline stores, Model 1 shows a difference from constraint (14) that corresponds to the limitation of the amount of waste. Constraint (32) define the volume of movement between facilities. After passing the defined storage period among the volumes stored in the mfc, it is moved to an offline store at the next time. Constraint (33) is a non-negative constraint for the variables.

V. RELEVANCE OF STOCHASTIC APPROACH

Stochastic approaches are known as much more difficult problem to solve than deterministic approaches. The uncertainty defined by the scenario is a factor that increases the dimension of the problem. Consequently, the complexity of the problem also increases significantly. Therefore, it is quite important to determine whether a stochastic methodology is appropriate by confirming how adopting a probability-based approach relates to adopting a deterministic approach [11]

Therefore, this study uses the Expected Value of the Perfect Information (EVPI) as a criterion for the relevance of using stochastic method. As can be seen from the name, EVPI means the value of the information when fully given. Therefore, higher EVPI is interpreted as meaning that the proposed stochastic model presented a more difficult solution to solve [19]

The definition for EVPI is as follow. The solution solved by a stochastic model to a problem situation in which uncertainty is defined is called the Here-and-now solution, and in this study, it corresponds to the objective function TC (TC_1, TC_2) of the TSO model. And the expected value of the objective function when all information on uncertainty is given is called the Wait-and-see Solution, and when it is WS, EVPI is defined as the following equation (34).

$$\text{EVPI} = \text{TC-WS} \tag{34}$$

WS is calculated as the expected value of the objective function when the scenario is applied to the deterministic model corresponding to the TSO model defined in this study. Therefore, the WS covered in this study is defined as (35) and (36) in Table 2 for Model 1 and Model 2.

TABLE 2. WS for each model.

Model1	$WS_1 = \mathbb{E}(WS_{1s}) = \sum_{s} p_s \Big\{ \sum_{j} f_j \cdot x_{js} + \sum_{t}\sum_{n} Q_{ns}^{t} \cdot c_n + \sum_{t}\sum_{i}\sum_{j} \overline{Q_{ijs}^{t}} \cdot c_{ij} + \sum_{t}\sum_{d}\sum_{n} \overline{Inv_{ns}^{t,d}} \cdot h_n + \sum_{t}\sum_{n} (\overline{Ql_{ns}^{t}} \cdot cl_n + \overline{B_{ns}^{t}} \cdot c_n) + p_{um}\Big(\sum_{t}\sum_{i} \overline{um_{is}^{t}} + \sum_{t}\sum_{r} \overline{um_{rs}^{t}}\Big)\Big\}$	(35)
Model2	$WS_2 = \mathbb{E}(WS_{2s}) = \sum_{s} p_s \Big\{ \sum_{j} f_j \cdot x_{js} + \sum_{t}\sum_{n} Q_{ns}^{t} \cdot c_n + \sum_{t}\sum_{i}\sum_{j} \overline{Q_{ijs}^{t}} \cdot c_{ij} + \sum_{d}\sum_{t}\sum_{i}\sum_{j} \overline{Q_{jrs}^{t,d}} \cdot c_{jr} + \sum_{t}\sum_{d}\sum_{n} \overline{Inv_{ns}^{t,d}} \cdot h_n + \sum_{t}\sum_{n} (\overline{Ql_{ns}^{t}} \cdot cl_n + \overline{B_{ns}^{t}} \cdot c_n) + p_{um}\Big(\sum_{t}\sum_{i} \overline{um_{is}^{t}} + \sum_{t}\sum_{r} \overline{um_{rs}^{t}}\Big)\Big\}$	(36)

For Model1, the objective function and constraints for the WS_{1s} problem corresponding to the WS of each scenario are as follows.

$$WS_{1s} = \sum_{j} f_j \cdot x_j + \sum_{t}\sum_{n} Q_{n}^{t} \cdot c_n + \sum_{t}\sum_{i}\sum_{j} \overline{Q_{ij}^{t}} \cdot c_{ij} + \sum_{t}\sum_{d}\sum_{n} \overline{Inv_{n}^{t,d}} \cdot h_n + \sum_{t}\sum_{n} (\overline{Ql_{n}^{t}} \cdot cl_n + \overline{B_{n}^{t}} \cdot c_n) + p_{um}\left(\sum_{t}\sum_{i} \overline{um_{i}^{t}} + \sum_{t}\sum_{r} \overline{um_{r}^{t}}\right) \tag{37}$$

Subject to

$$\sum_{j} \overline{Q_{ijs}^{t}} \le Do_{i}^{t} \quad \forall j \in J, \forall t \in T \tag{38}$$

$$\sum_{D} \overline{q_{rs}^{t,d}} \leq Dr_r^t \quad \forall r \in R, \forall t \in T \tag{39}$$

$$\sum_{d} \overline{Inv_{ns}^{0,d}} = 0 \quad \forall n \in N \tag{40}$$

$$\overline{Inv_{ns}^{t,d}} = \overline{Inv_{ns}^{t-1,d-1}} - \overline{q_{ns}^{t,d}} \quad \forall n \in N, \forall t \in T, \forall d \in D \tag{41}$$

$$\overline{Inv_{ns}^{t,0}} = Q_{ns}^t + \overline{B_{ns}^t} - \overline{q_{ns}^{t,0}} \quad \forall n \in N, \forall t \in T, \forall d \in D \tag{42}$$

$$\sum_{d} \overline{Inv_{ns}^{t,d}} + Q_{ns}^t + \overline{B_{ns}^t} \leq Cap_n \quad \forall n \in N, \forall t \in T \tag{43}$$

$$\overline{Inv_{ns}^{t,D}} = \overline{Ql_{ns}^{t+1}} \quad \forall n \in N, \forall t \in T \tag{44}$$

$$\sum_{d} \overline{q_{js}^{t,d}} = \sum_{i} \overline{Q_{ijs}^t} \quad \forall j \in J, \forall t \in T \tag{45}$$

$$\overline{um_{is}^t} = Do_i^t - \sum_{j} \overline{Q_{ijs}^t} \quad \forall i \in I, \forall t \in T \tag{46}$$

$$\overline{um_{rs}^t} = Dr_r^t - \sum_{d} \overline{q_{rs}^{t,d}} \quad \forall r \in R, \forall t \in T \tag{47}$$

$$Q_{min} \leq \overline{B_{ns}^t} \leq Q_{max} \quad \forall n \in N, \forall t \in T \tag{48}$$

$$\overline{Inv_{ns}^{t,d}}, \overline{q_{ns}^{t,d}} \geq 0 \quad \forall n \in N, \forall t \in T, \forall d \in D \tag{49}$$

$$\overline{Ql_{ns}^t}, \overline{B_{ns}^t} \geq 0 \quad \forall n \in N, \forall t \in T \tag{50}$$

$$\overline{um_{rs}^t} \geq 0 \quad \forall r \in R, \forall t \in T \tag{51}$$

$$\overline{um_{is}^t} \geq 0 \quad \forall i \in I, \forall t \in T \tag{52}$$

Newly defined variables are determined through a deterministic approach to the WS problem.

For Model 2, the objective function and constraints for the problem corresponding to WS in each scenario s are as follows.

$$\begin{aligned} WS_{2s} = & \sum_{j} f_j \cdot x_{js} + \sum_{t}\sum_{n} Q_{ns}^t \cdot c_n \\ & + \sum_{t}\sum_{i}\sum_{j} \overline{Q_{ijs}^t} \cdot c_{ij} \\ & + \sum_{d}\sum_{t}\sum_{i}\sum_{j} \overline{Q_{jrs}^{t,d}} \cdot c_{jr} \\ & + \sum_{t}\sum_{d}\sum_{n} \overline{Inv_{ns}^{t,d}} \cdot h_n \\ & + \sum_{t}\sum_{n} (\overline{Ql_{ns}^t} \cdot cl_n + \overline{B_{ns}^t} \cdot c_n) \\ & + p_{um}\left(\sum_{t}\sum_{i} \overline{um_{is}^t} + \sum_{t}\sum_{r} \overline{um_{rs}^t}\right) \end{aligned} \tag{53}$$

subject to

(38)-(40), (45)-(52)

$$\overline{Inv_r^{t,d}} = \overline{Inv_r^{t-1,d-1}} + \sum_{j} \overline{Q_{jr}^{t,d}} - \overline{q_n^{t,d}} \quad \forall r \in R, \forall t \in T, \forall d \in D \tag{54}$$

$$\overline{Inv_j^{t,d}} = \overline{Inv_j^{t-1,d-1}} - \sum_{r} \overline{Q_{jr}^{t,d}} - \overline{q_j^{t,d}} \quad \forall j \in J, \forall t \in T, \forall d \in D \tag{55}$$

$$\overline{Inv_r^{t,0}} = Q_r^t + \overline{B_r^t} + \sum_{j} \overline{Q_{jr}^{t,0}} - \overline{q_r^{t,0}} \quad \forall n \in N, \forall t \in T \tag{56}$$

$$\overline{Inv_j^{t,0}} = Q_j^t + \overline{B_j^t} - \sum_{r} \overline{Q_{jr}^{t,0}} - \overline{q_j^{t,0}} \quad \forall n \in N, \forall t \in T \tag{57}$$

$$\sum_{d} \overline{Inv_r^{t,d}} + Q_r^t + \overline{B_r^t} + \sum_{j} \overline{Q_{jr}^{t,d}} \leq Cap_r \quad \forall r \in R, \forall t \in T \tag{58}$$

$$\sum_{d} \overline{Inv_j^{t,d}} + Q_j^t + \overline{B_j^t} \leq Cap_j \quad \forall j \in J, \forall t \in T \tag{59}$$

$$\overline{Inv_r^{t,D}} = \overline{Ql_r^{t+1}} \quad \forall r \in R, \forall t \in T \tag{60}$$

$$\overline{Inv_j^{t,Dmfc}} = \sum_{r} \overline{Q_{jr}^{t+1,Dmfc+1}} \quad \forall j \in J, \forall t \in T \tag{61}$$

$$\overline{Q_{jr}^{t,d}} \geq 0 \quad \forall r \in R, \forall j \in J, \forall t \in T, \forall d \in D \tag{62}$$

As in the previously defined TSO model, the two models share several constraints in the WS model.

Accordingly, by equation (34), EVPI according to each problem situation can be calculated using WS and TC, which is a solution in the existing TSO model.

VI. NUMERICAL TEST

A. CASE STUDY

This study conducted a case study on Gangdong-gu and Songpa-gu in Seoul, Korea to apply the actual problem of the proposed mathematical optimization model. The area is subjected to daily delivery services of the Oasis Market, a distributor specializing in fresh food. They currently operate seven retail stores in the area. Also, they operate suburban DC in Seongnam-si, Gyeonggi-do, and provide the necessary supplies for each facility at the suburban DC. Accordingly, location information on retail stores in Gangdong-gu and Songpa-gu, Seoul, which are currently in operation, was collected and reflected in the study. Considering that the MFC covered in this study is a small size dark store located in a shopping mall or office-type real estate in the city, the candidate site for MFC's location was assumed to be a shopping mall and office real estate in the area. In order to reflect the characteristics of small logistics facilities, the size of the location candidate site was limited from $330m^2$ to $1322m^2$. The types of MFCs currently in operation can be defined in various aspects depending on the operator and service aspect, and there is no clear definition yet. Therefore, in this study, the size of MFC according to the area was calculated by referring to related data [7] Transportation costs were calculated in proportion to the distance, and the distance between the two points was calculated using the haversine method.

<Figure 3> shows the location of retail stores collected in the target area and the location of MFC location candidates. The green dot represents the retail store currently in operation, and the blue dot represents the candidate site of the MFC. The red dot refers to a large suburban DC located in Seongnam-si.

The logistics environment covered in the study reflected the domestic courier transport environment used in previous studies [20] <Table 3> summarizes the parameter values used in this study. In addition, various parameters, including

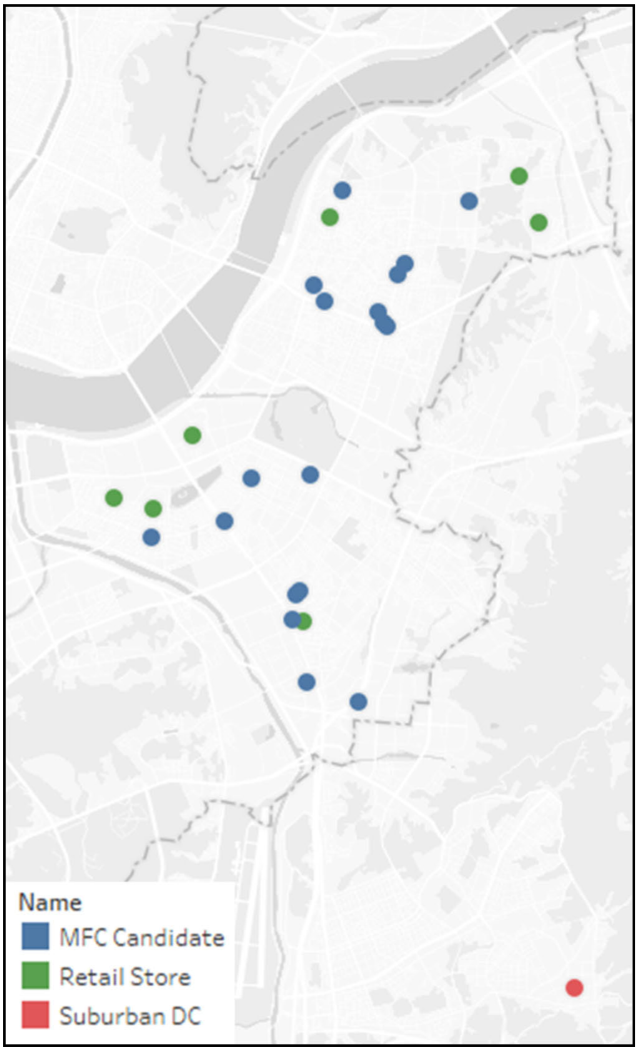

FIGURE 3. Independent network operation description.

inventory costs, were referred to previous studies, and the contents are included in the appendix.

The definition of the scenario for uncertain demand covered in this study and the probability for each are shown in <Table 4>. It was created by referring to online sales data from omnichannel distributor 'Jangbogo Food Materials Mart', and a total of three scenarios were generated. After creating a baseline scenario, it was divided into cases where the demand was lower than the standard by applying the amount of variation defined for each scenario and recording high demand.

The research environment is IBM ILOG CPLEX 20.1.0.0 version in a CPU AMD Ryzen 55600X, 16.0 GB RAM. The results of the objective function according to the experiment were derived as shown in <Table 5> below.

For all given situations, the distribution network connection case (Model2) shows a lower objective value than that of independent operation (Model1). In terms of total cost, distribution network connection shows a savings of about 4-15%, and on average, a cost reduction of about 8.13%.

TABLE 3. Parameter value used for case study.

Parameters	Value
c_n	300(won)
cb_n	450(won)
c_{ij}, c_{jr}	100(won)
$Cap_r,\ Cap_j$	Retail Store: 2,000unit MFC: 20unit / 3.3m^2
Q_{max}	3,000(ea)
Q_{min}	100(ea)
hc	2,500(won)
f_j	Naver real estate information.
cl	10,000(won)
p_{um}	10,000(won)
M	999,999

TABLE 4. Scenarios for demand uncertainty.

Uncertain Set	Scenario1	Scenario2	Scenario3
Dr_r^t	U(200,600)	$0.5 \leq \alpha_t \leq 1$	$1 \leq \alpha_t \leq 1.5$
Do_i^t	U(0,10)		
P_s	$P_1 = 0.4$	$P_2 = 0.3$	$P_3 = 0.3$

α_t: demand variation at time t

<Figure 4> and <Table 6> shows the location of MFC. The green dots represent the retail stores in operation and the orange color dots refer to the location of MFC installed.

B. EFFECT OF NETWORK CONNECTION

In this section, the effect of distribution network connection is demonstrated by checking the detail composition of the overall cost for the results of the case study.

TABLE 5. Case study results.

No.	$\|I\|$	$\|T\|$	Model1		Model2		Cost Gap(%)
			Cost(won)	Time(sec)	Cost(won)	Time(sec)	
1	*200*	*7*	148,069,998.8	9.83	126,641,425.7	11.83	**-14.47**
2		*14*	282,571,508.3	23.58	238,327,134.9	25.53	**-15.66**
3	*400*	*7*	196,868,973.5	13.38	183,784,180.5	30.50	**-6.65**
4		*14*	371,365,106.3	45.50	342,325,368.2	178.58	**-7.82**
5	*600*	*7*	253,185,402.0	81.31	240,632,592.5	51.99	**-4.96**
6		*14*	493,743,116.7	104.23	450,979,081.8	87.77	**-8.66**
7	*800*	*7*	317,250,815.9	56.38	296,415,141.0	85.23	**-6.57**
8		*14*	587,528,185.2	138.23	548,518,471.8	123.08	**-6.64**
9	*1000*	*7*	371,485,711.3	77.02	354,272,339.0	85.72	**-4.63**
10		*14*	704,619,908.3	129.89	667,619,142.9	184.66	**-5.25**
						Average Cost Gap :	**-8.13**

$$\text{Cost Gap} = \frac{Cost_2 - Cost_1}{Cost_1} \times 100(\%)$$

$Cost_1$: Cost for Model1

$Cost_2$: Cost for Model2

<Table 7> shows the cost composition according to the results of each experiment. Facility Cost refers to installation cost for MFC. Inventory cost is the cost for maintaining inventory. And all expenses equivalent to logistics movement is expressed by Delivery Cost.

Facility Cost has shown similar values>, because the actual installed MFC is selected from candidate sites No. 2, 8, 9, 13.

Inventory costs increased with the number of customer nodes covered by the experiment and the length of the period. In the case of differences by problem situation, Model 2 overall showed a lower pattern, and in the case of Experiments 5 and 6, the cost increased more in Model 2.

The most significant value among total cost was the Delivery Cost. In all cases, Model2 shows lower results than Model1. This suggests that connection between MFC and retail stores can reduce actual shipping costs.

Delivery Costs, which account for the highest proportion of the total cost, consist of regular promotion costs, last mile delivery costs, backorder shipping costs, and delivery costs through the connection between the facilities. Details related to the Delivery Costs are summarized in <Table 8>. In all cases where the experiment was conducted, Model 2 showed lower regular promotion costs and backorder costs than Model 1. According to the delivery costs between facilities showed similar patterns in two cases, T = 7 and T = 14, as can be seen in <Table 9>, the ratio of transportation costs between facilities to total transportation costs is gradually decreasing as the size of the problem increases.

Taken together, the integration of the distribution network can produce more efficient results than independent operation. In particular, the delivery cost has the biggest impact on the cost reduction.

As shown in <Table 9>, the delivery cost for the connected route between MFC and retail store is only 4.54% of the total delivery cost. Nevertheless, the fact that network connection showed 8% of the cost reduction for average compared to the independent operation suggests that the integration of the distribution network has a significant impact on the entire network operation.

C. RELATIVE EVPI

In this study, for an appropriate comparison of EVPI between problem situations, we will use a relative EVPI. It eliminates the magnitude differences, so it gives a proper information to compare.

$$EVPI_R = 100 \times \frac{1}{TC}(TC - WS) \tag{63}$$

FIGURE 4. MFC located in candidate no.13.

FIGURE 5. MFC located in candidate no.9.

FIGURE 6. MFC located in candidate no.8, no.9.

FIGURE 7. MFC located in candidate no.2, no.9.

FIGURE 8. MFC located in candidate no.2, no.8, no.9.

FIGURE 9. MFC located in candidate no.8, no.9, no.13.

TABLE 6. MFC location for each experiment.

Experiment no.	Model 1	Model 2
1	Figure 5	Figure 5
2	Figure 5	Figure 5
3	Figure 5	Figure 4
4	Figure 5	Figure 4
5	Figure 7	Figure 6
6	Figure 6	Figure 6
7	Figure 6	Figure 6
8	Figure 6	Figure 6
9	Figure 9	Figure 6
10	Figure 9	Figure 8

As it is introduced in chapter 5, the higher EVPI means the more difficult stochastic situation to solve. Since Model1 and Model2 use the same instances, model with the lower EVPI value means that can solve the same situation more easily.

<Table 10> shows relative EVPI for each experiment. For all experiments, Model1 and Model2 show levels of about 10-15% and 7-10%, respectively. In all cases, Model1 shows a higher level of EVPI than

TABLE 7. Objective value in details (won).

No.	Facility Cost		Inventory Cost		Delivery Cost	
	Model1	Model2	Model1	Model2	Model1	Model2
1	17,800,000	17,800,000	2,581,500	2,581,500	127,688,498.77	106,259,925.66
2	17,800,000	17,800,000	5,229,750	5,229,750	259,541,758.33	215,297,384.93
3	17,800,000	20,300,000	6,120,000	5,203,500	172,948,973.50	158,280,680.55
4	17,800,000	20,300,000	12,511,500	10,476,000	341,053,606.32	311,549,368.22
5	25,800,000	39,800,000	7,384,500	7,908,000	220,000,902.02	192,924,592.52
6	39,800,000	39,800,000	15,959,250	15,960,750	437,983,866.71	395,218,331.81
7	39,800,000	39,800,000	12,239,250	12,239,250	265,211,566.00	244,375,890.94
8	39,800,000	39,800,000	24,805,500	24,805,500	522,922,685.24	483,912,971.78
9	42,300,000	47,800,000	20,361,750	13,083,000	308,823,961.27	293,389,338.99
10	47,800,000	47,800,000	26,328,750	26,328,750	630,491,158.33	593,490,392.88

TABLE 8. Delivery cost in details(won).

No.	Regular Delivery Cost		Last Mile Delivery		Backorder Cost		MFC~Store
	Model1	Model2	Model1	Model2	Model1	Model2	Model2
1	46,555,879.78	38,483,199.30	8,454,002.45	8,454,002.45	217,629,450.00	153,528,495.75	8,325,295.22
2	94,824,189.60	77,339,732.40	16,963,067.71	16,963,067.71	442,475,186.40	311,398,996.95	17,669,397.62
3	59,841,089.10	53,257,286.70	17,949,308.19	17,249,604.20	284,704,736.85	245,751,603.75	6,735,158.91
4	117,861,477.00	104,326,399.80	35,585,018.19	34,224,766.01	561,276,348.30	483,107,480.10	13,628,836.08
5	70,103,915.70	65,278,343.70	23,612,975.89	24,954,861.57	379,815,161.40	284,124,310.20	7,946,266.67
6	147,124,134.90	134,061,227.40	50,804,485.55	49,972,218.27	718,761,145.05	580,928,054.40	17,511,442.28
7	87,629,364.99	81,982,073.70	32,927,044.96	32,642,192.18	432,948,135.60	363,099,622.94	8,595,680.21
8	172,266,284.10	162,098,951.01	65,731,741.87	65,242,690.41	852,710,746.95	721,548,877.50	15,832,220.06
9	101,353,702.20	94,841,191.20	39,112,563.31	38,236,722.97	504,114,032.70	459,005,162.40	7,864,099.47
10	204,484,872.60	191,585,297.40	77,420,021.60	76,822,697.04	1,046,717,625.15	930,965,478.30	15,979,759.77

Model2. Accordingly, the results shown in <Table 10> explain that the connected network has improved ability be cope with uncertain situations than independent operations.

TABLE 9. The ratio of the delivery cost from network connection to the total cost.

Experiment No.	1	2	3	4	5	6	7	8	9	10	Average
$ratio$ (%)	7.83	8.21	4.26	4.38	4.12	4.43	3.52	3.27	2.68	2.69	4.54

$$ratio = \frac{Cost_{MFC\sim RS}}{Cost_{Model2}} \times 100$$

TABLE 10. Relative evpi value.

No.	|I|	|T|	$EVPI_R$ (%)	
			Model1	Model2
1	200	7	15.03	8.92
2		14	14.50	8.89
3	400	7	11.70	8.73
4		14	12.27	9.74
5	600	7	12.30	10.24
6		14	13.00	8.25
7	800	7	11.50	7.86
8		14	11.19	7.52
9	1000	7	11.13	8.33
10		14	10.49	7.26

VII. CONCLUSION

The diversification of customer access channels is inevitable as the e-commerce industry grows. Several offline retailers operate online channels, and the opposite way is also happening like Amazon. In this aspect, the installation of logistics infrastructure in the urban area for faster service is an essential task according to competition for quick commerce services continues to intensify. With this context, importance for the installation and operation of MFCs is increasing. However, inefficiency in service operation including high rent and operating costs is a major obstacle to operate the quick commerce network, and appropriate countermeasures are needed.

This study determines the optimal location of MFC in establishing an omnichannel distribution network using MFC for the growing quick commerce environment and quantitatively measure the connection effect of online/offline distribution networks. The distribution network operation method was divided into independent operation and connected operation, and the Two-Stage Stochastic Optimization model was introduced to reflect the uncertain demand defined by the scenario. Through case studies, it was confirmed that the proposed mathematical optimization model presents the appropriate location of MFC. In addition, a comparison between the experimental results according to the two problem situations showed that the connection between the offline distribution network and the online distribution network could function more efficiently than each independent operation. Furthermore, the experiments find out that the effect of connection between distribution networks was most noticeable in transportation costs. The solutions of the two models presented differences from deterministic situations through the EVPI index. Based on the presented EVPI, it was confirmed that the distribution connected network operation alleviates uncertainty compared to the independent operation.

TABLE 11. References for the instances.

Parameters	References
c_n	[15] , [20]
cb_n	[14]
c_{ij}, c_{jr}	[21]
$Cap_r,\ Cap_j$	[7]
Q_{max}	Random Generation
Q_{min}	Random Generation
hc	[17]
f_j	[22]
cl	Random Generation
p_{um}	Random Generation

This study attempted to contribute to the quick commerce industry by showing the effect of the connection between distribution networks in the omnichannel logistics environment. By proving that it has economic results compared to independent operations, it supports the decision for appropriate operational measures in expanding the quick commerce logistics infrastructure. It can also contribute to the operation decision of MFC by showing the effect of connection of distribution network to uncertain demand. The MFC presented in this study not only functions as a dedicated warehouse for online demand, but also has the effect of sharing the demand burden of retail stores. This means that by expanding the operating range of MFC, the value of its utilization can be added. Therefore, the results of this study can be used as a basis for expanding the infrastructure of quick commerce services, including MFC, in the growing e-commerce industry.

In this study, we collect and utilize actual data to reflect the real world. However, due to practical restrictions, it was limited in many contents such as demand for online/offline distribution networks and actual facility operation costs. With precise data and information, stochastic approach will be applied to complicated uncertain problem with more scenarios. And this advanced approach can show the MFC's capability to cope with uncertain demand clearly. In addition, in this study, online/offline demand is strictly separated. In the actual omnichannel environment, various types of services such as delivery at offline stores, delivery at MFC/offline stores, and pickup at offline stores after online orders are possible. So, it is expected that research that better reflects the real situation will be conducted if various service models are presented and approaches are carried out accordingly.

APPENDIX

See Table 11.

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