# Strategic Optimization Technique for Achieving Sustainable Inventory Management in Medium-Sized Enterprises

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**Abstract**

Medium-sized enterprises face the dual challenge of optimizing inventory practices while aligning with sustainable objectives. Effective inventory management in medium-sized enterprises remains a critical factor in balancing operational efficiency and sustainability. This study addresses the challenge by investigating strategic optimization approaches for inventory control. The background explores the complexities of inventory management, emphasizing the need for enhanced techniques in medium-sized enterprises. The problem statement underscores the necessity of innovative methodologies to navigate the intricate landscape of inventory control and sustainability. To address these challenges, advanced methodology based on LightGBM is applied to forecast demand, assess vendor purchase costs, optimize stock levels, and evaluate predictive performance. Empirical findings, showcased through visualizations, revealed insights into the distribution of purchase costs among vendors, daily sales velocity by product, and comparisons between current and recommended stock levels for top products. Comparative analyses demonstrated LightGBM's superior predictive performance over baseline models, highlighting its potential as a valuable tool in decision-making for inventory management.

**Keywords**: Inventory control; Sustainability practices; Medium-scale businesses; Strategic management Inventory optimization; Sustainable supply chain; Environmental impact; Resource optimization; Eco-friendly practices; green inventory management.

## 1. Introduction

Inventory management remains a key driver of operational efficiency in companies, especially in mid-tier businesses [1-3]. The challenge of maintaining optimal inventory levels while aligning with sustainability goals has emerged as an important area of focus strategic [4]. Large firms operating in often competitive markets must balance economic efficiency with environmental responsibility [5]. The integration of strategic efficiencies is critical in the evolving business environment [6]. These strategies are important tools that empower companies to unleash the full potential of their inventory systems [7] . By implementing advanced strategies, companies can not only streamline their operations but also make a positive contribution to environmental sustainability. Especially for mid-sized businesses, strategic convergence requires micro-adaptive strategies tailored to their unique business processes [8].

This study emphasizes sustainability as a key objective in medium-sized enterprises, focusing on best inventory management practices It aims to explore and develop tailored strategies that balance economic efficiency with environmental considerations. While this research has delved into the complexities of conservation management, it seeks to identify and evaluate alternative strategies, assessing the feasibility and effectiveness of setting sustainability goals routinely encouraged in this particular work environment [9]. The main objective of this paper is to provide a comprehensive analysis and framework for achieving sustainable inventory management in mid-sized infrastructure. Through a multi-dimensional approach and methodology, this research aims to provide optimal strategies that



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minimize environmental impact and maximize reserve control In order to achieve this, the paper is organized as follows: first, it introduces the theoretical basis of optimization methods in inventory management and second, it describes methods an in-depth approach, including LightGBM and other models; Third, it presents empirical findings and discussion based on the application of these methods [14-17].

This paper is structured to effectively address the challenges of sustainable inventory related to mid-sized industries. The framework unfolds systematically, beginning with Phase 2, where a comprehensive survey is conducted. Section 3 delves into the methods used. Subsequently, Section 4 presents the specifics of the research design, methodology and application. Section 5 forms the core of this study, presenting the empirical findings. Finally, Section 6 consolidates the main findings.

## 2. Related Works

This section provide a review of scholarly articles, industry reports, and empirical studies is conducted to establish the current landscape of sustainable inventory management. Hofmann et al. [17] examined firm capabilities as drivers of environmental management and sustainability practices among small and medium-sized manufacturers. Their research highlighted the role of firm-specific capabilities in shaping sustainability initiatives. Karadag [18] delved into strategic financial management tailored for SMEs, offering insights into financial strategies optimized for the unique operational frameworks of smaller enterprises. Behrendt et al. [19] provided a comprehensive manual on life cycle design specifically aimed at addressing the challenges faced by small and medium-sized enterprises, aiding in the integration of life cycle design practices. Wiklund and Shepherd [20] explored the relationship between knowledge-based resources, entrepreneurial orientation, and the performance of small and medium-sized businesses, emphasizing the significance of knowledge-driven strategies in enhancing SME performance. Rauch et al. [21] elucidated the requirements and barriers related to the introduction of smart manufacturing in small and medium-sized enterprises, shedding light on the challenges and prerequisites for implementing smart manufacturing practices in the SME sector. Ab Rahman [22] conducted an empirical study on the effective implementation of global supply chain management in small to medium-sized companies in Malaysia, providing insights into practical challenges and effective strategies for global supply chain management in SMEs. Hallstedt et al. [23] proposed an approach to assess sustainability integration within strategic decision systems for product development, aiding SMEs in integrating sustainability considerations into strategic decision-making processes.

Jonsson and Mattsson [24] analyzed various inventory management practices and their implications on perceived planning performance, offering a comprehensive analysis of inventory management approaches and their impact on planning effectiveness. Pechmann et al. [25] developed a methodology to assess the potential for load-shifting at SME manufacturing sites, identifying opportunities for energy load-shifting practices contributing to sustainability in SMEs. Kasim et al. [26] conducted an in-depth assessment of inventory management practices within the Northern Region of Ghana among SMEs, offering insights into prevailing inventory management strategies and their effectiveness. Oluwaseyi et al. [27] evaluated the role of inventory management in the logistics chain of an organization, focusing on the significance of effective inventory management practices within the logistics operations of SMEs. Choudhary et al. [28] presented an integrated lean and green approach to improve sustainability performance, drawing from a case study of a packaging manufacturing SME in the UK, showcasing an innovative approach merging lean principles with environmental sustainability goals. Ližbetinová et al. [29] conducted an empirical study on the application of cluster analysis in marketing communications within small and medium-sized enterprises in the Slovak Republic, aiming to elucidate the effectiveness of cluster analysis in refining marketing strategies for SMEs.

## 3. Methodology

This part of our study delineates the systematic approach applied to investigate and examine the factors influencing stock control strategies, emphasizing the mixing of sustainability standards. LightGBM, a gradient-boosting framework evolved through Microsoft, stands as a robust system-gaining knowledge of approach utilized in this look at to model and analyze stock data within medium-sized establishments [19-21]. Distinguished for its excessive computational efficiency and accuracy, LightGBM employs a novel gradient-based method, utilizing tree-based totally studying algorithms. Its precise functions consist of the capacity to address large datasets efficaciously whilst providing excessive prediction accuracy. In the context of stock management, LightGBM allows the modeling of intricate relationships between numerous stock parameters, enabling the identity of key factors influencing inventory degrees, turnover, and demand fluctuations [25].

As a part of our proposed approach, LightGBM is carried out to model the inventory records inside medium-sized organizations. This involves a based method encompassing records preprocessing, function selection, and version schooling to correctly capture and examine inventory-related variables [27]. The dataset comprising ancient inventory


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records, call for patterns, procurement records, and related contextual factors is preprocessed to ensure facts nice and relevance. Feature engineering strategies are hired to extract significant functions and transform the records into a format appropriate for analysis by using LightGBM.

In supervised settings, the inventory data $\{(\mathrm{x_i}, y_i)\}_{i=1}^{N}$ consists of input features and their corresponding target values. LightGBM, like many other ML algorithms, aims to learn a model that predicts or estimates the target value $y$ given the input features $x$. This is achieved by minimizing a specific objective function during the model training process, which compose loss function and a regularization term as expressed bellows:

$$Obj = \sum_{i} l(y_i, \widehat{y_i}) + \sum_{k} \Omega(f_k) \tag{1}$$

Logistic loss functions play a fundamental role in the case of logistic regression algorithms or other algorithms that contain binary classification functions, and it is also known as log loss, which is commonly used to quantify the discrepancy between predicted probabilities and true binary outcomes.

$$l(\mathrm{y_i}, \widehat{\mathrm{y_i}}) = y_i \ln(1 + e^{-\widehat{y_i}}) + (1 - y_i) \ln\left(1 + e^{\widehat{y_i}}\right) \tag{2}$$

A regression tree with set of nodes and branches that help portioning the input space into distinctive regions according to feature values. Each leaf in the tress signify the a predicted value for the assigned input features that descend from coreepsonding branch.

$$F_T(X) = \sum_{t=1}^{T} f_i(x) \tag{3}$$

The alternate representation of the regression tree takes the form of $w_q(x)$, where $q$ belongs to a set from 1 to $J$, denoting the total number of leaf nodes within the tree. Here, $q$ signifies the decision rule governing the tree, while w stands for the weight assigned to each sample. Then, the above objective can be re-articulated as follows:

$$Obj^{(t)} = \sum_{\mathrm{i=1}}^{\mathrm{n}} l\left(\mathrm{y_i}, \mathrm{f_{t-1}}(\mathrm{x_i}) + \mathrm{f_t}(\mathrm{x_i})\right) + \sum_{k} \Omega(f_k) \tag{4}$$

In LightGBM, the Newton's method was applied to instantly approximate the objective value. To make things simpler, we apply set of derivations as described bellows:

$$Obj^{(t)} \cong \sum_{i=1}^{n} [g_i f_t(x_i) + \frac{1}{2} h_i f_t^2(x_i)] + \sum_{k} \Omega(f_k) \tag{5}$$

$$\begin{aligned} g_i &= \partial_{F_{t-1}(x_i)} \Psi(y_i, F_{t-1}(x_i)) \\ h_i &= \partial^2_{F_{t-1}(x_i)} \Psi(y_i, F_{t-1}(x_i)) \end{aligned} \tag{6}$$

Expressing the sample set of leaf $j$ as $I_j$, the above formula can be reconfigured in the following manner:

$$Obj^{(t)} = \sum_{\mathrm{j=1}}^{\mathrm{J}} \left[ \left( \sum_{\mathrm{i=I_j}} \mathrm{g_i} \right) \mathrm{w_j} + \frac{1}{2} \left( \sum_{\mathrm{i=I_j}} \mathrm{h_i} + \lambda \right) \mathrm{w_j^2} \right] \tag{7}$$

Given a previousl known structure of the tree q(x), it is viable to use quadratic programming to compute the ideal weight for each leaf node and determine the boundary of $L_T^*$ :

$$w_j^* = -\frac{\sum_{i \in I_j} g_i}{\sum_{i \in I_j} h_i + \lambda} \tag{8}$$

$$L_T^* = -\frac{1}{2} \sum_{j=1}^{J} \frac{(\sum_{i \in I_j} g_i)^2}{\sum_{i \in I_j} h_i + \lambda} \tag{9}$$

To calculate the gain, we use the following formula:


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$$G = \frac{1}{2}\left[\frac{\left(\sum_{i\in I_L} g_i\right)^2}{\sum_{i\in I_L} h_i + \lambda} + \frac{\left(\sum_{i\in I_R} g_i\right)^2}{\sum_{i\in I_R} h_i + \lambda} - \frac{\left(\sum_{i\in I} g_i\right)^2}{\sum_{i\in I} h_i + \lambda}\right] \quad (10)$$

## 4. Empirical configurations

In this section, we delve into the empirical configurations employed to investigate and analyze the strategic optimization of inventory management practices in the context of medium-sized enterprises. Comprising a multifaceted approach, this section details the methodologies, frameworks, and analytical tools utilized to empirically examine the application of strategic optimization techniques.

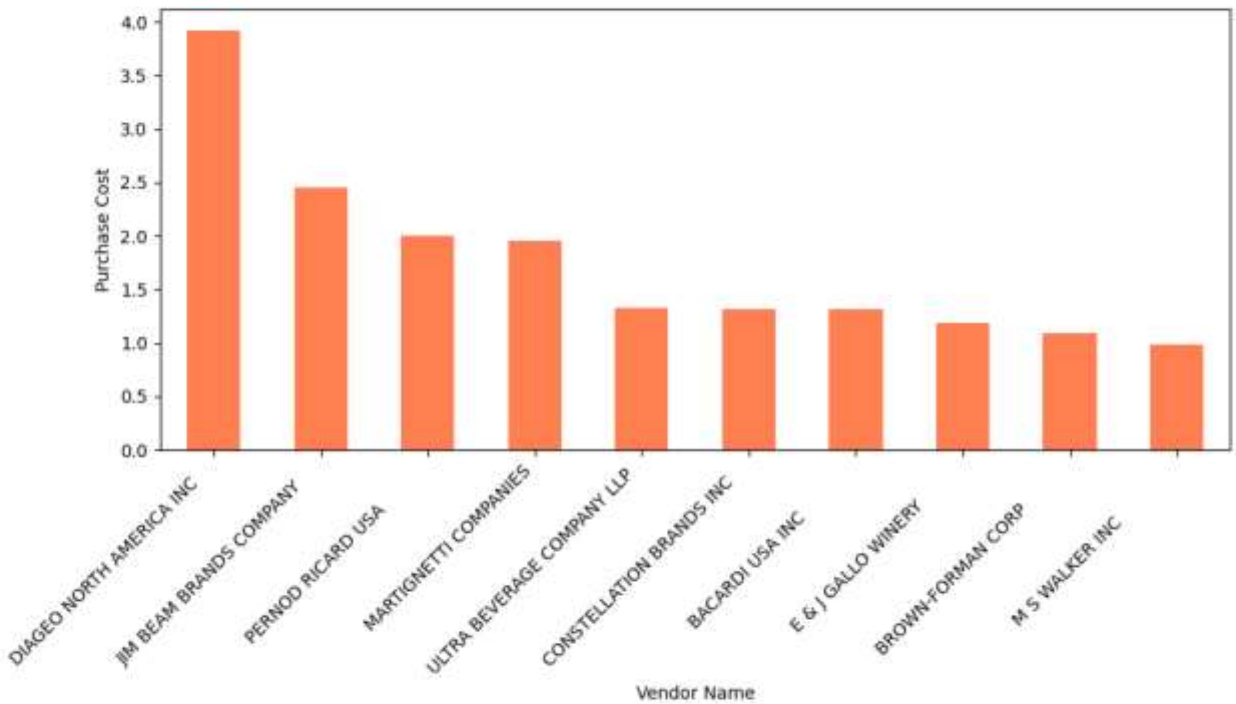


Figure 1: Top 10 Vendors by Purchase Cost

Within our case study, a comprehensive array of data is at our disposal, enabling an in-depth analysis of inventory management practices within the context of our enterprise. This dataset encompasses detailed inventory records, meticulously chronicling transactions encompassing purchases, production, sales, and adjustments. Coupled with historical sales data, we possess a foundation for robust demand forecasting across various product lines. Additionally, lead time data offers insights into the duration required for the procurement of raw materials and subsequent production, crucial for optimizing inventory levels. Complementing these datasets, information on costs associated with raw materials, production, and carrying costs provides a comprehensive overview necessary for strategic decision-making. To address our objectives effectively, a series of essential tasks have been identified: forecasting future demand, stratifying inventory items through ABC analysis, determining optimal order quantities through EOQ analysis, establishing reorder points to prevent stockouts, scrutinizing lead times, calculating carrying costs, identifying process inefficiencies, and evaluating inventory turnover ratios. Through these tasks, we aim to uncover actionable insights vital for enhancing inventory management efficiency and driving strategic improvements within our enterprise.

## 5. Results and Analysis

This section presents results that include those obtained from advanced efficiency strategies, aimed at increasing the efficiency and sustainability of inventory systems.



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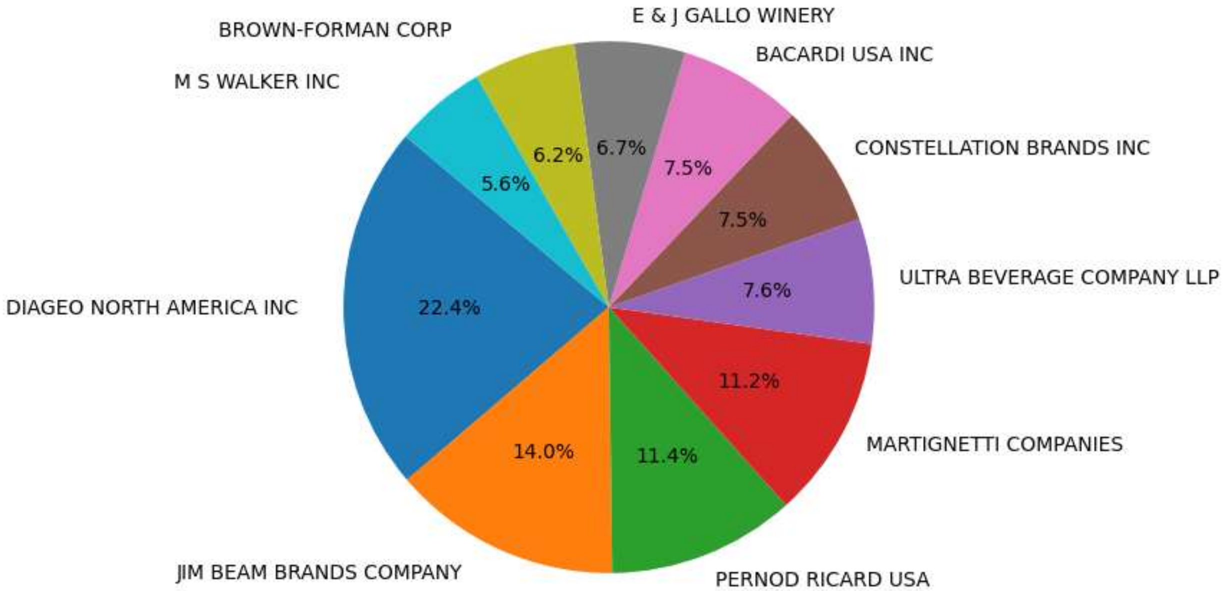


Figure 2: Distribution of Purchase Costs Among Top Vendors

In Figure 1, we present a visible illustration showcasing the top ten vendors labeled by using their respective buy expenses. This visualization serves as a pivotal tool in elucidating the big individuals to the overall procurement costs inside our organisation. It is notable that Diago north America INC attain the rca the highest purchase cost with 3.9 , this is followed by JIM BEAM BRANDS COMPANY with 2.4% , and PERNOD RICARD USA with 2. In addition, In Figure 2, we present a graphical representation of the distribution of acquisition costs among our best suppliers. By visualizing the distribution of shopping expenditure among these top retailers, we can note that that Diago north America INC attain the rca the best buy charges with 22.4% , this is followed by JIM BEAM BRANDS COMPANY with 14.0% , and PERNOD RICARD USA with 11.4%.

In In addition, Figure 3 showcases a graphical representation delineating the each day income speed attributed to various merchandise within our stock. The visualized bar chart serves as a essential tool in expertise the pace and frequency of product income over a specified time frame. it is notable that the josh cellars cap attain the highest valoum to ordre, followed by Bacardi superior rum, and JIM BEAM Travelers. From the observed depiction, w can permits swift identity of products experiencing better sales velocities, indicating gadgets with more rapid turnover fees and heightened consumer call.



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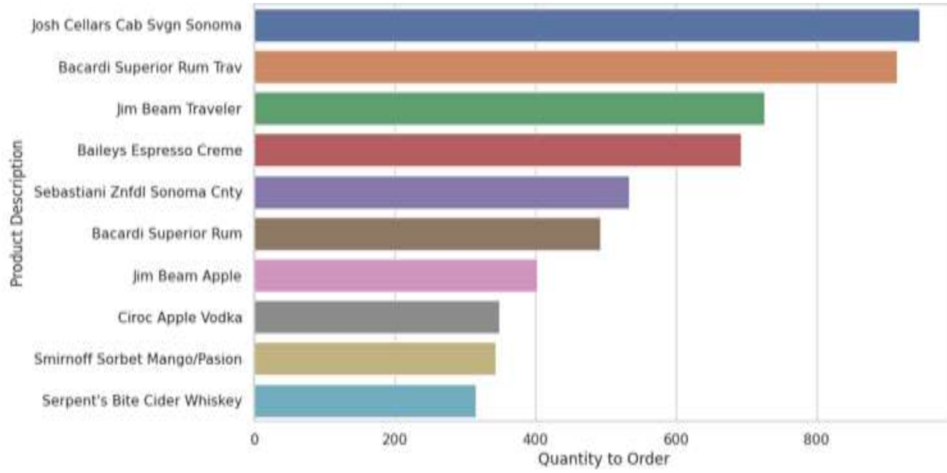


Figure 3: Daily Sales Velocity by Product

In Figure 4, we gift a graphical assessment of the pinnacle 10 products based on their order quantities, showcasing their current stock degrees against the endorsed tiers. This visualization serves as a essential device in evaluating the alignment among the prevailing inventory stages and the cautioned most excellent stock quantities. As shown, the figure helps short identification of products wherein inventory stages exceed or fall brief of the counseled benchmarks, thereby allowing strategic selection-making regarding inventory replenishment, making sure adequate stock availability, minimizing overstocking, and averting stockouts. This graphical illustration aids in optimizing inventory ranges, contributing to advanced operational efficiency and streamlined stock management practices within our organizational framework.

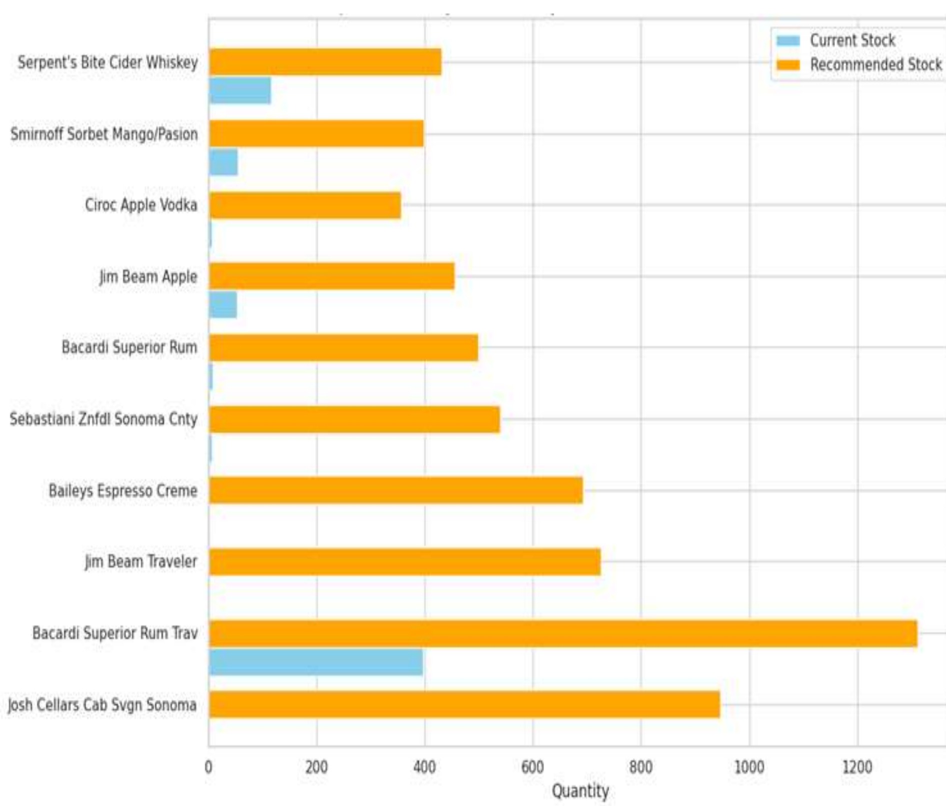


Figure 4: Current vs Recommended Stock Levels for Top 10 Products (by Order Quantity)

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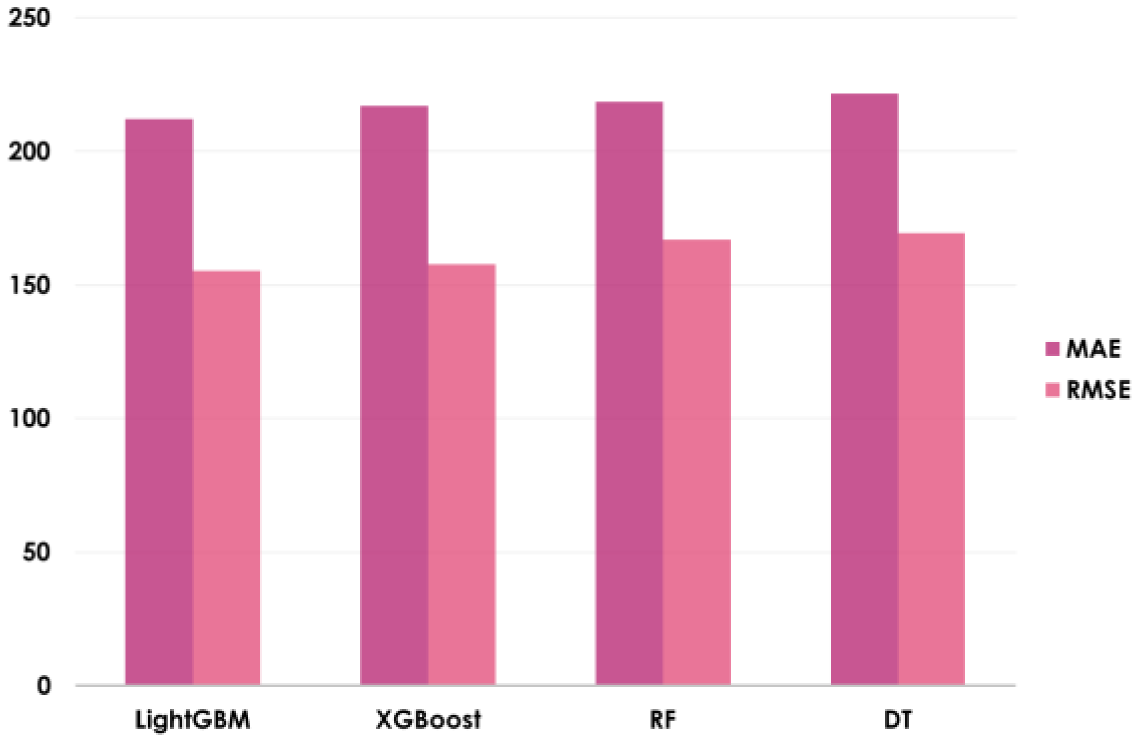


Figure 5: Prediction Performance Comparison of LightGBM against Baseline Models

Furthermore, Figure five offers a graphical representation showcasing the prediction overall performance of LightGBM, a ML version, juxtaposed in opposition to baseline fashions. This visualization serves as a important assessment tool to gauge the effectiveness and superiority of LightGBM in predictive accuracy as compared to set up baseline models. The visualization aids in figuring out the model that satisfactory captures the nuances of the dataset, thereby supporting in choosing the maximum suitable predictive model for inventory management functions. This graphical illustration is instrumental in comprehensively assessing the overall performance of LightGBM and ascertaining its efficacy as a predictive device inside our inventory management framework.

## 6. Conclusion and Future Work

Strategic optimization of inventory management for medium-sized enterprises stands as a must research to increase operational efficiency and sustainability This study explores the complex ground of inventory management practices, including LightGBM to forecast demand, for stock levels are better measure forecast performance etc. Our empirical findings, illustrated by graphs comparing vendors' purchase costs, sales velocity, and inventory quantitatively, compared LightGBM with original models that provide valuable insights into the nuances of inventory management Future efforts moving forward that focus on the potential Should focus on more key areas . First, the combination of deep insights and real-time data storage with IoT-enabled technology can make inventory forecasting and management planning more accurate and efficient. In addition, a detailed study to assess the long-term impact of cost reduction and sustainability on efficiency strategies in medium-sized industries provides valuable insights for industry-wide applications it can provide. Finally, exploring the incorporation of AI-driven processes beyond prediction, such as in dynamic pricing models or automatic inventory management, could be open greater strategies for effective profitability and sustainable inventory management practices.

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