Item-Location Assignment to Responsiveness for Fulfilling Rush Demands in a Manufacturing Network

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***Abstract*—This study investigates the business impacts of sustainability and managerial insights in terms of the robustness of a logistics system. A mathematical optimization model and a distribution responsiveness index are developed in this paper. The index includes stocking distributiveness, transportation link diversity, and service level. The study identified a discontinuous relationship between costs and responsiveness through the operational decision of redistribution. Knowing this relationship will allow managers to determine the minimum investment to drive performance improvement and thus, make the best business-level decision at the appropriate moment. In a proper ratio of urgent to non-urgent, the advantage of item-reallocation will be emphasized if distribution responsiveness is better after its reallocation. After reallocation, the distribution center can achieve better distribution responsiveness with low inventory costs and total cost (R/C ratio). When transportation costs increase after item-reallocation, item-reallocation cannot obviously help the distribution center enhance responsiveness (R/C ratio). When fixed costs are low and facilities increase after item-reallocation, distribution responsiveness (R/C ratio) is likewise high regardless of item-reallocation.**

***Index Terms*—Stocking item reshuffling (SIR), location-inventory network, Distribution network responsiveness.**

I. Introduction

A. Motivation and Research Opportunity

Responsiveness and operating costs are generally believed to contradict each other. A distribution center for fast delivery tends to significantly reduce inventory in each phase of the commodity circulation process as the cost and risk of goods on hand increases. Meanwhile, customers always ask for instant replenishment to supplies. A short lead time for order fulfillment is better; customers absolutely cannot tolerate shortage. To meet the requirement of retail terminals for replenishment, the distribution center must be capable of making fast delivery. Effective supply chain management can result in the rapid speed and elasticity in enterprises and reduce operating cost while improving the delivery promise capacity for customers. Conventional management strategies seek to address the uncertain requirements of customers by building distribution centers or enhancing the prepared inventory. Therefore, this strategy increases facility costs and the cost of inventories, eroding corporate profits. Unfortunately, increasing operating costs do not necessarily translate to any tangible improvement in performance. The relationship between operating costs and performance is nonlinear stepwise.

Overall, increases in storage capacity and inventory at the end can improve the response ability to deliver. In contrast, centralized storage in a central warehouse can reduce the cost of inventories, and centralized delivery can reduce transportation cost. However, decision makers encounter difficulties in judging how costs increase based on a simple rule to enhance the performance of a supply chain and whether achieving this performance is worthwhile. Only several parts, such as some after-market parts of automobiles, have to maintain a high supply rate to prevent customers from waiting. However, for the majority of parts with a low replacement rate, customers can understand a long wait. Managers are more or less convinced that centralized inventory can reduce costs and decentralized inventory can improve responsiveness. However, many decisions related to decentralized inventory do not enhance responsiveness but instead increase carbon emission because of transshipment.

Taking the planning of the distribution center and supply chain response speed in consideration, distributors make use of risks and benefits resulting from the distribution responsiveness of goods to determine the degree of distribution responsiveness based on customers' demand for delivery. When a distribution center's inventory management of items is conducted optimally, and when the number of facilities are increased or reduced according to the needs of retailers, distribution amount, and efficiency can be achieved by using a scale economy and thus, the total cost of inventories can be reduced.

In this research, a novel model is built for analyzing responsibility behavior. In this study, the best location of candidate distribution centers and an optimal item inventory for all distributors were determined based on the principle of optimal item-reallocation. We then analyzed the responsiveness of the suggested distribution network. The relationship among the principle of item-reallocation, distribution network responsiveness, and sustainability were identified.

A network inventory model was used in this paper to indicate item inventory. This study integrated network and inventory models to design a supply chain distribution network through nonlinear integer programming. The number of optimal distribution centersand inventory were then manually selected from the models to reach the minimum total cost of distributors. Finally, the distribution responsiveness index was analyzed to measure the response capacity of all the distribution supply chains.

II. Related Literature

Ref. [1] Employed a nonlinear model to integrate location

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and inventory models and successive approximation and algorithm to determine the costs service that distribution centers must pay in delivering goods to terminal retail outlets. [2] developed an integrated factory site and inventory model. Factory sites, transportation, and the cost of safe inventories were included in the same nonlinear model. Finally, the number of distribution centers and inventory was determined.

Ref. [3] believed that although the expansion of facilities could improve response speed, this requires the investment of additional costs. [4] Integrated lead time with ability to create a cost-effective and responsive supply chain as a mixed strategy for linking production and logistics. However, the supply chain network that these models investigated did not take into consideration the inventory location assignment of items in the network. This study aims to integrate the previous concept of supply chain with responsiveness and quantitatively analyze the distribution network model to develop a standard index for making business-level decisions.

Ref. [5] suggest decisions in a supply chain distribution system should be considered in integration to avoid sub-optimization. Among the facilities location, inventory management, and distribution decisions, any two of the integration are discussed extensively. Please refer to [3] for the location-routing models, [6] and [7] for the inventory-routing models, and [2] and [8] for the location-inventory models.

Supply of reused products need more sophisticated operation in the entire network design and inventory replenishment policy. Quantity, quality, and timing of returned products are unknown in advance. Blind optimization without incorporating uncertainty can cause the resulting performance degenerated significantly if conditions were changed from the original understanding. However, the common formulation in stochastic programming can only optimize the system in the sense of expectation over all possible scenarios.

The EPR goal through product recyclability is investigated in [9], which contend that regulation standards should be raised gradually in order to urge firms in a competitive market constantly improve their product recyclability. We further propose various recycling policy instrument for pursuing the goal of design for environment (DfE). In [10]-[12], we examine the recycling practice as well as its impacts on the collection, environment, economy and social, providing a good example of setting up an efficient paradigm and various alternative policies are suggested in these reports. We demonstrate that this improvement will indeed result in changes for entrepreneurs and manufacturers toward green design and financial benefits for flourishing the recycling industry. We have also asserted that market competition and green technology innovation are key to make a recycling system sustainable. In [13], we demonstrate that the EPR goal is attained by which independent remanufacturers help the host product manufacturers establish their market share.

III. Model

Since the development of the location-inventory problems started years ago, various considerations and techniques have been studies extensively. Complete and sophisticated modeling has been reported in the literature. However, to study the properties of Nash equilibrium and nonlinear robustness is completely new to the operation management field. As most models follow the same design principle, we keep the basic opening and product flow decisions in the model. Additionally, the nonlinearity of safety stock fulfillment has to be included for the purpose of packaging supply.

In the distribution network, the quantity of the item supply of the distribution center is considered in the inventory model. Moreover, the limitations of upstream supply are not considered. We also assume that (1) The supply quantity from all distributors in the supply end is known and fixed; and (2) Goods can be replenished either by central or local warehouses.

The parameters and symbols are listed as follows:

TABLE I: SUMMARY OF SYMBOLS IN THIS PAPER

D	: Index set of all distribution centers,
C	: Index set of all retailers,
G	: Index set of all goods,
X_j	: Selected distribution center from a candidate $j \in D$,
Y_{ijk}	: Indicating center j should serves retailer $i \in C$ for item $k \in G$,
S_{jk}	: Inventory of distribution center j,
c_j	: Capacity of the distribution center j,
u_{ik}	: Annual average demand of retailer i for item k,
d_{ij}	: Distance from distribution center j to retailer i,
T_{ij}	: Transport costs from distribution center j to retailer i,
w_j	: Unit turnover cost for distribution center j,
h	: Unit holding cost of inventory,
z_a	: desire service levels,
σ_i^2	: Variance of daily demand for retailer i,
APL_k	: Average required lead time for items k,
M	: Haul mileage in a unit time.

A. Problem Definition

In our circular logistics network, a preliminary program is extended from previous models. Let the binary decisions x_i and y_{ij} indicate that if retailer i is selected as a distribution center and is served from distribution center j, respectively. Set μ_i and σ_i^2 as a yearly demand and variance of daily demand at retailer i, respectively. Whenever open a distribution center, a fixed cost f_i has to be paid. To place an order to distribution center j, there is a fixed cost F_j. Let the cost to ship x units of goods from the plant to a regional distribution center j is $v_j(x)$ and the cost to ship from retailer j to retailer i is d_{ij}. Let α be the desired percentage of retailers orders satisfied, β be the weight factor associated with the transportation cost, and θ be the weight factor associated with the inventory cost. In the statistic distribution, z_a represent the level such that $Pr(z \le z_a) = \alpha$. Let h represent the inventory holding cost per unit of product per year and $w_j(x)$ be the total annual cost of working inventory held at distribution center j if the expected daily demand at j is x. In the stochastic fulfillment cycle, L be the fulfillment lead time. Let the total cost for retailer j is

The program is given as

$$\min \sum_{j \in D} f_j c_j x_j + \sum_{i \in I} \mu d_{ij} y_{ij} + w_j \left(\sum_{i \in I} \mu_i y_{ij} \right) + h z_a \sqrt{\sigma_i^2 y_{ij}} \quad (1)$$

$$s.t. \sum_{j \in D} x_j \ge 1, \sum_{j \in D} y_{ijk} = 1, \forall_i \in C, k \in G \quad (2)$$

$$y_{ijk} - x_j \le 0, \forall i \in D, j \in C, k \in G \quad (3)$$

$$\sum_{j \in D} s_{jk} = \sum_{i \in C} u_{ik} \forall k \in G \quad (4)$$

$$s_{jk} \le \sum_{i \in c} u_{ik} y_{ijk} \forall j \in D, k \in G \quad (5)$$

$$s_{jk} \le APL_k M, \forall i \in D, j \in C, k \in G, \quad (6)$$

$$x_i, y_{ijk} \in \{0,1\}, \forall i, j \in I$$

To build a supply chain distribution network that is highly responsive, this model employs a location model to determine the location of the distribution center. Moreover, the model is employed to identify the optimal location of the distribution center and the optimal allocation of items in the distribution center, which will allow retailers to select the optimal distribution center to make replenishment with the maximum profit for the distribution center. The target network model consists of four parts. The first part refers to the fixed costs of the distribution center, the second refers to transportation costs from the distribution center to the retailer, the third refers to the cost of inventories of the distribution center, and the fourth refers to safety stock cost. Constraint (1) indicates that at least one distribution center shall be selected from all candidates. Constraint (2) indicates that the retailer shall choose one distribution center from all candidates j for the replenishment to be made. Constraint (3) indicates that the items of the retailer shall be replenished by distribution center j selected from all candidates. Constraint (4) indicates that the replenishment of items of the retailer should be avoided without distribution center j. Constraint (5) shows that each distribution center is allowed to be unequal. Constraint (6) shows that the supply can meet the distribution center's demand. Constraint (7) shows that the lead time of the item is within the range of transportation mileage, and it is divided into two ranges, namely, 1-days and 3-days.

A distribution network considers the commodity stocks of distribution centers and the related replenishment speed to retailers. The present study integrated the model of economic order quantity with the transport channel option to build an optimal mathematical model related to the timing of customer demand for commodities. Responsiveness and cost of distribution center are the key conflict points. This paper investigates the difference between the costs for improving responsiveness after reallocation and without reallocation. As such, a distribution center considers the centralized or decentralized placement of items in distribution facilities. In this model, the types and features of items are not considered in non-reallocation. For reallocation, we consider the item types and features.

A distribution center facing market competition considers an inventory policy and the storage location of goods based on the features of goods. The above factors are used to design an optimal distribution center to serve customers. This paper focuses on the selection of the location of a distribution center that will result in high responsiveness and an inventory mechanism based on commodity features. The distribution network in this paper has several layers: the first layer is the supplier, the second is the distribution center, and the lowest is the retailer and customer. The variables that this paper considers are listed in Table I. The index set $\boldsymbol{D}$ refers to the candidate distribution center; $\boldsymbol{y_{ijk}}$ refers to items that the distribution center assigned to the retailer; and $\boldsymbol{u_{ik}}$ indicates the demand. Supposing that a distributor sends supply to the assigned distribution center, the distribution center simply accepts the goods from the assigned upstream distributors. While distribution centers make assignments to many customers after the former received goods, but customers only accept the goods from one distribution center.

The parameters that this paper considered include the annual average demand of the retailer, the annual cost of inventories of the distribution center, delivery costs from the distribution center to the retail outlets, and the fixed costs of facilities. The mathematical model constructed in this paper is used to determine the optimal location of the distribution center and the inventory of items. Considering the competition among all distribution centers, this paper supposes that upstream suppliers for two distribution centers have no limitations in terms of supply.

IV. Analysis

At present, the business behaviors of supply chains are generally characterized by low gross benefits, diversified product items with a small quantity, short product life cycle, compliant social responsibility, and large changes in sales. These business behaviors underscore the importance of reducing stock time and improving the turnover rate of inventories. In this regard, an effective distribution system can improve the service level, maintain environmental sustainability, and promote internal operation efficiency. To enhance responsiveness, order fill rate and continuous supply rate are key factors that should be considered [14]. Given the different lead times between functional and creative products, the lead time of distribution should likewise be considered, except for the responsiveness to lead time of production. In the scope of the services market of all distribution centers, the delivery of each type of goods to the points that customers need is expected, as well as the quick fulfillment of their order.

We distinguished items according to the difference in days. Two item categories, namely, urgent and non-urgent items, were considered as the distinction principle. When item reallocation has not been implemented yet, the number of facilities or inventories increases in the model with respect to the customers' responsiveness, resulting in too high costs and the failure to reach the operating efficiency. Thus, the reallocation of goods was achieved. Distribution responsiveness indicators were used to analyze and compare the related problems prior and after item allocation.

This proposition data considered the experimental data made by [15] as the discussion verification of the proposition. The distribution center candidate locations and customer locations in Guangdong Province, China were identified. The experimental data were modified as the materials for this research. This proposition includes 10 retailers and 8 distribution centers. The average service level required by these members is 95%. Table II refers to the capacity of the distribution center; Table III refers to its inventory turnover cost. The unit transport cost NT $1.27 is multiplied with the transport distance determined in this paper.

TABLE II: CAPACITIES OF EACH DISTRIBUTION CENTER

DC	capacity c_j	cost $f_j c_j$
D1	530,000	1,852,320
D2	500,000	1,634,100
D3	470,000	1,532,400
D4	620,000	2,105,300
D5	400,000	1,238,040
D6	480,000	1,563,060
D7	600,000	1,932,400
D8	370,000	1,127,090

TABLE III: UNIT TURNOVER AND HOLDING COST

DC	w_1	w_2	h
D1	800	2,600	750,000
D2	600	2,800	650,000
D3	700	2,500	520,000
D4	1,200	3,000	800,000
D5	500	1,800	350,000
D6	600	2,100	580,000
D7	1,100	2,200	790,000
D8	400	1,500	200,000

1) Observation 1. In the proper ratio of urgent to non-urgent, the advantage of item-reallocation will be underlined when the distribution responsiveness improves after reallocation.

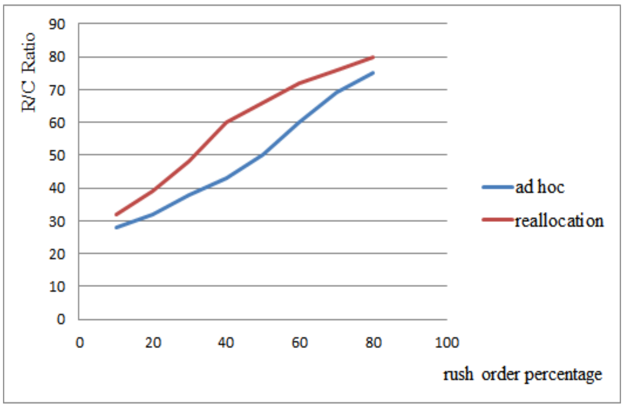

Fig. 1. The reallocation advantage when having more rush order demand.

When the number of items that must be managed in the distribution center increases, the proportion of the items stored should be considered, and item reallocation would be used to improve distribution responsiveness. The item-reallocation distribution center is then used to make a decentralized store of items with short lead time in the distribution center. In contrast, items with long lead time are stored in the distribution center. This paper aims to discuss reallocation on LAPL items (long average requiring lead time) and SAPL items (short average requiring lead time). The proportion of LAPL items to total items is used to represent the percentage of non-urgent items, as shown in Fig. 1. When the percentage of non-urgent items is used to compare the proportion of LAPL items with that of SAPL items, network responsiveness with item reallocation is better than those without item reallocation, as shown in Fig. 1. When the proportion of LAPL to the total items is up to 10%-30%, network responsiveness with item reallocation is higher than network responsiveness without item reallocation. However, the effect is not significant because of the large difference of proportions. When the proportion of LAPL to the total items ranges from 40% to 50%, and the proportions of LAPL and SAPL are relatively proper, the network responsiveness of item reallocation is significantly higher than network responsiveness without item reallocation by about 10%. With the increase of the proportion of LAPL, network responsiveness with item reallocation is still higher than that without item reallocation, but their responsiveness effects are gradually close, thus failing to underline the reallocation result.

2) Observation 2. After reallocation, the distribution center can achieve higher distribution responsiveness by using lower cost of inventories.

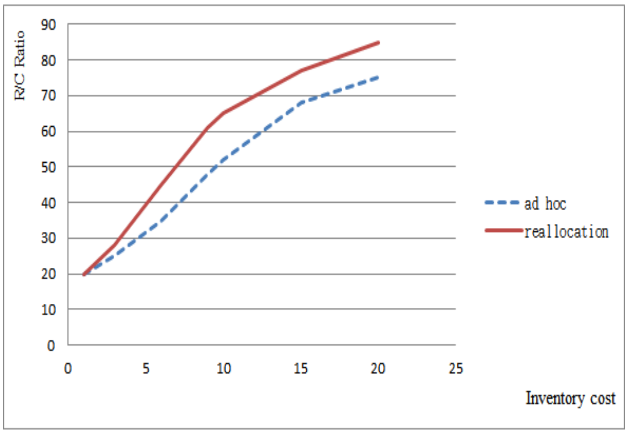

Fig. 2. The reallocation advantage when inventory cost is high.

To enhance distribution responsiveness and reduce costs, item reallocation can be used to induce the distribution center to attain higher distribution responsiveness with lower costs of inventories. Ideally, corporations aim to hold enough inventories to meet the retailers' demand for items. However, inventory holding costs preventing the distribution center from holding excessive inventories. Therefore, item reallocation can improve distribution responsiveness besides maintaining necessary inventories because of the customers' demand. The distribution center will locate LAPL in the central distribution center and make a decentralized placement of SAPL in the distribution centers by considering LAPL items and SAPL items as the basis of reallocation. Inventory cost analysis is shown in Fig. 2. When the distribution center realizes item reallocation, the network responsiveness is 10% greater than before. Thus, network responsiveness with reallocation is better than network responsiveness without reallocation under the same cost of inventories. The distribution center will place urgent goods in a local warehouse according to the characteristics of goods to quickly meet the customers' demand. As such, the safe inventory of the retailer can be reduced and goods can be obtained more rapidly. As shown in Fig. 2, two items are distributed to the central and local distribution centers according to their characteristics.

3) Observation 3. After reallocation, the distribution center should attain better network responsiveness with reduced total costs.

The costs of the distribution center are diversified, which include the costs of facilities, transportation, warehouse, inventory, materials, and handling. These activities are correlated. Costs were used to discuss distribution network responsiveness and analyze whether the item reallocation can make the distribution center improve distribution responsiveness with reduced total costs. The reallocation method was used to centralize or decentralize LAPL and SAPL items in the distribution center. When the distribution center invests more total costs to increase network responsiveness, the network responsiveness with reallocation was 10% higher than network responsiveness without reallocation. Therefore, with the investment of total costs, the distribution center selects item reallocation that can achieve distribution network responsiveness.

4) Observation 4. When the transport cost rises after item reallocation, item reallocation still hold advantage to help the distribution center to improve network responsiveness.

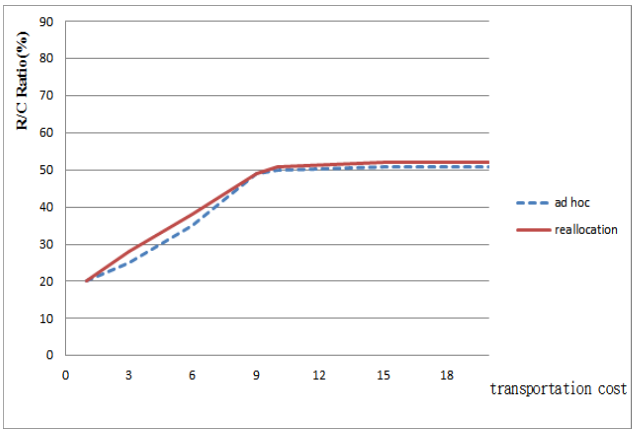

Fig. 3. The advantage of reallocation is invariant when transportation cost varies.

In the logistic cost of the distribution center, transport costs are essential. If the distribution center wants to improve transport costs and distribution responsiveness, item reallocation must be employed. In case of reducing delivery volume, reaching vehicle transport or a large-scale delivery cannot be achieved. However, retailers can frequently receive products, and thus trustworthiness can be improved. As shown in Fig. 3, the distribution center wants to increase transport costs from 20,000. Hence, network responsiveness can make the distribution center make more item distribution because of the investment of transport costs. However, when network responsiveness reaches up to 50% under a fixed transport distance, the increased transport costs come from multiple transports. Thus, with and without item reallocation, network responsiveness for transport costs increasing to more than 100,000 are maintained within the range from 50% and 55%, and no significant increase was observed.

5) Observation 5. The network responsiveness with and without item reallocation are identical when fixed cost varies.

The facilities in the distribution system have to determine the proper geographic location. The factors of the locations of retailers and manufacturers are usually examined. Transportation aims to connect all the points in the work, and thus, the location points must be set at the market position to improve distribution responsiveness. When firms believe that fixed cost is the key cause for improving responsiveness, each warehouse can be added at a low fixed cost to reach faster distribution and lower distribution cost, as expected. As shown in Fig. 4, when the distribution center started to expand market points and established more facilities to provide services with limited costs, network responsiveness with and without reallocation were largely different. Their network responsiveness will be maintained in a better responsiveness range. However, because the fixed cost is larger than other costs, corporations will find it difficult to reach this goal.

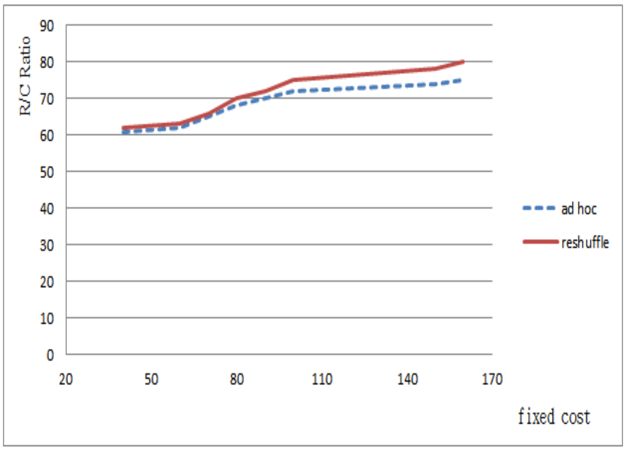

Fig. 4. The advantage of reallocation is invariant when fixed cost varies.

V. Conclusions

This paper primarily investigates responsiveness and the product features of distribution centers when enterprises make long-term planning. In addition, this study solves the minimum cost using a mathematical model. First, in terms of the proper ratio between urgent to non-urgent, the advantages of item reallocation were confirmed if distribution responsiveness is better after reallocation. Moreover, implementing centralized and decentralized items through item reallocation increased the responsiveness of the distribution center. After reallocation, the distribution center can achieve better responsiveness with reduced cost of inventories. Through reallocation, we centralized LAPL items in the distribution center and decentralized SAPL items in the local distribution center. Such actions reduced the inventory cost. Observation 3 is similar to the cost of inventories in Observation 2. After reallocation, the distribution center attained better distribution responsiveness with reduced total cost. Item reallocation does not significantly help in improving distribution responsiveness. Given that item reallocation cannot cause large-scale transportation and does not affect cost reduction, greater investment of transport costs cannot result in high responsiveness. When fixed cost is lower and facilities are greater in number, the distribution responsiveness is the same regardless of item reallocation.

In practice, goods will face different demands because of the slack and busy seasons. Therefore, we suggest that the uncertain factors of demand be added in future studies to find solutions that are appropriate for existing states. This paper simplified the cost set, and supposed transport costs were simply related to transport distance. In the industry, transportation with scale economy will reduce the unit cost by increasing transport times. Thus, in future studies, the economic scale of transportation can be considered.

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