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Correlated Storage Assignment Approach in Warehouses: A Systematic Literature Review

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Abstract:

Purpose: Correlation-based storage assignment approach has been intensively explored during the last three decades to improve the order picking efficiency. The purpose of this study is to present a comprehensive assessment of the literature about the state-of-the-art techniques used to solve correlated storage location assignment problems (CSLAP).

Design/methodology/approach: A systematic literature review has been carried out based on content analysis to identify, select, analyze, and critically summarize all the studies available on CSLAP. This study begins with the selection of relevant keywords, and narrowing down the selected papers based on various criteria.

Findings: Most correlated storage assignment problems are expressed as NP-hard integer programming models. The studies have revealed that CSLAP is evaluated with many approaches. The solution methods can be mainly categorized into heuristic approach, meta-heuristic approach, and data mining approach. With the advancement of computing power, researchers have taken up the challenge of solving more complex storage assignment problems. Furthermore, applications of the models developed are being tested on actual industry data to comprehend the efficiency of the models.

Practical implications: The content of this article can be used as a guide to help practitioners and researchers to become adequately knowledgeable on CSLAP for their future work.

Originality/value: Since there has been no recent state-of-the-art evaluation of CSLAP, this paper fills that need by systematizing and unifying recent work and identifying future research scopes.

Keywords: correlated storage location assignment problem (CSLAP), storage policy, order picking, warehouse management, systematic literature review

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1. Introduction

In the supply chain, the warehouse is an intermediate storing facility of goods connecting suppliers, distributors, and customers (Chiang, Lin & Chen, 2014; Pang & Chan, 2017; Zhang, Wang & Pan, 2019). Multiple suppliers, distributors, and customers can be connected through a single warehouse, making each product delivery economical and timely. The importance of warehouses is even more significant with the rise of online businesses (Kim, Méndez & Jimenez, 2020). Receiving, transporting, storing, order picking (OP), collecting, sorting, cross-docking, and shipping items for customers are all included in warehousing activities (Pang & Chan, 2017). However, warehousing costs are high, about 17% of the total supply chain management (SCM) cost (Sarker, Tayyab, Kim & Habib, 2019). As warehouses are integral to large supply chains, their efficiency is a considerable concern. Given the warehouse's diverse functions, there is scope for improvement in different aspects. Of them, order picking is a crucial function accounting for 55% of the total warehouse cost (De Koster, Le-Duc & Roodbergen, 2007).

The OP function involves traveling to the storage area, picking up stock-keeping units (SKUs), and returning to the depot. The large size of the warehouse caused around 50% of the total OP duration to be spent on traveling (De Santis, Montanari, Vignali & Bottani, 2018). Therefore, a reduction in travel time would result in an efficient OP, make warehouse operations effective, and reduce the overall SCM cost. There are four optimization aspects mentioned by Roodbergen and De Koster (2001): optimizing the pick-up route, zoning the warehouse, proper storage assignment of items, and order batching. Of the four, optimizing the storage location assignment problem (SLAP) would provide the maximum benefit as it involves strategic changes in the warehouse and affects the other three directly (Chiang, Lin & Chen,, 2011). Researchers have started focusing on the SLAP which is related to the placement of items within the warehouse. Proper placement of items will, in turn, maximize order-picking efficiency. The SLAP is complex due to volume, weight, or demand uncertainty (Reyes, Solano-Charris & Montoya-Torres, 2019). Chuang, Lee and Lai (2012) mentioned product demand dependence, inventory turnover rates, and requirement of storage spaces, among other things that can influence SLAP. It is further called a non-polynomial complicated problem for the same reason (Accorsi, Manzini & Bortolini, 2012). The SLAP has three joint objectives: boosting operational efficiency, lowering the storage cost, and minimizing the picking distance (Chuang et al., 2012).

Random, dedicated, class-based, closest-open, turnover-based storage location assignments are identified by De Koster et al. (2007) as five standard methodologies for assigning incoming items to storage locations. According to some academics, other systems for assigning incoming stock items to storage locations include cube-per-order index (COI)-based, volume or frequency-based, and correlation-based storage assignment strategies (Zhang, 2016; Yang & Nguyen, 2016; Ansari & Smith, 2020; Mirzaei, Zaerpour & Koster, 2021). Among them, the correlated storage assignment approach relies on calculating a suitable correlation index between the components of a product mix. Cluster analysis finds groupings of items that customers commonly order together, leading to storing highly correlated products close to one another. For instance, products A and B commonly go together in client orders; therefore, storing them nearby inside the system may be beneficial for more accessible selection tours.

Correlated storage location assignment problems (CSLAP) have been intensively explored during the last three decades. According to the literature, this assignment method comparatively performs better for minimizing travel distance than other storage allocation systems (Bindi, Manzini, Pareschi & Regattieri, 2009; Zhang et al., 2019; Lee, Chung & Yoon, 2020). Every day thousands of picking lists are processed in most local distribution centers. Each selection list always includes a variety of items and quantities. OP distance can be reduced by avoiding retracing down aisles if goods are categorized and sequenced efficiently (Liu, 1999). It is believed that the probability of minimizing the OP distance increases when more items with demand dependence are stored together. It applies to both part-to-picker and picker-to-part systems (Xiao & Zheng, 2010). Correlation-based storage location assignment looks for correlations between SKUs in a warehouse based on their demand structure. In current information systems, statistical correlations between SKUs should be readily available from historical order data. Customer order analysis is used to determine statistical relationships. Several products that are regularly purchased together have a strong correlation (Lee et al., 2020). Picking efficiency may be increased by recognizing these correlated goods and arranging them near each other. OP costs will increase when items with high correlation are

placed far away in the warehouse (Zhang et al., 2019). So, it is imperative to know about the different utilizations of the correlation among SKUs.

In recent years, the CSLAP is being considered in the automated robotic mobile fulfillment system (RMFS), that determines which items should be stored in which pods (Guan & Li, 2018; Xiang, Liu & Miao, 2018; Yuan, Li, Wang, Dou & Pan, 2021; Keung, Lee & Ji, 2021; Manzini, Bindi, Ferrari & Pareschi, 2012; Yang, 2022). A robot carries the entire inventory pod to a picking station whenever a product is needed to fulfill a customer order. Using product affinity, warehouses may group items that are likely to be ordered together into the same storage bin or pod, speeding up the time it takes to find what they need. The focus of research in this area has been the development of models and algorithms that can make intelligent decisions regarding storage assignment based on parameters such as the size and weight of products, the frequency with which they are requested, and their demand volatility. Guan and Li (2018) developed an integer programming model to solve scattered storage assignment problems based on association rules mining in RMFS and proposed a GA to solve large-scale problems. Xiang et al. (2018) suggested a collaborative optimization approach that considers product affinity for both storage assignment and order batching problems in RMFS. Yuan et al. (2021) developed different mathematical models and heuristic algorithms for the optimization of storage assignment in RMFS which was divided into products assignment and pod assignment stages. Keung et al. (2021) proposed a data-driven approach by providing a TO-BE analysis of robotic process automation cloud-based cyber-physical systems framework for zone clustering and storage assignment classification in RMFS. Yang (2022) investigated the simultaneous impact of storage assignment and order batching approaches on the order-picking process by using item similarity and order similarity in RMFS, and finally, a policy evaluation model was developed to measure the cost of order-picking.

Many researchers conducted effective and efficient ways to find the optimum policies for the CSLAP. To the best of our knowledge, this is the first systemic literature review solely in the field of CSLAP. This paper presents a comprehensive review to identify and summarize the key findings from previous research studies in this field. As a result, readers of this paper will gather advanced knowledge in this area. Moreover, this research has a valuable contribution to the field because it provides a general database of the main research of this prominent sector. We also provide new insights and perspectives on the recent advancements in this area which will serve as a starting point for future research. The authors addressed the following research questions according to the study's scope and the identification of the research gap:

i. What is the state-of-the-art (current status) of CSLAP research?
ii. What solution methods have been used to solve the CSLAP?
iii. Which storage layouts have been considered?
iv. What can be inferred from recent research findings that will suggest areas for future study?

This research evaluates and contrasts a variety of procedures for assigning associated storage space using clustering methods. This critical evaluation proposes to identify the solutions and constraints of each technique and expand the research scopes based on varying degrees of product correlation to establish guidelines for assisting managers and practitioners with design and control tasks. First, the literature review of CSLAP in OP strategy is presented, and then different state-of-the-art methods of solving CSLAP are systematically discussed in the following subsections. Finally, the trends and future research scopes of CSLAP are discussed.

2. Review Methodology

This study was conducted following a systematic literature review (SLR) on CSLAP using content analysis. Accordingly, the SLR method was chosen as a means of answering a specific research question, providing context for the topic at hand, developing and understanding particular underlying principles, analyzing outcomes on a quantitative and qualitative level, gathering data necessary for compiling an appropriate bibliography for further study, and suggesting new directions for the future CSLAP research (Rowley & Slack, 2004; Seuring, Müller, Westhaus & Morana, 2005). The following stages are conducted in sequential order to address the research questions:

2.1. Material Collection

At first, the review process selected the database randomly. It was found that before 1985, a few or negligible relevant papers were in the searched database. Therefore, the authors selected 1985 as the starting year to search the papers anonymously. All of the publications in our collection were reviews of the English-language literature on CSLAP written by academics in the field and span 38 years from 1985 to 2022. Articles in scholarly journals that have undergone a peer review process are used as the basis for this study. The fact that the CSLAP had been referred to in different terminologies from many other disciplines presented a severe challenge to the reviewers. In contrast, all of our searches were limited to inventory management terminology. A literature search was performed using the following terms to compile the paper sample:

i. For Google Scholar, Scopus and Web of Science: ("correlation-based" OR "correlated" OR "clustering based" OR "cluster-based" OR "association based" OR "similarity" OR "group" OR "data mining" OR "affinity" OR "frequent itemset mining") AND ("storage" OR "slot" OR "location" OR "space") AND ("assignment" OR "allocation") AND ("problem" OR "process" OR "policy" OR "rule").

ii. For Crossref: ("correlation-based storage assignment" OR "correlated storage assignment" OR "group-based storage assignment" OR "cluster-based storage assignment" OR "similarity-based storage assignment" OR "association-based storage assignment" OR "affinity-based storage assignment" OR "data mining based storage assignment" OR "frequent itemset mining based storage assignment").

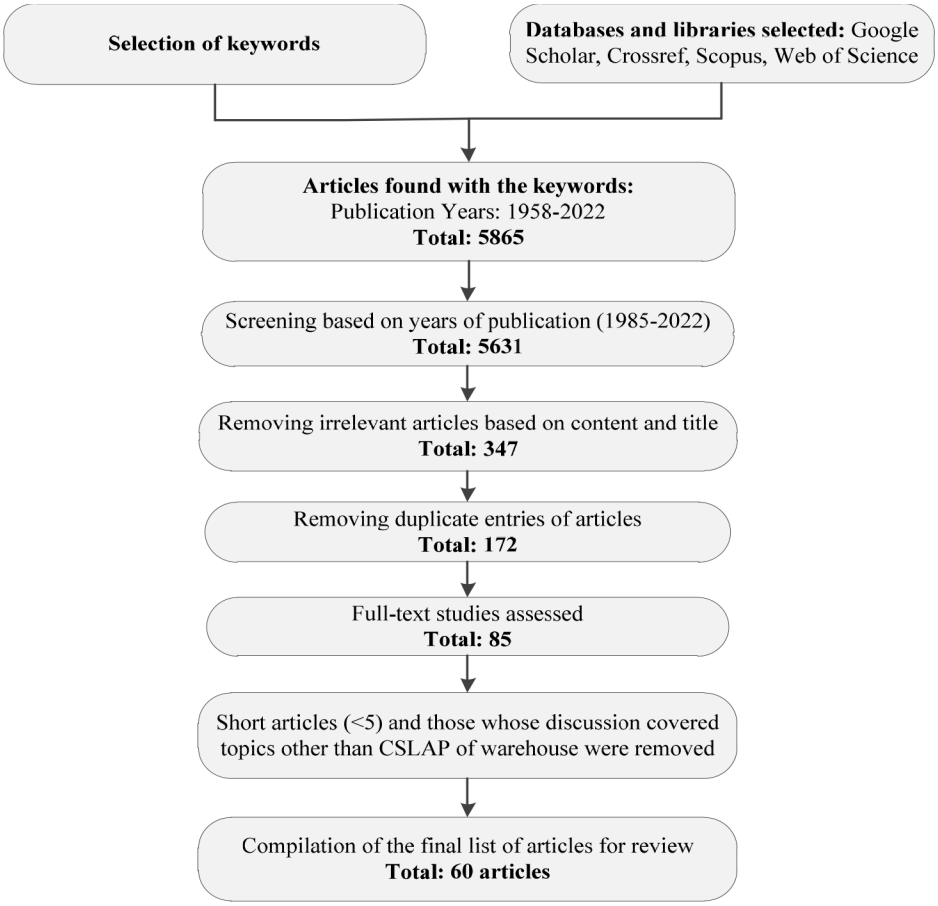

Figure 1. An overview of the article search and selection process

Google Scholar, CrossRef, Scopus, and Web of Science were consulted as part of the structured keyword search of major databases and library services. These resources yielded a total of 5865 publications. After checking that identified publications related to the CSLAP, we could restrict the selection of papers down to 60 as shown in

Figure 1. We analyzed each paper's title, abstract, and keywords to narrow the search space down to only the most pertinent articles.

2.2. Material Evaluation

The papers were evaluated using the standards mentioned earlier. We devised the following criteria to guarantee the review's relevance and credibility. Decisions about the classification were compared to create and evaluate the selection criteria for each category. Since a single publication may present several methods for achieving the same goal, the number of applications was calculated separately for each class. Finally, we assessed the findings, examined certain individual articles within the databases we visited, and consolidated the information in pre-established categorization forms.

3. Descriptive Statistics

The number of publications on the topic is increasing over time as shown in Figure 2. More and more researchers are acknowledging the importance of correlated storage assignments. The first publication that we observed was in 1989. Frazele and Sharp (1989) formulated the storage location assignment problem as an integer programming model. This is our earliest observed, well-cited journal article. The number of publications in the early days was relatively low, primarily due to technological limitations. However, newer ways to implement correlated storage assignment theories have been researched with technological innovations. Hence, we have seen more research on this topic in recent years. The 60 articles have been published in different journals and conference papers. "International Journal of Production Research" and "Computers & industrial engineering" seem to have published the most articles on this topic.

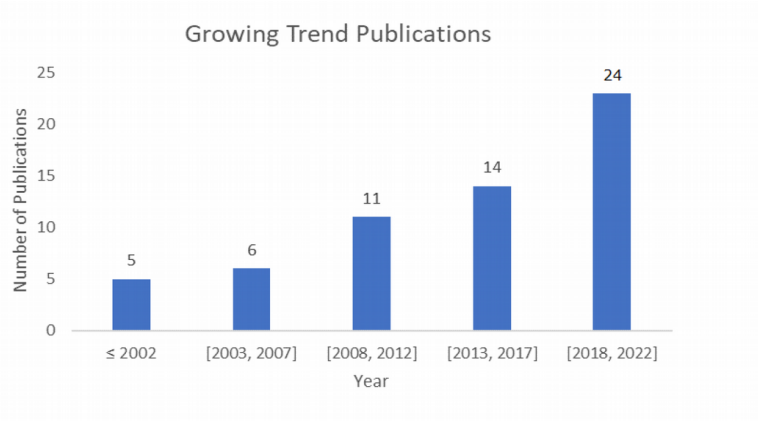

Figure 2. The number of publications on CSLAP over time

Elsevier and Taylor & Francis are the top publishers of CSLAP articles, publishing an almost equal number of articles over the years. A total of 14 publishers were identified, among which the top ones are shown in Figure 3. At the same time, Taylor and Francis published a few of the first articles on this topic. Compared to that, the first article from Elsevier involving CSLAP was published in 1999.

The number of citations per year reflects the health of research in this area. One can interpret a high citation number as a good quality of the research articles that are being published. On the contrary, bad research will not produce a decent number of citations in subsequent years. At the same time, a comparison of the total number of citations is being avoided, as an older article will likely have more years to get cited. Figure 4 shows that most articles get 1 to 3 citations annually. However, a few articles have received over 10 citations every year. Such articles include the ones by Jane and Laih (2005), Chiang et al. (2011), and Kovács (2011) with 219, 191, and 124 total citations, respectively. There were a few articles with no citations, however as they were published in recent years, it is logical for those papers not to have any citations. Overall, we can see decent health of the CSLAP research. However, it is also essential for the researchers to produce better-quality papers to increase the number of citations.

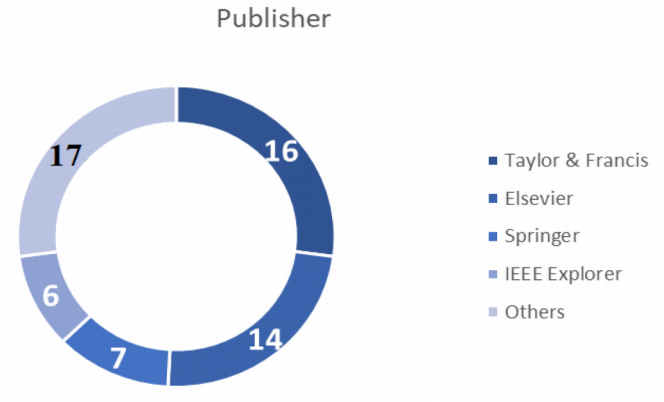

Figure 3. Selected publishers of the reviewed articles

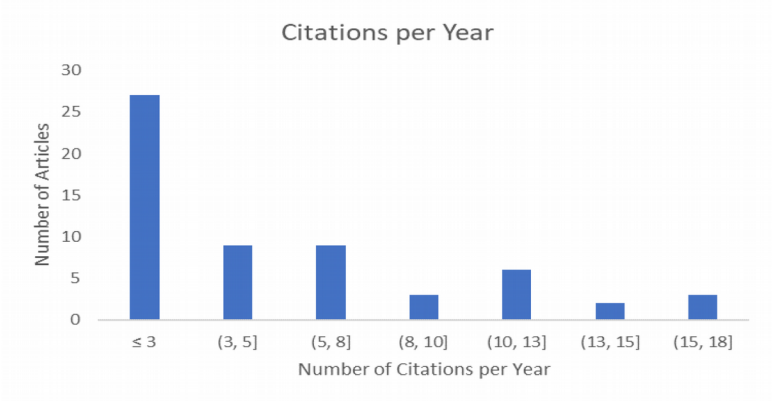

Figure 4. Citations per year of the reviewed CSLAP articles

Figure 5. Number of authors per CSLAP article

Most of the articles are written through the contribution of 3 or 2 authors as shown in Figure 5. The number of authors required behind a piece of work often indicates the level of expertise required in the field to write a paper. A low number of authors in CSLAP articles mean that the research conducted is easy enough to be pulled off by a group of 2 or 3.

4. Review Findings and Discussions

In this section, we will examine and discuss the current research to find knowledge gaps and potential research areas for the future. Table 1 summarizes 60 publications with their goals and characteristics that have been published in the literature evaluating CSLAP. The studies have revealed that CSLAP is evaluated with many approaches.

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Frazele & Sharp (1989)	Travel time	Two-phase heuristic	✓			Developed a two-stage heuristic method to solve an integer programming problem, resulting in a significant reduction in travel time compared to the COI rule	The space requirement of the SKUs could be considered in the proposed heuristic
Lee (1992)	Travel time	Heuristic-based on group technology				Presented a mathematical model and a group technology-based heuristic method for solving a storage layout problem, and used a space-filling curve to sequence the storage locations	Only compared with the COI-based assignment rule
Kim (1993)	Space requirement	Improvement heuristic				Proposed an improvement heuristic algorithm to solve the assignment problem of storage location and it performed better compared to the procedure introduced by Frazele (1990)	Only compared with the procedure developed by Frazele (1990)
Rosenwein (1994)	Travel distance	Branch and bound				Presented a *p*-median binary integer program to formulate the clustering problem and developed a branch and bound algorithm to solve the model that performed better than the random clustering method	The time required to calculate the objective function coefficients for processing the order history was too lengthy (two hours of CPU time)
Liu (1999)	Travel distance	Heuristic	✓			Developed a binary integer programming model for ítems and customers grouping problems and implemented an exact primal-dual algorithm to a local distribution center	Further efforts are necessary for investigating adequate mathematical models by integrating both the sequencing and clustering techniques
Kim, Heragu, Graves & Onge (2003)	Travel distance	Heuristic				Presented a clustering-based algorithm and an *x*-coordinate based heuristic for the optimal order-picking sequence, and proposed a modified algorithm for a flexible drop buffer allocation condition to efficiently use the gantry robots	The model was based on the assumptions that the length of the layout was considerably larger compared to its width, and the picker can only hold one item at once

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Garfinkel (2005)	Multi-zone orders	Lagrangian relaxation				Presented a mathematical model on CSLAP, and a cyclic exchange improvement algorithm was proposed as a solution approach that achieved a 15% improvement compared to the COI rule	Only considered to minimize the multi-zone orders
Ho & Liu (2005)	Travel distance	Heuristic	✓			Presented six similarity coefficients, two clustering heuristics, and two assignment rules for the CSLAP that achieved a significant improvement in minimizing the total travel distance	In the experiment, the warehouse was divided into three equal zones only
Jane & Laih (2005)	Travel time	Heuristic	✓		✓	Proposed a heuristic method for balancing the workloads among the order pickers to increase the system utilization and minimize the time required to complete each order	Further research on trading off picker workload is essential for the system utilization
Chen & Wu (2005)	Travel distance	Data mining	✓			Proposed an order-clustering approach based on association rule mining and 0-1 integer programming	The item space constraint could be considered in the order batching model
Bindi, Manzini, Pareschi, & Regattieri (2007)	Travel distance	Heuristic	✓		✓	Introduced different storage assignment rules to achieve a shorter order cycle time and improve the customer service	Higher-order item dependencies were not considered
Hua & Zhou (2008)	Travel distance	Genetic algorithm				Developed a new objective function that embedded into a genetic algorithm (GA) for clustering items and used a filling curve-based assignment method, resulting in a significant reduction in travel distance compared to the random storage policy	Only reduce travel distances significantly if natural clusters exist
Bindi et al. (2009)	Travel distance	Heuristic	✓		✓	A set of similarity coefficients and clustering techniques were developed to improve the order-picking efficiency	Higher-order item dependencies were not considered
Egas & Masel (2010)	Number of aisles visited	Iterative heuristic	✓			Proposed an iterative heuristic method for clustering items that can achieve a 20-30% reduction in the number of visited aisles compared to the demand-based assignment	The size of a cluster does not match the capacity of an aisle which may reduce the space utilization

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Xiao & Zheng (2010)	Travel distance	Heuristic	✓			Formulated a mathematical model and proposed a multi-stage heuristic algorithm based on the bill of material (BOM) information for solving CSLAP	A single-block warehouse was considered only
Kovács (2011)	Travel time	Mixed integer programming	✓			Proposed a mixed integer programming model to find class-based storage in a multi-command picking system, resulting in an up to 36-38% reduction in order cycle time compared to the COI approach	Their approach could be extended to a dynamic warehousing environment with considering the re-warehousing expenses
Chiang et al. (2011)	Travel distance	Data mining	✓		✓	Proposed an association rule mining-based storage assignment approach to determine optimal locations for newly arrived items. A binary integer programming with a new association index (AIX) was formulated to solve the SLAP	DMSA is unable to assign brand-new items without previous order information
Xiao & Zheng (2012)	Number of zones visited	Heuristic, Genetic algorithm	✓			Formulated a mathematical model by using the BOM information and propose two particular heuristics and two-hybrid GA with various crossover mechanisms to solve the CSLAP	The quantity of SKUs in the order was ignored in assessing the strength of the relationship
Chuang et al. (2012)	Travel distance	Clustering assignment problem model (CAPM)	✓		✓	Introduced a two-phase clustering assignment problem model (CAPM) for the customized order-picking problems, resulting in a 45% reduction in picking distance compared to the current set-up	A considerable amount of computational time might be required for a large number of SKUs
Kim & Smith (2012)	Pick wave makespan	Heuristic, Simulated annealing		✓		Presented a mathematical formulation and developed four two-phase heuristics to solve a slotting problem where SKUs were assigned to the slots in a zone-based picking system	Potential improvement may be achieved by simultaneously considering two interrelated assignment problems
Accorsi et al. (2012)	Travel distance	Hierarchical top-down	✓		✓	Introduced a systematic hierarchical top-down method by combining sequential decision phases related to the allocation and assignment problems	Further research could be conducted for diverse pick lists over longer periods

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Manzini et al. (2012)	Travel time	Heuristic			✓	Introduced various storage allocation and positioning rules with the help of an iso-time mapping of the storage facility	Further research could be experimented on warehouse design and management problems
Chiang et al. (2014)	Travel distance	Heuristics	✓			Introduced an association measuring technique based on the association rule mining and proposed two storage assignment heuristics to facilitate effective order-picking	Poor assignment decisions could occur by using a simple weighted score with a lift value
Kofler, Beham, Wagner & Affenzeller (2015)	Travel distance	Density based clustering	✓		✓	Developed a robust correlated storage assignment method where demand patterns are fluctuated over time and need to re-locate items	Multi-period slotting could be considered for further research
Wutthisirisart, Noble, & Chang (2015)	Travel distance	Two-phase heuristic	✓			Proposed a two-phase heuristic where the minimum delay algorithm (MDA) was developed in the first phase and an item storage layout was generated in the second phase	Further research could be investigated by incorporating the linear placement problem with different routing and picking policies
Matthews & Visagie (2015)	Travel distance	Heuristic		✓		Introduced four different correlation measures that were employed in a greedy insertion algorithm, resulting in a 20% reduction in travel distance compared to the historical assignments	The goal programming techniques could be included in further research
Yang & Nguyen (2016)	Travel distance	Heuristic	✓			Proposed a constrained clustering method combined with principal component analysis (PCA) to satisfy the requirement for clustering items based on the practical storage constraints	Only the horizontal distance was considered
Chuang, Lee & Tan (2016)	Travel distance	Clustering assignment problem model (CAPM)	✓			Introduced an efficient method for generating the rank of locations to the assignment problems rather than the time-consuming method utilized in the CAPM by Chuang et al., 2012 and achieved a 6.1% improvement in the travel distance	Only considered a single-block and single-aisle layout

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Wang, Mou & Wu (2016)	Transaction cycle time	Ant colony clustering			✓	Proposed a two-stage open queuing network model to evaluate the system performance and developed an ant colony optimization algorithm to identify storage partitions based on clustering SKUs	The influence of changes in arrival times on the analysis of the correlations among SKUs could be another scope for further research
Diaz (2016)	Travel distance and time	Heuristic	✓			Developed a quadratic integer programming-based heuristic method considering demand patterns and order clustering to generate a layout solution	Future research should investigate the impacts of cross-sections that allow the order-picker to exit the S-path without visiting the entire aisle
Zhang (2016)	Travel distance	Heuristics	✓			Proposed a correlated storage assignment strategy (CSAS) approach and presented two clustering algorithms, resulting in a 2.08% improvement in the travel distance compared to the full-turnover storage	The volume of the SKUs could be considered for further research
Li, Moghaddam & Nof (2016)	Travel distance	Greedy genetic algorithm	✓			A quadratic assignment programming (QAP) model was formulated for a dynamic storage assignment problem (DSAP) and developed a product affinity-based heuristic (PABH) and a greedy GA to solve the DSAP	Only two-sided affinity is considered among SKUs
Pang & Chan (2017)	Travel distance	Data mining	✓			Introduced an association rule mining-based storage allocation algorithm to minimize both order picking and put-away distance in a randomized warehouse	The routing decision on both order-picking and put-away operations could be investigated for further studies
Dauod, Lee, Chung & Yoon (2017)	Travel distance	Community detection and integer programming	✓			Presented a community detection method to find out the associations between SKUs and an integer programming model was developed to discover the best places for the communities	Future research should explore the implementation of the network science in various warehouse operations like order batching

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Kress, Boysen & Pesch (2017)	Idle time of pickers	Branch and bound				Proposed two mixed integer programming models and presented an ejection chain heuristic and a branch and bound algorithm to solve the SKU partitioning problem where the SKUs were split into disjoint subsets	Further research could be extended by integrating additional characteristics relevant to various storage systems
Xie, Mei, Ernst, Li & Song (2018)	Travel distance	Tabu search	✓			Proposed a new bi-level grouping optimization (BIGO) model based on which a tabu search algorithm and a multi-start random search method were developed to solve the SLAP	Only a single-block layout was considered
Xiang et al. (2018)	Number of visits of pods	Heuristic		✓		Developed a heuristic to solve the storage assignment and order batching problem in the Kiva mobile fulfilment system where a variable neighborhood search was also used to improve the solution	Pod storage location or robot path planning problems could be implemented for further research
Hadi & Djatna (2018)	Travel distance	Data mining			✓	Developed a graph model to solve a dynamic SLAP where an association rule mining and class-based storage policies were combined to find out the appropriate storage location	Further research could consider other warehouse operations such as cross docking, shipping, motion and handling aspect, etc.
Guan & Li (2018)	Total number of pods to be moved	Genetic Algorithm		✓		Developed an integer programming model to solve scattered storage assignment problems based on association rules mining and proposed a GA to solve large-scale problems and significantly reduced the number of pods to be moved compared to the random storage policy	The scattered storage strategy could have been implemented with different objective functions
Krishnamoorthy & Roy (2019)	Travel distance	Heuristic		✓		Presented a new utility-based storage assignment approach by using a top-k high-utility itemset mining technique and a heuristic method for the SLAP	Variations in the demand pattern could be considered for further research

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Yuan, Wang & Li (2019)	Travel distance	Greedy, Simulated annealing		✓		Established a mathematical model for the SLAP and proposed a two-stage hybrid algorithm where a greedy algorithm generates the initial solution in the first stage and a simulated annealing algorithm optimizes the initial solution in the second stage	Further research could consider the waiting time caused by congestion during the picking process
Xin, Liu, Deng & Lang (2019)	Travel distance	Heuristic based on text clustering	✓			Proposed an optimization algorithm based on correlation analysis and text clustering by considering the weak correlation among the SKUs to solve the SLAP	Only considered the weak associations among the items
Zhang et al. (2019)	Travel distance	Heuristic, Simulated annealing	✓			Formulated an integer programming model for the SLAP by using the concept of demand correlation pattern (DCP) and developed the simulated annealing (SA) and the minimum increment heuristic (MIH) methods to solve the model	Due to the nature of the dataset, it is often difficult to select an appropriate threshold value
Ansari & Smith (2020)	Travel time	Gravity clustering heuristic		✓		Proposed a heuristic method for clustering the SKUs based on the famous gravity model and achieved a significant reduction in travel time compared to the COI policy	As each SKU was considered sequentially, there was no longer a chance to change its group to improve the solutions
Engblom (2020)	Travel distance	Heuristic		✓		Introduced a framework by combining the class-based and family grouping methods to solve the SLAP and various order batching methods were experimented for deciding the best fit to solve the order batching problem	Further research could reinvestigate the picker routing policies for different warehouse layouts
Wang, Zhang & Fan (2020)	Travel distance	Heuristic	✓		✓	Introduced an efficient data-based approach (DBA) to determine a better assignment more quickly and developed an iterative algorithm that significantly outperforms other traditional methods	The proposed DBA is not suitable for warehouses with more than one block and one or more cross aisles in the middle

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Kim et al. (2020)	Travel distance	Data mining, Heuristic	✓		✓	Proposed two novel strategies based on association rule mining (ARM) and developed various storage assignment heuristics by using the proposed strategies to solve the SLAP	Higher-order item dependencies were not considered
Zhou, Sun, Li, Li, Cao & Higgs (2020)	Travel distance	Data mining		✓		Proposed a technique for improving the class-based storage policy based on an association algorithm and compared with the traditional ABC classification	Insufficient data span
Lee et al. (2020)	Travel time and picking delay	Metaheuristic	✓		✓	Developed a bi-objective optimization model to cluster items considering both the traffic flow balance and travel efficiency and the multi-objective evolutionary algorithms were used to solve the model	The computational costs were not investigated
Zhang, Onal & Das (2020)	Order fulfillment time	Heuristics		✓		Presented a mixed-integer program for the dynamic stocking location Problem and developed two heuristics to solve the problem efficiently in terms of time	Further research could investigate the issue of adjusting the replenishment rate to reduce fulfillment time
Mirzaei et al. (2021)	Travel time	Simulated annealing		✓		Proposed an integrated cluster allocation (ICA) approach based on product affinity and turnover and developed a greedy construction heuristic to solve the SLAP, resulting in a 40% reduction in retrieval time compared to the full turnover storage policy	The variations in the demand pattern were not considered
Li, Méndez-Mediavilla, Temponi, Kim & Jimenez (2021)	Travel time	Data Mining	✓		✓	Proposed a heuristic method based on association rule mining (ARM) to provide competitive layouts for distribution centers	As a result of the mining process, sometimes several SKUs may not grouped with the others
Keung et al. (2021)	Traveling cost	Heuristics			✓	Proposed a data-driven approach by providing a TO-BE analysis of robotic process automation cloud-based cyber-physical systems framework for zone clustering and storage assignment classification in RMFS	The deterministic system or the expert-augmented machine learning system could be adopted for further research

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Trindade, Sousa & Moreira (2021)	Travel distance	Two-phase heuristic	✓		✓	Introduced a modified grouping similarity index considering the similarity, shape, and weight of the products and embedded it into a storage assignment heuristic method for the SLAP	Further study could include a model of products' classification to investigate the impact on productivity
Zhu, Hu, Huang & Yuan (2021)	Total number of order splits	K-links heuristic			✓	Proposed a K-links clustering algorithm to optimize the allocation of product categories among different warehouses that performed well and significantly reduced order splitting	Further research could calculate the required storage capacity for each product category based on the number and size of goods
Jiang, Liu, Dong & Wang (2021)	Travel distance	Genetic algorithm, Particle swarm optimization	✓			Developed a 0-1 integer programming model based on the scattered Storage assignment approach and proposed a GA and a particle swarm optimization (PSO) algorithm to solve large-scale problems	The scattered storage strategy could have been implemented with different objective functions
Yuan et al. (2021)	Travel distance	Simulated annealing		✓		Developed different mathematical models and heuristic algorithms for the optimization of storage assignment in RMFS which was divided into products assignment and pod assignment stages	Further research could consider the dynamic storage assignment optimization
Mirzaei, Zaerpour & de Koster, (2022)	Travel time	Heuristic				Developed a mixed integer linear programming model for optimal product-to-cluster and cluster-to-zone allocation and proposed an efficient improvement heuristic method to solve the model	Further research could investigate the impact of inventory distribution on the replenishment time and the total effort.
Trindade, Sousa & Moreira (2022)	Travel distance	Two-phase heuristic	✓		✓	Proposed two-phase heuristic approach considering precedence constraints in multi-aisle warehouses to solve the SLAP and achieved up to 15% improvement in the travel distance	The batching operations, routing methods, and pallet construction processes could be considered for further research

Author(s)	Main Concern	Solution Approac	Configuration		Case study	Main Contributions	Limitations/ Future Scopes
			Single block	Multi block			
Yang (2022)	Travel time	Integer linear programming model		✓		Investigated the simultaneous impact of storage assignment and order batching approaches on the order-picking process by using item similarity and order similarity, and finally, a policy evaluation model was developed to measure the cost of order-picking	Further research could be extended by adding order quantity and space constraints of the SKUs

Table 1. Summary of CSLAP studies in the literature

4.1. Mathematical Formulation

Most correlated storage assignment problems are expressed as NP-hard integer programming models. In this regard, the objective function of the many studies focuses on minimizing the total travel distance (Wutthisirisart et al., 2015; Diaz, 2016; Xie et al., 2018; Krishnamoorthy & Roy, 2019; Zhang et al., 2019; Jiang et al. 2021; Li et al., 2021; Yuan et al., 2021; Trindade et al., 2022). Other objective functions have focused on minimizing the total travel time (Kim & Smith, 2012; Mirzaei et al., 2021, 2022), maximizing the sum of correlation between SKUs (Li et al., 2016; Xiang et al., 2018; Lee et al., 2020; Yang, 2022), and maximizing the total number of visits to zones (Xiao & Zheng, 2012). Kovacs (2011) mentioned the CSLAP in the study as a special case where the organizational structure that influences the correlation of the items is relevant and known. Furthermore, those can be exploited by using different mathematical models. Just as the problem was related to the organizational structure, the solution was made to be achievable by commercial software when the problem is of a certain size. Chuang et al. (2012) proposed the idea of implementing a two-phase clustering assignment problem model (CAPM) as a resource for customized OP problems in the warehouse. At first, the model determines clusters of items based on between-item support from the order history and creates a mathematical programming model to maximize total item support. The clusters are then allocated in the storage to keep the traveling distance minimum in the second stage. Kress et al. (2017) developed the SKU partitioning problem, which splits the SKUs into disjoint subsets to retrieve the smallest number of groups while obtaining a given order set according to the policy of pick-by-order. Two mixed integer programming (MIP) models are given concerned with the proposed partition issue. Xiang et al. (2018) introduced the idea of treating the number of pod visits as an objective function. Strategically, the SLAP decided which products go on which pods to maximize product similarity. Correlated and traffic-balanced storage assignment (C&TBSA) was presented by Lee et al. (2020) as a systematic and comprehensive technique to minimize pickers' travel time and the delays they experience due to traffic. The presentation broke down into two parts: grouping and then assigning. A bi-objective model was developed during the grouping phase to maximize travel efficiency and maintain a steady flow of traffic. Jiang et al. (2021) proposed a scattered storage strategy to mitigate unproductive picking time by assigning the same item to multiple locations. The allocation is based upon the pairing of items that are frequently ordered. A correlation matrix is developed to formulate the problem, and a 0-1 integer programming model is used to minimize the distance between the items. Yuan et al. (2021) used a dispersed storage strategy and a mathematical model that maximizes the overall correlation between items housed in the same pods. To reduce the time and effort required to choose items from shelves, a model was developed in the pod assignment phase that accounts for the location of each mobile unit. Trindade et al. (2021) introduced his zero-one quadratic assignment model to solve the CSLAP. The difference between this model compared to the others, in general, is that it considers the weight of the items. That is, precedence-constrained orders can have a better outcome with their model. Yang (2022) focused on the OP cost or efficiency of the robots. Order similarity is used to there to solve the item storage location problem. The integer linear program uses a clustering model to group items and batch orders. Mirzaei et al. (2022) designed an optimum mixed-integer linear algorithm to reduce the robot's

projected travel time. Different combinations of zones and stations need unique travel time expressions to be formulated.

4.2. Solution Approaches

Since the models for CSLAP are recognized as NP-hard problems (Li et al., 2016; Kim et al., 2020; Mirzaei et al., 2021; Trindade et al., 2022), it is computationally very expensive to get solutions for the large-scale problems. For this reason, the CSLAP is generally examined with different heuristics, meta-heuristics, or data mining approaches. The detailed investigation of these studies is given in the following sub-sections.

4.2.1. Heuristic Methods

The CSLAP is generally solved through a two-phase construction heuristic algorithm (Frazele & Sharp, 1989; Ho & Liu, 2005; Hua & Zhou, 2008; Bindi et al., 2009; Wutthisirisart et al., 2015; Zhang, 2016; Trindade et al., 2022). The first phase is to cluster SKUs according to their correlation, and the second phase is to assign these correlated SKUs near each other. Hua and Zhou (2008) propose a storage location assignment problem (SLAP) that indicates a cluster-based policy for warehouse management in a kitting area. A two-step heuristic procedure (cluster analysis and zoning process) is proposed to obtain the solution. In cluster analysis, a weighted grouping strategy is introduced. In the zoning process, clusters are assigned to locations in the kitting territory. Manzini et al. (2012) grouped comparable goods to guarantee that the items within the same group had strong correlations with each other and weak correlations with items in other clusters. In this study, the furthest-neighbor and closest-neighbor clustering techniques were used. Kofler et al. (2015) suggested an ABC slotting technique to construct more consistent assignments for volatile warehouse situations of associated demand. Until the zones of a warehouse are defined, this technique of re-location is used in storage assignment strategies. First, the researchers follow a density-based clustering approach to create an affinity-based storage allocation system. Then they use a local search of greedy type technique, which ranks the moving of re-location based on the predicted improvement in picker productivity and implements several re-locations each time. Zhang et al. (2016) recommended two heuristic methods for clustering items: the static seed and the sum seed. Item sets are searched and sequenced with the help of these algorithms. They are also used to find iterative solutions for improvement-based CSAS. In the SKU partitioning problem developed by Kress et al. (2017), an ejection chain heuristic providing high-quality results in a computational investigation is created. Krishnamoorthy and Roy (2019) proposed a novel strategy for storage assignments based on utility. For a successful assignment, a heuristic algorithm and a top-k high utility itemset mining are applied to this method. Xin et al. (2019) proposed a heuristic based on correlation analysis and text clustering. When the ordered items have a weak correlation, the initial step was the clustering of SKUs uniformly into a few classes. Then in the second step, the relationship between SKUs was analyzed by correlation analysis. Finally, the SKUs were allocated in storage locations to minimize the order-picking distance. Ansari and Smith (2020) proposed a new method for storage location assignment problems to perform better in multi-pick warehouses. The process was developed based on the famous gravity model. Kim et al. (2020) proposed a heuristic approach to slot selection and grouping items for large distribution centers. In the first stage, they presented the strategies for selecting slots and grouping frequent items. Then a heuristic is designed to arrange frequently ordered slots closely to minimize the distance traveled by the picker. Zhu et al. (2021) proposed a k-links heuristic clustering algorithm, divided into two ways, for minimizing the order splitting to reduce the shipping cost. Trindade et al. (2021) introduced a two-phase heuristic method to account for the item's weight class. The first phase includes using clustering techniques to group similar items. The second phase includes weight ordering so that heavy and light items can be distributed properly.

4.2.2. Meta-Heuristic Methods

Hua and Zhou (2008) utilized a genetic algorithm (GA) in their proposed model to group SKUs into a cluster based on the index matrix and the build frequency of components. Xiao and Zheng (2012) proposed two hybrid GA with various crossover mechanisms. Several experiments show that this study performs better than others and can be implemented in designing a warehouse. Li et al. (2016) presented a GA approach to analyze a storage assignment problem of dynamic type and develop a mechanism for optimization based on the mutual relation between SKUs and ABC classification. Jiang et al. (2021) improved the quality of the large-scale SLAP by applying

both the GA and particle swarm optimization (PSO) algorithms. Zhang et al. (2019) developed a simulated annealing (SA) method to solve the CSLAP model. Yuan et al. (2021) developed a two-stage hybrid approach that combines the greedy algorithm with SA to solve the pod's assignment model. Wang et al. (2016) used the ant colony optimization (ACO) technique for storage partitioning in a two-stage open queuing network model. Xie et al. (2018) proposed a tabu search algorithm based on the bi-level grouping optimization (BIGO) model. Lee et al. (2020) solved the bi-objective model using a multi-objective evolutionary algorithm (MOEA).

4.2.3. Data Mining Approach

It is currently observed that the CSLAP can be effectively solved by using the association rule-based data mining approach. Chiang et al. (2011) proposed an association rule mining-based approach in the warehouse. In the first stage, an association index (AIX) is computed between the newly arrived items and the unused storage locations. In the second stage, binary integer programming is applied to the SLAP with the help of AIX. Chiang et al. (2014) introduced an association measuring technique called weighted support count (WSC). As a WSC indicator, lift value and support are vital things to understand. Lift value and support value are used to symbolize the strength and type of connections between SKUs. Pang and Chan (2017) introduced a data mining-based allocation algorithm intending to minimize the activity of order pickers while picking orders on correlated items in a randomized warehouse. Zhou et al. (2020) proposed a modified class-based storage strategy for efficient order picking. Using data mining techniques, they employed the association rule to refine the ABC class-based storage policy and better cluster the ordered commodities for optimal storage site utilization. Kim et al. (2020) developed an association rule mining (ARM) based heuristic to optimize the order picking distance through frequent itemset grouping and slot selection. Li et al. (2021) proposed a data mining augmented post-processing heuristic to solve SLAP based on ARM. The first step is to divide the items into weight classes (heavy, medium, and light). The second step is to determine the support and confidence levels with the *a priori* algorithm to generate association rules. After obtaining the frequent item sets in the third step, the final step is to generate a layout with storage locations keeping the frequently ordered items close to each other.

4.3. Warehouse Layout

The size and layout of a warehouse is an important aspect that affects order-picking efficiency (Bindi et al., 2009; De Santis et al., 2018). A warehouse is typically specified by the number of blocks, aisles, and the size of storage racks. The warehouses are divided into blocks by the presence of cross-aisles (De Santis et al., 2018). For the early papers, the research was carried out in rectangular single-block layouts (Bindi et al. 2009; Xiao & Zheng 2010; Zhang, 2016; Pang & Chan, 2017; Xie et al., 2018; Zhang et al., 2019; Wang et al., 2020; Lee at al., 2020; Li et al., 2021). This type of layout consists of multiple parallel aisles of equal length joined at the front and back of the warehouse by the cross aisles as shown in Figure 6(a). Few studies have considered the actual warehouse scenarios such as multi-block warehouses with three cross-aisles (Kim & Smith, 2012; Zhou et al., 2020; Ansari & Smith, 2020; Mirzaei et al., 2021; Yang, 2022) as shown in Figure 6(b). Chuang et al. (2012) and Chuang et al. (2016) only consider a simple single-block and single-aisle warehouse for the computational experiment.

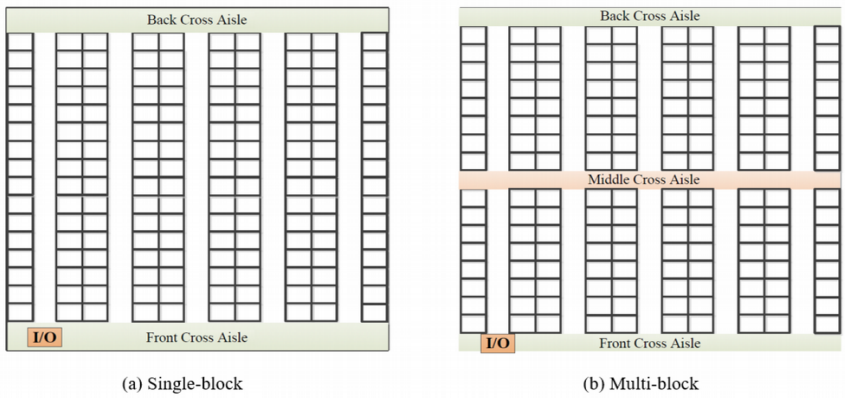

Figure 6. Different warehouse layouts considered in CSLAP (Dukic, Cesnik & Opetuk, 2010)

4.4. Routing Strategy

The routing method is a framework that defines how the order pickers should move throughout a warehouse to ensure the shortest conceivable travel distance. Figure 7 illustrates the common routing methods considered in the CSLAP studies. Since it is extremely difficult to determine the picking path for each order, the S-shape routing method is typically employed in many research because of its simplicity (Bindi et al., 2009; Xiao & Zheng, 2010; Chiang et al., 2011, 2014; Wutthisirisart et al., 2015; Diaz, 2016; Zhang et al., 2019; Zhou et al., 2020; Trindade et al., 2022). Few researchers used the return routing method (Bindi et al., 2009, Kovács, 2011; Kofler et al., 2015; Zhang, 2016). Ho and Liu (2005) and Xiao and Zheng (2010) followed the largest gap routing policy. The simple z-type routing method was incorporated in some studies (Liu, 1999; Chuang et al., 2012; Chuang et al., 2016). Other heuristics such as the nearest neighbor, insertion, and greedy routing method were also used in the literature (Pang & Chan, 2017; Dauod et al., 2017; Xin et al., 2019; Kim et al., 2020).

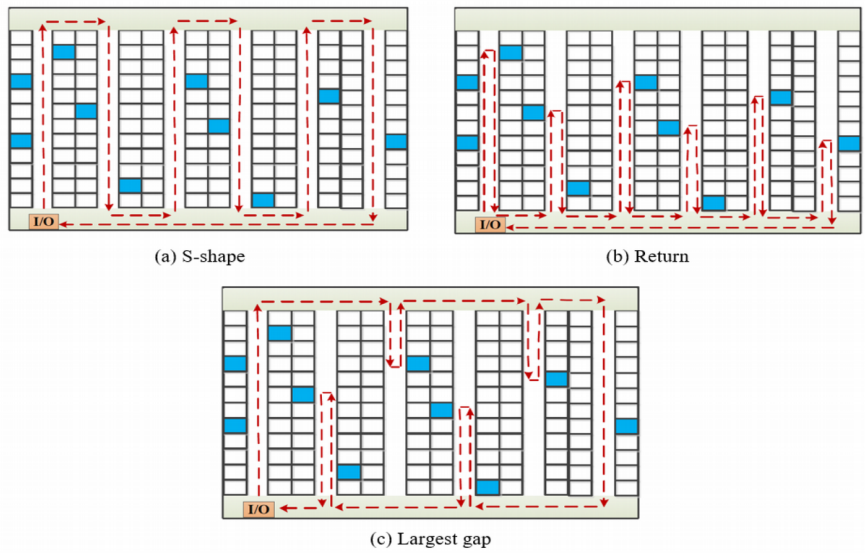

Figure 7. Different routing policies considered in CSLAP (De Koster et al., 2007)

5. Discussion of Trends and Future Research Scopes

The CSLAP has been researched for over three decades. Initially, basic single-block or one-sided racks were considered for ease of experimentation. With the advancement of computing power, researchers have taken up the challenge of solving more complex storage assignment problems, such as those involving multiple blocks and aisles (Mirzaei et al., 2021; Yuan et al., 2021; Yang, 2022). Furthermore, applications of the models developed through the research are being tested on actual industry data to comprehend the efficiency of the proposed solutions. Hao, Wang and Yan (2021) attempted to tackle the assignment problem of a very specialized automated pharmacy. Similarly, case studies and optimizations on retail food industries were done (Bindi et al., 2009; Li, 2021). Other industries that have been worked on include the tiles industry (Manzini et al., 2012), the fast fashion industry (Choy, Lam, Lin & Lee, 2013), and retail companies (Trindade et al., 2022). The tests are being carried out on varying industries to determine if some particular solution can better fit a particular industry.

Nowadays, there has been a rise in scholarly interest in the storage allocation problem in RMFS. The process of pod assignment in RMFS, a parts-to-picker storage system in which robots transport the mobile pods to the stationary pickers was also examined in some cases (Yuan et al., 2021; Keung et al., 2021; Manzini et al., 2012; Yang, 2022). The system becomes efficient by clustering the items often bought together on the same pod. By storing numerous SKUs in a single storage pod or bin, the system can retrieve fewer containers to satisfy orders. As a result, throughput can be increased by a large margin. We reviewed the articles that covered the benefits of deploying robotic process automation (RPA) in RMFS as part of cloud-based Cyber-Physical Systems. The warehouse intelligence level has been influenced by the rapid growth of online commerce. The RMFS proved that mobile-pod warehouse systems could complete several order-picking processes in the same amount of time as

other systems, resulting in significant cost savings and increased operational efficiency (Yang, 2022). Some recent CSLAP articles estimated the predicted OP travel time in parts-to-picker storage systems taking into account the effects of product correlation, turnover frequency, and inventory dispersion. In addition, there is a growing interest in the application of simulation and modeling techniques to investigate and evaluate the effect of storage assignment approaches on the overall performance of a fulfillment system.

Other variations in the CSLAP articles include the issue of varying weights. Trindade et al. (2022) consider weight constraints when calculating the similarity between items. Some weight classes might be better grouped for faster order picking. We recommend the following limitations and scopes to solve and consider in further CSLAP research:

- It is important to consider the item's dimensions, weight, and durability. For example, it is best to store heavy objects on the ground floor and high-demand items on the middle shelf.
- Several studies looked only at the relationship between two items. As a result, correlations between three or more items can be considered.
- The research needs to contain a reliable order history update mechanism to accommodate the ever-shifting trend in consumer demands.
- Several presumptions were made in the simulations utilized in the methodology of some reviewed papers. There is not a big enough sample size to accurately depict the actual scenario. An improved and realistic simulation model should be employed in future studies.
- Many related studies have focused on the S-shaped routing protocol. There is also the potential to incorporate the CSLAP with different routing methods.
- In addition, when high-demand, correlated items are placed at the I/O point, aisle congestion might have a negative impact on OP efficiency, which can be further investigated.
- It is important to keep in mind that different warehouse layouts can be single or multi-block depending on the data sets being used. Three-dimensional warehouse layouts with high racks are hardly investigated in the literature.
- Some studies simplify matters by assuming there is only one I/O point in the storage facility. The prevalence of several I/O points and the separating input and output points calls for additional research.
- Due to the manual nature of the picker-to-parts OP method, considering human factors is an interesting aspect to explore.
- Very few researchers in this sector go beyond creating a new solution and testing out their findings in a real-life scenario or on actual data. Future research could be conducted on how each model would perform in actual supply chain environments.

6. Conclusions

This study offers a thorough literature review on the CSLAP, in which 60 representative publications published between 1985 and 2022 were clustered into categories based on the objective functions and solution methods. We discovered there is no agreed-upon language for the CSLAP since many authors use terms like "storage allocation," "slotting," "space allocation," "product allocation," "item allocation," and "reserve allocation" to describe the same concept. Consequently, we propose that the word be universally used for the correlated storage location assignment problem (CSLAP).

In the studied literature, traditional methods like the integer programming mathematical model (NP-hard problems), heuristics, and meta-heuristics are all viable options for solving the problem. However, an alternative approach like an association rule-based data mining technique has become popular in recent years. Travel distance, time, similarity, and handling costs were categorized as the objective functions utilized for optimization methodologies in the studied literature. We stress that in recent years, ergonomics have been taken into account within manual recovery systems, with the realization that storage allocation has an immediate impact on workers'

health. Academics and professionals in the industry are increasingly using RPA to take advantage of the advantages afforded by the expanding capabilities of information and communication technologies (ICT). RMFS has proven that mobile-pod warehouses can complete more OP procedures in less time than traditional warehouses, resulting in cost savings and increased productivity. RMFS's zone clustering has been reviewed in our literature to advance the current state-of-the-art.

While there have been other articles on the CSLAP, we believe our current assessment to be the most comprehensive of its kind. We also call attention to the necessity for further study into the design of management tools that aid decision-making via the implementation of quantum computing technology in solving NP-hard problems. We also recommend that future study goes beyond academic publications published in journals with high academic rigor.

Declaration of Conflicting Interests

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