

Storage Location Assignment Problem in E-commerce: A Literature Review

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ABSTRACT

With the escalating demand for e-commerce, the management of warehouses has become indispensable in ensuring customer satisfaction. The storage and administration of products encounter intricate challenges owing to tight delivery deadlines, the substantial volume and small-scale orders. The efficient allocation of storage locations significantly impacts costs, time, and productivity. Nonetheless, e-commerce introduces distinctive hurdles to this allocation process. This paper reviews the emerging trends regarding the storage location assignment problem for e-commerce warehousing. A comprehensive literature review from 2019 to 2023, utilizing the Web of Science database, yielded 16 pertinent articles. An increasing interest is noticeable in the development of novel storage policies and the use of big data to identify product similarities and correlations through historical data. In automated warehouses, the integration of product allocation with pod allocation has been observed.

KEYWORDS. Storage Location. E-commerce. Warehouse management.

Paper topics: L&T - Logistics and Transport, ORI - Operational Research in Industry

RESUMO

Com o aumento da demanda no e-commerce, a gestão de armazéns se tornou essencial para garantir a satisfação dos clientes. O armazenamento e gerenciamento de produtos enfrentam desafios complexos devido ao grande volume, pedidos em pequena escala e prazos de entrega curtos. A designação eficiente de locais de armazenamento impacta custos, tempo e produtividade. No entanto, o comércio eletrônico apresenta desafios únicos nesse processo de alocação. Este estudo analisa as tendências emergentes na designação de locais para armazenamento no *e-commerce*. Uma revisão da literatura entre 2019 e 2023, usando a base de dados *Web of Science*, resultou em 16 artigos. Observa-se crescente interesse no desenvolvimento de novas políticas de armazenamento e uso de *big data* para identificar similaridades e correlações entre produtos por meio de dados históricos. Nos armazéns automatizados, foi observada a integração do problema de alocação de produtos com a alocação das prateleiras.

PALAVRAS CHAVE. Locais para armazenamento. Comércio eletrônico. Gestão de armazéns.

Tópicos: L&T - Logística e Transporte, POI - PO na Indústria

1. Introduction

Efficient warehouse management plays a critical role in optimizing the overall performance of the supply chain, as these spaces act as a vital connection between suppliers and customers [Micale et al., 2019]. Warehouses perform essential activities such as receiving, shipping, storage, and order picking. Effective coordination of these operations can be highly complex. The coordination of these operations can pose significant complexity [Alonso-Ayuso et al., 2013]. Nevertheless, the advent of e-commerce has triggered substantial transformations, not just in consumer buying patterns, but also across the logistics and retail sectors as a whole.

In this challenging context, the expansion of e-commerce and increased competition have created a pressing need for managers to enhance operations and minimize warehouse management costs [Fontana e Nepomuceno, 2017]. There has been a new generation of warehouses specifically designed to meet the needs of online retail in the business-to-consumer (B2C) segment. These warehouses have distinct characteristics such as processing orders with few items, a wide variety of products, scalability, and short delivery times. The new operational model differs significantly from traditional order fulfillment, increasing the complexity of logistics to deal with the requirements of e-commerce [Leung et al., 2017; Boysen et al., 2017].

According to Zennaro et al. [2022], efficient warehouse management in e-commerce can be achieved through the implementation of relevant strategies such as order picking, storage location assignment, and automation. The Storage Location Assignment Problem (SLAP) is a decisive aspect in this context, involving the allocation of products in storage spaces and the optimization of handling costs and use of available space. This problem depends on several parameters, such as storage area design, space availability, warehouse capacity, physical characteristics of products, arrival times, and demand behavior [Reyes et al., 2019; Zhang et al., 2020b].

Efficient storage allocation is crucial for optimizing picking operations, minimizing space waste and picking time, and reducing overall operational costs [Tu et al., 2021]. Since SLAP is one kind of assignment problem, and considered NP-hard, the computational effort, in general, required to find an optimal solution grows exponentially with the problem size [Wisittipanich e Kasemset, 2015]. Given the importance of this issue, the Storage Location Assignment Problem (SLAP) has been a subject of study for researchers over the years.

A review conducted by Reyes et al. [2019] analyzed 71 academic publications between 2005 and 2017, highlighting the subject of storage. In the context of e-commerce, Boysen et al. [2019] conducted a review that specifically examined storage systems designed to facilitate order fulfillment in the B2C segment for online retailers. Additionally, Li et al. [2022] conducted a recent study that reviewed literature from 2020 to 2022, focusing on the application of order picking strategies in e-commerce and emphasizing operational efficiency.

However, to the best knowledge of the authors, there is a gap in literature regarding a review of SLAP in the area of e-commerce. The objective of this study is to analyze the recent trends of SLAP in e-commerce warehouses and advancements in the field through a literature review covering the period from 2019 to 2023. In addition to this introduction, the paper consists of four other sections. Section 2 described in details the methodology used in the literature review. Section 3 discusses the findings, and Section 4 presents final considerations.

2. Methodology

The aim of this article is to investigate the current state of research on the assignment of product storage locations in warehouses in e-commerce. The selection process for studies is detailed next.

Initially, filters were applied to select works published in the analyzed period, and a scheme of the process is presented in Figure 1. The database chosen for the study was the Web of Science, due to its comprehensiveness with more than 21,000 journals [Clarivate, 2021].

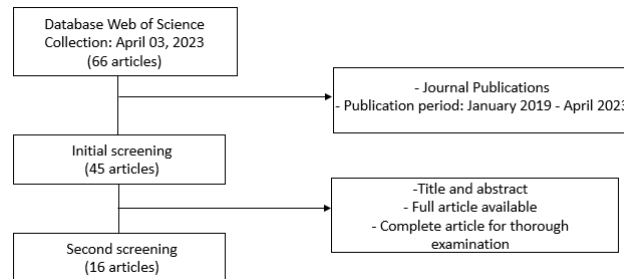


Figure 1: Process for article selection.
 Source: Authors (2023)

Reyes et al. [2019] pointed out the various terminologies associated with the SLAP (Storage Location Assignment Problem) and its relevance in different contexts. To cover these variations, we classified the keywords into two groups, as depicted in Figure 2. One group pertains to the SLAP in general, while the other focuses on e-commerce. The inclusion criteria for our research in the database consisted of combining these keywords with English language articles, resulting in a sample of 66 articles.

SLAP	E-commerce
"Storage location assignment problem" OR "product allocation" OR "storage allocation" OR "allocation" OR "space allocation" OR "reserve area" OR "storage" OR "slotting" OR "SLAP" OR "location".	"Online retailer" OR "e-commerce" OR "online retailing" OR "fulfillment" OR "e-fulfillment".

Figure 2: Search terms.
 Source: Authors (2023)

The initial screening process involved selecting publications within the temporal scope of January 2019 to April 2023 for article inclusion. Furthermore, we specifically focused on articles published in journals while excluding those from conferences, reviews, and books. In the second screening stage, we assessed the availability of the full articles in the database and carefully reviewed the title, abstract, and full text as additional criteria. This phase was conducted manually to ensure thorough evaluation. Several articles were excluded from the study as they did not align with the research scope, such as those addressing packaging operations, shelf assignment, pod assignment, warehouse design, rental of storage space, and the integration of multiple warehouses and physical stores. Ultimately, we selected 16 articles that met the predefined inclusion criteria for our research.

2.1. An overview of the publications during the analyzed period

Figure 3 depicts the distribution of articles throughout the analyzed years, with 2021 standing out as the year with the highest number of publications. It is important to note that, as this review was conducted in the second quarter of 2023, there may be an increase in the number of publications by the end of this year.

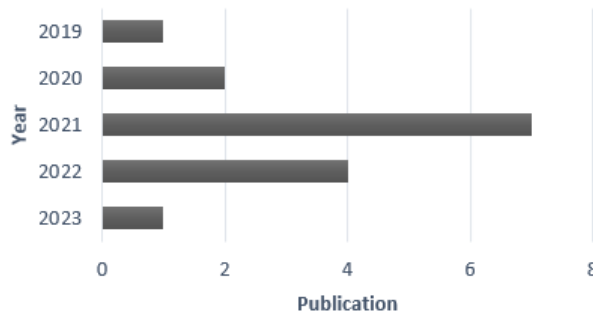


Figure 3: Publication distribution from 2019 to 2023.
 Source: Authors (2023).

The International Journal of Production Research emerged as the leading journal in terms of publications related to the subject, as depicted in Table 1. Additionally, the Complexity and Mathematical Problems in Engineering journals exhibited notable presence in this field. An extensive literature review conducted by Li et al. [2022] on e-commerce picking operations corroborated these findings, highlighting the International Journal of Production Research as the journal with the highest volume of publications on this topic. This substantial representation of research work in the journal signifies a pronounced level of engagement and interest in this specific area.

Table 1: Distribution of publications by journals

Journal	Publication
<i>INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH</i>	3
<i>COMPLEXITY</i>	2
<i>MATHEMATICAL PROBLEMS IN ENGINEERING</i>	2
<i>ADVANCED ENGINEERING INFORMATICS</i>	1
<i>COMPUTERS AND INDUSTRIAL ENGINEERING</i>	1
<i>COMPUTERS AND OPERATIONS RESEARCH</i>	1
<i>ENTERPRISE INFORMATION SYSTEMS</i>	1
<i>FME TRANSACTIONS</i>	1
<i>IEEE TRANSACTIONS ON AUTOMATION SCIENCE AND ENGINEERING</i>	1
<i>INFORMS JOURNAL ON COMPUTING</i>	1
<i>INTERNATIONAL JOURNAL OF PRODUCTION ECONOMICS</i>	1
<i>TRANSPORTATION RESEARCH PART E: LOGISTICS AND TRANSPORTATION REVIEW</i>	1

Source: Authors (2023)

Figure 4 illustrates scientific production by country, taking into consideration all authors' affiliations in the article. It is evident that China stands out as one of the main producers, followed by the United States and Belgium. In addition to its influence on scientific production, China has also been successful as a global export powerhouse. In recent years, the country has made significant investments in logistics and adopted advanced technologies to enhance its processes, including in warehouses.

In a study conducted by Hao et al. [2020], it was found that the rapid expansion of the Chinese economy has played a pivotal role in propelling the growth of the logistics sector, leading

to a notable upsurge in annual order volumes. This surge has been facilitated by the successful integration of cutting-edge technologies such as big data and machine learning. As a result, the total logistics cost as a percentage of Gross Domestic Product (GDP) has witnessed a remarkable decline from 17.8% to 14.6%, signifying increased cost efficiency. Moreover, the overall performance and effectiveness of the logistics sector have exhibited significant advancements. These positive developments have had a direct and substantial impact on international trade, enhancing the country's competitiveness within the global market.

In the analysis of the 16 articles examined, it was observed that mathematical modeling utilizing simulated data was the prevailing research method, as depicted in Figure 5. Following closely behind was mathematical modeling employing real data. Nevertheless, it is crucial to highlight a notable research gap regarding the utilization of real data, as emphasized by Davarzani e Norrman [2015] in their warehouse research agenda. The majority of studies tend to concentrate on mathematical modeling without practical application in real-world scenarios. This discrepancy poses a potential impediment to the practical applicability of the research findings. Efforts should be made to bridge this gap and promote research that encompasses real data to enhance the relevance and effectiveness of the conducted studies in practical settings.

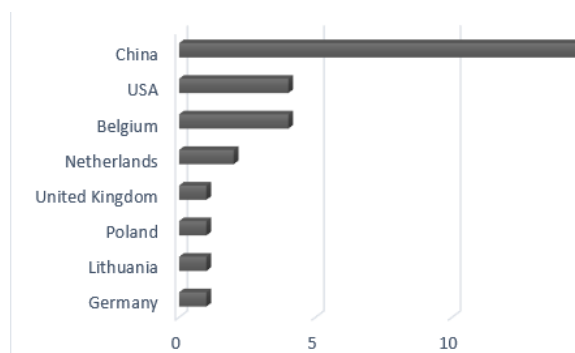


Figure 4: Scientific production by country.
 Authors (2023)

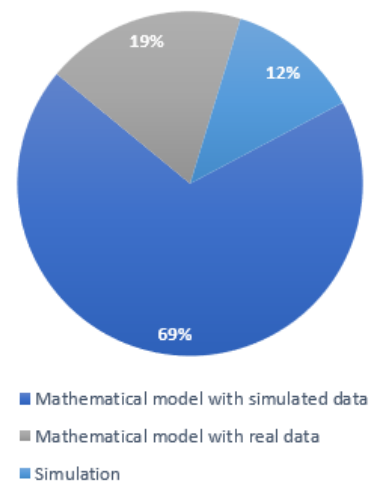


Figure 5: Types of research methods.
 Authors (2023)

3. Results and Discussions

Van den Berg e Zijm [1999] describe the storage system as a set of policies and equipment applied to the collection, storage, and retrieval of items. Among the challenges faced by warehouse managers, the separation of orders and storage location assignment policies stand out [Chan e Chan, 2011]. These two operations are inherently connected, as an effective storage location assignment policy can result in reduced average travel times for storage, retrieval, and order picking [Fontana, 2022].

In this context, as a way to optimize their processes and provide improved service to customers, warehouses are increasingly adopting advanced technologies in their activities. However, it is important to note that this transformation requires a significant investment of time and resources

for its effective implementation. The main objective of these technological innovations is to increase the efficiency and accuracy of storage operations. In this sense, researchers such as Van den Berg e Zijm [1999] and Da Costa Barros e Nascimento [2021] have developed classifications that take into account the degree of automation applied in warehouse activities.

A manual warehouse primarily relies on the physical handling of products by workers for tasks such as collection and storage on shelves. This can be accomplished either through the direct movement of workers or with the assistance of manual guides. On the other hand, automatic warehouses employ mechanisms that facilitate the automated or semi-automated transfer of items to the picker. An automated warehouse, in particular, exhibits a high level of intelligence, enabling it to efficiently collect and process items with minimal human intervention. It may also incorporate robotic systems to carry out order picking activities, as highlighted by Da Costa Barros e Nascimento [2021].

During the literature review, notable disparities emerged in the scholarly discourse on manual and automated warehouses in recent years. These discrepancies primarily revolve around divergent approaches to layout design, policies, and storage criteria adopted in these two warehouse types. Consequently, the obtained results will be presented in two separate subtopics, each addressing the unique perspectives associated with manual and automated warehousing.

3.1. Manual warehouse

Table 2 provides a comprehensive overview of the articles classified under the domain of manual warehouses, categorizing them based on performance measures, assignment policies, and Stock Keeping Unit (SKU) allocation prioritization criteria. The performance measure in these studies pertains to the optimized variables within the mathematical models employed. A literature review on SLAP conducted by Reyes et al. [2019] revealed that the most commonly utilized performance measure across various studies was the distance traveled during the picking activity. This measure has been extensively investigated since 2005. In line with these findings, the present study also identifies the estimation of travel distance and travel time in manual order picking systems as prominent topics of discussion. These topics are typically approached from various perspectives, often incorporating statistical analysis and operational research methods [Battini et al., 2015].

In a study conducted by Lorenc e Burinskiene [2021], a comprehensive approach is employed by integrating data from the Warehouse Management System (WMS) with product statistics and warehouse layout information. They utilize a k-means classification model to strategically position products within the warehouse, aiming to minimize the time required to fulfill orders. Additionally, they develop a time calculation algorithm and report significant reductions in order picking time ranging from 17.4% to 25.6%.

On a different note, Xu e Ren [2020] propose a novel model called Dynamic SLAP (DSLAP), which combines order picking and storage assignment operations into a single optimization step. The primary objective is to minimize both time and distance traveled during order picking, taking into account the popularity and correlations between different SKUs. To find optimal solutions, the model employs a genetic algorithm. The research results indicate that DSLAP is particularly effective in optimizing scenarios with strong demand correlations or small order sizes.

According to Fontana [2022], assignment policies play a crucial role in accurately identifying and efficiently locating stored items. In a previous study, De Koster et al. [2007] identified the most commonly adopted policies, including random storage, nearest open location storage, dedicated storage, total turnover storage, and class-based storage. However, in recent years, there has been a shift in the scenario regarding the policies used, driven by the growth of online retail. New

Table 2: Summary of literature related to manual warehouse

Authors	Performance measure	Assignment policy	Criteria for prioritization in allocation
Bahrami et al. [2019]	Time	Proposal of a new policy	Popularity
Xu e Ren [2020]	Time and distance	Dynamic storage assignment policy	Popularity and correlation between SKUs
Zhang et al. [2020b]	Distance, stability, and classification	Scattered storage policy	Dispersion among similar products
Wang et al. [2020]	Distance	Data-driven policy	Data collection frequency
Zhang et al. [2020a]	Time	Explosive policy	Correlation between SKUs
Guo et al. [2021]	Distance	Return policy for new products	Location and order-oriented rules
Goeke e Schneider [2021]	Cost	Scattered policy	Turnover
Lorenc e Burinskiene [2021]	Time	Cluster-based policy	Turnover
Jiang et al. [2021]	Distance	Duplicate scattered storage policy	Correlation among SKUs
Albán et al. [2023]	Distance	Paired distance scattered storage policy	Correlation among SKUs

Source: Authors (2023)

storage strategies have emerged to meet the specific demands of e-commerce [Weidinger, 2018]. Among them, we can mention explosive [Onal et al., 2017] and scattered policies [Weidinger e Boysen, 2018].

The choice of the appropriate policy depends on several factors, such as the number of pickers in the warehouse, the collection method (continuous or in batches), product characteristics, the route in picking, among others. These characteristics play a fundamental role in the search for new policies that adapt to the specificities of warehouses, as observed in studies. For example, Zhang et al. [2020a] formulated a mixed programming model for the DSLAP problem in an F-warehouse, using the explosive storage policy. Their operational objective was to minimize service time or the interval between order arrival and shipment. The authors developed two heuristics to solve the problem. Results indicate that the proposed stocking objective and associated heuristic reduced service time by 6.69% to 11.19% compared to the random storage policy.

Albán et al. [2023] proposed a new policy of scattered with paired distances. The policy assumes that a list of recently selected orders whose items need replenishing is known. When determining the position to store each replenished item, the algorithm tries to minimize the sum of the paired distances between all items belonging to the same order. The authors consider the correlation between previously ordered products as a criterion used for storing them in nearby positions. When compared to the volume-based storage policy, the authors' new policy showed a 65% reduction in distance traveled for order picking.

Prioritization criteria play a pivotal role in the allocation of products, as they dictate the sequence in which products are allocated based on factors such as sales volume, popularity, and turnover. Traditionally, the strategic placement of products in specific locations has been employed to optimize storage and picking operations. However, a recent emerging trend in scholarly research focuses on utilizing historical data for product allocation. This approach leverages correlation and similarity techniques among products to determine the most appropriate order, as evidenced by the studies conducted by Xu e Ren [2020], Zhang et al. [2020b], Zhang et al. [2020a], Jiang et al. [2021], and Albán et al. [2023].

3.2. Automated warehouse

The concept of automated warehouse is related to performing operations within the warehouse such as automatic restocking of inventory, autonomous identification of inventory, order picking, and routing of delivery systems for loading and unloading using a group control of autonomous robotic vehicles (Robot Mobile Fulfillment System - RMFS) [Yevsieiev e Demska, 2021]. In all the articles selected for review, assignment to storage locations was done through RMFS. A comprehensive summary of the studies is provided in Table 3.

In comparison to traditional manual warehouses, automated warehouses are specifically designed to handle lighter items and eliminate the requirement for pickers to physically locate and retrieve products. In this setup, robots are responsible for moving the shelves to designated pickers, and a sophisticated system directs pickers to the precise layer from which items should be retrieved. Consequently, pickers can concentrate on the actual picking process, thereby reducing the time spent on walking and searching for products. Wang et al. [2020] highlights that in automated warehouses, pickers primarily dedicate their time to retrieving and placing items in the appropriate order bin, resulting in substantial enhancements in order fulfillment efficiency.

Table 3: Summary of literature related to automated warehouse

Authors	Performance measure	Allocation Policy	Criteria for prioritization in allocation
Yuan et al. [2021]	Distance traveled and correlation between products	Scattered policy	Product correlation
Keung et al. [2021]	Distance traveled	Data-driven order correlation policy	Product correlation
Tu et al. [2021]	Time and workload	Storage heuristic for pick-and-pass in CPS based on genetic algorithm	-
Yang [2022]	Robot movement during picking	Combination of storage policy and batch picking of correlated products	Product similarity
Mirzaei et al. [2022]	Time	Correlated scattered storage policy	Correlation and turnover
Ma et al. [2022]	Product correlation	Scattered correlation policy based on product classification	Product classification and correlation

Source: Authors (2023)

According to Yuan et al. [2021], research has been neglecting the study of the combination of SKU and pod allocation, addressing them as distinct problems. However, it has been discovered in recent years that both authors and articles have been focusing on the gap identified by researchers. For instance, Yang [2022] propose a unified clustering model for location assignment and the separation of pods into zones based on requested product batches, aiming to maximize the allocation of similar products in both pod and bins to minimize robot movement during picking. The authors conclude that storage and batch allocation policies have a significant impact on order picking efficiency in warehouses with mobile pods.

Mirzaei et al. [2022] conducted a study in which they introduce a novel allocation policy that incorporates turnover frequency, product correlation, and scatteredness to assess the impact on the distance traveled during the picking process. In their proposed model, products are grouped based on their historical correlation, and each storage shelf contains a specific group of

products. Furthermore, the assignment of shelves to locations and storage zones takes into account the turnover rates of the products.

To solve the problem, the researchers formulated it as a mixed-integer program and developed a heuristic approach. The results demonstrated that the newly developed policy outperformed turnover-based, correlation-based, and random policies in terms of performance.

With the continuous advancement of big data, it is possible to estimate the correlation between products by analyzing a large volume of historical data [Jiang et al., 2021]. The correlation between orders in automated warehouses has been identified not only in the policies adopted but also in product allocation criteria, revealing a growing trend of considering correlation in storage models. To address this issue, Ma et al. [2022] proposed a dispersed correlation policy based on product classification.

For small-scale instances, the authors formulated the problem as a mixed-integer programming seeking to maximize the correlation of all products stored on shelves. For medium and large scales, they developed a search metaheuristic that combines adaptive parameters and acceptance criteria of the Simulated Annealing method to find near-optimal solutions. The authors' proposal involves combining different storage patterns with customer demand patterns, considering the asymmetry of customer demand, to achieve the best robustness and competitive order picking efficiency.

4. Conclusions

E-commerce has brought about a significant transformation in consumer behavior and the overall market dynamics. It has introduced several noteworthy characteristics, including fragmented and small-scale orders, shorter delivery times, serving customers in diverse locations, a wide range of product offerings, and the need for agile delivery services. These characteristics pose considerable challenges for the logistics sector, which has been actively striving to enhance its operations through technological advancements. Within the warehouse environment, the strategic selection of product storage locations directly impacts crucial metrics such as space optimization, order fulfillment time, costs, and overall productivity.

The objective of this study is to examine recent trends in SLAP within e-commerce warehouses. To achieve this, a comprehensive literature review was conducted using the Web of Science database, focusing on publications from 2019 to 2023. The review yielded a sample of 16 relevant studies. Considering the influence of technological advancements and the increasing adoption of automation in warehouses, the selected works were categorized according to the type of warehouse: manual and automated.

There is currently a growing interest in developing new product storage policies to improve efficiency. Two of the main approaches used as a basis are the scattered policy and the explosive policy, both derived from the random policy. In addition, there is widespread use of historical data to identify correlated or similar products, allowing their allocation close to each other. In automated warehouses, it was found that the allocation of products is carried out together with the allocation of pods, which has generated good results in terms of performance.

The reliance on generated data in many studies poses a challenge when it comes to applying the models to real-world scenarios. This limitation often stems from the difficulties in establishing partnerships between universities and companies. However, overcoming this challenge necessitates a focus on fostering collaboration and cooperation between the academic and business sectors. By actively promoting the sharing of relevant data and conducting joint research, academia and industry can achieve better model validation and enhance the practical applicability of proposed storage policies. This synergy between academia and industry holds the potential to bridge the gap

between research and real-world implementation, resulting in more effective solutions for optimizing storage operations. As a suggestion for future research, it is recommended to include additional databases for the review.

4.1. Acknowledgments

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