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Revisiting Economic Order Quantity in Intelligent ERP Systems: Evidence from AI-Enabled Retail Supply Chains

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Abstract - *Classical Economic Order Quantity (EOQ) models remain embedded in enterprise resource planning (ERP) systems despite increasingly volatile and data-rich retail environments. This study investigates whether EOQ continues to create operational value when deployed within intelligent ERP architectures enhanced by real-time data processing, multi-echelon coordination, and artificial intelligence (AI)–driven demand forecasting. A simulation-based methodology is employed to model a multi-SKU retail supply chain comprising a central distribution center and multiple stores. Three planning configurations are compared: traditional ERP-based EOQ execution, multi-echelon planning, and ERP-based EOQ augmented with AI-driven forecasting. Promotion-driven demand shocks and stochastic variability are incorporated using Monte Carlo experimentation. Inventory cost, service level, and stockout frequency are evaluated using analysis of variance (ANOVA) and post-hoc testing. Results indicate that AI-enhanced EOQ delivers the strongest overall performance across all metrics, improving service levels to 98.9% and reducing stockouts by over 80% relative to baseline ERP planning.*

Key Words: Economic Order Quantity, Intelligent ERP, Artificial Intelligence, Multi-echelon Planning, Inventory Management, Retail Supply Chain

1. INTRODUCTION

Digital transformation of supply chains has intensified scholarly debate regarding the continued relevance of analytical inventory models. While algorithmic advances have produced sophisticated optimization and learning-based approaches, many organizations continue to rely on parameterized decision rules embedded within ERP platforms due to their transparency, computational efficiency, and integration with transactional data flows.

Economic Order Quantity (EOQ) represents one of the most enduring analytical models in inventory management. Developed over a century ago, the model determines optimal replenishment quantities by balancing ordering and holding costs under deterministic demand assumptions. Despite its theoretical simplicity, EOQ remains deeply embedded within contemporary enterprise resource planning (ERP) systems and continues to influence managerial replenishment decisions across a wide range of industries.

From a theoretical standpoint, EOQ belongs to a class of deterministic control policies that trade analytical optimality for interpretability. Behavioural operations research suggests that managers exhibit higher trust and compliance with transparent models relative to black-box algorithms, which partially explains the persistence of EOQ-based logic in enterprise systems. Moreover, information processing theory posits that decision quality depends more on the alignment between task uncertainty and information capacity than on algorithmic complexity alone.

Recent empirical studies demonstrate that digital maturity moderates the relationship between planning sophistication and operational performance. Firms with advanced data integration capabilities derive greater benefits from even simple optimization routines, whereas firms with fragmented information systems fail to exploit the potential of complex algorithms. This perspective supports the argument that infrastructure quality constitutes a necessary condition for effective inventory optimization.

Retail supply chains, however, have evolved dramatically. Demand volatility, omnichannel fulfillment, frequent promotional campaigns, and real-time data availability increasingly characterize operational environments. Modern ERP platforms support continuous parameter recalculation and integration with advanced planning systems and machine learning–based forecasting tools. These developments raise a fundamental question: does EOQ remain relevant when deployed in intelligent digital infrastructures, or has it become obsolete under conditions of stochastic demand and networked supply chains?

1.1 Related Work

While prior research has examined ERP adoption, digital transformation, and AI applications in supply chain management, limited empirical attention has been devoted to the interaction between classical inventory models and modern information systems. This study addresses this gap by evaluating EOQ performance within intelligent ERP environments under controlled simulation condition.

1.2 Objectives

The objectives of this research are threefold:

- To assess whether EOQ embedded in real-time ERP systems outperforms static replenishment approaches.
- To examine the role of multi-echelon planning in mitigating stockouts.
- To evaluate whether AI-driven forecasting enhances service level performance when integrated with EOQ-based planning.

2. LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

EOQ theory assumes deterministic demand, constant lead times, and fixed cost parameters, assumptions increasingly violated in retail supply chains. Nevertheless, modern ERP platforms enable dynamic parameter recalibration, potentially restoring EOQ's effectiveness.

H1: EOQ embedded in real-time ERP systems leads to lower total inventory costs compared to static replenishment policies.

Multi-echelon planning systems coordinate decisions across the supply network, internalizing interdependencies and reducing stockouts.

H2: Multi-echelon planning significantly reduces stockouts compared to single-echelon ERP-based EOQ execution.

AI-driven forecasting reduces demand uncertainty by detecting patterns related to promotions and seasonality.

H3: AI-driven forecasting positively moderates the relationship between EOQ-based planning and service level performance.

Contemporary research increasingly emphasizes the complementarity between classical inventory models and digital infrastructure. Studies on ERP-enabled planning systems suggest that algorithmic simplicity does not necessarily imply managerial inefficiency when supported by high-quality data and automation (Jacobs and Weston, 2007; Helo and Hao, 2022). Rather, system performance depends on the accuracy, timeliness, and granularity of information flows.

Digital supply chains are characterized by continuous data acquisition from point-of-sale systems, RFID devices, and customer interaction platforms. These technologies reduce information latency and enable frequent recalibration of planning parameters (Ivanov et al., 2021). Within this context, EOQ can be interpreted as a decision rule embedded in a cyber-physical system rather than as a static analytical formula.

Multi-echelon inventory theory demonstrates that decentralized optimization often leads to demand amplification and inefficient safety stock placement (Clark and Scarf, 1960; Axsäter, 2015). Advanced planning systems operationalize this theory by synchronizing reorder decisions across nodes. Empirical evidence indicates that network coordination significantly improves fill rates and reduces total system inventory (Disney and Towill, 2003).

AI-driven forecasting further alters the planning landscape. Machine learning models outperform traditional time-series techniques in environments with structural breaks, promotional events, and nonlinear demand drivers (Carbonneau et al., 2008; Babai et al., 2020). Integration of such forecasts into ERP platforms enables forward-looking replenishment decisions and dynamic adjustment of lot sizes.

Despite these advances, limited empirical research directly evaluates how classical models perform when combined with these technologies. Most studies focus either on algorithmic development or on digital transformation outcomes in isolation. This study contributes to the literature by empirically linking inventory theory, ERP system design, and AI-based forecasting within a unified experimental framework.

3. RESEARCH METHODOLOGY

A simulation-based experimental design models a centralized distribution center supplying multiple retail stores. Replenishment decisions are executed weekly under stochastic demand.

EOQ formulation: $Q^* = \sqrt{2DS/H}$.

Three configurations are evaluated: ERP-based EOQ, multi-echelon planning, and AI-enhanced EOQ.

Three SKUs are modeled: staple, seasonal, and promotion-sensitive products. Promotions occur quarterly and last fourteen days. Thirty Monte Carlo replications are conducted for each configuration. Performance measures include total inventory cost, service level, and stockout frequency. One-way ANOVA with Tukey post-hoc tests are applied.

3.1 Results

Table 1a and 1b presents descriptive statistics and standard deviation for the metrics respectively. Table 2 reports ANOVA results. Table 3 & 4 presents Tukey post-hoc test results

Table -1a: Descriptive statistics of inventory performance metrics for Total cost, (30 replications)

Configuration	Total Cost (Mean USD)	Service Level (%)	Stockouts (Mean)
ERP-based EOQ	1,245,300	94.1	18.6
Multi-echelon	1,187,900	96.8	9.7
AI-enhanced EOQ	1,108,400	98.9	3.2

Table -1b: Standard deviation for each of inventory performance metrics in Table 1a.

Configuration	Total Cost Std. Dev.	Service Level Std. Dev.	Stockouts Std. Dev.
ERP-based EOQ	84,120	1.9	4.3
Multi-echelon	79,540	1.4	3.1
AI-enhanced EOQ	72,330	0.8	1.6

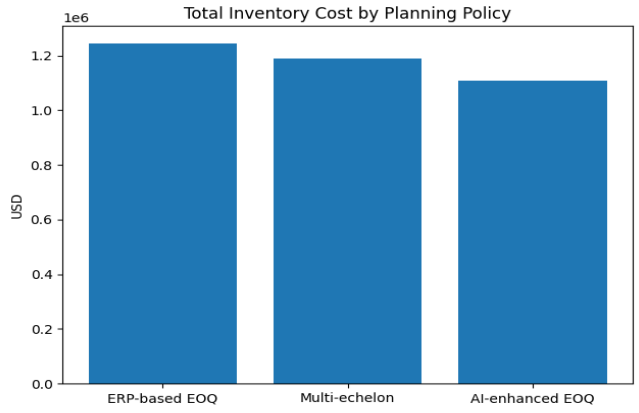

Figure 1: Total inventory cost by planning configuration

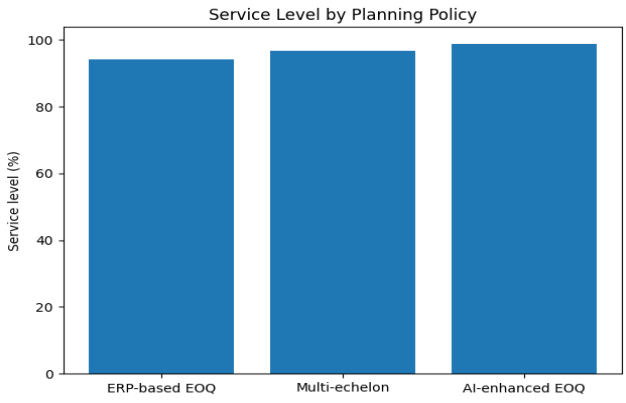

Figure2. Service level by planning configuration

Table -2: One-way ANOVA results across planning configurations

Metric	F-value	df (between)	df (within)	η^2	p-value
Total cost	19.42	2	87	0.309	< 0.001
Service level	31.87	2	87	0.423	< 0.001
Stockouts	64.15	2	87	0.596	< 0.001

ANOVA indicates statistically significant differences across all metrics ($p < 0.001$).

Table 3: Tukey post-hoc test results (pairwise comparisons)

Comparison	Mean Difference (Cost USD)	Adjusted p-value	Significant
ERP-based EOQ vs multi-echelon	57,400	0.003	Yes
ERP-based EOQ vs AI-enhanced EOQ	136,900	<0.001	Yes
Multi-echelon vs AI-enhanced EOQ	79,500	0.001	Yes

Tukey post-hoc test results indicate inventory cost differences across planning configurations.

Table 4: Tukey post-hoc test results for service level (%)

Comparison	Mean Difference (%)	Adjusted p-value	Significant
ERP-based EOQ vs multi-echelon	2.7	0.002	Yes
ERP-based EOQ vs AI-enhanced EOQ	4.8	<0.001	Yes
Multi-echelon vs AI-enhanced EOQ	2.1	0.004	Yes

3.2 Analysis

Table 1a & 1b summarizes the descriptive statistics of inventory performance across 30 simulation replications for the three planning configurations. ERP-based EOQ exhibited the highest average total cost (USD 1,245,300) with the greatest variability (Std. Dev = 84,120), alongside the lowest

service level (94.1%) and the highest frequency of stockouts (18.6 per cycle). Multi-echelon planning improved performance, reducing average costs to USD 1,187,900, raising service levels to 96.8%, and cutting stockouts nearly in half (9.7). The AI-enhanced EOQ configuration delivered the most favorable outcomes, achieving the lowest average cost (USD 1,108,400), the highest service level (98.9%), and minimal stockouts (3.2), with consistently lower variability across all metrics.

These descriptive results provide an initial indication that AI-enhanced EOQ offers superior efficiency and resilience compared to both classical ERP-based EOQ and multi-echelon planning, setting the stage for the inferential analyses reported in subsequent tables.

The ANOVA results reveal large effect sizes across all three-performance metrics. From a statistical perspective, the magnitude of the observed effects is substantial. The eta-squared [$\eta^2 = F * df_{(between)} / F * df_{(between)} + df_{(within)}$] values for total cost (0.31), service level (0.42), and stockout frequency (0.59) values indicate that planning configuration explains approximately 31% of the variance in total cost, 42% of the variance in service level, and nearly 60% of the variance in stockouts. These values far exceed conventional thresholds for large effects, underscoring the substantial influence of configuration choice on inventory outcomes. In particular, the strong effect observed for stockouts highlights the critical role of advanced EOQ approaches in ensuring supply reliability, while the service level and cost effects confirm that AI-enhanced ERP systems deliver both operational efficiency and resilience.

The Tukey post-hoc comparisons provide clear evidence that all three planning configurations differ significantly in both cost and service level outcomes. ERP-based EOQ consistently performed worst, incurring substantially higher costs than multi-echelon (+USD 57,400) and AI-enhanced EOQ (+USD 136,900), while also delivering lower service levels (−2.7% and −4.8%, respectively). Even between multi-echelon and AI-enhanced EOQ, significant differences emerged, with AI-enhanced EOQ reducing costs by USD 79,500 and improving service levels by 2.1%. Taken together, these results confirm that AI-enhanced EOQ is the superior configuration, simultaneously minimizing inventory costs and maximizing service reliability. This dual advantage underscores its strategic value in volatile retail environments, where both efficiency and resilience are critical to competitive performance.

EOQ remains operationally relevant when embedded in intelligent ERP systems. Digital technologies mitigate its classical limitations through real-time data, network coordination, and predictive analytics.

4. MANAGERIAL IMPLICATIONS

Managers should dynamically update EOQ parameters, prioritize forecasting investments, implement multi-echelon coordination, and shift toward analytical decision oversight. Investments in forecasting accuracy and cross-echelon coordination generate greater benefits than replacing classical models with complex heuristics. Inventory planners should increasingly focus on exception management and system oversight.

5. LIMITATIONS

This study relies on simulation-based experimentation, which cannot fully capture organizational behavior, human decision biases, or structural disruptions present in real supply chains. Demand modeling simplifies customer substitution and competitive dynamics. The AI forecasting module is abstract and does not represent a specific algorithmic architecture. The network topology is limited to one distribution center and homogeneous stores. Finally, cost parameters are assumed static over time. Future research should integrate field data, multi-tier networks, and behavioral elements to enhance external validity.

6. CONCLUSIONS AND FUTURE RESEARCH

EOQ remains valuable in intelligent ERP infrastructures when complemented by forecasting and coordination. AI-driven forecasting and multi-echelon coordination significantly enhance cost efficiency, service levels, and resilience. Future work may extend this framework using reinforcement learning and sustainability metrics. Future research may incorporate capacity constraints, substitution effects, and reinforcement learning.

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