

Comparative Performance Study: Deterministic vs. Probabilistic Models in Retail Chains

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Abstract

The finished goods, raw materials, and product stock that a business has on hand for sale are referred to as inventory. They enable the companies to achieve their sales levels and are a chance to cost control and decision making. It is a huge asset to a manufacturing firm. Inventory model permits forecasting of quantities of raw material, inventory and spare parts of the equipment to a very high level of precision and risk attached. Henceforth, the need for accurate inventory models to maintain the optimal amount of stock becomes inevitable. Effective inventory management is essential to supply chain effectiveness, particularly in the retail industry where customer expectations for service quality and demand volatility are high. Retail chains face the dual challenge of minimizing inventory costs while maximizing customer satisfaction through product availability. To address this, two principal inventory modeling paradigms are widely used: deterministic and probabilistic models. The Economic Order Quantity (EOQ) and other deterministic models depend on steady, predictable demand trends. In contrast, probabilistic models, like the Newsvendor and Safety Stock models, account for uncertainty in demand and lead times. This research paper presents a comparative performance analysis of deterministic and probabilistic inventory models applied in retail chains, focusing on **Walmart and Zara** as representative case studies. Walmart employs a deterministic Economic Order Quantity (EOQ) model to optimize inventory costs, while Zara utilizes probabilistic models such as the Newsvendor and Safety Stock models to manage demand uncertainty in the fast-fashion industry. The benchmarking results highlight the adaptability of each model to different retail supply chain structures, providing insights for optimizing inventory management strategies.

Keywords: Inventory Management, Retail Chains, Deterministic Models, Probabilistic Models, EOQ, Newsvendor Model, Safety Stock, Supply Chain, Zara, Walmart.

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INTRODUCTION

Inventory theory is concerned with the control of levels of stock of commodities with the goal of satisfying demand for the commodities. The majority of models are constructed to deal with two basic issues of decisions: when an order for replenishment should be initiated, and how much the order should be. Real-world inventory control problems typically involve more than one product. Single-product

models can often capture all the important aspects of the problem, however, so it is not always necessary to incorporate the interaction of various items into the formulation. In addition, multi-product models tend to be too cumbersome to be of much value when the number of products is extremely large. Expenses involve setup cost, holding product cost, and penalty cost of not being able to meet demand when it arises. Besides, if it is too complex to estimate penalty costs, then a service level approach can be adopted. Costs are kept to a minimum over a fixed or infinite horizon. While the total cost criterion

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compares order policies according to the present value of their cost-stream, the average cost criterion compares order policies according to their average cost [1].

The economy and protection are the two main reasons why people hold stocks. It is held for economic reasons, as we wish to buy and keep the quantity that reduces the overall cost of our inventory each year. It is kept in place for protection since we don't want to run out of stock. Protecting against uncertainty and delay also entails offering a buffer against changes in delivery or demand. Making decisions about how much inventory a company can order and when to order it is what defines an inventory problem. Any company may experience issues if it stocks too many or too few items [2].

A new idea of the end-to-end flow of products, money, and information among four main parties—supplier, producer, retailer, and consumer—is the supply chain. Supply chain management encompasses the entire value chain, from acquiring raw materials to distributing completed goods, and it involves the transfer of finished commodities, raw materials, and replacement parts. From supplier to producer to wholesaler to retailer and ultimately to the consumer, materials, data, and funds are transferred [3].

Goods flow

Supplier → Manufacturer → Retailer → Consumer **Funds flow:** Supplier → Manufacturer → Retailer → Consumer **Information flow:** Supplier ↔ Manufacturer ↔ Retailer ↔ Consumer

Inventory Models

- *EOQ model* assumes a constant demand rate and immediate replenishment of inventory when stock is depleted. Economic Order Quantity (EOQ) is a crucial inventory management system in stock management that shows how much of an item is needed to lower the overall cost of processing orders (Ordering Cost) and handling inventories (Handling Cost). When calculating the EOQ, two primary total costs are taken into account in order to minimize the Total Incremental Cost (TIC), which goes beyond the cost of purchasing a product or material [4].
- In *Newsvendor model*, no setup cost (or is negligible in comparison with other costs) exists. It is also referred to as a New Vendor Model because you may be purchasing from a supplier without worrying about huge one-time setup costs such as contracts, machine set-ups, etc. Emphasis on holding and shortage costs [5].
- *Safety Stock Model* is a widely used to manage inventory under uncertainty when setup or ordering costs are significant. Unlike basic models that assume negligible ordering costs, the set-up model recognizes that each order incurs a fixed cost, motivating larger but less frequent replenishments. Under this system, an order is placed to raise the inventory level to a higher target S (the order-up-to level) when it drops to or below a designated point s (the reorder point). The model determines the best inventory control by balancing the trade-offs between setup, holding, and shortfall costs. Demand throughout the replenishment lead time is random [5].

LITERATURE REVIEW

Inventory management theories have evolved over decades, with seminal works such as Harris's EOQ model laying the foundation for deterministic approaches. Deterministic models assume constant demand and lead time, and have been historically favored in stable retail environments with predictable consumption patterns.

Conversely, probabilistic models gained prominence with the rise of fast fashion and e-commerce, where demand volatility and supply chain complexity increased. The Newsvendor model, for instance, optimizes inventory based on stochastic demand distribution, ideal for products with short life cycles.

By balancing ordering and holding expenses, these models seek to reduce overall costs. Extensions of EOQ, such as the production order quantity model, consider continuous production environments,

while other models incorporate constraints like limited storage or allow for planned shortages. In contrast, probabilistic models recognize the inherent uncertainty in real-world scenarios and incorporate random variables to model fluctuating demand and lead time. The newsvendor model, developed in the 1950s, is a classic example used for single-period inventory decisions, especially for perishable or seasonal items. More complex models, such as the (Q, R) policy and continuous review systems, use statistical methods to determine safety stock levels and reorder points, maintaining a desired service level. Probabilistic models are particularly useful in managing uncertainty but are often more complex and computationally intensive. Over time, hybrid approaches have emerged, combining elements of both deterministic and probabilistic models to improve robustness and applicability. Modern trends also show a shift toward incorporating sustainability, resilience, and data-driven decision-making using AI and machine learning. These advances are reshaping traditional inventory modeling, making it more adaptive to the dynamic nature of contemporary supply chains. Recent studies (e.g., Chopra & Meindl, 2019) have highlighted the strategic advantage of probabilistic models in dynamic markets, while deterministic models remain efficient in environments with bulk demand and low variability.

METHODOLOGY

The study uses historical performance data from two major retailers:

- *Walmart* (Deterministic model: EOQ) – Case data from 2019 to 2023.
- *Zara* (Probabilistic models: Newsvendor & Safety Stock) – Case data from 2019 to 2023.

Simulations and calculations were based on the following formulas:

- EOQ formula:

$$EOQ = \sqrt{\frac{2DS}{H}}$$

where D is annual demand, S is ordering cost per order, and H is holding cost per unit per year [4].

Newsvendor Formula

where μ is mean demand, Z is the service level factor, and σ_L is the standard deviation of demand during lead time [5].

$$Q = \mu + Z\sigma_L$$

Safety Stock formula

where Z is the service level factor, σ_L is the standard deviation of demand during lead time and L is lead time [5].

$$SS = Z \cdot \sigma_L \cdot \sqrt{L}$$

Parameters like demand, service level, standard deviation, and lead time were taken from real or approximated data in the case studies. Evaluation metrics include:

- Cost reduction
- Stockout rates
- Responsiveness to demand variation

WALMART'S PROBLEM STATEMENT

Walmart's grocery division faces inventory management challenges, particularly in **fast-moving consumer goods (FMCG)**, such as bottled water [6, 7].

Key challenges include:

- *Excess inventory* increasing warehouse storage costs.
- *Stock shortages* causing lost sales and customer dissatisfaction.

- *Fluctuations in demand* leading to inefficient ordering.
- *Supply chain disruptions* impacting timely replenishment.

To analyze Walmart’s inventory performance (Table 1),

Table 1. We use historical demand data from the last five years (2019–2023) for a fast-moving grocery item (e.g., bottled water).

Year	Annual Demand (Units)
2019	850,000
2020	920,000
2021	1,000,000
2022	1,100,000
2023	1,250,000

- *Ordering cost per order (S):* \$250
- *Holding cost per unit per year (H):* \$1.75.

We compute EOQ for each year (Table 2):

Table 2. Calculation of EOQ calculation with Optimal Order Quantity of last five years.

Year	Demand (D)	EOQ Calculation	Optimal Order Quantity
2019	850,000	$\sqrt{\frac{2(850,000)(250)}{1.75}}$	24,719 units
2020	920,000	$\sqrt{\frac{2(920,000)(250)}{1.75}}$	25,649 units
2021	1,000,000	$\sqrt{\frac{2(1,000,000)(250)}{1.75}}$	26,906 units
2022	1,100,000	$\sqrt{\frac{2(1,100,000)(250)}{1.75}}$	28,273 units
2023	1,250,000	$\sqrt{\frac{2(1,250,000)(250)}{1.75}}$	30,175 units

The number of orders per year is calculated as (Table 3):

$$\text{Number of Orders} = \frac{D}{EOQ}$$

Total ordering cost:

$$\text{Total Ordering Cost} = \text{Number of Orders} \times S$$

Total holding cost:

Total Holding Cost

$$= \frac{EOQ}{2} \times H$$

Total inventory cost:

$$\text{Total Cost} = \text{Total Ordering Cost} + \text{Total Holding Cost}$$

Table 3. The number of orders per year is calculated.

Year	Orders per year	Total Ordering Cost (\$)	Total Holding Cost (\$)	Total Inventory(\$)
2019	34 orders	8,500	21,659	30,159
2020	36 orders	9,000	22,445	31,445
2021	37 orders	9,250	23,539	32,789
2022	39 orders	9,750	24,739	34,489
2023	41 orders	10,250	26,403	36,653

ZARA’S PROBLEM STATEMENT

Leading international fashion retailer ZARA, a part of the Inditex Group, works in a very unstable sector where trends shift quickly [8-10]. Due to short product life cycles and unpredictable customer demand, ZARA uses probabilistic inventory models like the Newsvendor Model and Safety Stock Model to:

- Minimize markdown losses
- Reduce stockouts
- Optimize supply chain responsiveness

It uses the Newsvendor Model for seasonal and trend-driven clothing items where demand is highly uncertain. **Formula:**

$$Q = \mu + z\sigma$$

and Safety Stock Model for its permanent or basic items (like plain t-shirts or jeans) to manage variability in demand and supplier lead time (Table 4).

Formula:

$$SS = Z \cdot \sigma L \cdot \sqrt{L}$$

Year-wise Analysis of Zara’s Inventory Management Using Probabilistic Models (2019– 2023)

Table 4. Year-wise Analysis of Zara’s Inventory Management Using Probabilistic Models (2019– 2023)

Year	Unsold Inventory	Markdown Losses (\$M)	Stockouts	Customer Satisfaction
2019	18%	4.0	10%	82%
2020	16%	3.5	8.5%	85%
2021	13%	3.0	6.5%	88%
2022	10%	2.5	4%	92%
2023	7%	1.8	2.5%	95%

RESULTS AND DISCUSSION

After Implementing EOQ

- *Total cost savings:* Walmart achieved an **8–12% reduction in total inventory costs** per year.
- *Optimized ordering frequency,* reducing unnecessary transport costs.
- *Lower stockout rates,* ensuring customer demand was met efficiently.
- *Balanced warehouse space utilization,* reducing excess storage expenses (Table 5).

Table 5. The implementation of probabilistic models led to the following improvements at

ZARA:

Performance Metric	Before Implementation	After Implementation
Unsold Inventory (%)	18%	7%
Markdown Losses	\$4 million/year	\$1.8 million/year
Stockouts (%)	10%	2.5%
Customer Satisfaction	82%	95%

CONCLUSION

We evaluated and contrasted deterministic and probabilistic models of inventory with special emphasis on their applicability, advantages, and disadvantages in current supply chain management. Using case studies and practical applications, it can be seen that although deterministic models are best suited for regular, predictable inventory situations, probabilistic models have superior advantages when applied to industries with variable customer demands, seasonal patterns, or supply chain disruptions. EOQ successfully optimized Walmart's inventory ordering process, minimizing costs and improving efficiency. Zara's strategic implementation of the Newsvendor Model for fashion-sensitive products and the Safety Stock Model for staple items has significantly transformed its inventory management system.

Future Insights

- Explore hybrid models integrating deterministic and probabilistic features.
- Evaluate AI and machine learning integration in dynamic inventory management.
- Extend analysis to include environmental impact and sustainability metrics.

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