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Review of Optimizing Inventory Management in the Supply Chain in the Manufacturing Sector Using Mathematical Models

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ABSTRACT:

Effective inventory management is vital for the success and profitability of small and medium-sized enterprises (SMEs) in the manufacturing sector. This paper reviews mathematical models to optimize inventory management within SME supply chains, aiming to reduce costs, improve stock levels, and prevent issues like stockouts and overstocking. SMEs often face challenges due to limited resources and inefficient traditional practices, which can lead to excess inventory or shortages. By applying mathematical models such as Economic Order Quantity (EOQ), Just-In-Time (JIT), and Vendor-Managed Inventory (VMI), SMEs can balance inventory holding costs, order costs, and service levels. Different mathematical models and analyses their applicability to SMEs, emphasizing how these models can enhance decision-making, reduce operational costs, and improve supply chain efficiency, even with limited technology investments. The research demonstrates that optimizing inventory through mathematical approaches can help SMEs respond better to demand fluctuations and increase their competitiveness in the manufacturing sector. This study highlights the value of integrating effective inventory management strategies to promote long-term growth and operational stability in SMEs.

1. INTRODUCTION

Supply Chain Management (SCM) is an important aspect of modern business operations, encompassing the coordination of production, transportation, and inventory management to guarantee that products reach end consumers promptly [1]. Effective SCM aims to balance supply and demand, minimize costs & improve customer satisfaction. Within this domain, inventory management plays a pivotal role, as it involves the regulation of stock levels to meet demand while avoiding overstocking and stocks out [3].

1.1 ROLE OF INVENTORY MANAGEMENT

Inventory management (IM) involves overseeing & controlling the ordering, storage, and utilization of both components & finished Commodities [9]. Its primary goal is to maintain sufficient supplies to meet customer's demand while minimizing holding costs & the risk of obsolescence. Ineffective inventory management (IM) can result in excessive costs, lost sales, and operational inefficiencies, highlighting the need for optimization in this area [6].

1.2 MATHEMATICAL MODELING IN INVENTORY MANAGEMENT

Mathematical modeling offers powerful tools for optimizing inventory management by providing structured approaches to analyzing and solving complex problems [10]. These models can capture various aspects of the supply chain, including demand forecasting, order quantities, lead times & service levels. By employing mathematical models, businesses can make informed decisions that effectively balance costs and service quality, ensuring efficient and responsive supply chains.

1.3 OBJECTIVES OF OPTIMIZATION

The primary objective of optimizing inventory management is to optimize total costs, which include ordering costs, holding costs & shortage costs while maintaining high service levels. Achieving this involves:

- Demand Forecasting
- Inventory Policies

- Cost Minimization
- Service Level Optimization

In today's globalized and interconnected world, efficient inventory management (IM) within supply chain networks is necessary for businesses striving to remain competitive and effectively meet customer demands. This process encompasses the strategic management of goods & materials from procurement to storage & distribution [14]. Optimizing inventory management is critical, as it directly influences operational costs, customer satisfaction, and overall profitability.

This introduction delves into the significance of optimizing inventory management (IM) in supply chain networks through the utilization of mathematical algorithms [17]. It begins by exploring the challenges and complexities associated with traditional inventory management practices, followed by an overview of how mathematical algorithms can revolutionize these practices. Subsequently, it discusses the objectives and structure of this study, highlighting the key areas that will be covered in-depth.

1.4 TYPES OF INVENTORIES

- **Maintenance Inventory:** This type of inventory consists of items which are needed for maintenance or repairing operations.
- **Raw Material Inventory:** In this type of inventory basic materials are kept that are used in the process of manufacturing.
- **Seasonal Inventory:** This type of inventory is required to fulfill the demand due to seasonal variation.
- **Transit Inventory:** This type of inventory includes the transfer of inventory products from manufacturing units to distribution centers and then to customers.
- **Anticipating Inventory:** In this type of inventory, a stock is kept for meeting the demand due to fluctuations in future.
- **Finished Product Inventory:** This type of inventory consists of those commodities that are ready for sale to the customers.
- **Lot Size Inventory:** This type of inventory exists when the demand rate becomes less than the production rate.

1.5 INVOLVEMENT OF MATHEMATICAL APPROACHES IN INVENTORY

Optimizing inventory management is to minimize the costs, which include ordering costs, holding costs, and shortage costs while maintaining high service levels. The following key points are involved:

- Demand Forecasting
- Inventory Policies
- Cost Minimization
- Service Level Optimization

2. LITERATURE REVIEW

- Sadeghi et al. (2023) presented a study in which they introduced a fresh challenge concerning the management of reusable product stocks within a network comprising a single vendor, multiple products, and multiple retailers. Various constraints, including budget limits, storage capacities, and order quantities, are incorporated in their stochastic nature to better reflect real-world scenarios. This study introduces the Grey Wolf Optimizer (GWO) and Whale Optimization Algorithm (WOA) as innovative metaheuristic approaches for finding solutions, while the Sequential Quadratic Programming (SQP) exact algorithm serves to validate their efficacy. The performance of these methods is statistically compared by using appropriate parametric and non-parametric tests. Results analysis reveals a significant distinction between the algorithms, with GWO demonstrating superior performance in solving the presented problem.
- Alkahtani et al. (2023) presented a model and optimize production and outsourcing operations within a supply chain while addressing environmental challenges. The proposed nonlinear mathematical model incorporated outsourcing, reworking, and carbon tax considerations. Sequential Quadratic Programming (SQP) was utilized to find optimal solutions. Recognizing the significant impact of transportation on carbon emissions, the study included these emissions in the total supply chain cost. Data from the automobile parts industry was used to test the model, and sensitivity analyses were conducted to examine the effects of individual parameters on total costs. The findings offer valuable insights for managers looking to optimize production and outsourcing to create a resilient supply chain.
- Golpira (2023) presented an innovative risk-based approach to optimize global closed-loop supply chain networks, utilizing a mixed-integer linear programming framework within a novel, uncertain, bi-level programming model. The findings reveal significant enhancements in solution robustness, with notable reductions in standard deviations of profit, income, and cost by approximately 28%, 34%, and 36% respectively, on average.
- Darmawan et al. (2022) declared that some manufacturing firms may encounter production limitations, resulting in backlogging when demand exceeds capacity. This study focuses on such scenarios, aiming to optimize inventory costs by determining the optimal make and buy quantities. A make-with-buy model is proposed and solved using the branch and bound method. The results validate the method's effectiveness in reducing overall inventory costs, including maintenance, order, setup, and purchasing expenses, as well as total product costs.
- Choudhury et al. (2022) conclude that the suppliers often provide trade credit incentives to retailers to boost sales. Retailers may need to lease extra warehouse space when orders exceed their storage capacity. Suppliers also commonly offer quantity discounts on larger orders as part of global marketing strategies. This paper presents an integrated inventory management (IIM) model that accounts for capacity constraints at the retailer, supplier trade credit terms, all-unit quantity discounts, partial back ordering of shortages, and production costs that vary with production rates. An optimization algorithm is developed to evaluate the optimal production and replenishment policies for both the supplier & the retailer under these factors. The model allows suppliers and retailers to maximize profits while coordinating inventory and credit terms.

- Gupta et al. (2022) discussed that the importance of SCM for organizational operations. We begin with an overview of the advancements in this field and proceed to examine the challenges associated with managing SC. Alternative definitions and key issues related to SCM are outlined, followed by a discussion on significant inefficiencies within supply chain management (SCM) practices. Finally, we conclude by providing an overview of ongoing research efforts and discussing future challenges in SCM.
- Setiawan et al. (2021) focused on designing a closed-loop supply chain network for different types of masks. The supply chain under study includes suppliers, manufacturers, distributors, and retailers in the forward flow, and collection centers, separation centers, recycling centers, and disposal centers in the reverse flow. A multi-objective mathematical model is proposed with the goals of increasing total profit, reducing total environmental impact, and maximizing social responsibility. The optimization of this model is carried out using a fuzzy optimization approach in GAMS software. The results indicate that maximizing profit, minimizing environmental effects, and maximizing social responsibility are often conflicting objectives. Additionally, the sensitivity analysis revealed that customer demand can simultaneously impact all aspects of the sustainable supply chain.
- Rubel (2021) conducted this study for effective inventory management practices is to minimize procurement costs by efficiently managing and optimizing inventory levels, ensuring that supply chain members are not impacted by excess or insufficient stock. Enterprise Resource Planning (ERP) systems play a vital role in integrating these processes and optimizing inventory levels through features such as demand forecasting, ABC analysis, FIFO method, safety stock management, and overall stock management. This paper introduces an Inventory Optimization and Cost Saving Model, leveraging a Genetic Algorithm (GA) to enhance inventory control & supply chain efficiency. The study focuses on using a genetic-based approach to refine inventory management systems in industrial asset management, specifically targeting the determination of optimal stock levels and deficit thresholds to minimize transaction costs.
- Elarbi et al. (2021) introduced proper drug inventory management as critically important across the pharmaceutical supply chain to ensure medicines are available when and where needed to save patients' lives. The paper proposes a collaborative multi-tier pharmaceutical supply chain model involving a central pharmacy, regional pharmacies, and hospitals. It uses a stochastic multi-period, multi-product mathematical optimization model to minimize inventory costs like shortages and holding costs. The stochastic model is solved using Lingo 18.0 software and a branch-and-bound method. The model's performance is compared against the current practice in the Tunisian pharmaceutical supply chain to demonstrate the research benefits. Effective inventory management and supply chain coordination can improve drug availability for patients while reducing costs.
- Chung et al. (2021) noticed that some optimization methods lack mathematical rigor, relying instead on intuitive reasoning, which raises questions about their logical validity. For instance, while their inventory models are intriguing, they examine the interrelations of functional behaviors (such as continuity, monotonicity, and differentiability) of the total cost function to identify the optimized solution. These omissions can impact the practical implementation of their inventory model.
- Kalaiarasi and Gopinath, (2020) conducted a study to determine the Economic Order Quantity (EOQ) to optimize the total Cost in supply chain management, where the reorder point holds significant importance. This research employs the Lagrange approach to calculate the optimal order quantity while minimizing overall costs. Inventory parameters are transformed into fuzzy parameters using fuzzy trapezoidal numbers, with defuzzification achieved through the graded mean integration method. The mathematical model proves to be greatly beneficial in enhancing product inventory management through a combination of trial-and-error methods and mathematical techniques.
- Poshtahani and Pasandideh (2020) addressed a bi-objective problem within a multi-product single-vendor single-buyer supply chain, focusing on a green vendor-managed inventory (VMI) policy built upon the (EPQ) model. The study employs three multi-objective decision-making methods—LP-metric, Goal attainment, and multi-choice goal programming with utility function (MCGP-U)—across various problem sizes to address the model. Two multi-criteria decision-making (MCDM) approaches, along with statistical analysis, are utilized to compare outcomes generated by the three proposed problem-solving methods. The GAMS/BARON software is employed to minimize objective function values.
- Karimian et al. (2020) introduced a multi-item EPQ model, considering shortages, within a single-vendor, multi-retailer supply chain under a vendor-managed inventory (VMI) policy amidst stochastic conditions. Three stochastic constraints are formulated in the model, and a geometric programming (GP) approach is utilized to optimize the nonlinear stochastic programming problem, aiming to minimize the mean variance of the total inventory cost. To tackle the problem's Signomial form, an algorithm is employed to convert it into a standard GP form. The effectiveness of the suggested model and solution method is assessed through computational experiments and sensitivity analysis. Additionally, a case study involving an Iranian furniture supply chain demonstrates the practicality of the suggested model, resulting in a 17.78% enhancement in total cost.
- Soltani & Golpira (2020) developed a new and robust mixed integer linear programming (MILP) approach, initially derived from an innovative uncertain programming problem, to efficiently design a closed-loop supply chain network. Through a numerical example, the model's performance is evaluated in terms of computational outcomes and robustness, with a comparative analysis. The numerical findings indicate that, on average, there is a reduction of approximately 100% in the profit variance.
- Santos et al. (2019) addressed the economic viability of forestry investments relies heavily on the expenses linked to harvesting and transporting wood, which represent a significant part of overall production costs. Hence, efficient management of these operations is crucial. This study introduces an innovative optimization model aimed at minimizing costs associated with machinery operation, movement, and wood transportation while considering demand constraints through daily and weekly planning of harvesting activities. Results suggest that transportation costs are the primary cost driver in these operations. The proposed model proves effective in optimizing the planning of harvesting activities, although scenarios with numerous stands may pose challenges due to increased complexity and computational requirements.
- Alfares and Ghaithan (2019) examined production-inventory control, highlighting how EOQ & EPQ models can help determine optimal order quantities for purchasing and manufacturing. Traditionally, these models have assumed constant costs; however, recent research has shifted focus to EOQ/EPQ models that account for varying costs, including holding, ordering & purchasing expenses. This paper reviews and categorizes EOQ & EPQ inventory models with variable holding costs into three groups: time-dependent holding costs, stock-dependent holding costs & multiple dependence, or other forms of holding cost variability.

- DE & Mahata (2019) focused on a three-tier supply chain network involving the movement of raw materials, the manufacturer, and multiple retailers, considering imperfect quality and learning experiences in fuzzy decision-making. While existing literature addresses supply chain models with full backordering and disruptions, our study introduces a production-inventory control problem with partial backlogging and random disruptions. They present a case study to define the problem & demonstrate practical application. To minimize overall supply chain costs, we employ the Triangular dense fuzzy lock set to control the cost vector of the objective function. By employing a new defuzzification method and selecting appropriate keys, determined by decision-makers, we can exclusively minimize average system costs.
- Shekarian et al. (2016) conclude that the EOQ formula, researchers have sought to extend it to accommodate real-world complexities. One such extension involves incorporating fuzzy set theory into EOQ models to address imprecise business environments. This integration often results in complex objective functions requiring advanced optimization methods, ranging from mathematical techniques to artificial intelligence algorithms. This research aims to explore and analyze various methods, techniques, and algorithms used to optimize and solve EOQ models. The findings of this study assist inventory researchers in selecting appropriate methods to solve their inventory models and determine optimal policies.
- Cárdenas-Barrón & Sana (2015) presented an EOQ inventory model for multiple items within a two-tier supply chain, where demand is influenced by promotional activities. The model incorporates a payment delay period from the supplier to the retailer for settling outstanding purchasing costs of finished products. Profit functions for both the supplier & the retailer are devised, accounting for setup costs, holding costs, selling prices, and shared promotional expenses. Furthermore, collaborative and non-collaborative systems are contrasted based on their average profitability. Numerical examples are included to exemplify the application of the proposed model.
- Mahamani & Rao (2010) introduced a well-coordinated VMI system that has the potential to enhance supply chain performance by lowering inventory levels and improving fill rates. This study delves into the implementation of VMI systems within the consumer goods industry, specifically focusing on the (r, Q) policy for inventory replenishment. The primary aim is to minimize inventory levels across the supply chain while maximizing service levels. The main contributions of this research include the development of a spreadsheet model for VMI systems, assessing total inventory costs through both spreadsheet-based and analytical methods, quantifying inventory reductions, estimating service efficiency levels, and validating the VMI spreadsheet model using randomly generated demand data. Results indicate that the inventory reduction achieved through the analytical method closely aligns with the spreadsheet-based approach, indicating the success of VMI.
- Radhakrishnan et al. (2009) defined that inventory management is a crucial aspect of supply chain operations, as it directly impacts customer service quality. Effective inventory management across the supply chain is essential for increasing customer satisfaction while minimizing costs. Determining optimal inventory levels at various stages of the supply chain is necessary to achieve cost efficiency. This involves optimizing total supply chain costs by reducing holding and shortage expenses throughout the supply chain. However, a significant challenge arises from the dynamic nature of excess and shortage levels over time. This paper presents a novel and efficient approach utilizing Genetic Algorithms to accurately determine optimal excess and shortage levels for inventory optimization in the supply chain, ultimately leading to minimized total supply chain costs.

Table 1. Details of different parameters considered in various studies and model used in study.

S. No.	Author	Year	Approach	Conclusion
1	Sadeghi et al.	2023	Grey Wolf Optimizer (GWO) and Whale Optimization Algorithm (WOA)	GWO and WOA proficiently explore the solution space, yielding results that closely match the optimal solutions from the SQP algorithm.
2	Alkahtani et al.	2023	Sequential quadratic programming, multi-stage production	It provides crucial insights for managers to optimize production & outsourcing, ensuring a resilient supply chain.
3	Golpira	2023	Bi-level programming	"The proposed approach boosts solution robustness, cutting the standard deviation of profit, income, and cost by about 28%, 34%, and 36%, respectively."
4	Darmawan et al.	2022	branch and bound method	This result demonstrates practicality and effectiveness by lowering both inventory expenses and total product costs.
5	Choudhury et al.	2022	Order-size-dependent trade credit & EOQ	Integrated inventory model with capacity, trade credit, discounts, and partial back ordering optimized using closed-form solutions. Provides managerial insights.
6	Gupta et al.	2022	Supply Chain Sustainability Index (SSI) & AHP	The proposed method assesses overall supply chain sustainability by evaluating each player's contributions individually.
7	Setiawan et al.	2021	fuzzy optimization approach & sustainable supply chain network design (SSCND)	Maximizing total profit, minimizing environmental impact, and maximizing social responsibility often conflict with each other.
8	Rubel	2021	Genetic Algorithm & MATLAB	Reduce inventory by 20-40% within 6 months, cut transportation by 35%, and boost productivity by reducing planning time by 60-80%.
9	Elarbi et al.	2021	Multi-product mathematical model & Lingo 18.0 software	The centralized system mitigates drug demand uncertainty, decreasing shortages and costs, and achieving an average cost gain of 6.74%.
10	Chung et al.	2021	financing via trade credit, partially permissible delay in payments & EOQ Model	The standard approach involves using calculus to explore the functional behaviors of the objective function

11	Kalaiarasi & Gopinath	2020	Economic Order Quantity (EOQ)	Significantly improves product inventory management using trial and error combined with mathematical techniques.
12	Poshtahani and Pasandideh	2020	multi-criteria decision-making (MCDM), Economic production quantity (EPQ), vendor-managed inventory (VMI), greenhouse gases (GHGs) emissions & GAMS Software	Improving supply chain effectiveness using multi-product EPQ models incorporating green initiatives and stochastic limitations shows encouraging outcomes.
13	Karimian et al.	2020	Economic production quantity (EPQ), Stochastic programming, Geometric programming (GP), GAMS & MATLAB Software	The proposed model results in a 17.78% reduction in total cost.
14	Soltani & Golpira	2020	Robust optimization	The average reduction in profit variance is 100%, but improving reliability and robustness comes with a cost.
15	Santos et al.	2019	Optimization Model	Optimization methods improve forest harvesting by reducing costs and enhancing planning, helping managers achieve profitability and operational efficiency.
16	Alfares &. Ghaithan	2019	Production-inventory control, economic order quantity (EOQ), Optimum Exact Algorithms (OEA) & Heuristic Approximate Algorithms (HAA)	The paper identifies prevailing research trends and offers several suggestions for future research directions in supply chain management.
17	DE & Mahata	2019	triangular dense fuzzy lock set, Partial Backlogging	The triangular dense fuzzy lock set, new defuzzification method, graphical illustrations, and sensitivity analysis are used to minimize the SC's aggregate cost.
18	Shekarian et al.	2016	EOQ and Fuzzy Economic order quantity (FEOQ)	This study aids inventory researchers in selecting optimal methods and policies for their models.
19	Cárdenas-Barrón	2015	EOQ models for multi-items as per demand	In the supply chain, promotional efforts have made real advancements for optimization
20	Mahamani & Rao	2010	Vendor-managed inventory (VMI)	VMI's success depends on the quality of buyer-supplier relationships, IT systems, and the intensity of information sharing.
21	Radhakrishnan et al.	2009	Genetic Algorithms & MATLAB 7.4	Genetic Algorithms effectively determine optimal excess stock and shortage levels, minimizing total supply chain costs for inventory optimization.

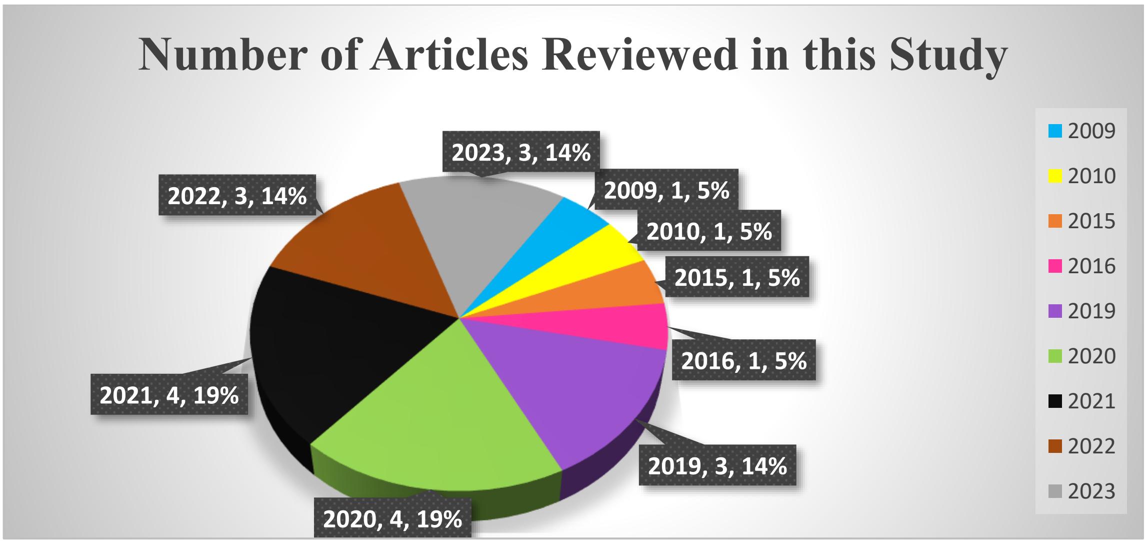

Figure 1. Pie chart of the number of researches reviewed with respect to time period considered in this study.

The sky blue colored area in the pie chart here represents the number of studies, considering data of the year 2009 while the yellow color area represents data of the year 2010, and the orange color area represents data of 2015. The pink area represents the data of the year 2016 which is dominant as compared to the studies in another year, the violet color area represents data of 2019, the green area represents the data of 2020 the black area represents the data of 2021, and the brown color area represents the data of 2022 while the gray color represents the data of year 2023 as shown in Figure 1.

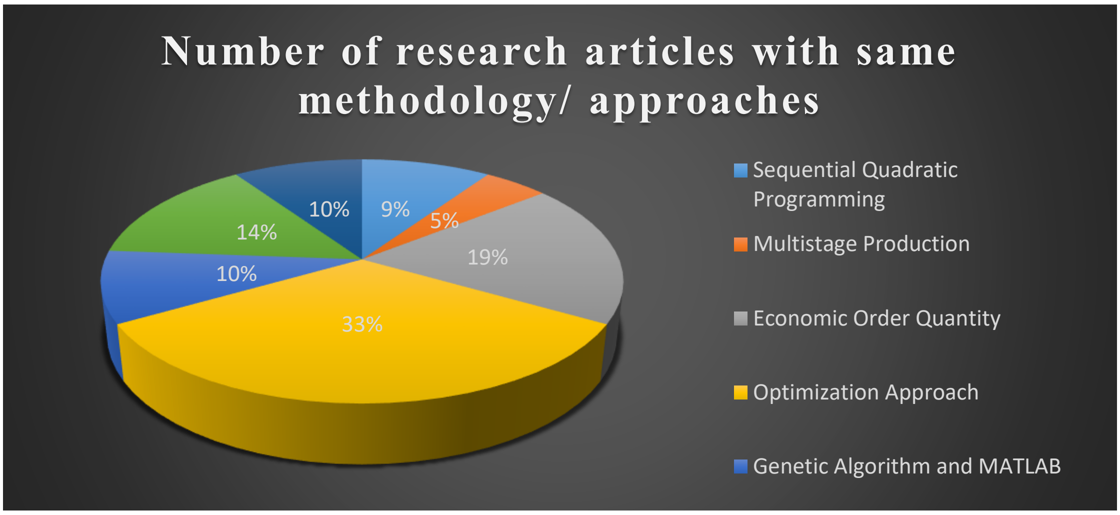

Figure 2. Pie chart of numbers of research papers with the same methodology considered in this study

The sky blue colored area in pie chat represents the paper with Multistage Production while the orange color area represents the paper with Economic Order Quantity Model, the Gray color area represents the paper related to Optimization Approaches, the yellow area represents the paper with Genetic Algorithm & MATLAB Programming and the dark blue area represents the paper with Vendor-Managed Inventory Model, as shown in Figure 2.

3. CONCLUSION

Optimizing inventory management in supply chain networks through mathematical algorithms presents a substantial opportunity for businesses to enhance operational efficiency, reduce costs & elevate customer satisfaction. By overcoming the limitations of traditional inventory management practices and harnessing the power of mathematical algorithms, organizations can achieve improved alignment between supply and demand. This approach not only addresses the challenges posed by uncertainty and variability but also enables businesses to respond more agilely to market fluctuations. Ultimately, the integration of advanced mathematical techniques into inventory management not only streamlines operations but also fosters a more resilient and responsive supply chain, positioning organizations for sustainable success in a competitive landscape.

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