

Dynamic Safety Stock Calibration and Replenishment Intelligence: Deep Reinforcement Learning for Multi-Echelon Inventory Optimisation

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1. Introduction to Inventory Management in Retail

Inventory management is a crucial domain in the retail sector that influences various operations. Managing inventory generically implies having the right items, at the right price, in the right quantity, in the right place, at the right time, and in the right condition. This task ensures that goods are available when needed, service levels are maintained, and costs of excess stock are minimized. Holding the right stock also allows managers to reduce the amount blocked in the asset, enhancing cash flow and reducing financial costs. In growing markets focusing on fast-changing customer needs, companies must improve their inventory management. Buyers today expect an instant response and for their preferred item to be in stock at all times. Conventional computing systems in inventory planning are unable to meet these demands. The system helps firms meet these expectations by optimizing safety stocks.

Traditional inventory planning systems are built upon three key modules: demand forecasting, order planning, and stock handling. The newly forecasted demand for all the final products of the organization is taken as input by the demand forecast module, and forecast consumption, and then forecast raw material and other finished goods demands are determined. The orders thus generated are then used by the order planning module to calculate the forecasted production the firm must optimize to satisfy the forecasted demands and at the same time minimize the production-related costs. Next, the general production output calculated by the order planning module is taken as input. The inventory parameters are modified and the consignment arrives at the stock handling module. With the details of the expected consignments and the optimized

general production output accounted for, this module fine-tunes the preservation inventories.

1.1. Challenges Faced in Traditional Inventory Management Systems

Traditional inventory management processes require a physical count of stock and an analysis of potential future demand. The challenge is to forecast demand and ensure that distribution centers are set up with the appropriate level of stock for demand. Typically, problems arise when demand or customer behavior does not match the forecast, with results ranging from disengaged customers who switch to alternative products or services to financial losses. The first challenge is to maintain an accurate view of stock levels. With large stock inventories and a large number of products, it becomes more difficult to maintain accuracy. Retailers need to be able to respond to customer demand quickly so that slow response times lead to customer dissatisfaction. Customers not only decide where they shop based on the availability of the product they want, but they also have expectations based on what an online platform or store can provide.

Our money and time are limited. Thus, managing supply chain transparency among two or more entities is a very difficult task due to the occurrence of exponential growth in business-to-business supply chain management. While a stockout negatively affects customer satisfaction, an overstock increases costs, blocks the flow of the product in the store, and uses up valuable shelf space. When stock situation information is not shared between departments, also known as integrated retail, replenishments are not optimized. Many retailers rely on demand forecasting techniques and legacy software systems, but traditional forecasting methods are no longer effective. Stock management based on a bullwhip effect tends to become more complex in long supply chains where suppliers struggle to keep stocks aligned with retailer demand. Manual methods and legacy systems in many operations are not robust enough to handle volatility and are slow to respond to changing customer habits and consumer behavior.

1.2. Role of AI and Machine Learning in Inventory Management

The transformative role of artificial intelligence and machine learning in inventory management processes is apparent. By analyzing vast quantities of data at rapid speeds, AI-powered systems can produce more effective insights and predictions. AI has the capacity to swiftly interpret complex data patterns and forecast demand more accurately than human inventory managers. Machine learning, a subset of AI, functions well in

such scenarios by allowing algorithms to learn from historic sales and market data in order to spot trends and forecast future fluctuations. In combination, AI and machine learning can automate manual, time-consuming tasks, such as stock replenishment, reducing the risk of error and driving greater efficiency. Unlike traditional inventory management software, which relies on predetermined rules and strategies that do not update according to changes in demand patterns or the market, AI can learn from these sudden changes and refine its future outputs accordingly.

The integration of AI-powered demand forecasting and stock optimization practices presents many opportunities for retailers in terms of inventory improvements. Reams of evidence support the potential that AI offers supply chain professionals. For example, businesses using AI-powered demand forecasting and stock optimization practices can direct stock levels to be between 20% and 50% leaner while achieving up to a 30% reduction in lost sales across supply chain segments. Other studies suggest that inventory management systems tailored to suit unique demand needs can deliver a 20% to 30% decrease in stock levels and a 5% improvement in service levels – typically achieved through the integration of AI-powered demand forecasting, stock planning, and replenishment solutions.

2. Fundamentals of Demand Forecasting

Forecasting consumer demand is pivotal because meeting customers' needs without overstocking is crucial for effective inventory management. Holding too little stock may result in customer dissatisfaction due to unmet demand. Moreover, stockouts reduce profits and operational efficiency. Demand planning assists retailers in creating accurate stock levels and avoiding overstock conditions, thus minimizing waste.

Forecasting is a method of anticipating future events by using past histories. Hence, demand forecasting streamlines inventory control, upcoming production, and commercial acquisitions. Demand forecasting involves numerous methods and strategies for estimating demand. Historical sales data is also employed to estimate sales for future inventory. Based on previous sales data, demand forecasting techniques fall into four categories: qualitative and subjective-based methods, time series analysis, causal models, machine learning, and AI forecasting. Furthermore, demand is affected by several external components, including market trends, seasonality, and shifts, among other things. To forecast demand, these external components must be in tandem.

Basic sales forecasting strategies may overlook these elements, leading to diminished forecasts. Aligning companies' strategies with forecasting strategies is important for forecasting accurate demand data. Dynamic solution updates are receiving more attention in the sectors of AI and software. Unlike typical strategies, dynamic AI strategy-tuned solutions dynamically modify themselves in response to changing conditions. Dynamic demand forecasting happens in near real time, allowing for adjustments over time. These possibilities take into account more real-world situations, allowing them to be applied in a wider range of industry options.

2.1. Importance of Accurate Demand Forecasting

The need to accurately forecast the demand for products is of extreme importance to the success of inventory management in the retail industry. Inaccurate demand forecasts will lead to holding costs that are increased when purchasing sell-through products, as well as markdowns due to lost sales opportunities from under-supervised inventory if demand is overestimated. With accurate demand forecasting, companies are able to implement more accurate and streamlined replenishment strategies, as well as make more cost-effective inventory decisions in terms of items to mark down. Holding the correct levels of inventory has large implications regarding operational efficiency and customer service level agreements of a company as well.

Many factors such as social media events, weather, and even competitor stock levels can affect consumer demand, which directly impacts inventory levels. In order to manage and capitalize on demand variation, accurate forecasting is an essential tool for any retailer. The issue, however, is that using forecasting as a precise science for inventory management becomes more complex when processing large amounts of forecasting data points. Individual departments within a business require forecasting information for various items in order to make strategic inventory decisions. It is not enough to rely on a product manager's consumer insights to maximize inventory performance, as even after products are sourced, various unrelated departments need to forecast the individual SKU in question for various different supply chain decisions.

2.2. Traditional Methods vs. Machine Learning Techniques

Machine learning techniques are becoming popular in demand forecasting ever since more businesses realized the limitations of traditional methods. Classical forecasting methods often extrapolate historical data based on subjective judgments of domain

experts. Nonetheless, such methods present limitations since they often rely on analyzing a small amount of data and do not consider external factors. The main issue with traditional methods is that they do not provide accurate forecasts if demand reacts to price, quality, or other promotional strategies of the present or even the current stock of the same or similar items. Machine learning algorithms fill these gaps and are capable of modeling and explaining complex multilayered relationships through the analysis of a wide variety of structured and, in many cases, unstructured data sources with sophisticated approaches to uncover even subtle patterns in the data. Different algorithms may be used, depending on problem complexity, data availability, and, last but not least, the degree of accuracy required.

A notable aspect of new approaches is that they make it possible to predict accurately and efficiently without a detailed understanding of the underlying processes or key factors such as stock levels, demographics, or consumption habits. Obviously, many other businesses have started to use artificial intelligence, and the results are self-explanatory for any research in this field: the demand forecast is more accurate. There are companies that state they improved forecast accuracy by over 30% compared to one year of data testing. AI and machine learning applications in demand forecasting are an inexhaustible subject chosen by researchers due to the high frequency of related studies. Such recent solutions complement traditional methods and are attractive to businesses aiming to optimize the function of their inventory management systems. The main interest of these businesses is to make accurate demand forecasts and establish competitive advantages in sectors as diverse as production, energy, retail, or logistics.

3. Stock Level Control Strategies

Retailers have to maintain optimal inventory levels in the store to keep up sales. Control of stock levels is important given their correlation with service level and, consequently, sales. An optimal stock level minimizes the risks of overstocking and stockouts. It is advised to keep stocks according to forecasted demand functions. In retail, the approaches to stock level control are not particularly different from standard inventory management practices. The offer proper for today's market sets high requirements for inventory policy control approaches to flexibility and adaptability to performance enhancement techniques. In practice, one of the approaches to inventory policy control is Just-in-Time. This strategy is based on the idea that it is not worthwhile to store

inventory if it can be produced and delivered each time it is needed. There are four principles of JIT, which can be employed separately from or together with the whole or part of the JIT system: visual control, flexible resources, inventory control, and lead time reduction. In retail inventory management systems, inventory control principles are crucial for supply process lead time reduction. One of the three different types of stock held in retail, known as safety stock, tends to serve as a buffer between demand variability and inventory availability. The need for safety stock is calculated on the basis of the reorder point, which triggers the repetition of orders. In other words, when stock replenishment is triggered by a fixed ROP, the main parameter of this inventory system is the one to optimize in order to improve flexibility in stock control.

3.1. Just-in-Time Inventory Management

Just-in-Time (JIT) inventory management constitutes adherence to a specific set of philosophies and principles in establishing the optimal inventory levels in a retail facility. American distribution centers have successfully applied the JIT principles made popular by the automobile industry and thereby benefited from the reduction of excessive inventory levels. JIT proposes that minimizing inventory levels is profitable, and the effort spent on perfecting production processes is a better investment than overstocking to cover quality deficiencies. A JIT system focuses on ordering raw materials and subsequently retail products from suppliers only when necessary. Basic objectives are providing an effective and efficient manner of synchronizing the flow of goods through the various components of the different supply chains by providing a systematic approach to institutional inventory control. Implementation of JIT can result in a reduction of safety or buffer stock and slower inventory turns, facilitating fewer inventory holdings with proportionally lower investment. The result would be an increase in the holding cost, the turnover ratio, and cash flow for the distribution center owner.

JIT philosophy has led to this shift from stock as the objective policy to response time being the objective policy. However, a JIT implementation is not a cure-all for all companies and speculation with no drawbacks. There are numerous risks and costs associated with keeping minimal inventory. One sudden product shortage can completely shut down a given operation. Moreover, JIT relies on suppliers being able to provide components reliably and efficiently. A strong relationship among companies

can significantly contribute to successful JIT implementation. The barrier to achieving JIT adoption in business is that it requires a profound systems and organizational overhaul. Despite the cost, the effort spent implementing JIT was found to be a source of competitive advantage in the industrial sector for quite some time, particularly that of the manufacture of high-demand products. The successful implementation of JIT in the Nissan Motor Company can be observed. The increase in DBR methods ensures that dealers will not be pushed beyond capacity in integration with JIT production.

More efficient modes of international transportation have ensured that JIT became a viable alternative for American companies reliant on best-cost-country sourcing. The equipment produced and transported in this manner has started to attract consumers within the U.S. The greatest advantage of JIT Mark II over traditional JIT is the customer orientation of the supply chain. It is concerned with filling orders directly from existing stocks or at least as fast as products are made. The JIT approach in the manufacture of trailers emphasizes minimizing production time and decision-making variability. Additionally, they attempt to maintain labor flexibility by offering specialized training to their staff. The process of utilizing JIT in production is termed 'east-meets-west.' This is because the countries of the east are invited to meet the industrial nations of the west in a network that transcends their differences. The strategy encourages the development of efficient and reliable supply chains instead of creating reliance on unreliable local sources that hold back growth.

3.2. Safety Stock and Reorder Point Optimization

In a retail setting, safety stock is considered the buffer stock that a retailer holds to mitigate potential inventory stockouts, especially when immediate stock replenishment is not achievable. Typically, the uncertainty of stock replenishment lead time and demand patterns of goods are regarded as essential considerations to determine the appropriate level of safety stock. An inadequate supply chain stock investment may lead to lost sales opportunities during demand surges. Alternatively, holding large buffer stock may increase stockholding costs due to the holding factor that represents the cost of tying up capital in stock.

Mathematically, stock inventory level is a continuous time-dependent variable. The reorder point (ROP) is a predetermined inventory level at which a retailer should generate the replenishment order. In a single-product inventory system, in the absence

of a replenishment order, a retailer consumes its available on-hand stock inventory. In essence, the retailer generally possesses a policy that highlights when to order new stock inventory. In turn, this replenishment signal would depend on the inventory level, which is invariably a function of stock on hand, stock on order, and the inventory details containing the safety stock level. Determining the appropriate ROP level is a very critical factor for a robust inventory stocking policy. Various situations of ROP optimization models are formulated with numerous assumptions and premises. In essence, these models focus on the inventory level in which an immediate replenishment signal to the supplier is issued to maintain the continuous stock replenishment policy. These ROP models consider variable demand, quantity discounts, imperfect and partial backlogging, imperfect good quality, and the delaying effects of inspection and lost sales opportunities. When ROP is optimally determined, the inventory system increases the trust of order and product reliability and satisfies consumer attitudes.

4. Case Studies and Real-World Applications

A plethora of case studies exist on how modern technologies such as AI and machine learning are applied to manage inventory planning, forecasting, and supply chain operations. Retail inquiry into deploying computer software to enhance the stock assortment started in the 1960s for department stores. Today, different international retail brands have incorporated AI technologies into their inventory management mathematically to automate time-consuming processes of stock management. For example, one brand aims to integrate AI and forecasting tools to correlate stock performance within its stores. Another group manages more than 600 stores. Replenishment of various brands has successfully managed reductions in inventory stock and cost savings by better controlling inventory purchasing and subsequently minimizing overstocks and stock-outs.

Since 2003, other global retailers have adapted different software to forecast demand from stores and from their suppliers. One retailer utilized AI in its stores to correlate stock arrival and equipment maintenance to store-specific pedestrian footfall, and another retailer determines inventory balance and stock replenishment dynamically based on its sales portfolio. From these projects, retailers have enhanced or attempted to upgrade the quality and speed of in-store demand forecasting, while some have tried to also increase their service levels. In the technical literature, our review indicates that

while AI and machine learning are consistently advocated for use in automated retail forecasting, the underlying mathematical and IT effects on firm performance have not been quantified. The conclusion of the existing literature may evolve into exclusion rules or templates for proposed usage relevant to a particular retail context. There are as yet no published thorough findings on the advantages gained from acquiring AI and/or ML knowledge within the retail industry, making the gathering of custom benefits unexplored terrain. For major accomplishments of AI research, we propose managers must always be aware of and be interested in AI/ML innovations.

4.1. Successful Implementations of AI in Retail Inventory Management

Some retailers have achieved early successes in this area through solutions from AI vendors. One retailer used an AI-driven demand-sensing application that helped them set more than 80% of shipments to store by midweek that closely met consumer demand that weekend, leading to fresh selling of increased quantities of nearly 1,000 more items. An AI-driven forecasting application that provides store-level granularity via prediction and easy drill-down capability for exception analysis can generate similar success. One of the primary challenges for this retailer was how to ensure exception skills were used 24/7 in a multichannel market with a dynamic replenishment strategy.

A good example of an omnichannel retailer that leveraged an AI-driven system to improve inventory visibility and place more accurate orders is a retailer that used a complex automated shelf inventory management system for their fasteners department. They were able to not only reduce time spent on manual inventory counting, but also upload/store data within their system to optimize stock levels in other departments of the store. As a result, the company saw reduced excess inventory. Another example of a company that leveraged AI to implement inventory optimization used an AI/ML system that transmitted and classified real-time conditions of patient inventory and parsed purchase orders from buyers by product and awarded items. Executives are now able to see their organization and demonstrate benefits to their CFO as well, which has reduced write-offs by 20% and raised customer satisfaction levels.

These cases emphasize how AI in retail can support significant cost savings, increased accuracy, and improvements in supply chain efficiencies that are traditionally appraised using only financial metrics. Also interesting is how each case is designed to excel for an entirely different retail segment, addressing specific challenges and impacts unique to

them. There are also a number of valuable lessons learned about implementing AI use cases in retail.

5. Future Trends and Innovations

The development of professional disciplines and technologies is accompanied by a set of trends and innovations. In the current rapid development of the field, such trends are difficult to grasp and may change very rapidly. We are now seeing rapid evolution in the field of AI, with new models and approaches being published on a regular basis. Integrating these model architectures in inventory management has the potential to process the flows of items in retail even further. In this section, we investigate some AI-driven trends and what future innovations lie ahead in inventory management.

AI-driven Predictive Modeling. The current trends in the application of AI to inventory management include more and more advanced predictive analytics methods. These new methods, such as demand forecasting based on AI, supply availability predicting AI, and predicting dynamic prices and discounts, utilize the current best practices in the field of natural language processing and deep learning to forecast customer behavior, supply chains, or stock shortages. Another innovation to be expected in the future regarding retail AI, from which inventory management would benefit as well, is autonomous inventory management systems, which carry out orders, automate planning of the entire flow, and create agile supply chains. To further increase the ability to create accurate forecasts, storing item history in an unchangeable digital ledger protected by cryptographic principles allows for a seamlessly trustworthy supply chain structure. When using blockchain to manage inventory, the supply chain can also greatly increase the transparency and traceability of assets, improving accuracy in inventory management decision-making. Currently, decision-making is data-driven. As a result, it is important to understand customer purchasing behaviors and businesses' required capabilities to meet demand. In addition to clarifying present methods of positioning items, such as cohesion sales and cross-sells, we anticipate that in the future, company possibilities for customer identification will be increased. Developments in this direction will lead to a better understanding of customer behavior. Hence, future trading models will rely on demands derived from behavior rather than historical data.

Based on the present publication trends in inventory management and the trends in retail, the future in this short segment will open to these approaches. By tracking these

developments closely, companies can be future-proofed. Finally, we foresee changes to customer behavior on the rather distant horizon. In recent years, there has been an increase in e-shopping rather than personal shopping, with the trend towards online shopping likely to increase in the future. This is partly to save costs for the consumer. Products are generally priced lower because their supply chain has been shortened. Brand effects are declining in these types of environments.

5.1. Advancements in AI for Inventory Optimization

Recent advancements in AI can revolutionize inventory management in the following ways: - Better demand forecasting – nowadays, sophisticated ML models manage to use big data for forecasting in a more accurate way. - Better decision-making in the supply chain – emerging MILP and reinforcement learning algorithms can answer difficult questions related to inventory management. - Replenishment automation – planning for procurement has become easier with emerging ML models that are tasked to set safety stock right for a company. Usually, an end-to-end model would incorporate forecasting, safety stock definition, and procurement replenishment. Machine learning practices have promoted supply chain integration and improved the overall financial status of a company. A lot of current work has focused on improving demand forecasting using AI. This is without counting other potential supply chain uses of AI illustrated here, such as consumer insights, proactive warehouse management, and democratizing information. Another application is in demand forecasting, one of the most common use cases. Further research groups forecast AI/machine learning adoption for the forecasting function to double within the next five years. The ability to track, in real-time, the inventory and know which products are where has significant implications for the popular SKU strategy. The reason for that is that what is more valuable in a warehouse is not a group of items but knowing where these items are. Finally, this type of AI increases the democratization of information; it no longer sits in the head of one person who has learned it over the course of years, but becomes a resource that can be accessed by or automated for everyone. For instance, integrating AI-based forecasting can lead to a 90% reduction in forecast error, a 20% reduction in overstock, and a 20% reduction in stockouts. This level of reduction can make significant inroads into enhancing corporate growth and profitability.

6. Conclusion

In conclusion, inventory management is key to retail organization and efficiency and to servicing the expectations and demands of consumers. With the increasing development of technology and applications based on machine learning and AI, it is important to consider the application of artificial intelligence in the field of electronic retailing. Inventory control is one of the oldest fields of investigation in operations management. One of its more alluded to challenges in supply chain management is to develop techniques for exchanging information efficiently between suppliers. Consequently, it is not unexpected that inventory control is a very vital area of research in several retail and manufacturing chains. The development of the optimal replenishment strategy with the availability of modern supply chain management can lead to effective overall supply chain performance. Numerous supply chain management strategies are seen to achieve inventory management efficiency. The objective of this paper is to recognize the various strategies and techniques utilized for achieving inventory control in a modern supply or distribution chain management paradigm and the empirical work done in this region, particularly in the field of supply chain management and how different supply chain management strategies associated with inventory optimization or other dimensions can lead the inventory department of firms towards better strategic decision-making. Their study can yield specific coordination in supply chain management opening up new areas of study and research for innovation in supply chain. A literature review indicates that, due to the complexity involved in inventory management and its interdisciplinary nature, the role of supply chain management in inventory optimization is significant in many retail companies. AI in retail inventory and supply chain management capability has the potential to transform the way business is conducted. The supply chain and business landscape is going through a period of rapid change. This, in turn, is forcing change at an unprecedented scale. This reflects the idea that most retailers need to anticipate a risk industry. Never before has it been so important to practice and augment your stocks. A demand-driven perspective is prompted by continuing to see the retailing business from the customer's point of view. It is recommended for retail managers that we need to continually innovate in terms of efficiency, customer service, and inventory handling. By following the strategies for reduction in determination of deciding the best overall structure for the supply chain as well as for the identification of location and sizing and configuration of facilities. Its intent is to study how inventories

should be maintained in supply chains to achieve all these objectives. Handling of inventory in a supply chain is difficult and unique. The goal of a reverse logistics based system is to tailor the system to the reverse user's purpose and inventory management and supply chain management importance is that aspect of maximizing revenues and minimizing costs.