Article

A Narrative Review: Optimization Algorithms for The Problem of Allocating Shelf Space in Retailing

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Abstract – The Shelf Space Allocation Problem (SSAP) is of great significance in the retail industry since it directly impacts the effectiveness of product placement and organization within a shop. This issue arises from a deficiency in comprehending the strategic arrangement of products, resulting in the wasteful utilization of space. Notably, SSAP has a significant negative impact on store operations and customer satisfaction, resulting in wasted space and a reduction in the number of products that can be displayed to customers. Hence, the careful selection of an optimization method is crucial for effectively managing the allocation of shelf space in retail operations. This study aims to examine optimization algorithm techniques for addressing the issue of shelf space allocation in a particular environment, such as enhancing sales, minimizing congestion, or optimizing space utilization. Several studies have considered several optimization algorithm methods that have been used in solving the SSAP, including Genetic Algorithm (GA), Linear Programming (LP), Dynamic Programming (DP), Simulated Annealing (SA), Particle Swarm Optimization (PSO), and Variable Neighborhood Search (VNS). These methods are selected based on problem characteristics, including nonlinearity, integer requirements for variables, and constraints such as limited rack space. This optimization method helps retailers to effectively optimize shelf space allocation and maximize sales and profits. The study thus reviewed previous papers examining optimization algorithm methods to solve the problem of shelf space allocation. Those methods are crucial in improving product organization efficiency, customer satisfaction, and overall business performance.
Keywords: "Shelf Space Allocation Problem", "Optimization Algorithms", "Systematic Analysis", "Retail Industry"

1. Introduction

In the business context, retailing refers to a collection of actions that add value to the goods and services offered to customers for their own personal, familial, or organizational usage. In general, retailing is typically connected with activities that take place within the context of selling things in stores. Two distinct points of view may be applied to the retail sector of

Malaysia: the traditional and the modern. Note that the term "traditional shops" refers to retailers who sell items at stalls as well as retailers who sell merchandise in small vehicles. Before Malaysia gained its independence, that sector started establishing a presence in the country. However, this sector is exposed to several risks, and the most critical is buying goods prior to selling them and giving credit to the buyer. In addition to appealingly exhibiting the product, the capacity of the retailer to make customers aware of the presence of the product on the premises is another element that can entice customers to purchase the product. All kinds of commodities, including those that are required daily, are sold in grocery stores. According to Czerniachowska et al. (2021), the Shelf Space Allocation Problem (SSAP) is a decision problem in which the objective is to produce the best possible outcome in a retail store while considering a variety of operational restrictions. Retailers are faced with the complex issue of allocating space for a large variety of items while considering the varying preferences of customers, seasonal changes, and promotional activities. Thus, striking the appropriate balance between maximizing product availability and exposure while simultaneously avoiding the trap of excess inventory or disregarding slow-selling items is the challenge that must be addressed.

The functions or loss functions that are utilized in the optimization of shelf space allocation and profitability often comprise maximizing profits through the objective function (Warras, 2019). It also considers profit and cost components (Warras, 2019) and occasionally includes loss functions to minimize revenue losses (Czerniachowska et al., 2021). Notably, optimization algorithms are essential in solving the intricate SSAP prevalent in the retail industry. Furthermore, Gencosman and Bergen (2022) and Düsterhoft and Hübner (2023) stated that this algorithm assists retailers in optimizing sales profits through the utilization of shelving that is adaptable, versatile, and straightforward to oversee and maintain. Hence, by determining the optimal number of facings for each product and allocating them as contiguous rectangles, these algorithms can maximize profit and increase the retailer's competitive advantage (Khatami, 2021). In addition, utilizing mixed-integer linear mathematical programming models and solution methods like logic-based Benders decomposition and exact 2-stage algorithms allows efficient and optimal solutions for real-world scenarios (Celik et al., 2023). Moreover, these optimization algorithms enhance shelf space allocation in retail stores and address analogous issues in other fields. This includes webpage design, allocation of product families in grocery stores, and flyer advertising.

In the retail sector, optimizing strategies and methods for allocating shelf space is essential for maximizing earnings and attracting customers. Various studies and research have been conducted to produce useful models through the application of quantitative techniques such as linear and Non-Linear Programming (NLP) (Düsterhöft & Hübner, 2023). Furthermore, heuristics and metaheuristic algorithms, such as Genetic Algorithms (GA) and firefly algorithms, have been proposed by researchers as a means of effectively resolving difficult SSAPs (Zheng et al., 2023).

Metaheuristic methodologies have been employed to optimize the utilization of shelf space in grocery stores. Sajadi and Ahmadi (2022) and Flamand et al. (2023) proposed innovative approaches for maximizing profitability by efficiently managing shelf space. These solutions utilize mathematical programming, evolutionary algorithms, firefly algorithms, and solver-free heuristics to tackle the intricacies of product placement on shelves. The product display should consider various factors, including facial features, category, and store layout, to enhance sales, generate consumer interest, and elevate salesperson motivation to a higher level.

There are other optimization techniques used for SSAPs, such as GA, LP (Lim et al., 2004), Dynamic Programming (DP) (Lim et al., 2004), Simulated Annealing (SA), Particle Swarm Optimization (PSO), and other metaheuristic algorithms that can quickly search for the best possible configurations. These optimization methods consider product placement, grouping, and limitations linked to shelf, product, and category. Moreover, the selection of an algorithm is contingent upon various factors, including the intricacy of the task, the quantity of available data, and the computer resources at one's disposal. Frequently, this results in hybrid methodologies that integrate various algorithms or employ machine learning techniques to enhance precision and adaptability within the retail sector. Some of the articles selected were between 1986 and 2023. Accordingly, 47 articles were selected and reviewed for Optimization Algorithms' significance and future studies' consequences. The aim or the basis of selecting this article is based on the result analysis and review of the Optimization Algorithms for the SSAP, which is to thoroughly analyze and combine existing literature, research, and methodologies related to the use of optimization algorithms in solving the SSAP in the retail sector.

2. Research Review of Study

2.1. Genetic Algorithm (GA)

GA is a computer methodology that draws inspiration from natural evolutionary processes. This technique is versatile and can be utilized to manage various optimization challenges, such as the task of organizing products on shelves in a grocery store. GA extensively optimizes solutions in diverse fields, including addressing retail sector obstacles such as allocating shelf space and inventory management. Correspondingly, Czerniachowska and Hernes (2020) introduced a pragmatic method for allocating shelf space using a GA to optimize the retailer's profit. In addition, Schabasser (2023) agreed that an increase in shelf space dedicated to products results in an increase in demand. At the same time, Hübner and Kuhn (2023) developed a method that considers shelf and storage limitations for assortment, replenishment, placement, and shelf space allocation. The optimization method proposed by Sajadi and Ahmadi (2022), which is the GA, can address the issues of shelf space allocation and inventory management.

This view is supported by Kim and Moon (2021), who studied that using GA in integrated planning for product selection and shelf space allocation, to name a few, makes it easier for customers to make decisions in product selection. Hence, employing GA to solve the SSAP is appropriate for optimizing product placement, particularly in the retail sector. Shen et al. (2020) employed a GA to enhance the efficiency of inventory management within the supply chain of perishable agricultural products. This demonstrates the versatility of evolutionary algorithms in addressing diverse challenges in inventory management. Moreover, previous studies have demonstrated the effectiveness of evolutionary algorithms in solving SSAPs. These algorithms maximize profitability, optimize inventory, and manage various limits. One of the reasons why GA is effective in solving shelf space problems is attributable to it consistently outperforming other methods, generating solutions with greater accuracy. Additionally, GA allows for the inclusion of different shelf, segment, and product characteristics, as well as hierarchical allocation rules and product closures. Czerniachowska (2022) has demonstrated the efficacy and feasibility of addressing the problem of allocating retail shelf space. However, Czerniachowska and Hernes (2020) have discovered certain limits in shelf space allocation using GA. These drawbacks include the neglect of non-linear profit functions, as well as the impact of space elasticity and cross-space. Furthermore, the optimization issue is highly intricate, and there is a possibility of early convergence on poor solutions.

2.2. Linear Programming (LP)

LP is one of the strategies that may be used to optimize the allocation of shelf space in the retail industry. LP can be employed in the context of shelf space allocation to optimize the arrangement of products on the shelf to maximize sales or profit. This is achieved by considering restrictions such as limitations on shelf space, product demand, and product compatibility. Notably, this method is effective in optimizing sales or profitability. Retailers can optimize their earnings and enhance consumer attraction by employing an integer LP model to determine the optimal arrangement of shop branches and shelf space allocation. This approach is highly efficient in maximizing sales or profits since LP considers various factors, including the proximity between the store and the customer, the positioning of the product within the store, and the visibility and organization of the product on the shelf. This has been demonstrated by a study conducted by Czerniachowska et al. (2023) and Flamand et al. (2023), in which retail stores may enhance their revenue and attract more customers by employing an integer LP model to ascertain the most advantageous store layout and allocation of shelf space.

Utilizing LP for shelf space allocation has numerous advantages. Firstly, it enhances profitability by determining the most advantageous product placement on the shelf, considering factors such as visibility, packaging, arrangement, and categorization (Warras, 2019; Gencosman and Begen, 2022). Moreover, it provides decision-assistance tools for retailers to assist in the efficient allocation of shelf space. The allocation of resources is determined by various restrictions, including the availability of shelf space, product allocation, the number of shelves, and category allocation (Zheng et al., 2023). Furthermore, the mathematical model obtained from LP is validated by employing real-world data sets and assessed utilizing benchmarking techniques to confirm its dependability and precision (Gencosman and Begen 2022). From the perspective of a retailer, it is crucial to prioritize the utilization of retail space to maximize its value and optimize the arrangement of shelves. Consequently, Czerniachowska and Lutosławski (2021) have demonstrated that utilizing linear shelf space in the retail industry is effective and efficient for allocating shelf space. This approach offers algorithmic solutions, ensures the validity and comparability of models, and enhances consumer satisfaction while minimizing revenue loss. Despite that, the LP method may not be appropriate for all types of problems related to allocating shelf space, particularly when the variables involved must be whole numbers. Furthermore, the goal function lacks differentiability. Under such circumstances, it might be more suitable to contemplate relaxation or alternate optimization tactics.

2.3. Dynamic Programming (DP)

DP is an effective optimization method employed in shelf space allocation to manage fluctuating demand patterns and seasonal variations, allowing for the flexible modification of shelf space over time (Bellman, 1957). DP decomposes intricate problems into more manageable subproblems and solves them recursively, considering the optimal allocation at each stage to attain an optimal solution overall. This method is highly beneficial for effective shelf space distribution management by considering the changing tastes of customers and the demands for different products throughout various periods. Note that optimal choice relationships in DP are derived by explicitly using optimality principles. The principal statement consists of a sequence of optimal choices that involve an initial condition and a subsequent decision. When making a decision, it is crucial to consider the outcomes of the statement, starting with the initial choice. DP involves several sequences of potential outcomes.

Efficiently managing retail operations requires making decisions and optimizing shelf space allocation. This emphasizes the importance of having a strategy for efficient allocation, as highlighted by Czerniachowska and Hernes (2020). Hence, according to Czerniachowska and Lutosławski (2021), DP is proposed as a solution for the issue of shelf space allocation in the retail sector. At the same time, Hübner et al. (2021) concurred that various heuristic and metaheuristic methods, such as DP, are appropriate for addressing shelf space allocation difficulties. The study conducted by Jajja, M.S.S (2013) and referenced in the search results discussed the use of DP as a method for allocating shelf space to maximize profit. This method considers various factors, including inventory turnover, space flexibility, and demand trends. In addition, Gajjar and Adil (2011) posited that DP is a very efficient optimization method that may be employed in retail operations management to allocate shelf space. The arrangement of shelf space has a substantial influence on customer behavior. According to Odunitan-Wayas et al. (2020) and Sajadi and Ahmadi (2022), the arrangement of shelf space significantly impacts consumer behavior in supermarkets during product purchases. Accordingly, DP plays a role in enhancing product allocation and optimizing shelf management, providing merchants with chances to enhance profitability, as explained by Lim et al. (2004).

However, it has several limitations that can hinder its applicability and effectiveness in practical scenarios, such as computational complexity. This might result in extended solution durations and substantial computing expenses, rendering it impractical for real-world applications with tight time constraints (Zufryden, 1986). Thus, it is necessary to integrate DP with a robust local search strategy to enhance its effectiveness in managing intricate product categories. This reinforces its significance as a crucial instrument in maximizing retail shelf space and enables the effective distribution of resources by dividing intricate problems into smaller sub-problems and storing solutions for future utilization.

Subsequently, implementing improved planograms and enhanced shelf management can result in increased sales.

2.4. Simulated Annealing (SA)

The allocation of shelf space in retail businesses is a significant concern due to spatial constraints. SA is an optimization method used to solve shelf space allocation difficulties. SA facilitates the exploration for the optimal solution by intermittently allowing suboptimal movements, thereby preventing the occurrence of becoming trapped in local maxima. Notably, SA can be employed in the context of shelf space allocation to systematically modify product placement, experimenting with various configurations to optimize the layout of shelf space. This is particularly advantageous when there are numerous potential arrangements and variations in product selections or customer demands over a period. In addition, SA can improve rack space allocation by implementing suboptimal modifications early on and progressively decreasing the probability of making poor decisions as the process advances. Moreover, SA has been proposed as a hyper-heuristic strategy to optimize shelf space allocation and maximize benefits. Beed et al. (2020) agreed that the method utilizes SA to optimize the allocation of products on the shelf to maximize profitability. At the same time, Zhao et al. (2016) used the SA method to set the shelf space and determine the display location. This view is supported by Ostermeier et al. (2021), who suggested that the use of SA has allocated efficient shelf space and contributed to sales profits.

On the other hand, SA has been employed in the domain of shelf space allocation to optimize profits. Ishichi et al. (2019) devised a category management model to aid retailers in making decisions when faced with restricted space. They also put forward a heuristic method using SA. Jenkins et al. (2022) emphasized the need to optimize shelf space allocation using DP algorithms and SA. Czerniachowska and Hernes (2021) sought to create a pragmatic model for allocating shelf space that allows for horizontal and vertical product grouping to maximize the retailer's profit.

Note that SA possesses several benefits and drawbacks when employed to optimize shelf space allocation. An advantage of this method is that it is a metaheuristic optimization technique that has demonstrated effective applications in diverse domains, including combinatorial optimization issues like shelf space allocation (Sen et al., 2013). It can tackle optimization problems on a large scale that include a distinct configuration space, such as allocating shelf space and determining display locations (Franzin et al., 2019). Furthermore, SA facilitates the examination of many algorithm components and variations, potentially resulting in improved performance and implementation, as demonstrated by Zhao et al. (2016). Nevertheless, there is a drawback associated with the use of SA, which is the management of elongated and narrow valleys in the configuration space, where many random movements involve ascending (Bai et al., 2013).

2.5 Particle Swarm Optimization

The PSO algorithm is a method of evolutionary computing initially proposed by Kennedy and Eberhart in 1995 (Gad, 2022), drawn from the social conduct of animals, such as a collective of birds in a flock. The population is generated using an algorithmic process and initially consists of randomly selected entities referred to as particles. By updating the generation, the most efficient solution will be achieved. The PSO algorithm considers various criteria, including product demand, profitability, shelf placement, and shelf space utilization, when allocating shelf space. Several research studies have proven the utilization of PSO to maximize profit by allocating shelf space. This method aims to determine the most advantageous configuration of products on a shelf that maximizes profit while adhering to constraints such as shelf capacity and product categorization. Correspondingly, Ouyang et al. (2019) highlighted the versatility of the PSO algorithm by proposing an enhanced version for allocating reliability excess. This study highlighted the capability of PSO in addressing various optimization challenges.

Moreover, the utilization of PSO in optimizing the allocation of shelf space through the application of DP methods has the potential to maximize revenue in the realm of retail operations management. The efficacy of PSO in resolving intricate global optimization issues further underscores its potential suitability in maximizing profits through shelf space allocation (Li et al., 2020). PSO has benefits and drawbacks when it comes to shelf space allocation. Furthermore, PSO has the advantage of being a straightforward and efficient method to implement (Ramasree et al., 2021). Additionally, it can rapidly converge, which might be advantageous for optimizing shelf space allocation (Liang et al., 2019).

When utilizing PSO to distribute shelf space in supermarkets, a hurdle arises in the necessity to consider multiple aspects that impact customer purchases, including the number of faces, product location, price, and proximity (Tamias et al., 2021). A further obstacle lies in the complexity of modifying current models and solution methods to conform to real-world limitations and parameters (Vannesch, 2023). Nevertheless, PSO may exhibit a deficiency in achieving an equilibrium between extensive exploration of the entire solution space and intensive exploitation of small regions. This limitation can potentially impact the efficacy of PSO in identifying the optimal distribution of shelf space (Kalpana et al., 2021). Although PSO has some limitations, it has been extensively utilized in diverse applications and has undergone enhancements by creating various versions and modifications (Li et al., 2019).

2.6. Variable Neighborhood Search (VNS)

Variable Neighborhood Search (VNS) is a highly effective metaheuristic method commonly employed to solve intricate optimization problems, including shelf space allocation. VNS has proven effective in solving diverse optimization challenges, including vehicle routing, job shop scheduling, and data clustering (Tao et al., 2022 ; Fattahi et al., 2020 and Ban, 2019). The algorithm's capacity to methodically modify its "neighborhood" to discover a solution renders it highly suitable for addressing intricate combinatorial optimization challenges. Notably, VNS provides the most optimal technique in the retail logistics sector, where the primary goal is to maximize efficiency in shelf space utilization.

This method employs a dual procedure that incorporates local search and shaking. First, it improves the first solution by thoroughly analyzing adjacent solutions inside a specified space. VNS effectively avoids local optima and navigates the complicated terrain of rack space allocation by combining the exploitation of the existing solution environment with the exploration of varied solution neighborhoods. In addition, VNS employs a multi-neighborhood method to systematically generate and enhance solutions through iterative processes. Neighborhoods are structured according to the extent of deviation from the existing solution. The VNS algorithm solves within a specific vicinity, enhances it by local exploration, and replaces the current solution if the new one is superior. This procedure persists until the stop criteria are fulfilled. Moreover, VNS has been employed to address the issue of SSAP and has demonstrated encouraging outcomes in terms of solution effectiveness and computing efficiency (Vincent et al., 2020). Accordingly, VNS effectively optimizes product placement in a retail setting by adjusting neighborhood and disruption strategies.

This optimization considers various criteria, including product dimensions, customer demand, visibility, and total space utility. Due to its demonstrated efficacy in addressing intricate optimization challenges and its capacity to enhance both solution quality and convergence speed, VNS holds great potential for resolving the issue of rack space allocation. Additionally, VNS is capable of efficiently discovering enhanced solutions, rendering it a suitable choice for tackling the intricacies of shelf space allocation in a retail setting. Moreover, the algorithm's adaptability and resilience, as evidenced in several optimization fields, highlights its potential efficacy in tackling issues about the allocation of rack space. While VNS exhibits flexibility and efficiency, it may encounter difficulties when addressing both linear and non-linear problems of practical magnitude, potentially affecting its scalability and applicability to larger retail scenarios (Lim et al., 2004).

3. Conclusion

The allocation of shelf space has a significant and profound effect on the business performance of a retail store. The greater the visual appeal of the items displayed on the shelves, the higher the number of customers will be attracted to the business, resulting in reduced demand for promotional efforts. Thus, the SSAP is a crucial concern in the retail industry, as it directly impacts profit optimization, customer satisfaction, and effective inventory management. However, the scarcity of shelf space presents a significant challenge for small retailers when it comes to displaying a product for sale. Optimization approaches, including GA, LP, DP, SA, PSO, and VNS, provide a complete approach for addressing the SSAP. Notably, GAs demonstrate adaptability and efficiency in optimizing outcomes through judicious shelf space allocation. Research undertaken by Czerniachowska and Hernes (2020) ; Schabasser (2023) and Hübner and Kuhn (2023) demonstrated the efficacy of GA in surmounting limitations and enhancing the optimization of products displayed on store shelves. Furthermore, LP is employed as a technique to address the issue of determining the optimal placement of items on shelves. This approach offers a methodical

approach to maximize revenue and enhance client attraction through strategic product placement. Meanwhile, Czerniachowska et al. (2023) and Flamand et al. (2023) highlighted the significance of utilizing LP in SSAP to maximize profitability. They emphasized the consideration of several factors, such as store distance, product prominence, and product arrangement on the shelf.
DP is an alternative optimization technique to LP. DP is renowned for its ability to manage variable demand and seasonal swings, providing adaptability in modifying shelf space over time. The primary distinction between LP and DP lies in the fact that LP is employed to optimize a linear objective function while adhering to linear constraints. In contrast, DP is employed to address optimization issues that entail overlapping subproblems (Gajjar et al., 2008). SA is beneficial as it methodically examines numerous rack configurations, optimizing the placement of racks in scenarios with multiple potential layouts or fluctuating demands. Research undertaken by Beed et al. (2020); Zhao et al. (2016) and Ishichi et al. (2019) demonstrated the positive impact of strategic shelf allocation on profitability through the utilization of SA flexibility. At the same time, Ouyang et al. (2019) and Liang et al. (2019) highlighted the capacity of PSO to optimize earnings while underscoring the significance of considering multiple influential variables. VNS is a highly efficient metaheuristic optimization technique for optimizing the allocation of shelf space. Every optimization method possesses distinct benefits and constraints while addressing SSAP. The examined research consistently demonstrates that optimization methods have emphasized the significance and efficacy of allocating shelf space, leading to increased retail profitability, enhanced customer satisfaction, and improved inventory management. Accordingly, optimization techniques assist retailers in maximizing earnings by strategically assigning shelf space based on product features and consumer demand.

4. Suggestions for Future Research

Retailing encompasses all the activities involved in providing goods or services to individuals or organizations for their ultimate consumption. This demonstrates that retailing encompasses more than simply selling a commodity. It entails providing the functionality of a product in a manner that allows consumers to readily derive satisfaction from it. In addition, this underscores the need to establish efficient strategies for allocating shelf space in grocery stores. This article offers a thorough analysis of optimization algorithms that especially focus on solving the SSAP in the retail sector. This research explores the efficacy and ramifications of several techniques, such as GA, LP, DP, SA, PSO, and VNS to acquire significant insights. Notably, GA is commonly used to optimize earnings by efficiently assigning shelf space, while LP ensures precise allocation by considering space limitations.

DP, on the other hand, is a powerful method approach for managing fluctuating requirements. In contrast, the strength of the SA method lies in its ability to make systematic adjustments to the optimal arrangement of racks. In addition to DP and SA, PSO also offers a benefit in terms of rack space solutions and is particularly recognized for its rapid convergence. Finally, the VNS method is an algorithmic approach that enhances the solution by systematically examining and assessing multiple neighborhoods in sequential stages.

Therefore, future research should prioritize the advancement of hybrid methodologies that integrate algorithms and machine-learning approaches. Moreover, this methodology should strive to fulfill the evolving demands of customers, maximize the utilization of shelf space, and effectively oversee inventories in a dynamic retail setting.

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