# Intelligent Fitness Equipment Supply Chain Optimization Considering Product Differentiated Service Level

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**Abstract.** With the rapid development of artificial intelligence technology and the growing awareness of people's exercise and fitness, the intelligent fitness industry is developing rapidly. Intelligent fitness equipment supply chain management faces the challenge of reducing cost and increasing efficiency and enhancing the competitiveness of enterprises. Therefore, on the basis of three-level supply chain, CDC was added to reconstruct supply chain, and the supply chain network optimization problem considering product differentiation service level was proposed, and the integer programming mathematical model of this problem was constructed. Secondly, the large-scale digital professional simulation software Supply Chain Guru (SCG) is used to analyze and compare the supply chain cost and product service level under the four scenarios by using the network optimization function. The simulation results show that the model and method can provide guidance for enterprises to make supply chain management decisions of product differentiation service level.

**Keywords:** intelligent fitness equipment; supply chain network optimization; differentiated service level; simulation

## 1 Introduction

With the construction of a healthy China, the rise of national fitness as a national strategy, and the transformation of people's lifestyles, participating in physical exercise is becoming a popular way of life. However, as the pace of work and life continues to accelerate for people at present, it is often difficult to fix their fitness time, even fitness venues and methods. Meanwhile, the rapid development of artificial intelligence technology has led to the upgrading of a large number of traditional sports equipment. By pushing comprehensive fitness services such as fitness plans, guidance, and reminders to users, intelligent fitness equipment has greatly improved the scientificity, entertainment, and fun of the fitness process. The market demand for the intelligent fitness equipment industry has increased significantly. Live streaming has led to an increasing popularity of home fitness, and intelligent fitness equipment has increasingly become a hot spot in the industry. The industry competition is becoming increasingly fierce. How to reduce the operating costs of the supply chain and improve the market competitiveness of intelligent fitness technology enterprises has become an urgent problem to be solved.

PMIS 2024, March 15-17, Changsha, People's Republic of China

DOI 10.4108/eai.15-3-2024.2346569

The theory of differentiation strategy mainly involves factors such as product, channel, price, and service. With the improvement of AI technology and living standards, the improvement of product quality and service has become an inevitable development trend to meet consumer demand [1-2]. Market segmentation and distribution methods are becoming the key to improving market competitiveness, so the differentiated service issue has become the focus of enterprise management. And relevant scholars have conducted a lot of research on differentiated services. For example, Gefen et al. proved that product service level was an effective means to improve customer satisfaction, expand market share, and improve the competitiveness of enterprises [3]. Differentiation strategy can influence customer perception, Nan et al. considered providing differentiated services for different customers [4]. Zhang et al. presented the differentiated service model through the mixed channels of network and entity and found that differentiated pricing had a certain relationship with service quality [5]. Ding et al. studied the supply chain channel coordination strategy based on differentiation strategy and consumer effectiveness [6]. Based on customer segmentation, Han et al. focused on improving customer satisfaction by adjusting service levels [7]. Ma et al. built a two-cycle dynamic pricing model based on the behavioral pricing perspective and game theory and studied the pricing strategy of enterprises by analyzing the degree of service differentiation and cost [8-9]. Wang et al studied the optimization problem of transportation subsidies with group differentiation [10]. Jin et al. built a supply chain game model to analyze the impact of brand differentiation on the market entry of invading manufacturers based on the manufacturer's after-sales service [11].

Facing the saturation of the product market and diversiform demand increasingly deeper, some enterprises not only provide products but also improve the service level to improve customer value. Jain et al. reduced the opportunity to exploit economies of scale in capacity decisions by investing in dedicated resources to extend product differentiation into services. Service level plays a key role in determining customers' purchase decisions, and customers with different evaluations of product quality may have different sensitivity to service level [12]. Allon et al. regarded the delivery cycle experienced by customers as a measure of service level [13]. Besides, other scholars considered distinguishing service levels through effective resource management. For example, Boyaci et al. studied the impact of capacity cost structure on firm pricing and product positioning [14].

Based on the above analysis, most of the existing studies on differentiated service focus on customer-differentiated service or a single product, but few studies on differentiated supply chain optimization of service level for multiple types of products. Therefore, on the basis of product demand classification, this paper takes into account the differentiated management characteristics of different categories of products, sets differentiated service levels for different types of products, and constructs a three-level and reconstructed supply chain cost minimization model under a competitive environment. In addition, Supply Chain Guru(SCG) software, a large-scale digital professional analysis tool, is used for simulation and optimization, and transportation costs, operating costs, inventory holding costs, and profits of different classified products are evaluated under the constraints of service levels. It provides decision-making support for intelligent fitness equipment technology enterprises to design different operational strategies for various products in the business process, to gain advantages in the fierce competition in the fitness industry.

## 2 Problem description and modelling

### 2.1 Problem description

Considering a three-level tree supply chain network consisting of factories, multiple Regional Distribution centers (RDCs), and several dealers, the network structure is shown in **Figure 1**. In the three-level tree supply chain network, dealers do not have inventory, the RDCs have inventory and adopt the inventory control strategy (s, S), and the factory has sufficient supply capacity under normal circumstances. In the first stage, the factories deliver products to RDCs, the factories are responsible for transportation and distribution, and the mode of full truckload (FTL) is adopted. In the second stage, RDCs deliver products to the dealers within the coverage of the distribution center in accordance with the principle of proximity, and RDCs adopt the mode of express parcel transportation.

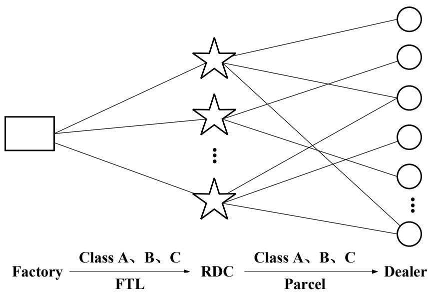


**Fig. 1.** Supply chain network structure.

In the reconstructed supply chain network, the procurement strategy is “Central distribution centers (CDCs) and differentiated service”, CDCs are added in the supply chain network. The factories deliver the products to CDCs for storage, and CDCs adopt the strategy of “differentiated” processing. The products of Class A will be delivered to RDCs from CDCs by FLT, and then RDCs provide services to dealers by the mode of express parcel transportation, aiming to improve the service level of Class A. The products of Class B and C are provided by parcel shipment from CDCs to dealers, as shown in Figure 2.

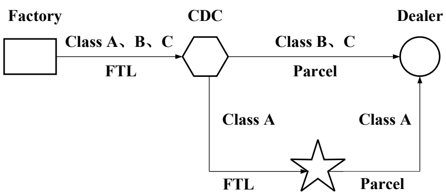


**Fig. 2.** The reconstructed supply chain network structure.

Assuming that the location of the factory, RDCs, CDCs, and dealers are determined, and the product demand of each dealer is known, how to determine the transport flow of the factory to each CDC, and each CDC and each RDC to the dealer is a problem to be solved.

## 2.2 Modelling

The model assumes the following:

(1) A RDC can only purchase products from a factory;

(2) A dealer can only purchase products from a RDC;

(3) A RDC can only purchase products from a CDC;

(4) A dealer can only purchase products from a CDC ;

(5) The quantity of available vehicles is infinite;

(6) The initial inventory of all facility sites is 0.

For a better understanding of the mathematical problems, here we give a comprehensive summary of all mathematical notations and definitions for various parameters and variables in Table 1.

**Table 1.** Mathematical notations and definitions of various parameters and variables.

| Var. | Definition |
|---|---|
| $m$ | Set of the factories in supply chain network |
| $n$ | Set of the dealers in supply chain network |
| $i$ | The RDC $i$ of RDCs in supply chain network |
| $j$ | The CDC $j$ of CDCs in supply chain network |
| $k$ | The number code of the delivery area |
| $l$ | The product number code |
| $g_l$ | The wight of product $l$ |
| $w$ | The product value |
| $Q$ | The total quantity of all products |
| $Q_{mi}$ , $Q_{mj}$ , $Q_{in}$ | The product transportation quantity from factory $m$ to RDC $i$ ,CDC $j$ , and dealer $n$ |
| $Q_{jn}$ | The product transportation quantity from CDC $j$ to dealer $n$ |
| $h$ | The percentage of inventory holding cost |
| $X$ | The truckload quantity to RDCs |
| $P_k$ | The unit price by parcel shipment in area $k$ |
| $P_{mi}$ , $P_{mj}$ | The unit price by truckload from factory $m$ to RDC $i$ ,and CDC $j$ |
| $P_{ji}$ | The unit price by truckload from CDC $j$ to RDC $i$ |
| $D_{mi}$ , $D_{mj}$ | The distance from factory $m$ to RDC $i$ , and CDC $j$ |
| $D_{jn}$ , $D_{ji}$ | The distance from CDC $j$ to dealer $n$ , and RDC $i$ |
| $F_m$ , $F_i$ , $F_j$ | The fixed operation cost of factory $m$ , RDC $i$ , CDC $j$ |
| $V_i$ , $V_j$ | The inventory level of RDC $i$ , and CDC $j$ |
| $Q_A$ , $Q_B$ , $Q_c$ | The quantity of products A, products B, and products C |
| $Y_{i,n}$ , $Y_{j,n}$ | If RDC $i$ and CDC $j$ delivery products to dealer $n$ , it is 1; Otherwise, it is 0 |

### 2.2.1 The baseline model

The total cost consists of three parts for the supply chain network: transportation cost, facility operation cost, and warehouse holding cost. The objective function is Equation (1)-(4).

$$\min f = TC + FC + HC \tag{1}$$

$$TC = \sum_{i=1}^{i} \frac{\overline{Q}_{mi}}{X} D_{mi} P_{mi} + \sum_{i=1}^{i} \sum_{n=1}^{n} \sum_{k=1}^{k} P_k D_{in} Q_{in} \tag{2}$$

$$FC = \sum_{m=1}^{m} F_m + \sum_{i=1}^{i} F_i \tag{3}$$

$$HC = \sum_{i=1}^{i} V_i wh \tag{4}$$

In the baseline model, the flow rate between all levels meets the conservation of flow, see Equation (5).

$$s.t. \sum_{m=1}^{m} \sum_{i=1}^{i} Q_{mi} = \sum_{i=1}^{i} \sum_{n=1}^{n} Q_{in} \tag{5}$$

### 2.2.2 The reconstructed model

The objective function of the reconstructed model is the same as that of the baseline model, but the cost of each part has changed, as shown in Equation (6) - (8).

$$TC = \sum_{i=1}^{i} \frac{\overline{Q}_{mi}}{Y} D_{mj} P_{mj} + \sum_{i=1}^{i} \frac{\overline{Q}_{mi}}{Y} D_{mi} P_{mi} + \sum_{j=1}^{j} \sum_{n=1}^{n} \sum_{k=1}^{k} P_k D_{jn} Q_{jn} + \sum_{i=1}^{i} \sum_{n=1}^{n} \sum_{k=1}^{k} P_k D_{in} Q_{in} \tag{6}$$

$$FC = \sum_{m=1}^{m} F_m + \sum_{j=1}^{j} F_j + \sum_{i=1}^{i} F_i \tag{7}$$

$$HC = \sum_{j=1}^{j} V_j wh + \sum_{i=1}^{i} V_i wh \tag{8}$$

In the reconstructed model, the flow rate between all levels meets the conservation of flow, so the constraint conditions are shown in Equation (9) and Equation (10).

$$s.t. \sum_{m=1}^{m} \sum_{i=1}^{i} Q_{mi} = \sum_{i=1}^{i} \sum_{n=1}^{n} Q_{in} \tag{9}$$

$$\sum_{m=1}^{m} \sum_{j=1}^{j} Q_{mj} = \sum_{j=1}^{j} \sum_{n=1}^{n} Q_{jn} \tag{10}$$

If the service level of products A, B and C is satisfied $\alpha$ , $\beta$ and $\gamma$ respectively within the range of $D$ , then

$$\sum_{i=1}^{i}\sum_{n=1}^{n}(D_{i,n} > D?0:1)Q_A Y_{i,n} \geq Q_A \times \alpha \tag{11}$$

$$\sum_{i=1}^{i}\sum_{n=1}^{n}(D_{j,n} > D?0:1)Q_B Y_{j,n} \geq Q_B \times \beta \tag{12}$$

$$\sum_{i=1}^{i}\sum_{n=1}^{n}(D_{j,n} > D?0:1)Q_B Y_{j,n} \geq Q_B \times \gamma \tag{13}$$

# 3 Case study

## 3.1 Background

Company X is a technology company mainly engaged in intelligent fitness equipment, with nine products in four series, including smart wristbands, sports watches, body-sensing balance vehicle, and VR glasses. According to the market demand for the products, these nine products are divided into three categories of products A, B, and C, in which category A is smart wristbands (accounts for 81% of the total demand). The remaining seven products are classified as products B and C (account for 19% of the total demand). It has one smart factory in Shenzhen, five RDCs in Beijing, Shanghai, Chengdu, Xi'an, and Changsha, two CDCs in Zhengzhou and Guangzhou, and 144 dealers. The operation fixed cost and inventory holding cost of each site are shown in Table 2. The transportation cost, transportation quantity, and transportation frequency from factories to RDCs, CDCs, and CDCs to RDCs are shown in Table 3. RDCs and CDCs deliver products to dealers by the mode of express parcel transportation. There are 144 dealers. The dealers are divided into four regions: I, II, III, and IV from RDCs and CDCs to dealers, and the regional transportation cost is shown in Table 4. The data in the model is selected from a total of 108,828 orders of the company in 2022, which are not listed one by one in the article due to the massive data.

**Table 2.** The operation cost and inventory holding cost of each site.

| Sites | Operation fixed cost (Yuan) | Inventory holding cost (%) |
|---|---|---|
| FTY_Shenzhen | 500000 | 15 |
| RDC_Beijing | 200000 | 18 |
| RDC_Shanghai | 200000 | 18 |
| RDC_Chengdu | 200000 | 20 |
| RDC_Xi'an | 200000 | 20 |
| RDC_Changsha | 200000 | 20 |
| CDC_Zhengzhou | 350000 | 12 |
| CDC_Guangzhou | 350000 | 12 |

**Table 3.** The transportation cost, transportation quantity and transportation frequency of each site.

| From | To | Transportation cost (Yuan/km) | Transportation quantity (kg) | Transportation frequency(Day) |
|---|---|---|---|---|
| FTY_Shenzhen | RDC_Beijing | 4.2 | 500 | 14 |
| FTY_Shenzhen | RDC_Shanghai | 3.75 | 500 | 14 |
| FTY_Shenzhen | RDC_Chengdu | 3.6 | 500 | 14 |

| | | | | |
|---|---|---|---|---|
| FTY_Shenzhen | RDC_Xi'an | 3.9 | 500 | 14 |
| FTY_Shenzhen | RDC_Changsha | 3.45 | 500 | 14 |
| CDC_Zhengzhou | RDC_Beijing | 3.9 | 500 | 5 |
| CDC_Zhengzhou | RDC_Shanghai | 3.6 | 500 | 5 |
| CDC_Zhengzhou | RDC_Chengdu | 3.45 | 500 | 5 |
| CDC_Zhengzhou | RDC_Xi'an | 3.3 | 500 | 5 |
| CDC_Zhengzhou | RDC_Changsha | 3.15 | 500 | 5 |
| CDC_Guangzhou | RDC_Beijing | 4.2 | 500 | 5 |
| CDC_Guangzhou | RDC_Shanghai | 3.75 | 500 | 5 |
| CDC_Guangzhou | RDC_Chengdu | 3.6 | 500 | 5 |
| CDC_Guangzhou | RDC_Xi'an | 3.9 | 500 | 5 |
| CDC_Guangzhou | RDC_Changsha | 3.45 | 500 | 5 |
| FTY_Shenzhen | CDC_Zhengzhou | 2.85 | 1500 | 14 |
| FTY_Shenzhen | CDC_Guangzhou | 3.15 | 1500 | 14 |

**Table 4.** The operation cost and inventory holding cost of each site.

| Sites | Transportation rate (Yuan/Parcel) |
|---|---|
| I | 25 |
| II | 30 |
| III | 40 |
| IV | 20 |

In recent years, although the enthusiasm for home fitness has been unprecedentedly high, the popularity of intelligent fitness continues unabated, and the company's revenue is relatively stable, but profits are declining year by year, and operating costs are gradually increasing. One of the necessary preconditions for enterprises to maximize profits is to reduce supply chain operating costs as much as possible. Based on the challenges of efficiency improvement, the requirements of supply chain resilience, and operational safety, company X need to formulate new development strategies, restructure the supply chain structure, and optimize the supply chain network to further improve the supply chain service level and operational efficiency, and improve the supply chain resilience and risk resistance.

The following scenario analysis is presented:

**Scenario 1**: Baseline model.

**Scenario 2**: Reconstructed model, the service level of products A is 95% within 960km.

**Scenario 3**: Reconstructed model, products A, meanwhile the service level of products B and C is 90% within 960km.

**Scenario 4**: Reconstructed model, at the same time, allows RDCs to purchase directly from the factories, and the target service level of products A reaches 95% within 960km.

### 3.2 Simulation results analysis and discussion

Supply Chain Gura (SCG) simulation software is applied to solve the model, the supply chain optimization goal is minimizing cost in the baseline model, and the total cost is 68,447,083 (Yuan). Setting the demand coverage of 960km in the map, then it generates the transportation network, in order to analyze the transport routes that do not meet service requirements (the purple area indicates the demand coverage of each RDC with a radius of 960km, green area is the demand coverage of a radius of 480km, as shown in Figure 3.


**Fig. 3.** Demand coverage within 960km (two days).

As can be seen from Figure 3, most RDCs can deliver products to dealers within two days, but some take more than two days. It can be seen from the analysis of the current situation that the location of the factories deviates from the central area of the supply chain network. Therefore, the transportation distance is long, and the transportation cost is high in the first stage of the supply chain network. The existing RDCs distribution is not reasonable, and the improper selection of some distribution areas and distribution routes leads to the slow response speed of the supply chain, the delay of transportation and distribution, and the increase of the supply chain storage cycle. Besides, the supply chain structure is simple, and FTY_Shenzhen is responsible for the delivery of all RDCs while undertaking the production task. Overall, there is a lack of measures to deal with demand fluctuations, and the supply chain flexibility is poor.

Based on the analysis of the baseline model, it can be seen that the current situation of the supply chain mainly has the following problems:

(1) The current supply chain network structure is simple, the quantity of sites is small, the supply chain resilience is low, and the ability to resist risks is poor.

(2) The RDC layout is irrational, the quantity and network layout of RDCs do not match the dealer demand, and the RDCs are used inefficiently, which reduces the supply network performance.

(3) The transportation route selection is unreasonable. The transportation routes between some RDCs to dealers are not the optimal routing and select further transportation distance, which reduces the service level of the supply chain.

(4) The supply chain network is inefficient. It would not only increase transportation costs for a single warehouse serving all the sub-warehouses but also reduce the response speed to dealers, resulting in low efficiency of the whole supply chain network.

After supply chain reconstruction and considering product differentiation service level, the supply chain flow relationship under four scenarios is shown in Figure 4, and the cost and service level are shown in Table 4.

According to the comparative analysis of the results, it considers the internal risks of the supply chain and the service level of Class A in scenario 2. After the optimization of the supply chain network, two CDCs were added, located in Guangzhou and Zhengzhou, and the Shenzhen factory transports products to CDCs, which reduces the difficulty of shipment processing and the delivery density in the southern region. At the same time, CDCs are equipped with full varieties, and RDCs are equipped with staple products. It increases the supply chain network level, and it is more resilient than the original supply chain network structure. In scenario 2, the profit is the largest and the cost is the least. In scenario 3, the service level of Class B and C within 960km is improved on the basis of scenario 2, the total cost increases by 14.04% and the profit decreases by 6.18%. In scenario 4, the transportation cost of Class A delivered from CDCs to RDCs is lower than the reconstructed model.

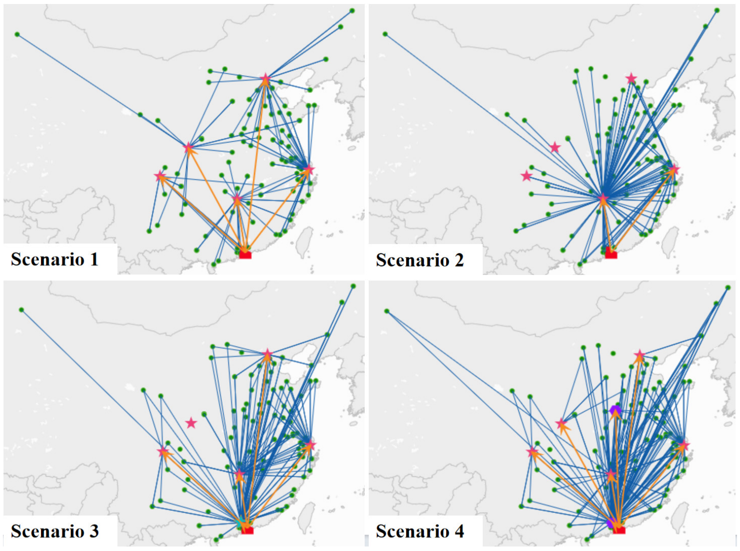


**Fig. 4.** Supply chain network under four scenarios (★ RDCs, ● Dealers, —The transport flow from sites to dealers, → The transport flow between sites).

**Table 4.** Comparison of financial data and service level in four scenarios.

| Scenario | Total profit | Total cost | Transportation cost | Operation cost | Stockholding cost | The proportion of demand for two-day arrival |
|---|---|---|---|---|---|---|
| 1 | 1127421465 | 68447083 | 62079369 | 1500000 | 4867715 | All products: 82.95%<br>Class A: 81.49% |
| 2 | 1145487755 | 50380793 | 45201340 | 1500000 | 3679453 | All products: 79.48%<br>Class A: 95.00% |
| 3 | 1138412070 | 57456478 | 51593645 | 1500000 | 4362833 | All products:94.06%<br>Class A: 95.00%<br>Class B and C: 90.00% |
| 4 | 1143670867 | 52197681 | 47344848 | 2200000 | 2652833 | All products: 79.73%<br>Class A: 95.00% |

## 4 Conclusion

With the development trend of the intelligent fitness industry, the multi-stage supply chain network optimization problem considering product differentiation service level is a practical problem with wide application prospects. How to reduce the cost, increase the efficiency and strengthen the chain? The companies can formulate the supply chain strategic layout of the differentiated service level of various products, to increase facilities utilization and improve the market competitiveness. In this paper, the supply chain optimization of intelligent fitness equipment considering product differentiation service level was proposed, and a three-level supply chain benchmark model was established by factories, RDCs and dealers. In order to improve the service level of staple products, DCDs were added to reconstruct the supply chain, and a supply chain network optimization model was established. In order to solve the model, SCG software is used to analyze the financial data and product service level in different scenarios. The study shows the impact of product differentiation service level on supply chain strategy under different scenarios, which can help intelligent fitness equipment companies formulate differentiated management strategic objectives, improving service level and operating efficiency. Future research could focus on node failures caused by emergencies, and study the issue of improving the level of supply chain resilience.

**Acknowledgments.** This work was supported by the Natural Science Foundation of China [Grant No.72201199].

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