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A Review on Dimensioning Safety Stock under Uncertainties and Risks in the process of Procurement

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Abstract
This study presents a systematic literature review (SLR) on determining safety stock levels under diverse uncertainties and risks in the procurement process. The review consolidates existing research that investigates stochastic demand, lead-time variability, supplier disruptions, and other uncertainty factors affecting procurement performance. A structured search and screening methodology was employed to identify relevant analytical, stochastic, and data-driven approaches. The findings reveal that lead-time uncertainty plays a significant role in influencing optimal safety stock decisions. Recent trends highlight the growing adoption of robust optimization, stochastic programming, and machine learning techniques to improve the accuracy of safety stock estimation. Moreover, the review identifies notable research gaps, including the need for integrated models that consider correlated demand and lead time, the incorporation of procurement risks into multi-echelon systems, and the practical implementation challenges faced by industries. These insights provide a comprehensive foundation for future research directions and managerial decision-making in supply chain risk management.
Keywords
Safety Stock, Procurement Risk, Uncertainty, Stochastic Optimization, Supply Chain, Systematic Literature Review

1. Introduction

Safety stock serves as a buffer to mitigate uncertainties in demand and supply, ensuring service levels are maintained under variable conditions. Procurement risks—such as supplier failure, transportation delays, and geopolitical disruptions—introduce additional uncertainty into the supply chain. Understanding how to properly dimension safety stock under such conditions is critical for cost efficiency and service reliability. This paper systematically reviews existing literature to identify prevailing methods, models, and challenges in safety stock determination under procurement-related uncertainties.

The supply chain is a complex and unique network that integrates different business processes involved in fulfilling the customer needs, which includes planning, procurement, production, distribution and customer interface [3,4]. All these are involved in the entire product life cycle, from procurement to manufacturing, distribution and customer service [5]. The importance of the supply chain management in business strategy, in attracting and retaining customers and markets, in the effectiveness of operation management and the profitability of companies results becomes a valuable way to ensure the competitive advantageandimprovingtheorganizationalperformance[5–7].Logisticsplaysanessentialroleinsupplychainmanagementanditisoneof the crucial factors of the supply chain success. The logistics planning management processes aims at establishing the right product, in the right quantity, in the right condition, to the right place, at the right time, and at the right cost (i.e., minimal cost).

The supply chain management deals with a significant number of uncertainty factors that affect its performance. These uncertainty factors introduce a large number of random factors and events, affecting all dimensions of the supply chain activities, and also make the risk and vulnerability a major challenge for organizations [8].Risks

and uncertainty factors have a direct influence on both customer satisfaction levels and supply chain related costs. To deal with some of these factors, bufferingtechniquessuchassafetystockisinclu dedasthewayforaidingtheoperationalplanning ofmanufacturingstages to cover both demand and supply uncertainties so that to provide the promised service level to the customers[9,10].Althoughahighersafety stock level represents a higher service level, it must be optimized in order to not increase the total costs of the supply chain [10].

Severalauthorshavestudiedthesafetystockr esearchproblemand proposed their inventory models considering different types of uncer- tainty and risks, using different approaches. The research problems related to safety stock involve typically issues such as dimensioning, management, and positioning, placement or allocation [11]. Safety stockdimensioningconsistsofsettingtheappro priatesafetystocklevel for each item. Safety stock management involves setting of both the safety stock levels and the time for replenishments. And, safety stock allocation, positioning or placement consists on setting safety stock levelsanddeterminewheretoallocatethemonsu pplychainstructure. There are several terminologies in the literature for the same problem of safety stock placement. Safety stock placement, safety stock allocation and safety stock positioning represent the same problem [12–14]. In this Systematic Literature Review (SLR)[1] we adopt the terminology safety stock placement to portray this problem.

Althoughthescopeofthisresearchisonsafety stockdimensioning strategies, we extend it and consider all safety stock dimensions (thisis,dimensioning,managementandplacem ent),sincethedimensioning issue is present ineach of thesedimensions. Schmidt etal. [15] argued

2. Theoreticalbackground

2.1 Procurement:sourcingandpurchasing

The terms purchasing and procurement are often used as the same concept, although they differ in scope. Purchasing is related to the actual buying of materials and the buying process activities. On the other hand, procurement has a broader scope comparing with purchasing [17,18]. It includes purchasing, warehousing, and all activities of receiving inbound materials [17]. Purchasing is the first step in procurement within a process-based supply chain.

ChopraandMeindl[3]definedProcurementas ‘‘theprocessofobtaining goods and services within a supply chain’’. Also, the [19] provides a definition for Procurement: ‘‘the activities associated with acquiring products or services. The range of activities can vary widely between organi- zationtoincludeallofthepartsofthefunctionsofP rocurementplanning, purchasing,inventorycontrol,traffic,receiving,i ncominginspection,and salvage operations’’.

Procurementrepresentsoneofthekeyproces sesinthesupplychain and can influence the success of the entire organization. It ensure the sufficient supplies of raw materials at the right price, of the required quantity, in the right place and at the right time [20]Theprocurementprocessincludesactivities suchasthe*‘‘makeor buy’’* decision process, purchasing and appraisal of both supplier and contractor.Fig.1representstheprocurementcycl einaresumedway.

2.1.1 Sourcing

Sourcing, also known as strategic procurement consists of a set of businessprocessesthatarerequiredtopurchase goodsandservices[3, 21]. It includes processes such as formalize specification, selecting suppliers and contracting process [6,21].

Formalizing specifications — in this process are defined the requirementsofpurchasing,aswellasthe*''makeorbuy''* decision (decision to make goods or provide a service rather than buying this goods/service) [6,20]. The first step of this process consists to define functional and technical specifications of items to be purchased [6];

2.1.1.1 Selecting suppliers — this process consists of searching and identifying suppliers in the market [6,21]. Important decisions, such as the method of subcontracting to be adopted (e.g., partial or total subcontracting, payment in fixed-price or in refundable cost), the criteria for the preliminary qualification of potentials suppliers, the requisition and analysis of received proposals and selection of suppliers are necessary to be taken [6,20];

2.1.1.2 Contracting — in this process are defined the terms of the contract(e.g.,deliveryconditionsandprice ,paymentsconditions, penalty clauses, and warranty conditions) and afterwards the signing of the contract [6].

3. Methodology

III. METHODOLOGY

This study adopted a systematic literature review (SLR) approach, structured in accordance with the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. The PRISMA guidelines ensure transparency, reproducibility, and rigor in the process of identifying, screening, and selecting relevant literature.

Comprehensive searches were conducted across multiple academic databases, including **Scopus**, **Web of Science**, **ScienceDirect**, and **IEEE Xplore**. The inclusion criteria focused on **peer-reviewed studies** addressing the dimensioning of safety stock under various forms of uncertainty—such as stochastic demand, lead-time variability, and procurement risks. Studies that dealt exclusively with unrelated topics in inventory management or lacked quantitative or analytical modeling were excluded from the review.

A total of **193 studies** published between **1995 and 2019** were initially identified. To ensure the review remained current, an **updated search** was performed to incorporate relevant literature published between **2020 and 2025**.

The adopted methodology comprises a structured process for the identification, screening, eligibility assessment, and inclusion of scientific publications. These steps collectively represent a rigorous filtering mechanism for selecting pertinent research works, ensuring a balanced representation of analytical, stochastic, and data-driven studies.

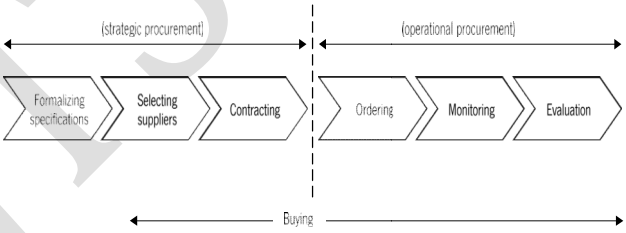

fig.1.StepsofProcurementprocessadapted from[6].

3.1 Searching phase

The majority of scientific publications are published in peer- reviewed scientific journals and them or relevant on are indexed in two of the major online databases: Thomson Reuters' Web of Science (WoS) and Elsevier Scopus. The coverage of journals in WoS is approximately 13.600 journals and in Scopus is 20.346 journals [68]. For this first phase of review methodology, all scientific publications are searched in both Web of Science and Scopus databases using the querydescribedinTable4.Thesearchqueryconsiderskeywordssuch as*''safetystock''*and*''safetyinventory''*sothat tocaptureinbroader

waytopicsrelatedtosafetystockproblem.Keywordsrelatedtofactors of uncertainty and supply chain risks in the sourcing process, such as *demand*, *price*, *lead-time*, *yield*, *order crossover*, *suppliers delay*, *variability*,*variation*,*fluctuation*,*uncertain*and*uncertainty* arealsoconsidered. Lastly, the query excludes all deterministic terms, aiming to focus only on uncertainty factors.

3.2 Selectingphase

Fortheselectingphasearedefinedthreescreeningcriterialevels in order to exclude bibliographic references that did not meet the defined criteria. For the first level of screening criteria, the choice of the consulted references was based on the following criteria:Inthesecondlevelofscreeningcriteria,theSCImagoJournalRank (SJR)indicator and thesubsequentjournalQuartilewasdefinedas the main selection criteria of articles for the next phase (Analysing phase). In this level of screening criteria, only articles published in journals ranked as Q1 and Q2 (Quartiles) in SJR were selected. The mainobjectiveistoconsider/selectrelevantarticlesforthisSystematic Literature Review (SLR) and exclude articles that did not meet the defined criteria.

The third level of screening criteria involves the reading of the abstract of selected articles, thereby excluding articles that did not address the safety stock research problem considering at least one ofrisksoruncertaintyfactorsdescribedpreviously.Afterthisphase, a total of 193 references are selected for the next phase (Analysing phase).

Theco-occurrenceanalysiswasperformedinordertovalidatethefilteringprocessandselectioncriteriaofresearchpapers(see, Section 4.2).

3.3 Analysingphase

This last phase aims to read the whole text of the article and select the more relevant ones and those that meet the purpose of this inves- tigation. After a final manual inspection of the obtained references, a totalof193articleswasselectedastheprimarybibliographicreference for this Systematic Literature Review (SLR).

After that, therefore classified into three safety stockresearchproblems:safetystockdimensioning,safetystockmanagement, or safety stock positioning (allocation or placement). This classification was made by reading each article and identifying the focus of it. Some of the articles contain explicitly the research focus (research problem), but in the majority of selected articles, this classi- ficationwasmadeexclusivelythroughourperceptionwherethearticle fits regarding the safety stock research problem.

4. Classification of Approaches

The reviewed studies were grouped into five main categories: (1) Classical analytical formulas, (2) Stochastic optimization and robust models, (3) Simulation-based methods, (4) Machine learning and forecasting-enhanced approaches, and (5) Hybrid and multi-echelon models.

Approach Type	Key Characteristics	Representative Studies
Analytical Models	Closed-form formulas using service levels and standard deviation of demand.	Eppen (1988); Chopra (2003)
Stochastic Optimization	Models incorporating random demand and lead times using probabilistic constraints.	Gonçalves et al. (2020)

Robust Optimization	Scenario-based buffers under procurement risk.	Barros et al. (2021)
Simulation-Based	Monte Carlo and discrete-event simulation for multi-echelon networks.	Babai et al. (2022)
Machine Learning	Predictive models for lead-time and demand variance estimation.	Demiray Kırmızı (2024)

5. Findings and Discussion

The analysis indicates that lead-time uncertainty is the most influential factor in determining safety stock. Traditional methods underestimate stock requirements when variability in lead-time or correlated uncertainties are ignored. Stochastic and robust optimization approaches provide better resilience but require high data quality. Machine learning models improve estimation accuracy for lead-time and demand variance, enabling more adaptive inventory control.

6. Research Gaps and Future Work

The following areas require further exploration: 1) Integration of procurement risks in multi-echelon inventory systems; 2) Correlated demand–lead-time uncertainty models; 3) Scalable data-driven solutions; and 4) Empirical validation of proposed models in industry settings.

7. Conclusion

This systematic literature review provides a comprehensive synthesis of research on safety stock dimensioning under uncertainty and procurement-related risks. The analysis confirms that uncertainty factors—particularly demand variability, lead-time fluctuation, and supplier disruptions—play a pivotal role in shaping optimal safety stock policies. The review highlights that **lead-time uncertainty** remains the most critical and frequently studied parameter influencing safety stock levels.Recent methodological progress in **stochastic program mming**, **robust optimization**, and **machine learning** demonstrates growing efforts to develop more resilient and adaptive models. These approaches aim to better capture complex, dynamic, and interdependent uncertainties in supply chain operations. However, their practical implementation is still limited due to challenges such as data availability, computational complexity, and integration with existing enterprise systems.

This review also identifies several key **research gaps**. First, the joint modeling of **correlated demand and lead-time uncertainty** requires further exploration to improve real-world applicability. Second, the incorporation of **procurement and supplier risks** within **multi-echelon supply networks** remains underdeveloped. Third, there is a need for **empirical validation** and **industry case studies** to assess the feasibility and effectiveness of advanced analytical and data-driven techniques.Future research should focus on bridging the gap between theoretical developments and practical implementation by integrating **data analytics**, **artificial intelligence**, and **decision-support systems** into procurement and inventory management. The continued evolution of digital supply chains and real-time data collection provides new opportunities to develop adaptive safety stock strategies that respond dynamically to changing risk environments.Overall, this study contributes to the growing body of knowledge on inventory and procurement risk management and serves as a foundation for advancing both academic research and industrial practices in safety stock optimization under uncertainty.

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