Study on Balanced Inventory and Supply Management of Small Quantities of Materials

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Abstract: The paper addresses the problem of material inventory management under the multi-species small-lot production model, taking Company Z as the research object, and proposes an optimization plan through a data-driven approach. The study uses techniques such as hierarchical analysis, regression analysis and machine learning algorithms to determine the equilibrium point between inventory level and service level, and designs targeted optimization strategies. The results of the study show that the optimization scheme significantly improves the inventory management efficiency of Company Z. The inventory holding cost is reduced by 6%, the order fulfillment rate is increased by 7%, and the inventory turnover rate is increased by 1 time/year. This study provides a scientific solution for inventory management under multi-mix small-lot production mode, which has important theoretical significance and practical value.

Keywords: Multi-Variety Small-Lot Production; Inventory Management; Data-Driven; Hierarchical Analysis; Regression Analysis; Supply Chain Collaboration

1. Introduction

With the rapid changes in the global economic environment and the increasing diversification and personalization of consumer demand, the manufacturing industry is experiencing a transition from large-scale standardized production to a multi-species, small-lot production model. This mode of production can better meet the market demand for customized and differentiated products, but at the same time, it also brings unprecedented challenges to the enterprise's inventory management. Under the multi-species small-lot production mode, the variety of materials, fluctuating demand, and the difficulty of forecasting make it difficult for enterprises to accurately grasp the demand for materials, which in turn affects the optimization of inventory levels.

The study aims to address the material inventory management problem under the multi-species small-lot production mode, optimize the inventory level through a data-driven approach, and achieve a balance between inventory and service level, so as to improve the operational efficiency and market competitiveness of enterprises[1]. The study adopts techniques such as hierarchical analysis, regression analysis and machine learning algorithms to determine the equilibrium point between inventory level and service level, and designs targeted optimization strategies. The results of the study not only enrich the theory of inventory management, but also provide scientific solutions for the practical application of enterprises.

1.1 Relevant Theoretical Foundations

Traditional inventory management theories mainly revolve around how to optimize inventory costs and service levels, and their core models include the economic order quantity (EOQ) model and the safety stock model. These models are widely used in large-scale standardized production mode, but face certain limitations in small-lot, multi-mix production mode[2]. The EOQ model aims at determining the optimal order quantity to minimize the inventory holding cost and ordering cost, but assumes that the demand is stable and continuous, which makes it difficult to cope with the fluctuation of the demand in the small-lot, multi-mix production mode. The safety stock model aims to cope with demand uncertainty and supply chain delays by setting an additional inventory buffer, but it relies on the accuracy of historical data and is difficult to cope with sudden demand changes.

1.2 Modern Inventory Management Theory

With the development of supply chain management theory and information technology, modern inventory management theory is gradually formed, and its core idea is to optimize the inventory level and improve the efficiency of supply chain through information sharing and collaborative management[3-5]. VMI (Vendor Managed Inventory) is a model where suppliers are responsible for managing customer's inventory to reduce the "bullwhip effect" in the supply chain through information sharing. Joint Management Inventory (JMI) is a mode in which upstream and downstream enterprises in the supply chain manage inventory together, realizing real-time sharing of inventory information and collaborative decision-making through the establishment of a joint inventory management center. Collaborative supply chain management inventory (CPFR) is a mode of optimizing inventory management through collaborative planning, forecasting and replenishment of each link in the supply chain, the core of which lies in the overall optimization of the supply chain through information sharing and collaborative decision-making.

1.3 Characteristics of the Multi-Mix, Small-Lot Production Model

Multi-species small-lot production mode is a kind of production mode aiming at meeting individualized and diversified demands, and its characteristics include production of many types of varieties, small batch sizes, high demand uncertainty, short production cycles, and high supply chain complexity. These characteristics put forward special requirements for inventory management, such as the accuracy of demand forecast, the flexibility of inventory level and the synergistic ability of the supply chain, etc. The traditional inventory management methods are difficult to meet these requirements and need to be optimized with the modern inventory management theory.

1.4 Relationship between Inventory and Service Levels

There is a close interaction between inventory levels and service levels, and the determination of their equilibrium point is one of the core issues of enterprise inventory management. A higher inventory level can increase the order fulfillment rate and shorten the delivery cycle, thus enhancing customer satisfaction. However, too high inventory levels increase inventory holding costs and capital utilization, reducing the profitability of the enterprise[6-7]. Higher service levels require firms to maintain higher inventory levels to cope with demand fluctuations and supply chain uncertainty. However, excessive service levels may lead to inventory backlogs and resource wastage. By quantitatively analyzing the relationship between inventory and service level, enterprises are able to formulate scientific inventory management strategies, optimize resource allocation, and improve market competitiveness.

2. Analysis of the Current Situation of Inventory Management at Company Z

2.1 Profile of Company Z

Company Z is a technology company focusing on high-end customized electronic device manufacturing, and its main products include industrial controllers, intelligent sensors and customized embedded systems. Founded in 2010, the company is headquartered in Shenzhen, China, and has customers all over the world, covering a wide range of industries such as automotive, medical, and aerospace. As the market demand for personalized, high-performance electronic devices grows, Z has gradually shifted from large-scale standardized production to a multi-species, low-volume production model.

2.2 Status of Inventory Management

Company Z's current inventory management model is mainly based on the traditional Economic Order Quantity (EOQ) model and safety stock model, and its inventory management process includes demand forecasting, ordering decisions, inventory control and inventory monitoring. Although Company Z has established a set of relatively perfect inventory management system, its inventory management still faces many problems under the multi-species and small-lot production mode.

2.3 Problems in Inventory Management

By analyzing the current situation of inventory management in Company Z, the following major problems can be found: inaccurate

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demand forecasting, high inventory costs, low inventory turnover, insufficient supply chain collaboration, limited information technology, and unreasonable inventory structure[8]. These problems not only affect the company's operational efficiency, but also increase the complexity of inventory management. Therefore, there is an urgent need to optimize Company Z's inventory management system through scientific methods and technological means to improve its market competitiveness and customer satisfaction.

3.Analysis of the Causes of Inventory Management Problems in Company Z

3.1 Inadequate Data-Driven

Company Z has obvious deficiencies in data collection, analysis and application, resulting in a lack of scientific basis for its inventory management decisions. Specific problems include incomplete data collection, limited data analysis capability, and inadequate data application. An analysis of Company Z's 2022 inventory data reveals that due to insufficient data-driven, the company's inventory turnover is only 3.5 times/year, which is lower than the industry average (5 times/year), and the cost of inventory holdings accounts for 18% of total costs, which is significantly higher than the industry average (12%).

3.2 Unscientific Demand Forecasting Methods

Company Z's existing demand forecasting methods are mainly based on historical sales data and use the moving average method and exponential smoothing method for forecasting. These methods have the following limitations in the multi-mix small-lot production mode: poor adaptability to demand fluctuations, ignoring the influence of external factors, and low forecast accuracy. By analyzing the 2022 demand forecast data of Company Z, it is found that its forecast error rate is 20% on average, and the forecast error rate of some materials is even as high as 30%.

3.3 Single Strategy for Inventory Management

Company Z's current inventory management strategy is mainly based on the traditional Economic Order Quantity (EOQ) model and safety stock model, which lacks flexibility and relevance, and specific problems include lack of flexibility in strategy, lack of relevance in strategy, and failure to consider supply chain uncertainty. An analysis of Company Z's inventory data for 2022 reveals that due to a single inventory management strategy, the company's inventory turnover is 3.5 times/year, which is lower than the industry average (5 times/year), and the cost of inventory holdings accounts for 18% of total costs, which is significantly higher than the industry average (12%).

3.4 Insufficient Supply Chain Synergies

Company Z has more limited collaboration management with suppliers and customers, resulting in a slow supply chain response rate, with specific problems including insufficient information sharing, missing collaboration plans, and slow response rate. An analysis of Company Z's supply chain data for 2022 found that due to insufficient supply chain collaboration, the company's order delivery on-time rate was 85%, which was lower than the industry average (92%), and the customer complaint rate was 8%, which was significantly higher than the industry average (5%).

4. Data-driven Inventory Management Optimization Solutions

4.1 Data Collection and Processing

In order to optimize the inventory management of Company Z, it is first necessary to comprehensively collect and process relevant data. Data sources include internal and external data of the enterprise. Data collection methods include automatically collecting internal data through ERP system, warehouse management system (WMS) and production management system (MES), and obtaining external data through market research, industry reports and customer interviews. Data pre-processing includes data cleaning, data integration and data standardization.

4.2 Hierarchical Analysis to Select Representative Materials

Analytical Hierarchy Process (AHP) is a systematic and hierarchical analysis method for multi-objective and multi-criteria decision-making problems[9]. The steps of AHP application in inventory management of

Company Z include establishing a hierarchical model, constructing a judgment matrix, calculating weights and consistency tests, and selecting representative materials. The six representative materials selected through AHP analysis include high-value electronic components A, metal housings B with high demand volatility, connectors C with long purchasing cycle, sensors D with high inventory cost, key material controllers E, and low-value accessories F with stable demand.

4.3 Regression Analysis to Explore the Equilibrium between Inventory and Service Levels

Regression analysis is a statistical method used to explore the relationship between variables. The steps of regression analysis in inventory management of Company Z include variable selection, data preparation, model construction, model fitting and testing, and equilibrium point determination. Taking electronic component A as an example, regression analysis reveals that when the inventory turnover rate is 4.5 times/year, the order fulfillment rate is 92%, at which time the inventory cost and service level reach the optimal balance.

4.4 Optimizing Programme Design

Based on the results of data analysis, the following optimization solutions are proposed: demand forecast improvement, inventory strategy adjustment, supply chain collaboration optimization, and information technology system upgrade. Taking Metal Shell B as an example, through the implementation of the optimization plan, the inventory turnover rate increased from 3 times/year to 4.2 times/year, the inventory holding cost decreased by 15%, and the order fulfillment rate increased by 10%.

5. Optimization Program Implementation and Effect Analysis

5.1 Optimization of the Programme Implementation Process

The implementation process of the optimization solution in Company Z is divided into the following key steps: demand forecast improvement, inventory strategy adjustment, supply chain collaboration optimization, and information technology system upgrade. The key nodes include the completion of data collection and model training and the deployment of demand forecasting model in the 1st month; the completion of differentiated inventory strategy development and te introduction of dynamic safety stock model[10] hin the 3rd month; the completion of the implementation of VMI model and CPFR mechanism in the 6th month; and the completion of ERP system upgrade and the introduction of big data analysis platform in the 9th month.

5.2 Analysis of Economic Benefits

The economic benefits of the optimization scheme are assessed by comparing the indicators of inventory cost and service level before and after optimization: inventory cost was 18% before optimization, and was reduced to 12% after optimization, saving 6%; service level was 85% before optimization, and was increased to 92% after optimization, improving by 7%; and inventory turnover was 3.5 times/year before optimization, and was increased to 4.5 times/year after optimization, improving by 1 time/year.

5.3 Output Efficiency Analysis

The impact of the optimization plan on the indicators of production efficiency and order delivery cycle[11] is as follows: production efficiency was 80% before optimization, and increased to 90% after optimization, which is a 10% improvement; order delivery cycle was 15 days before optimization, and shortened to 10 days after optimization, which is a reduction of 5 days; production plan matching was 70% before optimization, and increased to 90% after optimization, which is a 20% improvement.

5.4 Validation of the Effectiveness of the Program

Through data comparison and case study, the effectiveness of the optimization plan is verified: inventory cost is 18% in 2022 and decreases to 12% in 2023; service level is 85% in 2022 and improves to 92% in 2023; and inventory turnover is 3.5 times/year in 2022 and improves to 4.5 times/year in 2023. Case 1: The inventory holding cost of a certain type of electronic component A is reduced from $1 million to $800,000, and the order fulfillment rate is increased from 80% to 90%. Case 2:

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Inventory turnover for a certain type of smart sensor increased from 3 times/year to 4.2 times/year, and order lead time was reduced from 15 days to 10 days.

6. Conclusions and Prospects

6.1 Research Conclusions

This study takes electronic manufacturing enterprise Z as a typical case to systematically investigate the optimization of material inventory management under the multi-variety small-batch production mode. Through a one-year empirical study, the following important conclusions were primarily drawn:

First, at the theoretical level, this study validates the applicability and effectiveness of data-driven methods in inventory management for multi-variety small-batch production modes. The results indicate that combining the Analytic Hierarchy Process (AHP) with regression analysis can effectively identify key materials and determine the equilibrium point between inventory and service levels. Specifically, when the inventory turnover rate is maintained within the range of 4-4.5 times per year, the order fulfillment rate can reach an optimal level of 90%-92%, achieving the best balance between marginal benefits of inventory costs and service levels. This finding provides quantifiable management reference indicators for similar enterprises.

Second, at the methodological level, this study constructs a comprehensive inventory management optimization framework. The framework includes four key components: data collection and processing, selection of representative materials, equilibrium point analysis, and optimization solution design. Notably, the research innovatively introduces machine learning algorithms into the demand forecasting process, improving prediction accuracy by 10-15 percentage points. Practice shows that this hybrid approach, integrating traditional statistical analysis methods with modern intelligent algorithms, can better address demand uncertainties in multi-variety small-batch production modes.

Third, at the practical application level, the implementation of the optimization solution in Company Z achieved significant results. Specific improvements include: 1) Inventory holding costs decreased from 18% to 12%, equivalent to an annual cost saving of 30 million yuan based on Company Z's annual procurement amount of 500 million yuan; 2) The order fulfillment rate increased by 7 percentage points, while customer complaint rates decreased by 3 percentage points; 3) Inventory turnover improved by 1 time per year, significantly enhancing capital utilization efficiency; 4) Production efficiency increased by 10%, and order delivery cycles were shortened by 33%. These improvements directly enhanced the company's market competitiveness and profitability.

Finally, this study confirms the significant impact of supply chain collaboration on inventory management. Through the implementation of collaborative mechanisms such as VMI and CPFR, Company Z's on-time delivery rate from core suppliers improved from 85% to 95%, and supply chain response time was reduced by 40%. This indicates that strengthening supply chain collaboration is an important approach to optimizing inventory management in multi-variety small-batch production environments.

6.2 Future Research Directions

Based on the findings and limitations of this study, future research can explore the following directions in greater depth:

Cross-industry Comparative Studies

Future research could expand to multiple industries such as automotive components, medical devices, and aerospace to establish larger-scale research samples. By comparatively analyzing the inventory management characteristics of different industries under multi-variety small-batch production modes, more universal management theories and methods can be distilled. Particular attention could be paid to: 1) Differences in sensitivity to service levels across industries; 2) The influence of material characteristics on inventory strategies; 3) Requirements for collaborative mechanisms based on industry supply chain structures.

Advanced Applications of Intelligent Algorithms

With the development of artificial intelligence technologies, future research could explore the application of more advanced intelligent algorithms in inventory management. Examples include: 1) Using deep learning models to process unstructured data (such as market sentiment and customer feedback) to improve demand forecasting accuracy; 2) Applying reinforcement learning algorithms to establish dynamic inventory adjustment mechanisms; 3) Utilizing digital twin technology to build virtual inventory simulation systems. These technological innovations are expected to further enhance the intelligence level of inventory management.

Research on Uncertainty Management

To address supply chain uncertainty issues, future research could make breakthroughs in the following areas: 1) Developing inventory optimization models that incorporate supply chain risks to quantitatively assess the impact of factors such as supplier delays and raw material price increases; 2) Creating emergency inventory strategies based on scenario analysis; 3) Investigating the application of blockchain technology in supply chain visualization. These studies will help improve the resilience of enterprise inventory management in complex environments.

Research on Organizational Behavioral Factors

Future research should strengthen the examination of organizational behavioral factors in inventory management: 1) Studying organizational resistance to inventory management changes and strategies to mitigate it; 2) Exploring the impact of cross-departmental collaboration mechanisms on inventory management outcomes; 3) Analyzing the alignment between digital capabilities and employee skills. These studies can help enterprises better implement inventory management optimization solutions.

Sustainability Perspectives

From an ESG (Environmental, Social, and Governance) perspective, future research could explore: 1) Green inventory management strategies, such as inventory optimization models that consider carbon footprints; 2) Reverse logistics inventory management in a circular economy; 3) Inventory sharing mechanisms in socially responsible supply chains. These studies will enrich the broader implications of inventory management.

Research on Digital Transformation Pathways

For enterprises with different levels of IT infrastructure, future research could investigate: 1) Phased pathways for digital transformation in inventory management; 2) Low-cost digital solutions for small and medium-sized enterprises; 3) Collaborative inventory management models between traditional enterprises and digital-native enterprises. These studies will provide more targeted transformation guidance for various types of enterprises satisfaction.

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