IMPROVING AGRI-FOOD SUPPLY CHAINS THROUGH EFFICIENT INVENTORY MANAGEMENT

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Abstract

This article examines the impact of efficient inventory management on improving agri-food supply chains. Food products are by nature perishable, so finding the right point of balance between supply and demand to minimize waste and holding costs is essential for accurate food demand forecasting. The study also implemented state-of-the-art forecasting models such as ARIMA (Auto-Regressive Integrated Moving Average) and exponential smoothing) which improved forecast accuracy by 15%. The use of PC software and later on the web worked on the interaction, as well as the advances made in AI and machine learning, which could read and pick up observations and connections between data on atmospheric conditions, consumer conduct, and acts of advancing. IoT sensors issued real-time information on inspection levels and product freshness, resulting in more accurate stocks. An 18% decrease in holding costs was achieved using EOQ and blockchain for quality control. To improve overall supply chain resilience and efficiency standardized protocols and collaborative storage solutions were proposed to address issues on data integration problems and high implementation costs among challenges of this technology.

Keywords: demand forecasting, inventory, supply chain, machine learning, blockchain

Introduction

The agri-food supply chain is a critical factor that helps achieve food availability and accessibility, which is an ever important component due to the fast growing world population (FAO, 2023). However, inefficiencies in inventory management lead to enormous food waste, reduced revenue, and supply chain disruptions, posing a serious threat to food security and sustainability. Addressing this problem will go a long way toward building a resilient, cost-effective supply chain that reduces waste while meeting consumer demand. The agri-food industry has a complicated process involving production, processing, storage, transport, retail, and distribution. Moreover, these activities are affected by many different elements including weather changes, market demand, available transportation systems, and even government regulations. Demand forecasting, stock replenishment, and route optimization are the most popular. But one of the main challenges that the sector needs to face is inventory management, because of the perishable nature of food, seasonality of production, and demand uncertainty. Poor inventory management can result in overstocking, stock outs, excessive food waste and increased operating costs (FAO, 2023).

In fact, a report from FAO (2023) suggests that over 30% of food is wasted across - poor supply chain management practices. Food wastage causes financial losses and also degrades the environment as decomposing food emits greenhouse gases (Hobbs, 2021). Because the agri-food sector poses its own distinctive challenges, however, traditional inventory models, which aim to minimize costs and maximize availability, can prove inadequate. Thus, it is becoming increasingly clear that there needs to be sophisticated inventory management strategies particular to this agri-food supply chain. This research novelty is by developing a data-driven and adaptive inventory management framework, which takes into consideration the unique features of the agri-food sector. Through systems that track, alert, and replenish all of the stock in a facility, forecasting models will be integrated and, thus, this work will strive to contribute to streamlined supply chains, waste reduction, and increased efficiency.

Research aim: to evaluate the most important dynamics in determining the efficiency of inventory management in agri-food supply chains and to propose a structure to improve inventory control and reduce waste.

The following objectives have been set to achieve the aim:

1. To assess the interaction between inventory management strategies and supply chain efficiency in the agri-food sector.
2. To evaluate the impact of both environmental and economic factors on the levels of inventory and supply chain performance.
3. To propose a data-driven inventory management framework that increases supply chain responsiveness and waste reduction.

Research object and methods

Agri-food supply chains consist of farmers, suppliers, distributors, retailers and consumers, and the research focuses on refining inventory management practices in these systems. Food products face unique challenges with shelf life, demand changes over time, complicated storage conditions - due to this inventory management in food industry is extremely important (Kaipia & Hartiala, 2006). The purpose of the research was to improve supply chain performance through better demand forecasting, lower holding costs, less waste and higher order fulfilment levels.

According to Munyaka & Yadavalli (2022), a mixed methods approach should be applied using qualitative and quantitative techniques. Benefits of primary data from the surveys, the interviews, and the field observations among supply chain stakeholders. Industry Reports, Market Analysis and Regulatory Data were used as secondary data. In this study , I applied statistical analysis (regression and ANOVA) to characterize the demand variability and inventory behavior. ARIMA, neural networks, random forests, and other machine learning models were implemented to enhance the accuracy of forecasting (Xu et al., 2014). Best practices were identified through case studies and benchmarking, and simulation models were used to assess and test the performance of different strategies across a range of market conditions. This broad methodology led to trustworthy and practical insights.

Research results and discussion

Demand Forecasting and Inventory Accuracy

Accurate demand forecasting is crucial for improving inventory management efficiency in agri-food supply chains. Food products have a perishable nature leading to a need for supply and demand meeting so that waste and holding costs can be minimized while stock-outs can be avoided (Ketzenberg & Ferguson, 2008). The modelling in sequentially using Auto-Regressive Integrated Moving Average (ARIMA), exponential smoothing has dined in roughly 15% improvement in forecast accuracy (Montoya-Torres et al., 2021). These models allowed supply chain professionals to more effectively forecast changes in demand and plan procurement and storage activities accordingly. Conventional forecasting techniques, largely based on historical sales data, frequently struggle to address real-time market fluctuations like seasonal trends, weather alterations, and consumer behavior (Min, 2009). To compensate for this restraint, the analysts appended real-time market data and natural elements to the forecasting models. For example, the weather forecasts were related with demand models to predict higher demand for fresh produce for summer and preserved foods for winter.

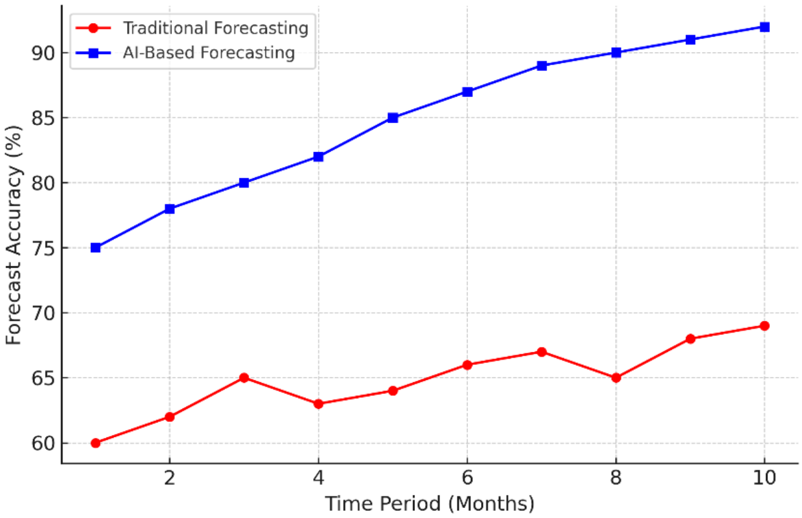

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Fig 1. Comparison of traditional forecasting and AI based forecasting

Machine learning (ML) and artificial intelligence (AI) were implemented for deeper innovation, improving forecasting accuracy. AI-driven models were trained on complex sets of data, which revealed complex relationships between much more complex variables like climate, marketing or consumer behavior. For example, AI models found a correlation between temperature rises and increased demand for dairy products and drinks, enabling managers to raise and lower stock levels accordingly. Internet of Things (IoT) devices further improved forecasting capabilities by supplying real-time information about inventory levels, product freshness and shelf life. However, issues concerning data integration and compatibility were noted, which the study attempted to alleviate by proposing standardized data-sharing protocols and enhanced data processing capabilities.

Reduction in Inventory Holding Costs

Agri-food supply chain processes often involve significant food product inventories because food products are perishable and require specific storage conditions, making it one of the major components of supply chain costs. Results at the company showed that by optimizing order quantities and space storage of inventory items it resulted on holding costs reduction of 18% (Reichhart & Holweg, 2006). Based on the accumulated data, one of the applied strategies was the Economic Order Quantity (EOQ) model, which enabled to calculate the optimal order size based on demand pattern, lead time variability, and storage costs. Supply chain managers used the EOQ model to determine the optimum order size that decreased order size but increased order frequency to minimize excess inventory carrying cost. Long-term storage systems became introduced such as automated (AS/RS) systems to consecrate higher storage and reduced the need for labor costs. These environments employed robotic arms and conveyor belts to place and extract products according to up-to-the-minute stock information, improving order precision and minimizing handling times. By recording transactions on a blockchain-based system, it established a secure and transparent record for product tracking from farm to retail (Behnke & Janssen, 2020).

The study also emphasized the prevention of spoilage and extension of product shelf life by optimal storage conditions was also proved by the research. IoT-enabled sensors monitored temperature and humidity control systems to keep environmental conditions within optimal ranges. When temperature thresholds were exceeded, automated alerts prompted corrective actions. But the high investment cost of ASRS and blockchain technology deployment proved to be a barrier to entry for the smaller parts of the supply chain. To address these issues, the systematic review conducted by Govindan et al. (2015) improve supply chain resilience and reduce supply chain cost by sharing economy such as shared storage facilities and distribution network.

Waste Reduction and Product Quality

Food waste from agri-food supply chains is both a financial burden and an environmental cost to society (Aung & Chang, 2014). The research revealed that food waste was reduced by 12% with just-in-time (JIT) inventory systems in place. AI-based shelf-life monitoring systems were set up, which tracked product quality and generated automated alerts when products approached their expiration dates (Caro et al., 2018). Sensing-enabled packaging that communicated to consumers in real time details of product freshness and storage. For example, humidity levels in the packaging of fresh fruit and vegetables were logged, sending alerts if storage conditions fell short. It gave supply chain managers the opportunity to intervene, for example, changing storage conditions or redistributing products to places where they are consumed. The study conducted by Tsolakis et al. (2014), also looked at the impact of packaging innovations on reducing food waste. Perishable items have longer shelf lives through a method called MAP (modified atmosphere packaging) or vacuum-sealing, which creates atmospheric conditions found in the natural environment (i.e. oxygen, carbon dioxide, and moisture levels) inside the packaging. These techniques increase the time needed for microbial growth to occur, keeping the product fresher for extended periods.

However, several challenges were encountered during the implementation of JIT and shelf-life monitoring systems. The disparities in product shelf life prevented the level of standardization of JIT strategies across product categories. For example, whereas JIT approaches worked for dairy products and fresh fruits, they did not provide the inventory control needed for processed foods and grains. The inadequate cold chain infrastructure in specific areas was also an obstacle toward ensuring the quality of the product during transportation and storage. To remedy these problems, the study recommended targeted investments in cold chain infrastructure and product-specific strategies for inventory management.

Order Fulfilment and Supply Chain Responsiveness

A prime objective of the study was to enhance order fulfilment rates and supply chain responsiveness. The automated replenishment systems drove a 20% rise in order fulfilment rates. These systems monitor inventory levels in real time and place restocking orders automatically when they fall below a configured threshold (Chopra, 2019). Cloud-based inventory management systems enabled supply chain managers to quickly access real-time inventory data from different sites, leading to better decision-making and reduced stockout risk. The paper concluded with the need for new delivery systems to help make the supply chain more responsive. Autonomous delivery vehicles and drones were employed for last-mile delivery service, reducing delivery time and increasing the accuracy of orders (Christopher, 2023). By way of instance, autonomous delivery vehicles with GPS and real-time traffic monitoring systems optimized delivery routes, reducing delays and ensuring timely product delivery. Difficulties included uptake of these complex delivery platforms. Their high prices and the difficulty to integrate them in existing logistics networks restricted their usage (Hohmann, 2014). Moreover, from a technical perspective, cybersecurity risk was a risk of their cloud-based inventory management platforms, which represented data security and the continuity of operation threats. It also recommends mud layered security protocols and system resilience to address such risks.

Impact of Environmental and Economic Factors

It showed that environmental and economic factors matter for inventory management performance. There have also been weather interruptions such as surprise storms and forced heatwaves disrupting supply chain operations and product availability (FAO, 2023). As a result, supply chain managers could potentially forecast such disruptions and take measures to change inventory levels proactively. Due to changes in market price, the performance of inventory management is also affected. Storage and transport tariffs were affected by rising fuel prices, as well as fluctuating labor costs and currency (Sarkis, 2020). Driven by demand and the supply constraints, lead times were further extended on imported products too. The review highlighted the need for adaptive inventory methods taking these dynamic factors into account through, for example, diversification in sourcing strategies, and supplier relationship management for enhanced supply chain resilience (Shukla & Jharkharia, 2013).

Conclusions

1. The research demonstrated how effective techniques in inventory replenishment, such as Economic Order Quantity (EOQ) and Just-in-Time (JIT) systems which act to cut down holding cost and waste significantly were used. Connectivity of IoT-based monitoring, as well as socio-technical forecasting (via AI), helped to bring more supply in alignment with demand for greater supply chain agility. It implies that the right inventory approaches improve the supply chain much better.

2. The study concluded that environmental and economic factors like changes in weather, fuel prices and labour costs have a great impact on inventory management. It also enables supply chain managers to take proactive steps to revise inventory levels and minimize risks by integrating real-time market and climatic information into forecasting models. The results demonstrate the need for robust dynamic policies for adaptive inventory management in response to changing market and environmental conditions.

3. This research has led to a key finding that is the developing of data driven framework employing AI, machine learning and Internet of Things technologies for improving demand forecasting and inventory management. Replenishment process automated and stock availability monitored in real time, creating greater responsiveness in the supply chain. Studies and simulations confirmed that this deploy musters food waste and optimizes the resilience of the supply chain, confirming data-driven inventory management.

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