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RESEARCH ON INVENTORY CONTROL METHOD BASED ON DEMAND RESPONSE OF POWER BIG DATA

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Abstract. The supply chain functions as a complex web, interconnecting various stakeholders such as suppliers, manufacturers, wholesalers, retailers, and ultimately, end consumers. Central to effective supply chain management is the meticulous handling of inventory, a critical factor influencing both cost efficiency and service excellence throughout the entire network. The management of inventory within this context extends beyond the confines of individual enterprises, bearing significance across the entirety of the supply chain. Consequently, achieving optimal performance necessitates a cohesive, holistic approach to management, aligning with the overarching objectives of the system.

Through dynamic data analysis of multiple types of power materials, a dynamic inventory control model for power materials is constructed to achieve optimal adjustment of inventory management. Ultimately, a multi-granularity inventory control method based on big data analysis of power warehousing is constructed, which effectively improves inventory management efficiency and reduces logistics management costs for enterprises.

Through big data analysis of power material warehousing, the characteristics of power material demand are excavated, and a classification method for power material demand is constructed to achieve an overall inventory control strategy for power materials.

The implementation results show that the controlled inventory can better meet the changing demand, thereby improving inventory management efficiency.

The multi-granularity inventory control method based on big data mining of warehousing combines inventory and multi-objective optimization theories, proves the applicability and feasibility of the proposed method, effectively improves inventory management efficiency, reduces logistics management costs for enterprises, and provides practical guidance and decision-making reference for improving the intensive management level of power production and maintenance materials.

Key words: Power big data; Demand side response; Inventory control; Intelligent system; Warehouse data mining

1. Introduction. The rapid development of China's power industry has driven the continuous expansion of the operation scale of power groups and the increase of the demand and variety of power materials. Effective inventory management can not only satisfy the normal production and operation needs of enterprises, but also prevent delays in production progress or power supply due to shortages, and lower enterprise costs and risks. Currently, power groups mainly use three inventory management modes: physical reserve, agreement reserve and dynamic turnover. Among them, physical reserve is the most direct and effective method, but long-term and large-scale reserve will consume a lot of funds, impede the flow of materials, and may cause material waste. Agreement reserve and dynamic turnover can enhance the efficiency of material use and reduce inventory costs. However, with the rapid expansion of power grid scale and the growing number of engineering projects, traditional distribution networks need to urgently transform and upgrade to smart distribution networks. Power grid business data exhibits explosive growth, and big data "volume, variety and velocity" features become more evident. The traditional static power material supply chain will be gradually replaced by a highly flexible and data-driven supply chain. This poses higher demands for the precision of inventory control.

Inventory management of power groups is vital for enterprise operation and development. First, a reasonable inventory level can satisfy the normal production and operation needs of enterprises, and prevent delays in production progress or power supply caused by shortages. Second, efficient inventory management can lower enterprise costs and risks. By rationally determining the order quantity and order time, over-purchasing and

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material accumulation can be avoided, and enterprise procurement costs and storage costs can be reduced. Moreover, good inventory management can also enhance the service quality and customer satisfaction of enterprises. When enterprises respond to customer needs promptly and provide high-quality power materials, customer satisfaction will improve, thereby laying a foundation for the long-term development of enterprises.

Inventory control of power groups is essential for enterprise sustainable development. First, a reasonable inventory level can enhance enterprise operation efficiency. By optimizing inventory structure and increasing material turnover rate, enterprises can better cope with market demand fluctuations and improve operation efficiency. Second, effective inventory control can reduce enterprise environmental impact. Excessive physical reserve will lead to material accumulation and waste, increasing environmental burden. By rationally using agreement reserve and dynamic turnover, enterprises can lower inventory level and mitigate environmental impact. Furthermore, good inventory control can also strengthen enterprise competitiveness. In the context of intensifying market competition, by fine-tuning inventory management and precise inventory control strategy, enterprises can better satisfy customer needs and boost market competitiveness.

However, there are some drawbacks in the current inventory management. First, inventory control strategy is not refined enough, often only considering the demand and cost of materials, while neglecting other influencing factors, such as the quality, procurement cycle, transportation time of materials, etc. Second, there is a lack of tracking and monitoring of the usage of materials, resulting in the inability to adjust the inventory management strategy timely, and difficulty in achieving fine-grained inventory control. In addition, power groups also face challenges such as low level of informatization and insufficient data sharing, which hamper the improvement of inventory management level. Therefore, with the diversification and uncertainty of demand increasing, the traditional inventory management method is hard to cope with new challenges. Hence, exploring the multi-granularity inventory control method for demand-side response of power system has significant theoretical and practical value.

This paper analyzes the classification features of power materials, and models their demand characteristics. Based on historical consumption data, it designs a general inventory control strategy for power materials. For different categories of power materials, it constructs a dynamic inventory control strategy, and innovatively uses multi-objective optimization theory to implement a multi-granularity inventory control method. This research can help power enterprises develop reasonable inventory control strategies and optimize processes, thus enhancing their operation efficiency, lowering their costs and achieving sustainable development.

2. Related Work. The inventory control problem is a well-established topic in the field of optimization theory. According to literature [1], both the deterministic demand model and the random demand model for a given demand distribution have reached a relatively mature level. In terms of related demand, the theory of material requirement planning (MRP) and enterprise resource planning (ERP) have been developed based on these models, and have effectively solved these types of problems.However, with the progress of time, market demand has undergone significant changes, and the demand for many products exhibits non-stationary distribution characteristics. In the context of inventory control in a two-level supply chain, literature [2] compared the models of retailers holding inventory separately and a central inventory, and found that by establishing multiple retailers, inventory managers can reduce the total cost of inventory control and increase company income.In the aspect of cooperation and competition in the supply chain, literature [3] conducted a detailed analysis and used the game theory method to derive the optimal strategy. Literature [4] established a system that includes multiple retailers, multiple suppliers, and a warehouse model. Literature [5] examined the advantages and disadvantages of information sharing under the multi-retailer model. Finally, literature [6] provided a comprehensive summary of current supplier inventory management models.

In the domain of multi-level supply chain inventory control, literature [7] delved into the optimal purchase quantity problem under the supplier-managed inventory mode in the multi-level supply chain. Literature [8] investigated the issue of economical batch ordering of consumable inventory earlier. The literature [9] enhanced the dynamic inventory model originally proposed by Arrow-Harris-Marshak, factoring in the evolution of customer demand distribution over time and also examined the inventory control problem when demand information is unknown. In this context, the demand distribution remains stable with unknown parameters, but with some prior distribution knowledge. Literature [10] assumed that the prediction error follows a normal distribution and, from the perspective of satisfying service level constraints, proposed a non-stationary demand inventory control strategy based on heuristic algorithm.

Jun [11] has developed a mathematical model for the emergency material supply network, successfully reducing the dimensionality of both the cost function and time function. The composite of these two functions was then weighted, enabling a comprehensive analysis of the time and cost components of emergency material supply. The study also implemented an optimal material supply chain plan for emergency materials, recommended an emergency supply reserve model, and verified the feasibility of the mathematical model through specific case studies.

The demand sensitivity of inventory control is primarily manifested in the timely acquisition and dynamic optimization of demand. For instance, in a smart home setting, HEMS receives real-time electricity prices through a smart meter. With this price information, the EMC can utilize optimization algorithms to perform the scheduling of home appliances, thereby fulfilling one or more objectives from the consumer's perspective [12].

Based on the aforementioned research on adaptive inventory control, both domestic and international, it is evident that adaptive inventory control can effectively handle non-stationary demand and enhance system efficiency. Utilizing adaptive inventory control allows for the adaptive tracking of inventory control targets, resulting in an optimal model. However, most of the aforementioned documents are continuous demand-based and do not account for the adaptive inventory control strategy for discrete random demand. This paper aims to address the inventory control problem in non-stationary random demand supply chains and proposes an improved control strategy that can ensure the inventory model meets the given service level while reducing the bullwhip effect.

3. Demand-side response power material inventory control.

3.1. Demand-side classification method of electric power materials. To explore inventory control methods for different types of power materials in response to demand, it is essential to first grasp the properties of power materials and the fundamental workings of inventory management, specifically the classification of power supplies. Nevertheless, a noteworthy challenge lies in the classification of power materials due to their diverse types, varieties, and applications. Hence, the classification principles may vary. From different perspectives, power materials can be classified as follows:

(1) According to the nature of the project. Based on the nature of the project, power materials can be classified into three categories: overhaul materials, daily maintenance materials, and emergency repair materials. Among them, overhaul materials mainly refer to the replacement and planned overhaul of power supplies and equipment, daily maintenance materials mainly refer to the planned maintenance of non-overcurrent power materials, and emergency repair materials mainly refer to emergency repairs caused by an increase in power load, such as weather-related repairs, external forces, and general emergency repairs.

(2) By material category. Power materials can be divided into different categories based on their material type. These include raw materials (such as metal and building materials), overhead line equipment, substation equipment (including primary, secondary, and tertiary components), cables and accessories, tools, and office supplies (including non-production equipment), among others.

(3) According to the use of the team. Based on the team's usage, power materials can be classified into three categories: materials for the electric test shift, materials for the relay protection shift, and materials for the installation and succession shift.

(4) According to the supply method. Power materials can be classified based on their supply method. These include supply materials provided by the warehouse, direct transfer materials sent directly to the site by the supplier, and adjustment materials transferred from the warehouse.

(5) According to purchasing frequency. Based on the frequency of procurement, power materials can be divided into three categories: weekly procurement of materials, monthly procurement of materials, and quarterly procurement of materials.

(6) According to grid standards. Based on grid standards, power materials can be classified into large categories of materials (including primary and secondary equipment, installation materials, metal materials, and tools), medium-level materials (such as transformers, fuse boxes, and cables), and small materials (such as line angle iron cross arm, ordinary bolts, and cement products, commonly used fittings, etc.).

3.2. Extraction and analysis of demand-side features of power materials. The extraction and analysis of the demand characteristics of power materials serve as the cornerstone for both the classification of power materials and the design of strategies for inventory control of power materials. This holds significant theoretical value and practical relevance for managing power materials inventory. Electric power supplies typically exhibit a wide array of types, diverse specifications, varying degrees of standardization, distinct levels of planned demand for materials, diverse rules, varying degrees of volatility, and varying rates of update speed. Therefore, taking into account the specifics of warehouse power materials, we establish the demand characteristic model Q for devising strategies related to power materials inventory as follows:

$$Q=\{M,U,P,V,R,S,L,G\} \tag{3.1}$$

where M represents importance, U represents urgency, P represents periodicity, V represents universality, R represents regionality, S represents substitution, L represents liquidity, and G represents regularity.

(1) Key characteristics are employed to delineate the value attributes of power materials and the pivotal metrics for gauging service levels. Utilizing the ABC analysis principle, power materials are predominantly categorized based on their significance. The underlying principle of ABC analysis posits that "the vital few outweigh the trivial many," wherein goods are prioritized according to cumulative turnover as the yardstick for classification. Consequently, power materials are segmented into three distinct categories: A, B, and C. Category A comprises materials characterized by either substantial quantities or high demand, earmarked for intensified management and control, with a designated importance level of 3. Category B encompasses materials with moderate quantities or demand, managed and controlled through conventional means, with an assigned importance level of 2. Category C encompasses materials with limited quantities or demand, meriting straightforward management and control methods, with an importance level of 1. Thus, the importance value range, denoted as M, is {3, 2, 1}, signifying three tiers of significance: very important, generally important, and unimportant, respectively. In accordance with actual scenarios, guidelines are established as follows: materials of high value or substantial demand (approximately 80%) merit an importance level of 3, designating them as very important; materials of moderate value or demand (approximately 15%) with a moderate quantity of items (ranging between 20% and 50%) are assigned an importance level of 2, categorizing them as generally important materials; materials of lower value (approximately 5%) with a larger quantity of items (exceeding 50%) are deemed unimportant, warranting an importance level of 1.

(2) The concept of urgency is pivotal in delineating the intensity of customer demand for the prompt delivery of required materials. This characteristic is intricately linked to the prevalence of emergency repairs, serving as a barometer for measuring the immediacy of response required. In the context of business operations, each outbound record for electrical materials is accompanied by a unique order number, with the leading digit indicative of the specific purpose of the outbound materia – be it for overhaul, emergency repair, infrastructure enhancements, among others. Consequently, the urgency index (U) is derived through a nuanced assessment of these factors, encapsulating the imperative need for swift action in fulfilling customer requirements. The urgency index (U) can be quantified using the following formula:

$$U = q/X \times 100\% \tag{3.2}$$

where q represents the quantity of materials dispatched for emergency repairs from the warehouse, while X denotes the total volume of materials dispatched overall. An urgency index (U) is established based on the ratio of emergency repair dispatches to total dispatches. When the urgency index surpasses 48%, it signifies a relatively high level of urgency, indicating a significant proportion of materials allocated for emergency repairs. Conversely, when the urgency index falls below 15%, it suggests a relatively low urgency level, indicative of a lesser portion of materials allocated for emergency situations.

(3) Periodicity encapsulates the temporal spacing between significant junctures within the power supply procurement process, extending from the preceding purchase to the current acquisition. This encompasses various temporal metrics, notably including the purchase lead time and the purchase cycle duration. These metrics serve as vital benchmarks in understanding the rhythm and cadence of procurement activities, offering insights into the timing and frequency of resource replenishment.

(4) The concept of universality pertains to the alignment between the existing condition of power materials stored in the warehouse and the technical specifications mandated by the State Grid Corporation. It essentially gauges the extent to which inventory adheres to standardized norms and requirements. This metric serves as a barometer of consistency and compliance within the inventory management framework, highlighting the efficacy of standardization practices in ensuring operational efficiency and regulatory compliance.

(5) Regional characteristics refer to the classification of power materials based on their specific applicability within certain geographic areas. This classification is determined by assessing the attribute characteristics and technical specifications of the materials. It involves discerning whether a material is specialized for a particular locale or if it serves a broader function across the entire Fujian Province or Fuzhou area.

(6) The substitution characteristics of electric power materials elucidate their capacity to fulfill similar functions across diverse applications, thereby determining their interchangeability. This evaluation goes beyond a simple comparison of item counts and delves into the nuanced aspects of functionality, technical compatibility, and operational efficacy. It entails a comprehensive analysis of whether materials can effectively substitute for one another under varying order requirements, reflecting the dynamic nature of their utility in different contexts.

(7) The liquidity characteristics of power materials encompass the velocity and frequency of their circulation within a defined timeframe. This includes metrics such as the monthly quantity of materials leaving the warehouse, the average monthly rate of material outflows, and the typical volume of each outgoing batch. Liquidity (L) can be quantified as follows:

$$L = \varepsilon_1 N + \varepsilon_2 T + \varepsilon_3 E \tag{3.3}$$

In the given equation, N denotes the total count of monthly shipments, T signifies the mean monthly shipment frequency, and E represents the average volume of each individual shipment. The variables ε_1, ε_2, and ε_3 denote the corresponding weight coefficients, the optimization of which will be conducted as part of the experimental process.

(8) The regularity characteristic assesses the presence of patterns or regularities in historical demand for power materials. This evaluation typically involves statistical analysis, such as computing the coefficient of variation for consumption data. The regularity (G) can be quantified using the following formula:

$$\mathrm{G} = \sigma/\mathrm{x} \times 100\% \tag{3.4}$$

where σ is the standard deviation and x is the average.

In terms of material utilization, maintenance materials exhibit low regularity. A regularity index (G) exceeding 80% indicates a high degree of consistency, while values between 50% and 80% suggest moderate regularity, and G below 50% indicates weak regularity. Materials demonstrating strong regularity facilitate more accurate prediction of future demand, enabling precise inventory planning

3.3. Inventory control strategy for demand side response. The power materials supply chain encompasses suppliers, multi-tiered warehouses, and project sites, each with distinct demand characteristics necessitating varied distribution modes and inventory management strategies. Special regulations govern aspects such as urgency and safety. Typically, materials are sourced from suppliers and routed through specialized warehouses before reaching project sites. General planned materials are subject to a two-tier inventory control strategy, with suppliers provisioning regional distribution centers for centralized inventory management. These centers sort and distribute materials to front-end warehouses, employing circular distribution or cross-docking methods for secondary distribution. Framework agreement materials and emergency procurement items are expedited directly from suppliers to project sites to minimize construction delays.

Prior to formulating a comprehensive inventory control strategy for electric power materials, it is essential to categorize the inventory based on the degree of item overlap. Item overlap refers to the extent to which various specifications of each material, serving different purposes, coincide. This categorization yields two distinct classifications: planned inventory and order inventory. Planned inventory comprises materials with a high overlap ratio, necessitating a predetermined quantity to be stored in warehouses throughout the year. Conversely, materials with low overlap ratios are categorized as order inventory, requiring procurement in accordance with specific orders placed.

Based on the distinct demand patterns of electric power materials, the division between planned inventory and order inventory can be further refined. This paper proposes an inventory control strategy rooted in demand-side responsiveness, deploying diverse control algorithms tailored to different material demand profiles. For planned inventory materials with irregular demand, particularly emergency repair items, a dynamic inventory control approach is advocated. This entails dynamic adjustment of inventory levels at specific intervals based on the demand characteristics of different power materials. Control strategies are implemented by flexibly modifying inventory upper and lower limits. In contrast, for planned inventory materials with consistent demand patterns, such as overhaul materials, the MRP (Material Requirements Planning) system is recommended for inventory control. Under this replenishment strategy, materials of greater importance are subject to more frequent inspections, typically on a weekly basis, while less critical items undergo less frequent assessments, perhaps on a monthly basis.Similarly, order inventory can be stratified based on demand regularity. For materials with sporadic demand, adopting the Vendor Managed Inventory (VMI) replenishment model[13] is advocated. In this approach, a collaborative relationship is established with suppliers, allowing them to manage inventory based on a master plan formulated by the power material company. This facilitates timely and accurate demand information transmission, ensuring precise inventory control. Conversely, for order inventory materials characterized by consistent demand, the Just in Time (JIT) distribution model is proposed. JIT distribution, orchestrated from a coordination center, emphasizes timely delivery of the appropriate products in the exact quantities specified by the customer. Leveraging small-batch and multi-frequency delivery methods, JIT distribution aims to minimize inventory and waste while accommodating the diverse and personalized needs of customers. To enhance supply chain stability, inventory control strategies may involve forging alliances with nearby suppliers or agents and entering into contractual agreements, such as framework agreements, to ensure timely power supply distribution.

(1) Real-time inventory management approach. The real-time inventory management paradigm operates on a swift and continuous inventory inspection cycle, ensuring constant oversight of stock levels. Through meticulous parameterization, lower and upper inventory thresholds are meticulously defined. Upon reaching the lower threshold, an automatic replenishment signal is swiftly dispatched to restore inventory levels to the upper limit. This approach is particularly well-suited for the management of materials characterized by their high value, liquidity, and urgency, ensuring optimal inventory levels to meet dynamic demand fluctuations.

(2) Material requirement planning inventory management. The inventory management approach within the material requirement planning system typically adopts an extended inspection cycle, commonly on a monthly basis. Replenishment occurs upon reaching the inspection point, provided that the safety stock threshold is not breached, resulting in the addition of inventory up to the upper limit. This strategy is generally applicable to materials of moderate value and liquidity, encompassing supplies with varying levels of urgency.

(3) Vendor managed inventory stock refill strategy. Vendor Managed Inventory (VMI) involves suppliers managing the inventory of users with the users' consent. This approach relies on close collaboration between the parties to ensure efficient material delivery. The supplier assumes responsibility for determining inventory levels and devising strategies to maintain them. VMI is particularly effective in the relationship between suppliers and distributors at the first tier of the supply chain. Typically, the inventory control strategy in VMI operates on a monthly inspection cycle. Replenishment signals are promptly triggered when inventory levels fall below the designated threshold. The replenishment quantity can be calculated using predetermined models. VMI is generally suitable for managing high-value, low-liquidity, and emergency materials of superior quality.

(4) Just in Time strategy.. The fundamental principle of Just in Time (JIT) is to deliver the precise materials to the designated location exactly when they are needed, while considering excess inventory as wasteful. Typically, the JIT control strategy aligns its inspection cycle with the occurrence of demand, often employing a monthly inspection frequency. Replenishment is triggered upon reaching the inspection point, provided that the safety stock threshold is not breached. The replenishment quantity can be calculated using predetermined models. This approach is generally suited for materials of moderate value, with relatively low turnover and urgency.

$$\mathrm{E} = \mathrm{e} \times \mathrm{MAD} \tag{3.5}$$

$$\mathrm{Q} = \mathrm{q} \times \mathrm{n} \tag{3.6}$$

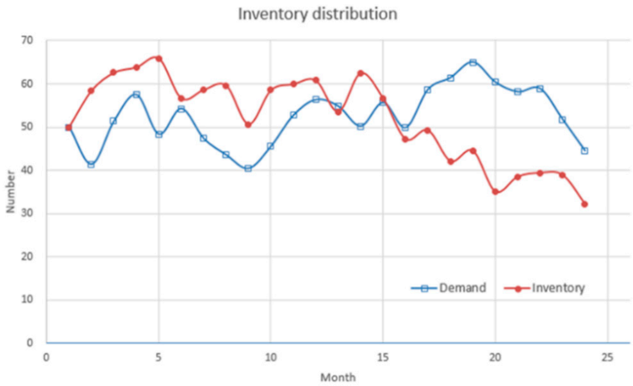

Fig. 4.1: Inventory and demand curve.

Through a meticulous examination of demand characteristics and cluster analysis, an adaptive inventory control strategy is devised for each category of power materials. However, it's essential to recognize that the demand landscape and clustering outcomes of power materials are dynamic and subject to change. Consequently, the company undertakes annual reassessments to refine its inventory control strategy in response to evolving analysis results and real-world conditions. This underscores the remarkable adaptability and responsiveness of the inventory control strategy grounded in demand characteristics analysis, facilitating a more nuanced and effective approach to inventory management that better aligns with the company's operational needs and objectives.

4. Experiment. In the simulation example, a two-level supply chain consisting of a warehouse and multiple suppliers is considered. The MATLAB simulation test is mainly performed when the demand distribution of power projects is unknown, and then the experimental model when the demand distribution is known is compared with the former. A certain type of commonly used materials is used as the object to experiment to evaluate the pros and cons of the model established in this chapter.

4.1. Inventory simulation when demand distribution is known. When the demand is known, the demand information is predicted by exponential smoothing once. Assuming that the demand per unit time is D~N(50,102), the actual initial demand is the random number generated in the interval [45,55], the predicted initial demand is 50. The model runs for 24 cycles (months). And the simulation runs 20 times to get the average data. The model time is taken as the unit time.

Figure 4.1 shows the actual data of demand and inventory when the demand distribution obeys the normal distribution, where the box represents the demand number, and the dot represents the inventory number. We can see that there are 13 cases where the inventory is greater than the demand, and the average demand overflow is 21%; there are 10 times when the inventory is less than the demand, and the average under-demand rate is 24%. Excessive inventory will lead to occupation of inventory space, thereby resulting in waste; insufficient inventory will lead to unsatisfied demand. Therefore, it is not good if the inventory is too large or too small.

4.2. Inventory control simulation. Through the dynamic inventory control strategy, MRP system inventory control strategy, VMI inventory replenishment control strategy, and JIT control strategy proposed in this paper, multi-granular inventory control is carried out. The results are shown in Figure 2 as follow.

Figure 4.2 reflects that the controlled inventory can better meet the changes in demand, thereby improving the efficiency of inventory management.

5. Conclusion. In light of the expanding landscape and escalating intricacies of power projects, the imperative for sophisticated inventory control mechanisms has been underscored. Within this evolving context, the paradigm of multi-granularity inventory control, particularly from a demand-centric perspective, has emerged as a pivotal domain of interest, heralding its agility in real-time assessment and adaptability. This discourse

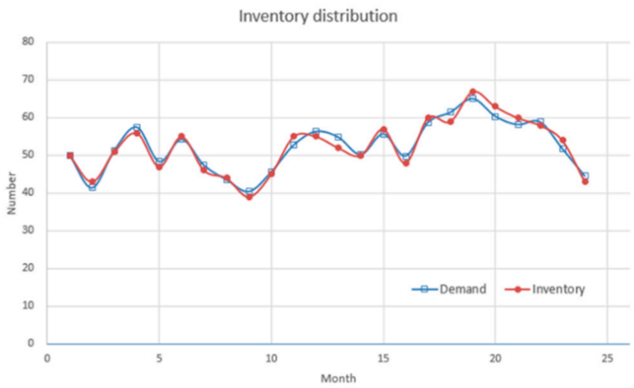

Fig. 4.2: Curve of multi-granularity inventory control results.

unveils a pioneering methodology in multi-granularity inventory control, synthesizing tenets from inventory management and multi-objective optimization theory. Beyond mere conceptualization, empirical validation of this framework not only attests to its practical viability but also illuminates actionable insights and strategic imperatives aimed at optimizing the management of power production and maintenance materials.

As we navigate the next phase of this scholarly endeavor, the spotlight shifts decisively toward the conception and realization of a dynamic inventory management architecture bespoke to the exigencies of power materials. This ambitious undertaking encompasses a comprehensive reassessment of dynamic safety inventory thresholds, meticulously calibrated against a nuanced backdrop of supply cycles, lead times, historical safety stock data, and procurement trajectories. In parallel, the augmentation of this framework entails the dynamic modulation of parameters within the demand management framework, ultimately coalescing into the construction of a dynamic, multi-tiered inventory management infrastructure. This adaptive infrastructure, characterized by its responsiveness to evolving demand dynamics, not only serves to mitigate inventory bottlenecks but also acts as a bulwark for ensuring the resilience and continuity of the power grid, all while effectuating optimal capital deployment across inventory holdings.

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