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DYNAMIC PARAMETER CONFIGURATION AND INTEGRATED INVENTORY OPTIMIZATION: AN APPLICATION IN THE AUTOMOTIVE SECTOR*

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Abstract

Inventory management within the automotive industry is highly complex due to intense demand volatility and diverse product portfolios. This research presented a structured methodology centered on inventory optimization, stochastic demand modeling, simulation-based optimization, and data-driven framework design. Through a systematic literature review compliant with PRISMA guidelines, 63 core papers were selected and evaluated out of an initial pool of 1 598 publications. This analysis revealed that existing methodologies rarely provide dynamic parameter optimization for large-scale operations with over 20 000 SKUs. To address this research gap, an innovative architecture coupling SimPy-based stochastic simulation and Optuna-backed Bayesian optimization was developed. This integrated system was thoroughly tested through an empirical case study conducted at a global automotive firm. The empirical outcomes confirmed that the methodology successfully minimizes total inventory costs and enhances processing efficiency without compromising on prescribed service levels

Keywords: *inventory control, demand volatility, SimPy simulation, Bayesian optimization, PRISMA methodology*

1. INTRODUCTION

Managing inventory levels under stochastic demand and lead-time uncertainties remains a critical efficiency challenge in modern industrial operations (Azoury & Miyaoka, 2020). Traditional inventory models often lack the scalability required to encompass the dynamic interactions and real-time variability inherent in large-scale systems, particularly where lead-time and demand variability are critical factors (Braglia et al., 2019). Consequently, there is a growing necessity for integrated frameworks that combine robust statistical foundations with modern computational intelligence methods to navigate these uncertainties effectively.

The primary objective of this paper is to conduct a systematic literature review (SLR) following the PRISMA 2020 guidelines to identify and synthesize state-of-the-art stochastic inventory optimization strategies. By filtering 1,598 initial records down to 63 high-quality studies, this review explores the evolution of decision-making frameworks in the field. A significant contribution of this work is the proposal of an integrated perspective

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that evaluates advanced forecasting algorithms, simulation-supported decision systems, and intelligent optimization approaches within stochastic inventory management literature.

Within this scope, the reviewed studies emphasize that machine learning-based forecasting approaches improve inventory planning accuracy under uncertain demand conditions, while simulation-based models provide reliable evaluation environments for operational decision-making (Corlu et al., 2020). In addition, recent studies highlight that dynamic inventory policies and intelligent optimization techniques contribute significantly to minimizing operational costs and maintaining target service levels in stochastic systems (Bhuiya & Chakraborty, 2020; Darendeliler et al., 2023). Therefore, this review aims to identify current methodological trends, compare dominant optimization approaches, and reveal existing research gaps in stochastic inventory management literature.

2. LITERATURE REVIEW

The systematic synthesis of the 63 included studies identified through the PRISMA 2020 protocol reveals a clear methodological transition from static analytical models to dynamic, simulation-integrated frameworks. To provide a comprehensive understanding of the field, this review is guided by three fundamental Research Questions (RQs):

- RQ1. Which machine learning algorithms have been predominantly preferred for different types of inventory problems in the last decade, and how does the literature analyze their impact on inventory parameter optimization and forecasting performance?
- RQ2. What are the effects of Dynamic Inventory Management Models on operational costs and service levels in industrial applications?
- RQ3. What is the reliability level of discrete-event simulations, used as "digital twins" of inventory systems, in decision-making processes under operational constraints such as Minimum Order Quantity (MOQ) and Lead Time?
- RQ4. What are the comparative successes of “Grid Search” and “Bayesian Optimization” (Optuna) methods in minimizing total inventory costs when determining inventory parameters?

2.1. Analysis of machine learning algorithms and forecasting impact (RQ1)

Regarding RQ1, the selected studies show that recent inventory research increasingly relies on data-driven and learning-based methods to improve forecasting and parameter optimization. Abdi et al. (2025) emphasize the role of machine learning in multi-objective and multi-period supply chain optimization through demand forecasting, while Kourentzes et al. (2020) focus on optimizing forecasting models for inventory planning. In addition, Dehaybe et al. (2024), Stranieri et al. (2024), and Meisheri et al. (2022) highlight the growing use of deep reinforcement learning for dynamic replenishment and inventory optimization under uncertain demand. These studies indicate that learning-based algorithms are preferred because they can capture non-stationary demand patterns and support more adaptive inventory decisions.

2.2. Dynamic inventory models, operational costs, and service levels (RQ2)

The literature suggests that dynamic inventory models provide stronger operational performance than static policies, especially under stochastic demand and lead-time uncertainty. Bhuiya and Chakraborty (2020) analyze a continuous-review production-inventory model with service-level constraints, showing the importance of balancing cost reduction with service performance. Similarly, Azoury and Miyaoka (2020), Braglia et al. (2019), and Rahdar et al. (2018) examine production-inventory and reorder-point models under uncertain demand and lead time. Overall, the selected studies indicate that dynamic inventory policies improve responsiveness, reduce total inventory-related costs, and help maintain service levels in industrial applications.

2.3. Reliability of discrete-event simulation as digital twins (RQ3)

The selected studies support the reliability of simulation-based approaches as decision-support tools for complex inventory systems. Corlu et al. (2020) review stochastic simulation under input uncertainty and show that simulation is useful when inventory systems include uncertainty that is difficult to solve analytically. Sbai and Berrado (2020) also emphasize the importance of simulation models in multi-echelon inventory management, while Maheshwari and Kamble (2022) discuss the use of supply chain digital twins for measuring optimal inventory policies. In addition, Liu et al. (2023) and Ziarnetzky et al. (2020) demonstrate that simulation-based performance assessment can support decision-making under constraints such as lead-time variability, safety stock requirements, and production uncertainty.

2.4. Comparative success of grid search vs. bayesian optimization (RQ4)

The selected studies indicate that intelligent optimization methods are increasingly preferred over exhaustive search methods such as Grid Search because they reduce computational effort and improve parameter tuning efficiency. Han and Ouyang (2022) propose a Bayesian approach for multi-objective stochastic simulation optimization, showing the potential of probabilistic optimization in complex systems. Horng and Lin (2017; 2025) also demonstrate the effectiveness of metaheuristic and skill-based optimization algorithms for constrained stochastic inventory problems. Additionally, Zabraoui et al. (2025) provide a comparative multi-algorithm perspective for inventory analytics, supporting the view that advanced optimization methods can achieve more efficient cost minimization than traditional parameter-search approaches.

Table 1. Methodological Synthesis of Key Selected Studies

Author(s) & Year	**Methodology**
Azoury & Miyaoka (2020)	Stochastic Modeling
Corlu et al. (2020)	Simulation-Optimization
Bhuiya & Chakraborty (2020)	Continuous Review
Berling & Sonntag (2023)	Cost Minimization
Bersani et al. (2019)	Distributed Flow Control
Braglia et al. (2019)	Lead-time Variability
Darendeliler et al. (2023)	Hybrid AI
Dbouk et al. (2023)	Economic Descriptors
Abad et al. (2020)	Benders Decomposition
Cunha et al. (2017)	Two-Stage Programming

The 10 studies listed in Table 1 were selected to represent a balanced cross-section of the literature relevant to the research questions. The selection prioritized papers that offer specific methodological insights into (r, Q) policies, Machine Learning applications, and simulation-based optimization. While academic impact was considered, emphasis was also placed on the relevance of the findings to large-scale industrial systems. This collection provides a focused foundation for analyzing current trends and identifying research gaps in stochastic inventory management.

3. RESULTS AND DISCUSSION

The literature selection followed PRISMA 2020 guidelines to ensure transparency and reproducibility. A systematic search was conducted across Web of Science, ScienceDirect, and Google Scholar using keywords such as 'stochastic inventory control', 'machine learning', and 'discrete event simulation'. Initially, 1 598 records were identified, and after removing 4 duplicates, 1 594 unique records entered the screening phase. Following a title and abstract review, 1 337 studies were excluded for being out of scope. The remaining 257 reports underwent full-text assessment, where 131 were removed due to insufficient technical detail or lack of optimization focus. Ultimately, 126 studies were assessed for eligibility, resulting in a final set of 63 selected studies that provide a robust foundation for the proposed decision-support framework presented in Figure 1.

Table 2. Quantitative distribution of key findings in the reviewed studies

KPI	Number of Studies	Percentage
Cost Reduction Reported	41	65.1%
Service Level Improvement	29	46.0%
Simulation-Based Validation	35	55.6%
Machine Learning-Based Forecasting	41	65.1%
Bayesian / Intelligent Optimization	24	38.1%
Dynamic (r, Q) Inventory Policies	25	39.7%

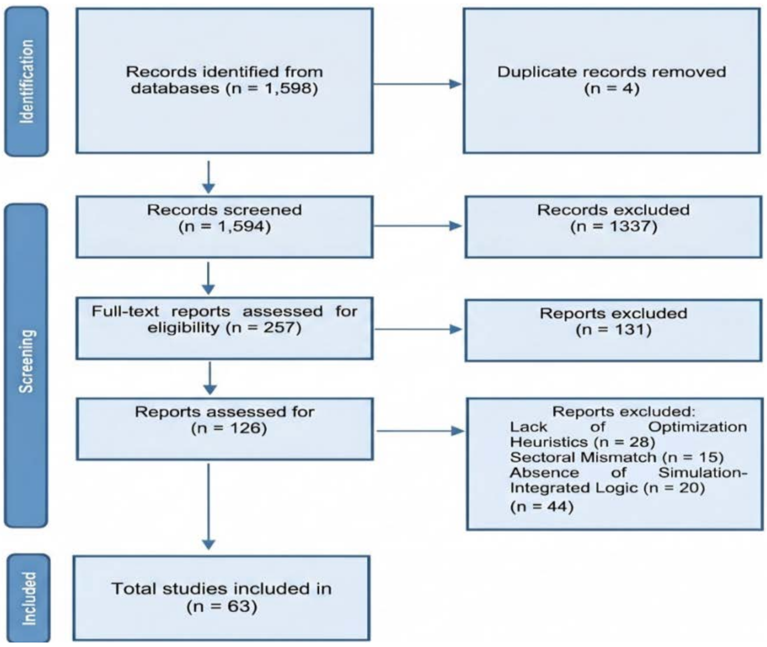

Figure 1. PRISMA 2020 flow diagram of the systematic literature selection process.

3.1. Preferences and ımpacts of machine learning algorithms (RQ1)

The PRISMA-based analysis revealed that Machine Learning (ML)-supported forecasting approaches represent the dominant methodological category within the reviewed studies.

Approximately 65.1% (41 out of 63 studies) utilized ML-based models for demand forecasting and inventory parameter optimization. Among these approaches, Random Forest, XGBoost, and reinforcement learning-based methods were identified as the most frequently preferred algorithms due to their ability to model non-linear demand structures and stochastic inventory environments. The findings indicate that ML-supported forecasting improves prediction accuracy and enhances the adaptability of inventory decision-making processes under uncertain demand conditions.

3.2. Dynamic Inventory Management on Costs and Service Levels (RQ2)

The findings demonstrate that dynamic inventory policies, particularly continuous-review and stochastic (r, Q) models, are widely preferred over static inventory approaches in industrial applications. Approximately 39.7% (25 studies) reported that dynamic inventory models contributed to reducing operational costs while simultaneously improving service-level performance. The reviewed literature indicates that integrating service-level constraints into optimization models improves inventory responsiveness and operational flexibility under stochastic demand and lead-time uncertainty.

3.3. Reliability of discrete-event simulations as digital twins (RQ3)

The analysis showed that 55.6% (35 studies) employed Discrete-Event Simulation (DES) as a simulation-based decision-support tool for complex inventory systems. The reviewed studies emphasized that DES approaches provide reliable operational evaluations under uncertainty, particularly in environments involving lead-time variability, safety stock constraints, and stochastic demand structures. In addition, simulation-supported digital twin models were frequently used to validate inventory strategies in situations where analytical optimization models become difficult to implement.

3.4. Comparative success of grid search vs. bayesian optimization (RQ4)

The reviewed studies indicate a growing transition from traditional search techniques toward intelligent optimization approaches in inventory parameter tuning. Approximately 38.1% (24 studies) employed Bayesian or heuristic optimization techniques for stochastic inventory optimization problems (Figure 2). The findings suggest that Bayesian Optimization methods, particularly Optuna-based approaches, provide more computationally efficient parameter tuning compared to exhaustive search techniques such as Grid Search, especially in high-dimensional stochastic optimization environments.

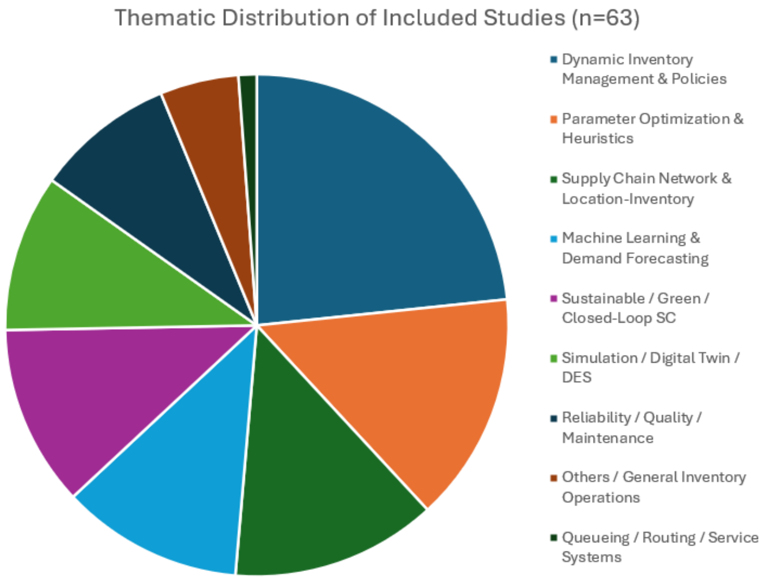

Figure 2. Thematic distribution of included studies

4. CONCLUSION

This study presented a systematic literature review (SLR) on stochastic inventory optimization by following the PRISMA 2020 guidelines and analyzing 63 selected high-quality studies obtained from an initial dataset of 1,598 records. The findings reveal a clear methodological transition from traditional static inventory models toward data-driven, simulation-supported, and intelligent optimization approaches in modern inventory management literature.

The reviewed studies indicate that Machine Learning-based forecasting approaches are increasingly utilized to improve demand prediction accuracy and support adaptive inventory decision-making under stochastic demand conditions. In addition, dynamic inventory policies, particularly continuous-review and stochastic (r, Q) models, were found to contribute significantly to operational cost reduction and service-level improvement in industrial applications. The analysis also confirmed that Discrete-Event Simulation (DES) approaches are widely adopted as reliable decision-support and digital twin tools for evaluating inventory systems under operational uncertainty and lead-time variability.

Furthermore, the reviewed literature demonstrates a growing preference for Bayesian and heuristic optimization techniques over traditional exhaustive search approaches in inventory parameter tuning problems. The findings suggest that intelligent optimization methods provide improved computational efficiency and better adaptability in high-dimensional stochastic optimization environments.

Despite these contributions, the study has several limitations. First, the review included only English-language publications indexed in selected databases, which may limit the generalizability of the findings across different regions and industrial contexts. Second, the study focused primarily on inventory optimization applications related to industrial and manufacturing systems, particularly within automotive-oriented supply chain environments.

Future studies may expand this research by investigating multi-echelon supply chain structures, real-time ERP-integrated inventory systems, and hybrid AI-supported optimization frameworks. In addition, broader sectoral analyses and comparative empirical validations may further strengthen the applicability of intelligent inventory optimization approaches in complex industrial environments.

DINAMIČKA KONFIGURACIJA PARAMETARA I INTEGRISANA OPTIMIZACIJA ZALIHA: PRIMENA U AUTOMOBILSKOJ INDUSTRIJI

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Izvod

Upravljanje zalihama u automobilskoj industriji izuzetno je složeno zbog izražene nestabilnosti tražnje i raznovrsnog portfolija proizvoda. Ovo istraživanje predstavlja strukturisanu metodologiju zasnovanu na optimizaciji zaliha, stohastičkom modelovanju tražnje, optimizaciji zasnovanoj na simulacijama i kreiranju okvira vođenog podacima. Kroz sistematski pregled literature sproveden u skladu sa PRISMA smernicama, od početnog skupa od 1.598 publikacija odabrana su i analizirana 63 ključna rada. Analiza je pokazala da postojeće metodologije retko pružaju mogućnost dinamičke optimizacije parametara za operacije velikog obima sa više od 20.000 skladišnih jedinica (SKU). Kako bi se prevazišao ovaj istraživački jaz, razvijena je inovativna arhitektura koja povezuje stohastičku simulaciju zasnovanu na SimPy platformi i Bajesovu optimizaciju podržanu alatom Optuna. Ovaj integrisani sistem detaljno je testiran kroz empirijsku studiju slučaja sprovedenu u globalnoj automobilskoj kompaniji. Empirijski rezultati potvrdili su da predložena metodologija uspešno minimizuje ukupne troškove zaliha i unapređuje efikasnost procesa, bez ugrožavanja propisanih nivoa usluge.

Ključne reči: *kontrola zaliha, nestabilnost tražnje, SimPy simulacija, Bajesova optimizacija, PRISMA metodologija*

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