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Research on Supply Chain Optimization: A Case Study of Enterprise O

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Abstract. With socioeconomic development and population growth, demand rises steadily. Against the backdrop of global collaborative and intelligent supply chain development, issues like frequent bullwhip effect, low automated operation efficiency and scattered warehouse goods restrict overall supply chain performance and corporate core competitiveness, calling for targeted optimization. This study focuses on the field of supply chain management, aiming to mitigate the bullwhip effect, improve the efficiency of automated operations and enhance the density of goods storage. This study adopts the literature research method and case analysis method to verify the feasibility of optimization strategies. The study shows that promoting multi-enterprise cooperation can mitigate the bullwhip effect and reduce manual workload; constructing a three-dimensional best-selling index model with the entropy method to formulate storage location scheduling can enhance storage density. This study can provide references for supply chain management practices and help enterprises boost their core competitiveness in the supply chain.

Keywords: Logistics and Supply Chain Management, Bullwhip Effect, ESG; Entropy Weight Method, Efficiency Optimization

1. Introduction

The global supply chain system is undergoing an unprecedented transformation toward collaboration and intelligence. As the world's population grows and socioeconomic development continues, supply chain operations face more and more pressures and difficulties due to the growing worldwide demand [1]. The core dilemmas are manifested in the following aspects: the bullwhip effect amplifies demand layer by layer along the supply chain, resulting in distorted demand information and warehousing space planning and utilization still have room for optimization. The bullwhip effect causes demand information to be magnified progressively along the supply chain, leaving Enterprise O trapped in the coexistence of unbalanced production planning, overstock, and stockouts, impairing order delivery efficiency and customer satisfaction [2]. With the upgrading of operational modes, scientific planning of warehousing space and goods location allocation serves as a critical support for enhancing operational efficiency [3]. The lack of scientific warehousing space planning contributes to inefficient storage, with disorganized goods and inefficient picking routes.

This study integrates CPFR technology and ESG theory to establish a collaborative planning, forecasting, and replenishment system. Adopting literature review, case analysis, and the entropy

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method, it also constructs a three-dimensional hot-selling index model incorporating seasonality, frequency, and quantity. It aims to provide feasible solutions for mitigating the bullwhip effect and improving warehousing operational efficiency and intelligence.

2. Overview of relevant theories and models

The bullwhip effect refers to the information distortion phenomenon in the supply chain where the fluctuation range of orders placed is significantly greater than that of end-consumer demand and amplifies step by step when demand information is transmitted to suppliers [2]. In actual operations, upstream enterprises formulate specific production plans and material supply decisions based on the actual demand information fed back by downstream partners. Once demand information is distorted, its negative impact will be continuously transmitted and amplified along the supply chain, resulting in an obvious deviation between the demand information obtained by the original suppliers at the source of the supply chain and the real demand information of consumers in the end market [4].

Collaborative Planning, Forecasting and Replenishment (CPFR) achieves full-chain synchronization of demand forecasting, production planning and inventory replenishment through information sharing, joint decision-making and process coordination among upstream and downstream enterprises. It improves supply chain responsiveness, reduces costs and enhances resilience, representing an upgrade and extension of Vendor Managed Inventory (VMI) and Efficient Consumer Response (ECR) [5]. As a typical collaborative management technology, it is reflected in operational, tactical and strategic aspects [6]. It relies on transparent information mechanisms and joint forecasting to realize multi-dimensional collaborative implementation [7].

ESG is the collective term for Environmental, Social, and Governance, serving as a core theoretical framework for measuring corporate non-financial performance. It emphasizes long-term value creation rather than short-term financial returns [8]. The environmental dimension (E) focuses on ecological practices including carbon emissions, energy use, pollution control and green operations; the social dimension (S) emphasizes responsibility to employees, supply chains, customers and communities; the governance dimension (G) stresses internal governance, compliance and risk prevention. The three dimensions jointly constitute the institutional and practical foundation for the sustainable development of enterprises [9]. ESG effectively enhances enterprises' capacity for sustainable development and long-term operational resilience, while providing important theoretical and practical support for investment decision-making, risk management, and high-quality sustainable social development.

The three-dimensional index model is a quantitative evaluation tool that uses three interrelated dimensions and assigned indicator weights to create comparable indexes from the characteristics of an evaluated object.. It overcomes the limitations of single-dimensional evaluation, and supports decision-making. Its indicator system should be systematic, complete, quantifiable, easy to obtain, and standardized. Weight distribution must be scientific, using a combination of qualitative and quantitative methods to ensure the total weight equals 1. This model can shift from qualitative analysis to quantitative measurement and form a scientific and reliable decision-making basis. It is widely applicable and provides a theoretical framework for the optimization of evaluation systems.

3. Mitigating the bullwhip effect through the integration of CPFR technology and ESG

This study proposes integrating CPFR technology with ESG theory to weaken the bullwhip effect on supply chains. For instance, Enterprise O has applied the CPFR model to for enhanced collaboration, planning, forecasting, and replenishment. The two enterprises have connected

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upstream and downstream platforms (WMS→WES) to achieve real-time data synchronization and transparent warehouse management, improving supply chain collaboration, resilience, and resource efficiency, in line with ESG environmental and governance standards [10]. Enterprise L formulates strategies with Enterprise O based on production capacity and efficiency, and cooperates with multiple enterprises to build a platform for timely data transmission and feedback [11]. Enterprise L shares brand-side data, while Enterprise O synchronizes logistics information. They have jointly built a data sharing platform to unify objectives in production, warehousing, and distribution. The implementation of CPFR brings values. Enterprise L optimizes production scheduling to avoid stockouts and overstocking, raising inventory turnover. Enterprise O achieves precise replenishment to reduce warehouse congestion and improve distribution and order fulfillment rates.

On this basis, their cooperation extends to the environmental (E) and social (S) dimensions of ESG. Environmentally, the two enterprises reduce energy consumption and logistics emissions to achieve low-carbon operations. Socially, stable supply ensures consumer experience and employment security, shifting supply chain collaboration from efficiency improvement to social value creation. The governance (G) dimension of ESG provides a long-term guarantee for CPFR collaboration. The two enterprises realize full-chain traceability and integrate collaborative data into the ESG disclosure system. This standardizes cooperation, stabilizes supply and demand fluctuations, and transforms the effect of mitigating the bullwhip effect from short-term operational improvement into long-term sustainable supply chain ecosystem construction.

4. Introduction of the three-dimensional index model and K-Means clustering

4.1. Data preprocessing

Analysis of Enterprise O reveals bottlenecks caused by seasonal demand fluctuations. Hot-selling and slow-moving products have not been allocated to appropriate storage locations based on data analysis, resulting in low picking efficiency. To systematically address these issues, a three-dimensional indicator system consisting of sales volume, frequency, and seasonality is constructed. The clustering analysis model is adopted to accurately identify and screen hot-selling SKUs, and the storage layout of goods is dynamically optimized based on the analytical results. Categories with high sales volume, high turnover, and significant seasonal characteristics are prioritized for placement near the shipping area, thereby shortening handling paths, reducing operation time, and effectively improving the overall efficiency of the sorting process.

The current season's outbound volume data is exported from the WES system, and blank data is cleaned before conducting a full-table pivot analysis. SKUs are set as row labels, and the sum of original order quantities is set as values to obtain the required pivot table. After that, the influence weights of each dimension are comprehensively evaluated and determined.

4.2. Construction of the three-dimensional index model

Standardization of the collected data is a core step to eliminate interference caused by differences in dimensions and magnitudes across various indicators, ensuring that data from different dimensions can be compared and calculated under a unified standard [12].

Step 1: Preprocess the original data through normalization to eliminate dimensional differences among different indicators.

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$$a_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j) + \varepsilon} \tag{1}$$

Where a_{ij} denotes the j-th indicator value of the i-th SKU, and ε represents an infinitesimal constant approaching zero to avoid a zero denominator.

Step 2: Calculate the proportion of each dimension indicator.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{2}$$

Step 3: Calculate the entropy value of each dimension indicator.

$$e_{ij} = -\frac{1}{\ln(n)} \bullet \sum_{i=1}^{n} \left(b_{ij} \bullet \ln\left(b_{ij}\right)\right) \tag{3}$$

Where e_{ij} represents the variation degree of the j-th indicator, and n is the total number of SKUs.

Step 4: Calculate the information utility value (difference coefficient).

$$d_j = 1 - e_j \tag{4}$$

Step 5: Determine the weight of each indicator.

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{5}$$

where m is the number of indicators.

After running the programming code and calculating the hot-selling index results for each SKU, partial results are presented in Table 1.

Table 1. Examples of partial scores of apparel SKUs after seasonal weight adjustment

Serial Number	SKU Code	Comprehensive Evaluation
1	**B03-3/XXL	56.51361234
2	**B03-3/S	5.224076754
3	**830-2/M	1.314440348
4	**825-2/L	6.507906168
5	**828-2/M	0.877505941
6	**823-2/L	1.693084952
7	**177-5/XXL	4.567647089
8	**025-7/M	20.83852826
9	**980-1/3XL	2.181477185
10	**025-7/L	21.66994777
11	**184-3/XL	1.749097429
12	**161-3/XL	21.28510212
13	**D09-7/XL	20.28034156
14	**021-6/L	4.544331168
15	**153-8/L	21.48535032

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Table 1. (continued)

16	**047-1/XL	35.96601385
17	**153-8/M	14.649583
18	**346-2/XL	5.858175596
19	**980-2/L	6.754357335
20	**957-1/L	4.74910936

The data indicates that the constructed three-dimensional (sales volume, frequency, seasonality) index model can be used to analyze the distribution characteristics of hot-selling products in different seasons, providing quantitative analysis and decision support for the refined management and control of inventory. Specifically, the storage location layout of SKUs can be optimized based on the index values output by the model, and the display locations and replenishment frequencies of hot-selling products can be dynamically adjusted, thereby achieving dual improvements in outbound efficiency and customer satisfaction.

4.3. K-Means clustering analysis

To further objectively classify the hot-selling degree scores obtained from the aforementioned three-dimensional index model, the K-Means clustering algorithm is used to determine the corresponding score thresholds, thereby achieving a scientific classification of product popularity levels. For this purpose, a clustering analysis table (Table 2) is compiled.

Table 2. Summary table of clustering analysis results for apparel SKUs

Overall Clothing Evaluation Report							
Cluster	SKU Types	Mean Value	Standard Deviation	Mid-Value	Minimum	Maximum	Median of The Group
1	558	33.101274	10.0454800	30.674823	20.2463	55.6614	30.674823
2	213	78.342322	14.5654509	75.878123	56.2095	105.5382	75.878123
3	2067	7.155539	5.3572633	5.827901	.8775	20.1158	5.827901
Total	2838	17.599691	21.4551190	9.135990	.8775	105.5382	9.132263

According to the above statistical results, Cluster 2 has the highest average comprehensive score (78.34) and is classified as hot-selling products; Cluster 3 has the lowest average comprehensive score (7.16) and is classified as slow-moving products; Cluster 1 is at a medium level and is classified as ordinary products.

Thus, through the construction of the three-dimensional index model and K-Means clustering analysis, Enterprise O can adjust storage locations according to the popularity levels of different seasonal SKUs, and arrange goods placement based on the forecasted shipment volume, thereby improving picking efficiency. The warehouse layout diagram with rearranged storage locations according to product popularity levels is shown in Figure 1.

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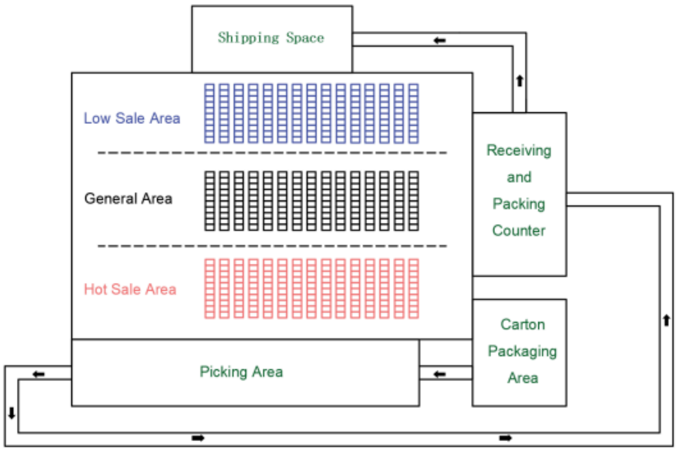

Figure 1. Warehouse layout with rearranged storage locations

5. Conclusion

Using literature review, case analysis, and the entropy method, this study conducts optimization research from two dimensions: supply chain collaboration and warehouse storage location optimization. Targeted strategies and schemes are proposed to provide theoretical references and practical paths for enterprises' supply chain management upgrading. The research verifies the practical value of the integrated model and optimization methods, which can effectively solve the supply chain operation problems of Enterprise O and enhance its core competitiveness.

However, this study only takes Enterprise O as a single research object, and the universality of the optimization strategies needs to be verified. The research on the mechanism design and quantitative evaluation of the integration of CPFR and ESG is relatively preliminary, lacking specific indicators and standards. In the future, research samples can be expanded to extract a universal framework, the quantitative research on their integration can be deepened, and simulation tools combined with actual operation data can be introduced to verify the effectiveness of strategies.

Future research can explore the cross-industry application of the integration of CPFR and ESG and explore the application value of digital technologies. Low-carbon environmental protection and operating costs can be incorporated into the storage location optimization model, and the integration path of intelligent equipment and optimization models can be explored combined with new warehouse models. A supply chain resilience evaluation system can be constructed by integrating bullwhip effect mitigation, warehouse efficiency improvement, and risk prevention and control, so as to explore adaptive supply chain optimization strategies.

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