Received 12 December 2023, accepted 12 January 2024, date of publication 23 January 2024, date of current version 16 February 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3357689

TOPICAL REVIEW

Hybrid Genetic Algorithms for Order Assignment and Batching in Picking System: A Systematic Literature Review

SAMNANG OU[1], ZOOL HILMI ISMAIL[2], (Senior Member, IEEE), AND NOHAIDDA SARIFF[3]
[1]Malaysia–Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur 54100, Malaysia
[2]Centre for Artificial Intelligence and Robotics, Universiti Teknologi Malaysia, Kuala Lumpur 54100, Malaysia
[3]School of Engineering, Faculty of Innovation and Technology, Taylor's University, Subang Jaya, Selangor 47500, Malaysia

Corresponding author: Zool Hilmi Ismail (zool@utm.my)

This work was supported in part by Dana R&D MOSTI MIMOS-UTM Collaborative Project: Edge-Based Sensor Fusion for Reliable Environment Perception under Grant R.K130000.7343.4B904.

ABSTRACT The Order-Picking System (OPS) is vital for inbound logistics, ensuring efficient customer order fulfillment and minimizing costs. Efficient execution and implementation of OPS are critical to meeting customer demands and reducing dissatisfaction, necessitating a thorough examination of the process of order picking features. The order picking, a cornerstone of warehouse operations, involves meticulous selection and gathering of items from designated storage locations, unfolding through stages like order assignment and order batching. In order assignment, specific orders are methodically delegated to pickers or teams, considering factors like urgency, order size, item location, and picker availability. The overarching goal is to optimize resource utilization and simultaneously reduce the time needed for order fulfillment, ensuring a streamlined and efficient approach. Conversely, order batching strategically groups multiple orders for concurrent picking, aiming to minimize trips and enhance overall efficiency and productivity. Throughout the order-picking process, pickers utilize tools like pick lists, barcode scanners, and automated storage and retrieval systems (AS/RS) for precise item location and retrieval. Post-collection, items are transported to a dedicated packing area for meticulous preparations before shipping to the customer. Orchestrating the order-picking process requires careful planning, coordination, and execution for punctual and precise customer order fulfillment. This paper highlighted a systematic reviewing process which analyzed relevant research papers, with a primary focus on the problems of order assignment and batching—a key area within the order-picking process. The objective was to provide a comprehensive overview of hybrid Genetic Algorithm solutions for these challenges, achieved through a systematic review from 2018 to 2023 using Web of Science and Scopus databases. After screening, the relevant references were selected, focusing on terms like storage assignment problems. A thorough examination delved into various subcategories, encompassing recent approaches of genetic algorithms and openly accessible datasets. The resulting review offers a concise summary, highlighting key findings, challenges, and potential directions associated with hybrid genetic algorithms, specifically in relation to storage assignment, storage location assignment problems, and order batching issues.

INDEX TERMS Order picking system, order assignment, order batching, hybrid genetic algorithms, systematic literature review.

I. INTRODUCTION

In recent times, manufacturing companies have faced various challenges in meeting customer demand. To address these challenges, companies have recognized the importance of reducing and eliminating total costs to improve the productivity of their logistics systems. The warehouse stands as a vital component of in-house logistics, playing a pivotal role in the supply chain systems of manufacturing firms. Among its various functions, the warehouse is tasked with efficiently

The associate editor coordinating the review of this manuscript and approving it for publication was Bin Xu.

and accurately storing, organizing, and tracking products throughout their lifecycle, from arrival to departure. A well-managed warehouse is crucial for contemporary logistics systems, and the efficiency of warehouse operations can have a substantial impact on the overall performance of the supply chain [1].

Efficient warehouse management is essential for contemporary logistics systems, and the overall performance of the supply chain can be notably influenced by the success of warehouse operations. Standard warehouse processes encompass a range of key operations such as receiving, put-away, internal replenishment, order picking, accumulation and sorting, packing, cross-docking, dispatch, and shipping. The inbound processes typically include receiving and storage, while the remaining operations are considered outbound processes. In many types of warehouses, products that arrive in large-scale units are typically rearranged and prepared for shipment at packaging stations [2].

Effective control and optimization of inventory and storage systems are integral aspects of supply chain management, encompassing the critical component of warehouse management. The primary aim of warehouse management is to ensure that products are stored, organized, and tracked efficiently and accurately throughout their lifecycle, from arrival to departure. It involves the use of sophisticated technology, automated systems, and specialized software to manage inventory levels, monitor stock movements, and optimize space utilization within the warehouse. Effective warehouse management practices are essential for businesses to remain competitive in today's global marketplace. By implementing efficient inventory management techniques, businesses can reduce storage costs, increase productivity, and improve order fulfillment accuracy.

Additionally, optimized warehouse management systems can improve customer satisfaction by reducing order processing and delivery times, and by ensuring the accuracy and quality of shipped products. The key elements of successful warehouse management include inventory control, order fulfillment, and workforce management. Inventory control entails overseeing stock levels, recognizing obsolete or slow-moving products, and sustaining optimal inventory levels to meet customer demand. Order fulfillment refers to accurately and promptly meeting customer orders, and workforce management involves ensuring that personnel are adequately trained, organized, and motivated to perform their roles efficiently. In brief, effective warehouse management is a crucial component of supply chain management, demanding a strategic and integrated approach to enhance inventory control, order fulfillment, and workforce management. By implementing efficient and effective warehouse management practices, businesses can improve productivity, reduce costs, and enhance customer satisfaction.

The order picking process is a crucial operation within warehouse management that involves the retrieval and consolidation of products to fulfill customer orders as shown in Figure 1. This is a intricate and time-intensive procedure that can have a notable impact on the overall efficiency and productivity of the warehouse. The order picking process usually includes multiple stages, such as identifying and retrieving products from storage locations, consolidating products to complete orders, and packaging and labeling products for shipment. The process requires precise coordination and timing to ensure that orders are fulfilled accurately and on time, while minimizing errors and waste. Effective order picking operations require a range of specialized technologies and tools, including handheld devices, barcode scanners, conveyor systems, and automated storage and retrieval systems. These technologies can help to optimize the picking process by reducing the time required to locate and retrieve products, and by improving accuracy and order fulfillment rates. To enhance the efficiency of the order picking process, warehouses might utilize different picking approaches, such as zone picking, wave picking, or batch picking. These strategies can help to minimize the amount of time and effort required to fulfill orders, while optimizing the use of warehouse resources and labor.

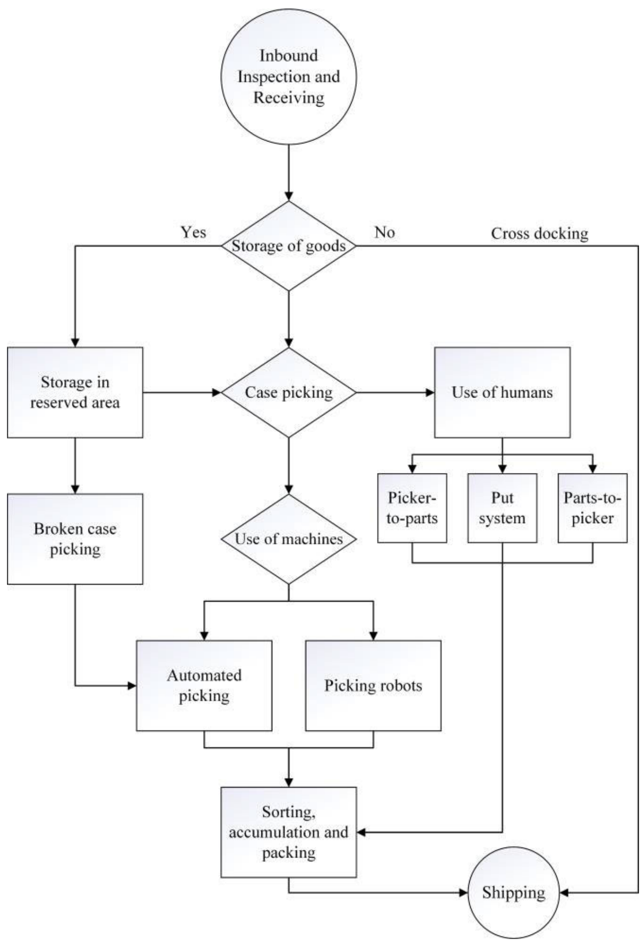

FIGURE 1. The entire map of order picking process.

On the whole, the order picking process stands as a vital element in warehouse operations, demanding meticulous planning, coordination, and management for the accurate and efficient fulfillment of customer orders. Successful order picking operations contribute to heightened customer satisfaction, cost reduction, and an overall improvement in supply chain performance. In recent years, both the research community and technology-driven companies have made significant advancements in creating innovative solutions to enhance supply chain management. Within logistics, the order picking process encompasses the planning, retrieval, and transportation of mixed stock keeping units (SKUs) from various locations within the warehouse system to the pick-up and drop-off area. Here, they undergo inspection, packaging, and shipment to fulfill customer orders. In practical terms, order picking is the costliest process and should be executed with precision and efficiency. As the preparation for several customer orders is increasing, every order is anticipated to sort up at a minimum cost, it is then considered order assignment as one of the tools to minimize the sorting up efforts and as well as costs [3].

Genetic algorithms (GAs) are an optimization technique inspired by natural selection. They involve evolving a population of potential solutions over multiple generations using natural selection, crossover, and mutation as shown in Figure 2. GAs can find optimal solutions to complex problems with large or poorly understood search spaces, and can handle a wide range of objective functions and constraints. However, selecting appropriate parameters can be a challenge, and GAs can be computationally expensive. Hybrid Genetic algorithms have found application in diverse fields such as engineering design and finance. They operate on entire populations of data, generating solution populations instead of a singular solution. Ongoing efforts by researchers involve the creation of novel variants and enhancements to the fundamental GA algorithm [3].

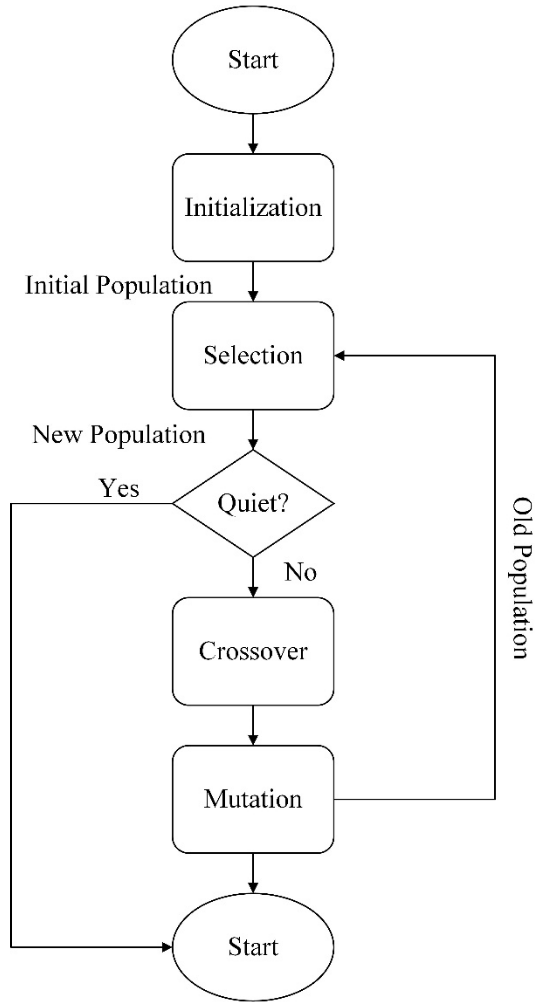

FIGURE 2. Genetic algorithm flowchart.

II. SYSTEMATIC LITERATURE REVIEW

A number of previous works using GA have been employed in the tackling the problems of order picking process. A number of researchers have attempted to employ a variety of approaches to solve the order picking processes for both clinical and scientific reasons, with varying degrees of success. Table 1 contains a comprehensive list of all abbreviations mentioned in this literature review.

TABLE 1. List of terminologies used in the literature.

TERMINOLOGY	
GA	Genetic Algorithm
SA	Simulated Annealing
ACO	Ant Colony Optimization
OPS	Order Picking System
MOEAS	Multi-Objective Evolutionary Algorithms
MOGA	Multi-Objective Genetic Algorithm
MCDM	Multiple-Criteria Decision-Making
MIP	Mixed Integer Programming
IP	Integer Programming
ANNS	Artificial Neural Networks

A. RESEARCH METHODOLOGY

A general literature review involves a thorough examination of existing research on a specific topic, aiming to understand the current state of knowledge, identify gaps, and recognize trends. Its primary goal is to provide a contextual background for further research, aiding in the development of a theoretical framework. Researchers use this review to position their work in the scholarly discourse, highlight areas for additional investigation, and establish the relevance of their study. In contrast, the Systematic Literature Review (SLR) is a widely accepted methodology extensively employed to identify, assess, and comprehend crucial research domains related to a specific subject, topic, or area of interest. It serves as a complementary study that endeavors to examine research with similar scopes, critically assess their methodologies, and compile them through both quantitative and qualitative assessments whenever possible.

B. DATABASE SELECTION

Different database engines can be utilized to monitor academic publications, including Scopus, Web of Science, PubMed, and Google Scholar. Falagas et al. [4] conducted a study which demonstrated that the Scopus database was superior to other databases. In contrast, Wang and Waltman [5] undertook a research project in which they preferred the journal categorization system of Web of Science. In this study, both Scopus and Web of Science databases were employed, with Google Scholar serving as an additional tool.

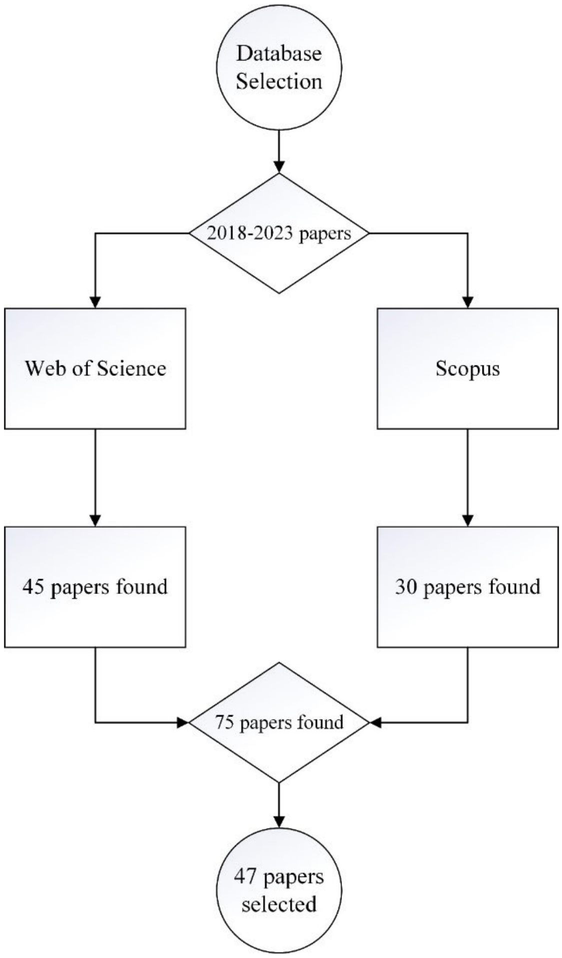

FIGURE 3. **The database search.**

For the initial literature search of this review, the subject areas of "Order Assignment Order Picking Systems Genetics Algorithm" and "Order Batching Order Picking Systems Genetic Algorithm" were selected, and both Web of Science (WoS) and Scopus were utilized as search engines.

Keywords: "Order Assignment Order Picking System Genetics Algorithm" AND "Order Batching Order Picking System Genetic Algorithm"

Publication Years: PUBYEAR>2018 AND PUBYEAR <2023

Afterwards, relevant articles were chosen and downloaded, starting with the oldest and working up to the most recent, with duplicates removed. The primary aim of this phase was to demonstrate the attention given to order assignment and order picking systems, as well as genetic algorithms used in research, while also clarifying the study's limitations.

In the second phase, the search was focused more specifically on order picking systems. 75 articles that dealt with databases and storage assignment, as well as order batching problems, were found to be the majority of the results. Additionally, 20 articles were dedicated to order batching problems, and 10 articles were focused on storage location assignment problems. Although this narrowed down the number of papers, the end result was deemed satisfactory for our research objectives. Nevertheless, the aforementioned articles were excluded despite meeting the search criteria.

During the third phase, the articles were visually assessed, and their abstracts and keywords were scrutinized. Articles that were deemed irrelevant were excluded, while those that focused on GAs and their strategies and methodologies for resolving the current issues were included.

III. RESULTS

During the first stage of the screening process, 45 papers were identified from WoS and 30 papers were identified from Scopus, and after eliminating duplicates, 47 papers remained. As depicted in Figure 3, there was a notable rise in the quantity of published papers, with a minimum of four papers released each year between 2018 and 2023. Notably, 13 papers were published in 2020 under the same search criteria applied in preceding years.

During the second phase of evaluation, the chosen papers' abstracts and keywords were scrutinized, with some indicating potential for advancement to the subsequent stage while others requiring deeper scrutiny. The third stage of analysis centered on assessing the paper's aim and whether it tackled current issues in the research domain. In addition, the introduction and conclusion were evaluated, leading to the exclusion of several publications that were not consistent with the research direction. Some articles utilized pre-existing datasets, while others utilized commercial datasets, resulting in difficulties replicating their outcomes due to the exorbitant cost of these datasets. The research papers discussed in these reviews were obtained from 43 distinct publications. Out of these, the Journal of Intelligent Manufacturing from Springer had the highest number of publications, with three papers, while the rest had only one publication each as shown in Figure 4 and 5, respectively.

The papers have shown that the authors utilized various types of methods to tackle the problems starting from conventional methods to sophisticated methods such as GA and hybrid GA as shown in Figure 6.

The papers demonstrated that there are the parameters, which have frequently been solved as shown in Figure 7.

IV. DISCUSSION

In this section, the content of selected articles were divided into three categories: Order Assignment- GA related, Order Batching-GA related, Order Picking and Batching-GA Optimization algorithms variation.

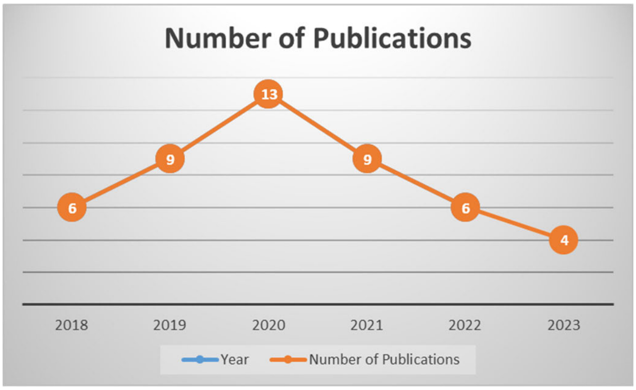

FIGURE 4. Number of publications published between years 2018 and 2023.

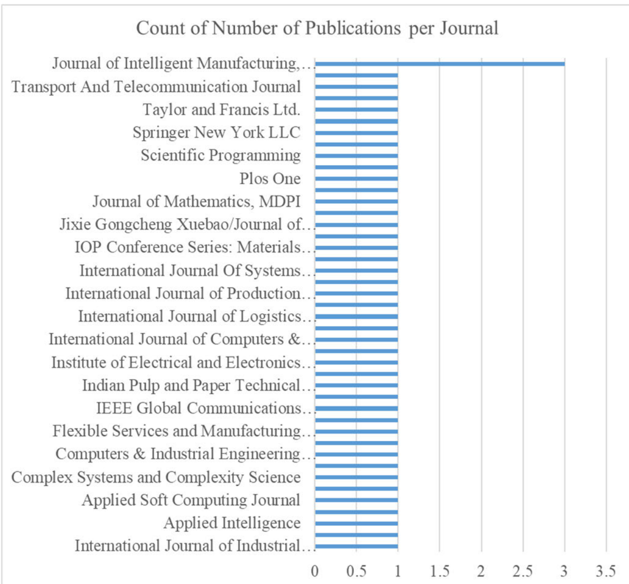

FIGURE 5. The number of publications per publisher Using GAs.

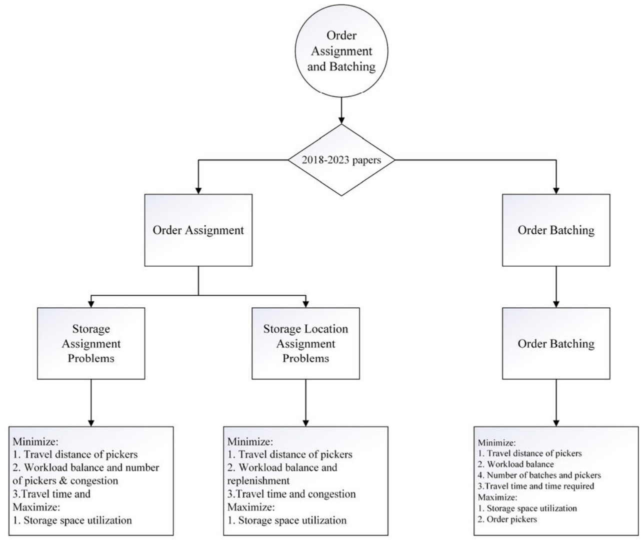

FIGURE 6. Problems mapping of order assignment and batching.

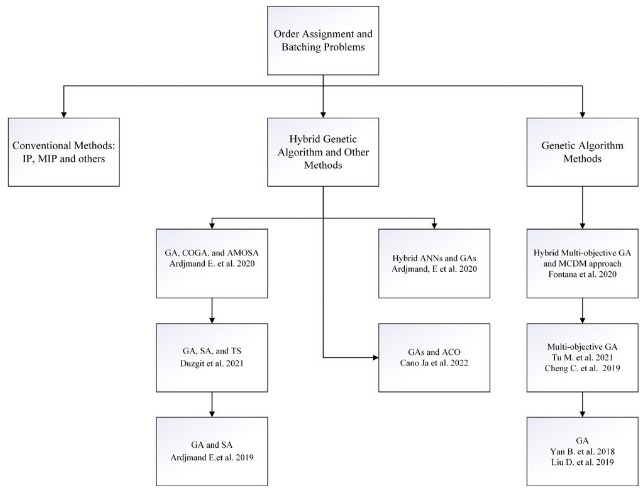

FIGURE 7. GA-related approach of order assignment and batching.

A. ORDER ASSIGNMENT-GA RELATED

Previous research was conducted on how the Robotic Mobile Fulfillment System (RMFS) affects conventional scheduling in warehouse operations [6]. Emphasis was placed on improving storage allocation for Fishbone Robotic Mobile Fulfillment Systems (FRMFS). A proposed model aimed at optimizing storage assignments to increase operational effectiveness and evenly distribute tasks among aisles. The study created various scenarios with different task sizes and storage cells to assess the Adaptive Genetic Algorithm (AGA) in addressing the storage assignment optimization model. Results indicated that the AGA surpassed four other algorithms in terms of fitness value, convergence, and stability. The findings suggested that the proposed model and AGA could reduce goods movement and travel distance, enhancing order picking efficiency in FRMFS. However, the study acknowledged the need for further research to consider factors like the correlation between orders in storage assignment and the adaptability of intelligent algorithms for other challenges in FRMFS. In summary, the article emphasized the significance of optimizing storage assignments in FRMFS and highlighted the efficacy of the AGA in addressing this issue.

Melinda and Ginting [3] highlighted the warehouse's crucial role in the broader supply chain, emphasizing the pivotal significance of the order picking process within warehouse operations. The paper proposed utilizing the Genetic Algorithm method to improve the order picking process by considering variables such as travel time, search time, pick time, setup time, number of workers, and worker efficiency. It underscored the advantages of genetic algorithms over traditional optimization techniques. The expected outcome of implementing this method was to enhance warehouse efficiency by identifying the optimal combination of product storage locations, minimizing time, and maximizing work efficiency. In essence, the paper aimed to contribute to a more comprehensive understanding of warehouse management, particularly in the context of the order picking process, and its profound impact on warehouse productivity.

Saleet [7] observed that the COVID-19 pandemic has posed increased challenges for warehouse management systems (WMS) within the lean supply chain. A crucial issue addressed by WMS is the Storage Location Assignment Problem (SLAP), involving the allocation of stock keeping units (SKUs) to appropriate storage locations. Decisions made in SLAP significantly influence the efficiency of order-picking operations. The study proposed a smart logistics solution utilizing data analytics and genetic algorithms to tackle the SLAP. The research introduced a generic association-based assignment algorithm grouping SKUs based on their frequency of being ordered together in the same picking orders. This algorithm assigned nearby locations in the racking system to SKUs. The study validated the proposed approach, employing a genetic algorithm to find the optimal or near-optimal solution. The percentage difference between the optimal solution and the solution from the proposed approach was approximately 5.6%, showcasing the effectiveness of the proposed approach in addressing the SLAP and enhancing WMS efficiency. Future research should explore various SLAP scores related to pick-up delay, distance moved, storage capacity, and physical constraints on pallet size and shape. In conclusion, this study presents a promising solution to the challenges faced by warehouses during the COVID-19 pandemic. The proposed smart logistics solution, integrating data analytics and genetic algorithms, can efficiently optimize storage location assignment and improve WMS efficiency.

Xu and Ren [8] concentrated on the challenges posed to traditional static storage location assignment methods in warehouses due to the fluctuating demand in the online retail industry. In response, a multistage storage location assignment process termed Dynamic Storage Location Assignment (DSLA) was introduced, allowing real-time adjustments to the storage location of stock keeping units (SKUs) based on changes in demand. The study utilized a genetic algorithm to determine the final adjustment solution, and numerical experiments demonstrated that DSLA effectively reduces the walking distance and working time of pickers. This approach streamlines the warehouse operation process by integrating the picking operation and storage location assignment into one, without altering the pickers' current walking routes. This ease of implementation makes DSLA suitable for picker-to-parts picking systems in online retail. However, further research could explore the optimization impact of storage location assignment with different routing methods and consider changes in pickers' walking routes. In summary, DSLA has the potential to enhance logistics costs and customer purchasing experiences for online retailers, offering a promising solution to challenges in the online retail industry.

In [9], the issue of assigning storage locations in e-commerce warehouses, particularly those using mobile racks or automated robots for order picking, has been tackled. Two existing strategies, random storage assignment (RAS) and good-clustering storage location assignment (GCAS), were contrasted with an innovative genetic algorithm (GA)-based method that employs rack-moved-number (RMN) as its fitness function. The proposed method exhibited a superior RMN efficiency, surpassing the other two strategies by approximately 50%. The paper suggested that future studies could explore alternative crossover and mutation methods to improve GA convergence rates. Additionally, incorporating additional objectives, such as order dispatching, could further enhance the efficiency of the picking system.

A multi-objective genetic algorithm with random weights has been highlighted in [10] to address the storage assignment problem (SAP) in order picking systems, aiming to minimize the overall operational cost of the warehouse. The algorithm took into account workload balance and replenishment and was evaluated against simulation models of random and first-come-first-served assignment policies. The outcomes indicated that the proposed algorithm surpassed the typical assignment policies, resulting in improved efficiency in the picking operation of pick-and-pass warehouse systems.

Meanwhile, Cheng and Weng [11] as well as Gajsek et al. [12] independently explored the critical issue of storage allocation to stocks before order picking to enhance cost efficiency. In the study by Cheng and Weng, a genetic algorithm was introduced as a solution to the storage assignment problem. This algorithm aimed to achieve three objectives: minimize routing length, maximize the likelihood of picking adjacent stocks together, and minimize storage distance to the access point for popular stocks. The study also proposed a method for final storage assignment selection from a set of Pareto solutions. Through simulation, the performance of the proposed method was compared to the existing operational method, demonstrating its superiority in both item storage and order picking. Similarly, Gajsek et al. advocated for the use of a genetic algorithm to address the storage assignment problem, focusing on the same three objectives. Their study also introduced a method for determining the final storage assignment from a set of Pareto solutions. Through simulation, the proposed method was found to outperform the current operational method in both item storage and order picking. In summary, both studies highlight the effectiveness of genetic algorithms in optimizing storage allocation for improved warehouse efficiency and cost reduction.

A storage assignment approach named Correlated and Traffic Balanced Storage Assignment (C&TBSA) has been introduced in [13] with the aim of enhancing the efficiency of warehouse order picking operations. C&TBSA was structured in two stages: clustering and assignment, utilizing multi-objective evolutionary algorithms (MOEAs) to address conflicts between travel time and picking delays arising from traffic congestion. The bi-objective optimization model underwent evaluation through an actual warehouse case study, demonstrating that C&TBSA surpasses other storage assignment methods. The study concluded that optimizing order picking operation performance requires considering both picking delays and travel efficiency in storage location assignments. While the proposed method proves effective for warehouses experiencing frequent congestion, additional enhancements could be achieved by incorporating other warehouse performance factors and conducting further case studies with diverse scenarios.

Fontana et al. [14] proposed an innovative hybrid decision model designed to address the Storage Location Assignment Problem (SLAP), amalgamating Multiple Objective Genetic Algorithms (MOGA) with Multi-Criteria Decision Making (MCDM). Results from simulations indicated that the additive-veto model assists decision makers in scrutinizing the Pareto front and incorporating qualitative criteria. The study asserted that decision-making grounded in multiple key performance indicators is more pragmatic and provides more relevant information for the process. However, a limitation of the research lies in its consideration of solely known and predictable data; future studies should delve into the system's behavior under uncertainties and risks. In summary, the paper illustrated that hybrid methodologies can produce compelling outcomes for complex problems such as SLAP.

The implementation of a cyber-physical system (CPS)-based intelligent warehouse picking system as presented in [15], utilizing a heuristic multi-objective genetic algorithm to address the storage assignment problem (SAP) in e-commerce-oriented warehouses. The proposed algorithm considered workload balance and emergency replenishment during picking operations, leading to improved efficiency as evidenced by software simulations. Traditional storage assignment policies fell short in e-commerce-oriented warehouses due to the abundance of SKUs and diverse lot sizes. The proposed algorithm addressed the replenishment problem, introducing random weight in the fitness function to identify Pareto optimal solutions. It achieved a balance between workload and emergency replenishment by translating stock quantity and SKU allocation into twin-chromosomes. The proposed system represented an initial step toward an automated and intelligent enterprise logistics information system, with future research poised to expand its capabilities to handle SKUs of varying sizes, order sequencing, and various storage conditions. The development of a real CPS-based PKPS poses challenges that require practical insights.

Liu et al. [16] delved into the importance of improving the efficiency and accuracy of order picking operations within distribution centers, recognizing it as the most expensive and time-consuming process. Automated picking systems, especially sophisticated ones, are commonly employed to enhance efficiency. The article introduced a model for a fundamental complex automated picking system and a time-based operational model rooted in a serial order picking strategy. It put forward an optimization algorithm for item assignment, employing an enhanced niche genetic algorithm based on k-means clustering, leading to a 7.5% reduction in total order picking time compared to conventional methods. Comparative experiments verified the effectiveness of the optimization method, and practical guidance was provided for item assignment optimization in complex automated sorting systems. The study recommended that future research should evaluate the impact of order batches on total picking time and thoroughly investigate how different system components affect the overall picking time of the system.

Recently, Sgarbossa et al. [17] introduced a robotic picking system and detailed a methodology for allocating products to two distinct warehouse zones—one designated for robot pickers and the other for human pickers. Utilizing the Non-dominated Sorting Genetic Algorithm II (NSGA-II), the approach aimed to minimize human workload and maximize product category similarity within each zone. The case study illustrated the precise optimization of both objectives. The paper suggested that future advancements in robotic technology should prioritize the picking of heavy products in high demand to alleviate human workload and mitigate the risk of injuries. However, a limitation of the method lies in its indirect calculation of costs, necessitating a case-by-case examination of trade-offs. Future research should encompass costs related to ergonomics, injuries, and the entire grocery supply chain. Additionally, the method overlooks the sizing of the consolidation area between zones, a factor deserving attention in subsequent investigations.

The study in [18] explored the challenge of reducing labor costs in supply chain operations, specifically concentrating on improving picking efficiency through precise order combining and strategic placement of goods. While ABC analysis is a traditional method for determining goods placement, recent research suggests that an approach involving genetic algorithms is more effective. This study aimed to enhance the genetic algorithm approach by incorporating factors such as labor costs and warehouse topology and verifying its efficacy in a real warehouse environment. The results indicated that, with the relocation of goods and the addition of a new aisle, picking time decreased by up to 60%. This method, with some adjustments to the physical layout, has the potential for application in various warehouses.

The significance of storage in the movement of goods was also examined, emphasizing the necessity to optimize warehousing and the allocation of goods locations [19]. The research work focused on employing a genetic algorithm to improve the strategy of assigning goods locations in a stereoscopic warehouse handling electronic products. By developing a multi-objective goods location assignment model, the study utilized MATLAB simulation to boost efficiency. The results revealed that the adaptive genetic algorithm successfully optimized goods location, maintained warehousing efficiency, and improved operational efficiency and storage capacity. However, the study faces limitations, including the necessity for alternative intelligent algorithms and the consideration of additional assignment principles to further refine the model.

The surge in e-commerce has brought about significant transformations in the retail and logistics sectors, necessitating effective handling of irregular arrival patterns of e-commerce orders and ensuring reliable delivery schedules. Logistics service providers (LSPs) are required to be highly efficient in executing the order fulfillment process to avoid delays that could impact customer satisfaction. In an effort to enhance efficiency in managing e-commerce orders, Leung et al. [20] introduced a cloud-based e-order fulfillment preprocessing system. This system incorporates a genetic algorithm to support decision-making in order grouping and a rule-based inference engine for generating operational guidelines. By consolidating pending e-orders and rationalizing an optimal internal order processing plan, LSPs are no longer compelled to process individual e-orders immediately upon receipt. This streamlined internal order processing flow in e-fulfillment centers reduces processing times, meeting the increasingly stringent delivery requirements of online customers. The intelligent system has significantly contributed to the evolution of the e-commerce business environment by enhancing the capabilities of logistics service providers in understanding the logistics of e-commerce. This, in turn, enables retailers to cultivate brand images and loyalty by meeting consumer needs and expectations and facilitates end consumers in receiving their purchased items promptly, without prolonged waiting times.

Recent studies, including the investigation in [21], centered on enhancing the efficiency of order picking in warehouses with multiple cross-aisles by addressing challenges in storage location assignment. This research specifically focused on correlated items.The goal is to optimize the picking process by determining the shortest route and updating customer orders based on their preferences. A fitness function is formulated to evaluate the benefits of rearranging item locations, thereby minimizing the costs associated with picking. The proposed method, termed the storage location assignment for correlated-item approach, utilized authentic retail data and considered three crucial factors: item correlations in customer orders, penalties associated with cross-aisles during warehouse traffic, and the use of a real retail dataset. By accounting for item correlations and assessing the suitability of storage locations, the method effectively reduced warehouse operation costs and improved overall efficiency. Numerical analysis conducted with a real ecommerce dataset demonstrates that the proposed method can achieve a 5-10% reduction in travel distance compared to a conventional turnover-based storage policy. Additionally, the method exhibits significant enhancements in picking time, especially in large warehouses when a moderate penalty for crossing-aisles is considered.

Ma et al. [22] examined the intricacy of designing a Customized Bus (CB) service tailored to individual passenger travel requirements. The primary objective was to efficiently manage a fleet of vehicles with limited capacity, incorporating holding control considerations, which involved determining stop durations. To address this challenge, the authors introduced a mathematical model utilizing mixed-integer linear programming. This model optimized vehicle routes, timetables, and passenger assignments. The authors decomposed the model into a bilevel formulation and devised a hybrid algorithm known as GA-LNS-BB (genetic algorithm - large neighborhood search - branch-and-bound) by integrating genetic algorithm and large neighborhood search techniques. For exceedingly large-scale problems, the authors introduced the OC-D&C approach (order clustering-based divide and conquer). This approach formulated the order clustering problem as an integer linear programming task. The proposed model and solution methods underwent evaluation through numerical experiments on both the Sioux Falls network and a real-world city-scale network. The results revealed that holding control enhances the flexibility of the CB service and significantly increases the carrier's profit. Moreover, the GA-LNS-BB hybrid algorithm and the OC-D&C approach surpassed other standard algorithms, delivering high-quality solutions swiftly for large-scale and ultra-large-scale problems. Meanwhile, Pinta and Nagano [23] presented a computational tool designed to integrate and optimize two interrelated challenges, namely Optimized Billing Sequencing (OBS) and Optimized Picking Sequence (OPS), within a warehouse utilizing a low-level picker-to-parts system. While existing literature addressed these problems independently, the proposed tool aims to bridge this gap by providing more robust methods for OBS/OPS optimization. The tool, created through the integration of two Genetic Algorithms named GA-OBS and GA-OPS, demonstrated its effectiveness in producing satisfactory solutions for OBS/OPS instances across varying complexity levels. This tool enables managers to make more informed decisions regarding the trade-off between customer service and warehouse efficiency. Future research should explore the application of the tool with dynamic variables, incorporate additional parameters, operators, and genetic representations, conduct comparative analyses, and potentially develop a versatile hybrid GA.

B. ORDER BATCHING-GA RELATED

The most recent research delves into how order batching and genetic algorithms (GAs) optimize processes within warehouses, particularly focusing on the dispatching of bins in a ''part-to-picker'' system using an enhanced GA-based model. It effectively addresses the challenges inherent in manual order picking systems, emphasizing the effectiveness of GA-based metaheuristics in reducing both picking time and labor costs. GAs also demonstrate proficiency in a rule-based heuristic designed for order picking in online retail settings. Furthermore, the optimization of travel time and picking sequences in put wall-based order picking introduces versatile genetic algorithms. The exploration of the ''part-to-picker'' system introduces an adaptive GA designed to reduce costs and improve efficiency. These approaches' effectiveness is corroborated through empirical findings, computer simulations, and real-world case analyses, highlighting their applicability across diverse scenarios. Wu et al. [24] explored the significance of regulating the frequency of bin entry and exit in a ''part-to-picker'' picking system utilizing a shuttle storage system. It proved advantageous to dispatch the necessary bins for a specific batch of orders in a single operation when a sufficient quantity of goods was present in a bin. The efficiency of the picking system can be enhanced by optimizing the grouping of similar orders into batches and minimizing the number of bins entering and leaving the warehouse. To achieve this objective, an order batching optimization model was formulated, aiming to decrease the number of bins leaving the warehouse. The researcher developed an improved genetic algorithm, incorporating a hybrid crossover strategy and partial search on elite chromosomes to enhance the convergence speed and accuracy of the algorithm. Simulation results verified the effectiveness of the proposed approach in reducing the total number of outgoing bins and improving the picking efficiency of the system.

In [25], Cergibozan and Tasan delved into the order batching problem, a challenge prevalent in manual order picking systems, with the goal of identifying optimal groups of orders and picking routes to minimize the distance covered by the order picker. The significance of this problem increased with the growing scale of operations. In this investigation, two genetic algorithm-based metaheuristics were introduced to address the order batching problem, and a practical case study was executed in the distribution center of a prominent retailer in Turkey. The outcomes demonstrated the practicality and efficacy of the developed algorithms in real-world scenarios, leading to a substantial reduction in picking time and notable savings in labor costs. Future research avenues could explore assessing picker performance, optimizing layout design and storage locations, and considering factors such as constraints on delivery times, fluctuations in demand, and optimization within automated integrated systems.

Previous study by Hossein Nia Shavaki and Jolai [26] explored the complexities online retailers face in order picking and delivery planning. To tackle these issues, they introduced a rule-based heuristic algorithm that encompasses decisions regarding order batching, picking schedules, order assignment to trucks, and the scheduling and routing of trucks. Three distinct batching methods were employed, and a numerical experiment was conducted to assess the algorithm's efficiency. The findings indicated that the genetic algorithm outperformed others in terms of system cost and productivity, with similarity-based batching proving more effective than the recalculating savings method. Moreover, the proposed algorithm demonstrated applicability for estimating system cost and capacity. Future investigations could delve into alternative routing and batching methods, as well as address the unique challenges associated with selling perishable products.

A research work in [27] concentrated on the design and operation of a warehouse system handling a substantial number of orders within a constrained machine layout for product picking. The research team proposed a mathematical model that integrates integer and linear techniques to address the challenge of concurrent order batching and picker routing. To accommodate parameter uncertainties, robust possibilistic programming was employed, and three meta-heuristic algorithms (GA, PSO, and ABC) were developed to address the formulated model. Results revealed that GA exhibited the most efficient performance in terms of CPU time. Potential extensions of this study involve incorporating multi-shelf warehouses and accommodating multiple products on each shelf. Additionally, exploring novel meta-heuristics or exact methods to solve the problem could be pursued. Furthermore, a multi-objective model could be employed to minimize both order transshipment time and associated costs. On the other hand, Cano et al., [28] introduced a genetic algorithm designed to address the order batching problem within multi-parallel-aisle warehouse systems. This algorithm employed a novel chromosome representation, with each gene representing a customer order, ensuring feasibility in the mutation operator and minimizing the need for correction of chromosomes generated by the crossover operator. Comparative analysis demonstrated that the algorithm resulted in substantial savings in both travel distance and the number of batches compared to the conventional first-come-first-served rule. These savings translated into potential cost reductions of up to 12% in total order picking, up to 7.2% in total warehouse management, and up to 1.4% in supply chain operating costs. The algorithm offered seamless integration into warehouse management systems and contributes to the sustainability of warehouses and distribution centers by reducing energy consumption. Future research avenues could explore solving the joint order batching and picker routing problem using metaheuristic or exact solution approaches, with consideration for multi-block warehouses and multiple pickers.

Previously, a metaheuristics model has been introduced to reduce overall travel time and completion time in a put wall-based order picking system [29]. Three metaheuristics were employed to tackle this problem: a genetic algorithm (GA), a coevolutionary genetic algorithm (COGA), and an archived multi-objective simulated annealing (AMOSA). Results indicated that GA and COGA yielded a more diverse set of solutions compared to AMOSA. Furthermore, the study challenged the notion that batching orders together might not necessarily reduce makespan, emphasizing the importance of considering both total travel time and makespan in picking solutions. While the proposed methods exhibited promising outcomes, further research is required to ascertain their optimality gap. Future investigations could explore avenues such as reducing CPU time through parallelization, hybridizing the proposed methods, and examining order batching in scenarios where orders are released as they are received. Pinto and Nagano [30] research explored the Optimized Picking Sequence (OPS) problem, a variant of the Order Batching and Sequencing Problem (OBSP) encountered in warehouse picking procedures. OPS aimed to minimize picking time and overall costs, striking a balance between customer service and operational efficiency. To address this, the authors introduced a computational tool named GA–OPS, utilizing two genetic algorithms (GABATCH and GATSP) to group products into batches and determine optimal picking routes. GA–OPS demonstrated effectiveness across various OPS instances, showcasing its adaptability to different configurations and warehouse setups. The article suggested potential avenues for future research, emphasizing the enhancement of GA–OPS performance and its comparison with alternative optimization approaches. In summary, this OPS solution addressed a gap in the existing literature, contributing innovative methods for developing and implementing picking optimization strategies in real-world warehouse scenarios.

Meanwhile the study in [31] delved into order picking operations within put wall-based systems, necessitating the examination of order batching, picker routing, and scheduling due to constrained put wall capacity. Researchers reported a mathematical formulation and conducted a performance comparison involving two genetic algorithms, a list-based simulated annealing, and a hybrid GA-LBSA, benchmarked against Gurobi 7.0. LBSA exhibited superior performance in terms of solution quality for smaller problems, while GA-II proved more efficient for larger problems when considering CPU time. The study highlighted potential future research directions, including the integration of shipping decisions, formulating a model for minimizing make span and completion time, and accounting for the stochastic nature of customer orders and changes in warehouse layout. The proposed methods and guidelines offer valuable insights for reducing labor costs in warehouse picking operations.

The rise of e-commerce, particularly in the B2B sector, has presented both opportunities and challenges for retailers and logistics service providers (LSPs). To enhance their capability in managing B2B e-commerce orders, Leung et al., [32], introduced a novel approach. They developed an Intelligent B2B Order Handling System (IOHS) that seamlessly integrated cloud database management, fuzzy logic, and genetic algorithms. This innovative approach streamlined B2B order pre-processing and grouping, resulting in a substantial enhancement of the throughput rate for handling B2B e-commerce orders. The IOHS aimed to achieve information transparency and align supply chain processes between 3PLs and sellers, fostering the concept of smart logistics through the efficient and intelligent management of B2B e-commerce orders. The pilot implementation of IOHS demonstrated the feasibility of implementing lightweight IT applications with the assistance of AI techniques. Future endeavors could focus on expanding its application scope and enhancing the internal order processing capabilities of logistics practitioners, thereby benefiting all partners across the supply chain. Kunpeng et al. [33] examined the "part-to-picker" picking system, a system leveraging automated guided vehicles (AGVs) for automated picking processes. In this system, AGVs transport shelves to designated picking stations where pickers retrieve goods. Efficient order batching plays a pivotal role in optimizing system efficiency, determining the appropriate number of AGVs, and minimizing manual picking times. In the context of intelligent e-commerce warehouses, the model considers practical factors such as orders involving multiple goods, storage distributed across various shelves, and unknown matching relationships between orders and shelves. The mathematical model is designed to minimize the combined cost of manual picking and AGV transportation. To address this problem, an enhanced adaptive genetic algorithm was developed. This algorithm incorporates a heuristic strategy for generating the initial population, introduces adaptive transformation probabilities for crossover and mutation operators, and includes a local search process to enhance optimization capabilities. The effectiveness of the model and algorithm was validated through experimental tests, highlighting the superior performance of the population initialization method. Additionally, sensitivity analysis was conducted to provide informed recommendations for the allocation of turnover box quantity. This study offers practical insights for e-commerce companies seeking to enhance picking efficiency and reduce costs through optimized order batching. Furthermore, it establishes a scientific foundation for implementing the "part-to-picker" picking system in real-world scenarios.

The outcomes showcased notable enhancements brought about by the suggested order batching algorithm employing a hybrid time window, indicating diminished response times in comparison to fixed and variable time windows. The improved ant colony algorithm additionally heightened the efficiency of AGV task allocation by enhancing convergence. Moreover, through the optimization of the selection of static picking stations and the dynamic adjustment of picking stations based on queue conditions, the research effectively curtailed queue-waiting and picking completion times, fostering increased adaptability and efficiency in the picking process. To summarize, this study presented effective strategies and algorithms for optimizing the order picking process, resulting in heightened efficiency and reduced completion times within the distribution center.

C. ORDER PICKING AND BATCHING-GA OPTIMIZATION ALGORITHMS VARIATION

A plethora of scholarly works has addressed diverse challenges in warehouse operations and order picking efficiency, covering a wide array of topics such as storage assignment optimization, picker routing, stacking pattern optimization, and various aspects of order batching and sequencing.

These studies predominantly employ genetic algorithms and a few other optimization techniques to enhance warehouse operations, optimize storage assignments, and reduce costs. The effectiveness of these methods is demonstrated through experimental results, computer simulations, and case studies, showcasing their applicability across different complexities.

Xie et al. [34] delved into the design of a tape carrier packaging machine equipped with multiple sucking discs, a critical element in high-speed packaging production lines within electronic manufacturing. The efficiency of part-picking directly impacted the overall efficiency of the packaging process, presenting a challenge comprising three interconnected sub-problems: determining the number of picking rounds, establishing the matching relationship between parts and sucking discs, and deciding the picking order. Effectively addressing this multidimensional combinatorial optimization problem within a constrained timeframe proved challenging, particularly in real-time or soft real-time scheduling scenarios. State-of-the-art algorithms like genetic algorithms and simulated annealing algorithms, while advanced, were time-consuming due to their intricate encoding and decoding processes when applied to this problem. In contrast, the ant colony algorithm exhibited advantages in terms of convergence rate and parallel computing, especially in dynamic environments when exploring high-dimensional paths.

To further enhance the overall performance of the ant colony algorithm and tackle multidimensional optimization problems with tight time constraints, the authors introduced a novel approach termed the two-layer heterogeneous ant colony system. This system incorporated three strategies: (1) employing a bottom-up two-layer solution framework to segregate the tightly coupled problem into two loosely coupled sub-problems, (2) implementing a candidate cluster augmentation strategy based on Delaunay triangulation to amplify cluster diversity and quality, and (3) facilitating co-evolution between two different colonies by judiciously combining high-quality pheromone and integrating prior knowledge. Comprehensive comparisons demonstrated that the proposed Two-layer Heterogeneous Ant Colony System, integrating these three strategies, achieves an average picking efficiency that is 13-16% higher than other popular heuristic algorithms.

The COVID-19 pandemic posed a significant challenge to supply chains, especially in manual order picking operations, where the risk of infection spread among workers is notably high. In response to this challenge, Ardjmand et al. [35], introduced a novel overlap objective to assess the potential for infection transmission among pickers. The study revisited the order batching problem, aiming to minimize the risk of infection while concurrently reducing total travel time and makespan. Through the application of three metaheuristics and experimentation with data from a logistics company based in the US, the research discovered that decreasing picking overlap and minimizing travel time were not conflicting objectives; in fact, they exhibited a positive correlation. However, the study also highlighted that the advantages of minimizing overlap could be undermined by a low picking capacity. Additionally, the research recommended reducing wave size for warehouses characterized by high makespan and proposed future investigations to address the stochastic nature of pickers' travel times, as well as to explore the implications of pandemic considerations on tactical problems within supply chains.

A new hybrid heuristic approach reported by Ardjmand et al. in [36] to minimize makespan in manual order picking operations within fulfillment centers. This method combines column generation, a genetic algorithm, and an artificial neural network. Comparative analysis with other optimization methods revealed the superior performance of the CG heuristic in terms of makespan reduction and workload balance achievement, as demonstrated through numerical experiments. The study also provided valuable managerial insights into the interplay between picking capacity, the number of pickers, and workload balance. To further advance the field, the authors proposed three future research directions: exploring the application of soft computing methods, employing a branch and price schema, and extending the scope of the problem to operational and tactical-level supply chain challenges.

Liang et al. [37] detailed a study focused on improving the order picking process within a distribution center through the implementation of a "parts-to-picker" system. The primary goal was to efficiently respond to customer demands while minimizing the picking time, considering the uncertainty in the arrival times and quantities of orders. The study presented several methodologies and algorithms designed to enhance efficiency. Initially, it addressed the conversion of dynamic orders with uncertain details into static picking orders with known information. A hybrid time window technique, incorporating both fixed and variable time windows, was introduced, alongside an order consolidation batch strategy aimed at reducing the number of target shelves for picking. To further optimize the process, a heuristic algorithm was developed to select a shelf selection model that meets the requirements of the selection list effectively. Task allocation for multiple automated guided vehicles (AGVs) was conducted to determine the optimal pairing between target shelves and AGVs, as well as the appropriate order in which the AGVs should fulfill their picking tasks. Subsequently, a scheduling strategy model was created, prioritizing task completion time as the primary objective and utilizing an enhanced ant colony algorithm to address the problem.

V. MAIN CHALLENGES AND ITS WAY FORWARD

Significant contributions were made to the optimization of order batching and picking processes in warehouse operations by several researchers. However, there are three main challenges identified from the previous section:

i. Complexity of GA Optimization Problems: The challenges include addressing complex multidimensional combinatorial optimization problems within constrained timeframes, especially in real-time or soft real-time scheduling scenarios. This is evident in the design of tape carrier packaging machines, where determining the number of picking rounds, matching parts to sucking discs, and deciding the picking order simultaneously presents a significant challenge.

ii. Integration of Advanced Algorithms in Dynamic Environments: While state-of-the-art algorithms like genetic algorithms and simulated annealing are advanced, they can be time-consuming due to intricate encoding and decoding processes when applied to complex problems. The need for algorithms that can adapt to dynamic environments, such as the ant colony algorithm, which shows advantages in convergence rate and parallel computing, is highlighted. The development of novel approaches like the two-layer heterogeneous ant colony system also indicates the need for more integrated and efficient solutions.

iii. Balancing Efficiency with Other Constraints: The COVID-19 pandemic brought forward the challenge of balancing operational efficiency with health and safety concerns, like minimizing the risk of infection spread among workers in manual order picking operations. The introduction of novel objectives, such as assessing the potential for infection transmission among pickers, requires a reevaluation of existing algorithms and the development of new ones that can accommodate these additional constraints without compromising on efficiency.

Drawing from the outcomes of this Systematic Literature Review, attention should be directed towards the following areas for additional contributions to the field:

- explore the use of GA and machine learning algorithms for storage assignment optimization.
- investigate the effects of incorporating real-time data into the genetic algorithm-based approach proposed in the paper.
- explore the use of hybrid optimization methods for improving the effectiveness of picker-to-parts retrieval systems.
- explore the application of other evolutionary algorithms to the storage location assignment problem.
- explore the use of hybrid optimization methods for improving the efficient outcome of the proposed approach.
- investigate the performance of other metaheuristic algorithms for solving the picker routing problem in multi-block high-level storage systems and explore the use of hybrid optimization methods for improving the efficiency of the proposed approach.
- explore the effective result of the cluster analysis and genetic algorithm-based approach for storage location assignment in different types of warehouses and investigate the impact of incorporating real-time data into the optimization model.
- examine the efficacy of the suggested item assignment optimization method for automated picking systems with diverse attributes and investigate the utilization of machine learning algorithms to enhance the effectiveness of the proposed approach.
- examine the efficiency of the ergo-zoning approach in robot picker solutions across various order picking systems and explore alternative ergonomic optimization techniques to enhance the effectiveness of the proposed approach.
- evaluate the efficiency of various metaheuristic algorithms in addressing the multiblock warehouse order picking problem and examine the efficacy of the proposed approach across diverse warehouse types.
- explore the effectiveness of different warehousing system designs for order picking processes, investigate the impact of incorporating advanced technologies into the proposed warehousing system designs and explore the use of other optimization techniques for solving the storage location assignment problem in the proposed warehousing systems.

To sum up, this systematic literature review encompasses a succinct summary of the findings and offers valuable insights for future research endeavors. The studies included in the SLR have employed diverse and sophisticated methodologies, including Genetic Algorithms and hybrid GAs in conjunction with other approaches. The selection of these methods was based on the research objectives, ensuring a robust analysis. The papers examined various facets related to storage assignment, location assignment, and order batching, addressing a broad range of topics within warehouse management. Notable areas of investigation encompassed warehouse storage allocation, storage location assignment, picker routing, item assignment, and challenges associated with order batching and sequencing. These investigations collectively showcased the effectiveness of optimization methods and algorithms in enhancing the efficiency of warehouse operations. To propel the field forward, forthcoming research should concentrate on devising more sophisticated techniques that consider the complexities and variations inherent in warehouse operations, such as dynamic demand patterns and inventory levels. Additionally, the incorporation of emerging technologies machine learning shows potential for improving warehouse management systems, making it a subject worthy of exploration in future studies.

VI. CONCLUSION

This review is based on publications from 2018 to 2023, focusing on order assignment, batching in order picking systems, and genetic algorithms. The papers cover various optimization techniques, including genetic algorithms, metaheuristics, clustering analysis, and hybrid approaches. Some papers focus on storage location assignment, proposing genetic algorithm-based methods for optimizing assignments in different warehouse systems. Others concentrate on order picking systems, proposing genetic algorithm-based methods to optimize processes considering multiple objectives. Some papers address both storage location assignment and order picking simultaneously using multi-objective genetic algorithms. Moreover, there exist publications suggesting alternative optimization approaches like metaheuristics and clustering analysis. These papers target the improvement of efficiency in order batching, sequencing, picker routing, and delivery planning within warehouse management systems. Researchers introduced diverse optimization methods and algorithms, encompassing genetic algorithms, simulated annealing, and rule-based heuristics. Certain articles delve into the examination of combined order batching and sequencing issues in low-level picker-to-parts systems, presenting genetic algorithm-based solutions.

REFERENCES

[1] A. R. Ahmadi Keshavarz, D. Jaafari, M. Khalaj, and P. Dokouhaki, "Order picking process: State-of-the-art on classification," *J. Qual. Eng. Prod. Optim.*, vol. 6, no. 1, pp. 15–48, 2021.

[2] J. Habazin, A. Glasnović, and I. Bajor, "Order picking process in warehouse: Case study of dairy industry in Croatia," *Promet-Traffic Transp.*, vol. 29, no. 1, pp. 57–65, 2017.

[3] T. Melinda and R. Ginting, "Design of warehousing system in order picking process: Literature review," in *Proc. IOP Conf., Mater. Sci. Eng.*, 2020, vol. 801, no. 1, Art. no. 012126.

[4] M. E. Falagas, E. I. Pitsouni, G. A. Malietzis, and G. Pappas, "Comparison of PubMed, scopus, web of science, and Google scholar: Strengths and weaknesses," *FASEB J.*, vol. 22, no. 2, pp. 338–342, Feb. 2008.

[5] Q. Wang and L. Waltman, "Large-scale analysis of the accuracy of the journal classification systems of web of science and scopus," *J. Informetrics*, vol. 10, no. 2, pp. 347–364, May 2016.

[6] Y. Wang, R. Man, W. Zhao, H. Zhang, and H. Zhao, "Storage assignment optimization for fishbone robotic mobile fulfillment systems," *Complex Intell. Syst.*, vol. 8, no. 6, pp. 4587–4602, Dec. 2022.

[7] H. Saleet, "Smart solution for enhancing storage location assignments in WMS using genetic algorithm," *Int. J. Eng. Res. Technol.*, vol. 13, no. 11, p. 3456, Nov. 2020.

[8] X. Xu and C. Ren, "Research on dynamic storage location assignment of picker-to-parts picking systems under traversing routing method," *Complexity*, vol. 2020, Nov. 2020, Art. no. 1621828.

[9] D. Zhang, Y. Si, Z. Tian, L. Yin, J. Qiu, and X. Du, "A genetic-algorithm based method for storage location assignments in mobile rack warehouses," in *Proc. IEEE Global Commun. Conf. (GLOBECOM)*, Dec. 2019, pp. 1–6.

[10] M. Tu, P.-H. Shih, M.-F. Yang, C.-K. Lin, and S.-L. Kao, "Using multi-objective genetic algorithm on order picking system," in *Proc. Int. Multiconf. Eng. Comput. Scientists* (Lecture Notes in Engineering and Computer Science), S. I. Ao, O. Castillo, C. Douglas, D. D. Feng, and A. M. Korsunsky, Eds. Hong Kong: Newswood Limited, 2019, pp. 35–39.

[11] C.-B. Cheng and Y.-C. Weng, "Warehouse storage assignment by genetic algorithm with multi-objectives," in *Proc. 2nd Int. Conf. Intell. Hum. Syst. Integr. (IHSI): Integrating People Intell. Syst.* San Diego, CA, USA: Springer, Feb. 2019, pp. 300–305.

[12] B. Gajsek, G. Dukic, M. Kovacic, and M. Brezocnik, "A multi-objective genetic algorithms approach for modelling of order picking," *Int. J. Simul. Model.*, vol. 20, no. 4, pp. 719–729, Dec. 2021.

[13] I. G. Lee, S. H. Chung, and S. W. Yoon, "Two-stage storage assignment to minimize travel time and congestion for warehouse order picking operations," *Comput. Ind. Eng.*, vol. 139, Jan. 2020, Art. no. 106129.

[14] M. E. Fontana, V. S. Nepomuceno, and T. V. Garcez, "A hybrid approach development to solving the storage location assignment problem in a picker-to-parts system," *Brazilian J. Oper. Prod. Manage.*, vol. 17, no. 1, pp. 1–14, Feb. 2020.

[15] M. Tu, M.-F. Yang, S.-L. Kao, F.-C. Lin, M.-H. Wu, and C.-K. Lin, "Using a heuristic multi-objective genetic algorithm to solve the storage assignment problem for CPS-based pick-and-pass system," *Enterprise Inf. Syst.*, vol. 15, no. 9, pp. 1238–1259, Oct. 2021.

[16] D. Liu, X. Zhao, and Y. Wang, "Items assignment optimization for complex automated picking systems," *Cluster Comput.*, vol. 22, no. S3, pp. 5787–5797, May 2019.

[17] F. Sgarbossa, A. Romsdal, F. H. Johannson, and T. Krogen, "Robot picker solution in order picking systems: An ergo-zoning approach," *IFAC-PapersOnLine*, vol. 53, no. 2, pp. 10597–10602, 2020.

[18] A. Avdekins and M. Savrasovs, "Making warehouse logistics smart by effective placement strategy based on genetic algorithms," *Transp. Telecommun. J.*, vol. 20, no. 4, pp. 318–324, Dec. 2019.

[19] B. Yan, C. Yan, F. Long, and X.-C. Tan, "Multi-objective optimization of electronic product goods location assignment in stereoscopic warehouse based on adaptive genetic algorithm," *J. Intell. Manuf.*, vol. 29, no. 6, pp. 1273–1285, Aug. 2018.

[20] K. H. Leung, K. L. Choy, P. K. Y. Siu, G. T. S. Ho, H. Y. Lam, and C. K. M. Lee, "A B2C e-commerce intelligent system for re-engineering the e-order fulfilment process," *Expert Syst. Appl.*, vol. 91, pp. 386–401, Jan. 2018.

[21] Y.-L. Chou, V. F. Yu, and C.-H. Wu, "An efficient data-driven method for storage location assignment under item correlation considerations," *Int. J. Syst. Sci., Oper. Logistics*, vol. 10, no. 1, Dec. 2023, Art. no. 2228447.

[22] H. Ma, M. Yang, and X. Li, "Integrated optimization of customized bus routes and timetables with consideration of holding control," *Comput. Ind. Eng.*, vol. 175, Jan. 2023, Art. no. 108886.

[23] A. R. F. Pinto and M. S. Nagano, "Genetic algorithms applied to integration and optimization of billing and picking processes," *J. Intell. Manuf.*, vol. 31, no. 3, pp. 641–659, Mar. 2020.

[24] Y. Wu, X. Meng, Y. Wang, and J.-C. Hu, "Order sequence optimization for part-to-picker order picking system," *J. Mech. Eng.*, vol. 52, no. 4, pp. 206–212, 2016.

[25] Ç. Cergibozan and A. S. Tasan, "Genetic algorithm based approaches to solve the order batching problem and a case study in a distribution center," *J. Intell. Manuf.*, vol. 33, no. 1, pp. 137–149, Jan. 2022.

[26] F. Hossein Nia Shavaki and F. Jolai, "A rule-based heuristic algorithm for joint order batching and delivery planning of online retailers with multiple order pickers," *Int. J. Speech Technol.*, vol. 51, no. 6, pp. 3917–3935, Jun. 2021.

[27] M. Yousefi Nejad Attari, A. Ebadi Torkayesh, B. Malmir, and E. Neyshabouri Jami, "Robust possibilistic programming for joint order batching and picker routing problem in warehouse management," *Int. J. Prod. Res.*, vol. 59, no. 14, pp. 4434–4452, Jul. 2021.

[28] J. A. Cano, A. Correa-Espinal, and R. Gómez-Montoya, "Using genetic algorithms for order batching in multi-parallel-aisle picker-to-parts systems," *Int. J. Appl. Decis. Sci.*, vol. 13, no. 4, pp. 417–434, 2020.

[29] E. Ardjmand, E. M. Youssef, A. Moyer, W. A. Y. Ii, G. R. Weckman, and H. Shakeri, "A multi-objective model for minimising makespan and total travel time in put wall-based picking systems," *Int. J. Logistics Syst. Manage.*, vol. 36, no. 1, pp. 138–176, 2020.

[30] A. R. F. Pinto and M. S. Nagano, "An approach for the solution to order batching and sequencing in picking systems," *Prod. Eng.*, vol. 13, nos. 3–4, pp. 325–341, Jun. 2019.

[31] E. Ardjmand, O. Sanei Bajgiran, and E. Youssef, "Using list-based simulated annealing and genetic algorithm for order batching and picker routing in put wall based picking systems," *Appl. Soft Comput.*, vol. 75, pp. 106–119, Feb. 2019.

[32] K. H. Leung, C. K. M. Lee, and K. L. Choy, "An integrated online pick-to-sort order batching approach for managing frequent arrivals of B2B e-commerce orders under both fixed and variable time-window batching," *Adv. Eng. Informat.*, vol. 45, Aug. 2020, Art. no. 101125.

[33] L. Kunpeng, L. Tengbo, and L. Wenli, "Improved adaptive genetic algorithm for order batching of 'part-to-picker' picking system," *Chin. J. Mech. Eng.*, vol. 59, no. 4, pp. 308–317, 2023.

[34] L. Xie, X. Li, and X. Wei, "A two-layer heterogeneous ant colony system with applications in part-picking planning," *J. Comput. Inf. Sci. Eng.*, vol. 23, no. 2, Apr. 2023, Art. no. 021014.

[35] E. Ardjmand, M. Singh, H. Shakeri, A. Tavasoli, and W. A. Young II, "Mitigating the risk of infection spread in manual order picking operations: A multi-objective approach," *Appl. Soft Comput.*, vol. 100, Mar. 2021, Art. no. 106953.

[36] E. Ardjmand, I. Ghalehkhondabi, W. A. Young II, A. Sadeghi, G. R. Weckman, and H. Shakeri, "A hybrid artificial neural network, genetic algorithm and column generation heuristic for minimizing makespan in manual order picking operations," *Expert Syst. Appl.*, vol. 159, Nov. 2020, Art. no. 113566.

[37] K. Liang, L. Zhou, J. Yang, H. Liu, Y. Li, F. Jing, M. Shan, and J. Yang, "Research on a dynamic task update assignment strategy based on a 'parts to picker' picking system," *Mathematics*, vol. 11, no. 7, p. 1684, 2023.

SAMNANG OU received the Engineering degree in industrial engineering from the Institute of Technology of Cambodia, Cambodia, in 2017, and the M.Eng. degree in logistics and supply chain systems engineering from the Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand, in 2019. He is currently pursuing the Ph.D. degree with the Malaysia–Japan International Institute of Technology, Universiti Teknologi Malaysia.

ZOOL HILMI ISMAIL (Senior Member, IEEE) received the B.Eng. and M.Eng. degrees in mechatronics engineering from Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia, in 2005 and 2007, respectively, and the Ph.D. degree in electrical engineering from Heriot-Watt University, Edinburgh, U.K., in 2011. He was a Senior Lecturer with Universiti Teknologi Malaysia, in 2011. He was also a Visiting Researcher with Kyoto University and the Jordan University of Science and Technology, in 2014 and 2016, respectively. He is currently a Research Member of the Malaysia–Japan International Institute of Technology and the Center for Artificial Intelligence and Robotics, UTM Kuala Lumpur. His current research interests include edge computing, model-predictive control, path planning, and task allocation based on deep-reinforcement learning. He is a member of the Society for Underwater Technology, the Institution of Engineering and Technology, the Institute of Electrical and Electronics Engineers—Oceanic Engineering Society, and the Asian Control Association. He is a Registered Professional Engineer of the Board of Engineers Malaysia. He is a member and a Registered Chartered Marine Engineer of the Institute of Marine Engineering, Science and Technology. In 2017, he was a Committee Member of International RoboCup@Home Education. He has received several awards from the International RoboCup Competitions (Service Robot Category).

NOHAIDDA SARIFF received the degree in electrical engineering (automation and robotics) and the M.Sc. degree in electrical engineering from University Teknologi Mara (UiTM), Malaysia, in 2011, and the Ph.D. degree in control robotics from University Teknologi Malaysia (UTM), in 2021. She is currently a Senior Lecturer with the School of Engineering, Faculty of Innovation and Technology, Taylor's University, Malaysia. She has contributed to several peer-reviewed indexed journals and conference proceedings. Her current research interests include automation and robotics, mobile robot navigation, and path-planning algorithms. She is a member of the Board of Engineers, Malaysia. She has actively participated as a reviewer for both internal journals and Elsevier.