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Research Article

The order batching problem: A state-of-the-art review

Esra BOZ[1], Nil ARAS[2]

[1]*KTO Karatay University, Türkiye*
[2]*Eskişehir Technical University, Türkiye*

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ABSTRACT

The Order Batching Problem (OBP) has received a lot of attention from researchers in recent years. Until now, this problem has been considered as a whole with different problems or it has been studied on its own, with different solution methods, in different warehouse layouts, with different data structures. The aim of this study is to provide the researchers with a general analysis for studies using the OBP. In accordance with this purpose; the OBP is analyzed by an extensive literature review that includes all relevant studies to date. This literature review is based on a specific method and the studies are grouped into specific classes. Accordingly, the most studied problem with the OBP is the Picker Routing Problem (PRP) with 17% and 51% of the studies were solved by metaheuristic algorithms. The most widely used metaheuristic algorithms are Neighborhood Search and Genetic Algorithms.

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INTRODUCTION

A supply chain is a network of suppliers and retailers that provides raw materials and later turns these raw materials into intermediate and finished goods, ultimately providing consumers with a finished product [1]. Warehouse management is an important isue within the context of supply chain management. Warehouse operations have been a defensive tool employed by many firms to improve their competitive standing within a given marketplace. Similarly, warehouse processes are a set of operations relating to the receipt, storage, picking, and shipping of products under a number of operational and technical circumstances [2] flexibility and reliability of supply chains. For this purpose, warehouse process and the most common sub-processes and activities included in it were characterized. Additionally, it was noted that, warehouse processes may be implemented in many different ways and under various strategies. Selection of particular warehouse strategy usually depends on basic warehouse tasks, structure and size of customer orders, handled logistic units, costs of materials handling in particular sub-processes (both financial and time costs. Therefore, the warehouse functions are (I) Receiving products from a source; (II) Storage of products

***Corresponding author.**
*E-mail address: esrayasaarr@gmail.com

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until needed; (III) Picking of products when needed; (IV) Shipping of products to appropriate users [3].

Warehouse management systems are costly due to the extent to which are time-consuming and the physical nature of the operations. Tompkins et al. analyze, the costs associated with these four major warehousing operations, as can be seen in Figure 1 [4]. The percentages of warehousing operations are shown in Figure 2 [5]. The receipt and placement operations fall within the scope of the general reception processing actions of the warehouse. The packing and loading processes occur during the shipping phase of the warehousing operations. Inventory can be defined as an order-picking activity. Services that add value to a product include re-labeling, re-packaging, pricing, promotional services, partial assembly, repair and renovation, and the incorporation of components into products in response to certain market demands. As can be seen from these charts, the order-picking process is the most critical operation concerning all warehouse processes, as it has the largest impact on profitability.

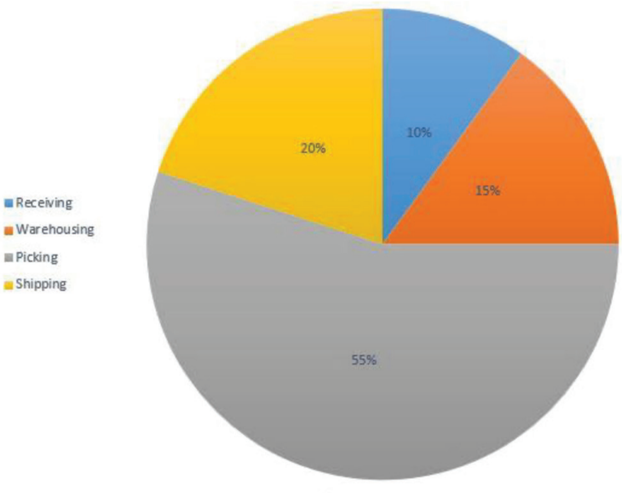

Figure 1 The percentages of warehousing costs [4].

The problem of order-picking is a vital issue in warehouse operations. There are several explanations for this. Firstly, the order-picking process is the costliest procedure among all of the warehouse operations. Order-picking is also the most labor-intensive function in the warehouse. As such, much research has been performed on the subject to tackle the issue of labor stress. However; as a consequence of this stress, however, the majority of the mistakes made in a warehouse are attributable to order-picking. Secondly, the management of order-picking is extremely difficult. In reality, this complexity is accompanied by the introduction of technologies such as 'just-in-time' production, cycle time reduction, and rapid return to warehouse processes. These applications also allow smaller orders from a given warehouse to be shipped to clients and provide more Stock Keeping Units (SKU). Thirdly, revived topics in quality control and customer service have driven warehouse managers to re-evaluate the value of minimizing product losses as well as the optimization of transition times in order-picking activities [6].

In this order picking process, which differs according to warehouse and order type, orders can be collected separately or in a group depending on the quantity and density of the order. In warehouses where the order size is small and the order frequency is high, it will be an efficient

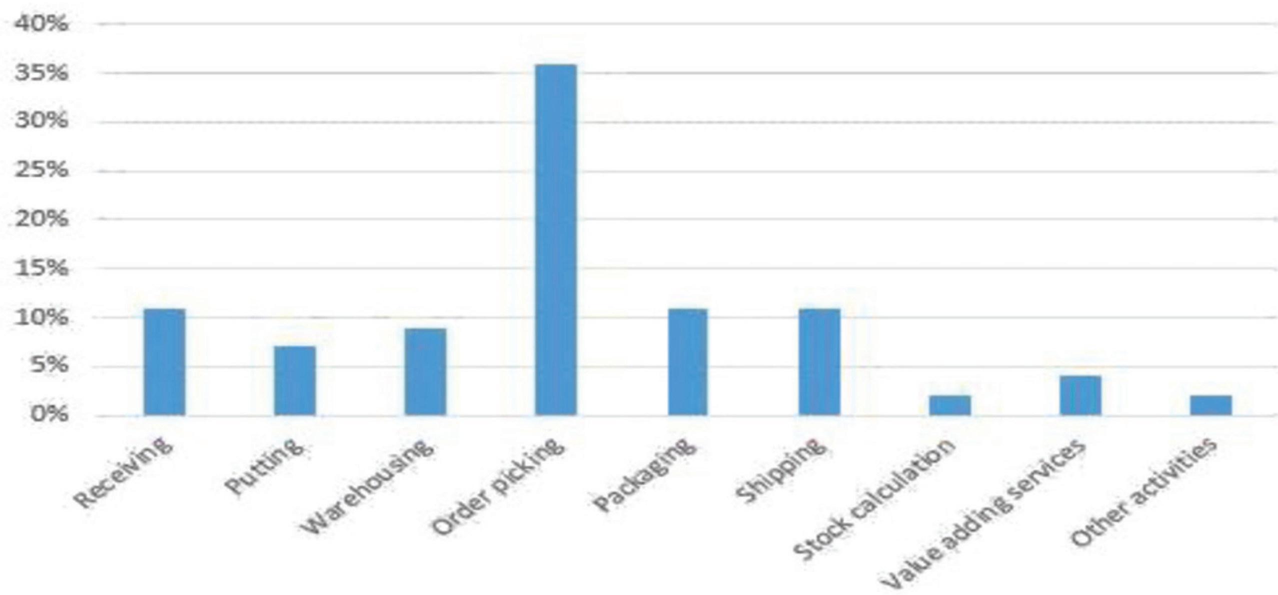

Figure 2 The percentages of warehousing operations [5].

process in terms of both time and distance to collect orders in groups. If the order is collected in a batch, the problem of attempting to determine the order groups that will be collected together for a specific purpose is called the OBP. With the practise of this problem, improvements will occur in the warehouse, both for the picking time of orders and for the picking distance of orders.

Note that the distinction between the order batching and batch-picking policy is important. Batch picking includes only the gathering and ordering of a specified group, while the selection of orders within the batch is concerned with order batching. While orders in the OBP come in a set, the order-picking problem is interested in the order and calculates the order routes [7]. Therefore, the problem of order batching is a sub-problem of order-picking.

The OBP is a problem that attempts to assign orders to batches simultaneously and to refine an objective function. The purpose of the functions in this problem is to reduce the total travel time by tackling sub-optimal logistics to shorten the total distance traveled [8]. Therefore, these concepts of grouping are represented as the range of proximity and time ([9] from [8]). In other words, as it relates to proximity, the closeness of group collection points is taken into account. In a similar way, concerning a time frame, the time at which the orders come to the warehouse is considered [10].

Gademann and Velde consider the OBP as a set partitioning problem and develop an integer programming formulation [8]. In this formulation, the notation is given in Table 1, the objective function aims to minimize the distance of the order picking tour. With this objective function, it enables the batch to be collected over the distance of the batches as the batch with the least distance.

Let s be a set of all batches feasible. The batches to be formed will be shown as $s \in S$

$$\sum_{j} c_j a_{js} \leq C$$

If order set j appears only in category s, then $a_{js} = 1$. When the total distance of travel of all commands in the s batch is expressed in d_s for the value of X_s defined by 0–1 value;

$$\min \sum_{s \in S} X_s d_s \tag{1}$$

Subject to:

$$\sum_{s \in S} a_{js} X_s = 1 \quad \square j \in J \tag{2}$$

$$X_s \in \{0,1\} \quad \square s \in S \tag{3}$$

Function (1) is the objective function and is intended to minimize the distance of the picking route. Equation (2) ensures that one batch is allocated to each order. Constraint (3) is the restriction of the sign.

In a study by Gademann and Velde (2005), the OBP was proven to be an NP-hard problem [8]. The most efficient solution to NP-hard problems cannot be achieved in a reasonable time. Many real-world optimization problems are NP-hard problems where effective algorithms are not demonstrably present. A viable alternative to solving these class problems is the use of heuristic algorithms [11]. Therefore, heuristic methods are developed in the literature to solve the OBP. These methods are divided into two classes as seed algorithms and saving algorithms. The first algorithm is seed algorithm. In the first stage of seed algorithms, a seed order is selected. Afterwards, orders are added to this order with different criteria (such as a random order or an order with fewest picking locations) and proceed by adding orders. Seed order selection rules can be found in these studies [12–18]. All seed order selection rules can be applied in two different ways, single mode and cumulative mode. In single mode, the seed order is selected only once. In the cumulative mode, the seed order is renewed each time a new order is received [19]. After the seed order is selected, new orders are added to the group according to the algorithm proximity criteria. The criteria or measurements are shown in the Table 2 [20].

The second algorithm is the saving algorithm. These algorithms are viewed as saving algorithms, because the difference between the time it takes to pick two orders and the time it takes to collect the combined order represents saving. It is based on the heuristic algorithm developed by Clark and Wright (1964) for the vehicle routing problem [24]. In these algorithms, there are special algorithms such as equal algorithm, and the big-small algorithm.

In the rest of this study, a literature review is conducted, based on a specific methodology related to the OBP and studies are divided into groups by improving a classification in the second section. The findings of this literature review are provided in the third section, and the results are expressed in the fourth section, Conclutions and recommedations are given in the final fifth section.

Table 1 Notation

	Parameters
S	Batches set
d_s	Picking distance of all orders to be collected in batch *s*
J	Order set
C	Order picker capacity
c_j	Capacity required by the order
a_{js}	Binary decision variable if order j is in batch *s*
	Variables
X_s	Binary decision variable if batch *s* is selected

METHODOLOGY

Literature research is the description of a topic area, which helps to identify specific research questions [25]. The methodological basis for resource research is a document analysis, typically conducted as an analysis of the material. For this purpose, the criteria that allow research and classification of relevant literature should be selected first. This description is part of the study [26]. When the studies on review analysis in the literature are examined, the foundations on which a general structure will be based for resource analysis are examined and the analysis is built on these foundations [25–28]. Firstly, questions regarding the research subject will be outlined within the framework of the resource study:

(1) What other issues did the authors integrate with the OBP, and what types of problems are they?
(2) Which methods were used to solve the OBP?
(3) What sort of measurements were used to analyze the performance of the solution?
(4) How was the parameter data that was created for the problem edited, and how were the parameter values determined?
(5) What is the layout of the warehouse in which the question arose?

Table 2 Order proximity measurements [20]

Proximity criteria	Examples
Number of common locations between two orders	[12]
Position number of two orders	[13]
Total distance between each location of an order and the nearest location of the order	[13]
Difference of order-theta values of two orders defined based on gap filling curves	[14]
Number of additional passages to be passed when two orders are combined	[21]
Travel earnings when two orders are combined	[22]
Gravity measure	[21]
Economic convex-based measurement	[23]
Common areas and regions	[16]

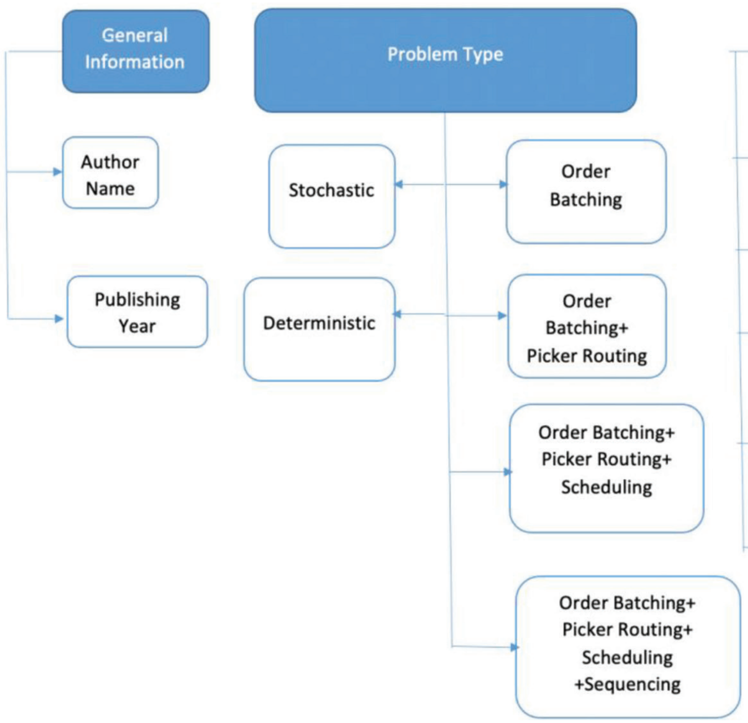

Figure 3 Categories in the OBP assessment.

Table 3 Number of studies of the OBP by year in the literature

Databases	2010–2020	2000–2020	All times
Google Scholar	127	152	160
Web of Science	54	66	71
Scopus	77	91	96

Within the scope of this study, literature research was conducted by seeking out the answers to the above questions within the framework of the following foundations:

Material Collection: This study used the Google Scholar, Web of Science, and Scopus databases. These databases examined relevant studies, books, and conference papers published in academic journals as given in Table 3.

Descriptive Analysis: The main results obtained from the analysis of selected publications are subdivided in this section according to the annual publishing distribution factor [27].

Category Definition: The categories are as shown in Figure 3. The first category, the general selection of information, is 'general knowledge' and refers to the extent to which one has a generalized understanding of the study. The 'problem' category, which is the second category, primarily deals with understanding the problem class that is shown in the study. Generally, these studies can be grouped into two classes; (I) dynamic problems which refer to issues where data can change and; (II) static problems where such data is previously specified. At the same time, a new classification can be made by considering the problems that are integrated into the OBP examined in these studies. Today's studies concentrate on analyzing sub-problems according to the preliminary and successive processes in an integrated system. Classifying a problem in this way will therefore serve as a useful means of expressing the problem and in understanding its place in the process. The extent and effects of using the techniques are therefore better understood. The "method" category of the solution, which is the third category, deals with understanding the method through which the problem is solved. In the data usage section that comprises category four, the focus is on the data structure in the studies. Here parameter values are examined after checking whether the data is real data. The 'warehouses category', which comprises the fifth and final criterion, investigates whether a given warehouse has a single-block or a multiple-block structure. In this way, it obtains information about which types of warehouses are weighted and which are less studied.

Study Evaluation: The studies obtained following the criteria specified in the section on the selection of materials were analyzed within the context of the research questions. The categories and analyses produced were made based on the parameters of this review. There are several studies in the literature concerning the grouping of orders. Studies titled "Order Batching" were viewed in the databases listed in the section on material processing, as shown in Table 2. In most of the literature studies on the subject, the OBP is found under order-picking or warehouse management titles only as subtitles [20,29–31]. Selected studies focus solely on the OBP literature. Cergibozan and Tasan (2019) explore the question of order batching as it relates to the overarching order-picking process [32], while Henn et al. (2012) analyze solution approaches to order batching [33] and Ma and Zhao (2014) examine solution algorithms in the OBP [34].

SOLUTION

Exact Solution Methods

The first of the order batching studies addressed issues relating to resource availability via exact solution methods. Vinod (1969) provides an analysis using two integer programming formulations: one with a linear purpose and the other with a quadratic purpose. The coefficients of the objective function are generated by assigning a value to each row. An example is given which considers the creation of seven lots of fourteen orders. In the study, he establishes the basis for order batching in mathematical modelling [35]. A second study was performed by Armstrong et al. (1979) [36]. The authors build a mixed-integer programming model for the OBP solution in this report and compare small sample solutions from the semi-automated order-picking method with those in the Bender approach [37].

Gademan et al. (2001) examine an OBP aimed at minimizing the maximum preparation time for each batch. The authors suggest one of the standard solution approaches, the branch and bound algorithm, and use the 2-opt heuristics to evaluate the upper limits in the algorithm. As a result of the analysis, a solution for a medium-sized problem can be found using this algorithm in real-time, and the algorithm will be sufficient in practice [38]. Using this study data; Gademan and Velde (2005) develope a branch and price algorithm. The authors show that this algorithm's proposal for small-scale problems produces better results than those gleaned from the analysis of 2001[8].

Bozer and Kile (2008) build a mixed-integer programming model for the OBP and contrast the results with the algorithms of Clarke and Wright along with the heuristic algorithm of Ruben and Jacobs [39]. It has been demonstrated, as a result of the analyses, that the current methods perform extremly well using boundaries [40]. In the same way, Wang and Tang (2008) also create a mixed-integer programming model, taking into account order flexibility and technological constraints. The authors develope a solution methodology that works in concert with Lagrange relaxation, dynamic programming, and heuristic methods [41]. In another study, Tang et al. (2011) develope a mixed-integer programming model to minimize all costs, including those associated with the assignment, stock-keeping, and penalties. In assessing the relationship between Lagrange relaxation and column generation, the authors were able to solve this model. The question was based on real data obtained from a major steel plant and randomly-generated large-scale samples. Results show that in a reasonable calculation time, the algorithm can achieve a tighter lower bound and higher quality solution compared to the conventional Lagrange relaxation algorithm [42]. Later; Muter and Oncan (2015) address the OBP in their studies using S-shaped, return, and midpoint routing strategies along with column generation. It is claimed that the best solutions are reached through the samples using a maximum of 100 orders [43]we deal with the Order Batching Problem (OBP. In addition to these studies Valle et al. (2016) develop an integer programming formulation for a holistic the Order Batching and Picker Routing Problem (OBPRP) in their study and solved it via the branch-and-cut algorithm. The authors developed test results based on partly public real-world data [44]. In another study, the authors again formulate the OBPRP, indicating a large number of legitimate inequalities, and demonstrating that these inequalities improve outcomes [45].

Apart from the studies which used integer programming, there are studies on linear programming. For example; Briant et al. (2020) develop a linear programming model for the OBPRP and suggest the column generation method as a means of solving this integrated problem. The authors prove that this approach is effective when applied to two separate sets of data [46].

Metaheuristic Methods

Hsu et al. (2005) develop a genetic algorithm approach for the OBP and solve this problem to minimize navigational distances in 2D and 3D warehouses of different layouts. As a result of their work, the authors state that, in terms of navigation distance, the proposed approach achieves quality solutions [47]. Oncan (2013) proposed a genetic algorithm for the OBP in his study, taking into account S shape and return-routing heuristics. The proposes method was tested on samples generated at random and compared to the saving algorithm [48]. Pinto and Nagano (2019) suggest a genetic algorithm solution to the OBSQP [49]. Ardjmand et al. (2019) offer a mathematical model for the OBPRP in their study and proposed genetic algorithms and simulated annealing algorithms to solve the problem with randomly generated data of small and large sizes [50]. In addition to studies considering the genetic algorithm, there are also studies using the hybrid algorithm combined with the genetic algorithm and nother algorithms in the literature. Examples of these include; Azadnia et al. (2013) put forward a hybrid approach to the OBP. The authors first use a weighted association rule mining method to cluster customer orders, followed by a binary integer programming model to generate batches. These developments enable them to establish a genetic algorithm for the picker routing problem [51]. Following this, Chen et al. (2015) use a hybrid algotirhm. The authors develop a nonlinear mathematical model that aims to minimize the delay of customer orders by simultaneously solving order-batching, sequencing, and picker-routing problems. They use mixed genetic and ant colony optimization algorithms as a solution for this model. The authors indicate that the hybrid algorithm used in the analysis is preferable to certain other algorithms in the literature [52].

In addition to genetic algorithms, group genetic algorithms were also used to solve the OBP or related problems. Pan et al. (2015) present a batching method based on the group genetic algorithm to reduce the number of batches to match each selection area's workload and to boost system performance. A simulation model based on FlexSim was used to implement this proposed algorithm and to compare yields for the different batching policies [53]. Koch and Wascher (2016) suggest a group genetic algorithm with the OBP. As a result of the study, the new genetic algorithm based on the group-oriented coding scheme is said to be preferable for the OBP and the algorithm offers high-quality solutions in reasonable calculation times [54]. Mutingi and Mbohwa (2017) offer a hybrid group genetic algorithm method for the OBP in the study. The authors state that, as a result of the study, this method can provide better solutions compared with other methods in the literature [55].

Neighborhood search algorithms are also used a lot in existing studies such as genetic algorithms. The first of these is the study of Albareda-Sambola et al. (2009). The authors improve a variable neighborhood search algorithm for the OBP and analyze four different types of warehouses. The authors state that the proposed method is competitive and applicable according to the results obtained [56]. After this, Henn (2015) promotes a mathematical model for the OBSQP, which aims to reduce total customer order delays, suggesting variable neighborhood descent and variable neighborhood search algorithms as a solutions [57]. Menendez et al. (2017) propose a search algorithm for the min-max OBP for a variable neighborhood [58]. They suggest a variable neighborhood search algorithm for the OBSQP solution in another study carried out by Menendez et al. The authors state that, when comparing solutions with different examples in the literature, the algorithm is better in both quality and computation time [58]. In their study, Scholz et al. (2017) build a simultaneous mathematical model for Order Batching, Batch Assignment, and Sorting, Picker Routing Problems (OBBAPRP), and propose a variable neighborhood descent algorithm to solve this problem theyhad created [59]. Xiang et al. (2018) examine a mixed-integer programming model for the Stock Assignment Problem and Order Batching Problem (SAOBP) in their research. The authors solve the problem with a variable neighborhood search algorithm, within the Kiva mobile fulfillment system. The objective of the stock assignment problem, which is the first stage of this problem, is to increase product similarities in the compartments, and the OBP's goal, the second stage of the problem, is to decrease the number of visits to the compartments. As a result, it is reported that the proposed algorithm has good performance for medium-scale and large-scale problems on both solution quality and solution time compared to the genetic algorithm [60]. Pei et al. (2019) advance an OBP mathematical model and develop a variable neighborhood search algorithm for a model solution [61]. Gil-Borras et al. (2019) offer a neighborhood search algorithm with various variants for OBP in their analysis, with several pickers to solve along with two different routing strategies [62]. Kuhn et al. (2020) also develop the OBP and the Vehicle Routing Problem (OBVRP) incorporated into their research. A mathematical model is developed in this research, which uses real data, to minimize the delay of all orders, and an adaptive large neighborhood search algorithm is proposed for its solution [63]. Matusiak et al. (2017) build a mathematical model for Order Batching and Generalized Assignment Problem (OBGAP). The method consists of two parts in this study; the first part estimates group collection times based on the characteristics of past groups, and the second part proposes an Adaptive Large Neighbourhood Search algorithm for this integrated problem. The study also emphasizes that managers should take into account employee skills and abilities in the decision-making process [64]. A hybrid adaptive large neighborhood search and tabu search algorithm for the OBP is promoted by Vzulj et al. (2018) The authors evaluate this algorithm built for samples up to 600 orders and report that they have found an effective solution [65].

After the studies solved by genetic algorithms and neigborhood search algorithms on the OBP, most studies in the literature are related to local search algorithms. The first of these is Henn et al. (2010) who improve iteration methods for local search algorithms and ant colony optimization for the OBP, in their study. The authors compare the results they obtained to different studies in the literature with two different routing strategies and report that the iteration local search algorithm yields more streamlined results concerning time than ant colony optimization [66]. In another investigation, Henn (2012) proposes a first-come-first-served model proposed by Clarke and Wright, as well as iteration local search algorithms, which are implemented in two routing strategies. In this study, the author also shows how algorithms used for the OBP can be applied to the Online Order Batching Problem (OOBP) [67]. Henn and Schmid (2013) suggest an attribute-based hill climber algorithm as well as an iteration local search algorithm based on a tabu search algorithm for the Order Batching and Sequencing Problem (OBSQP) [68]. Oncan (2015) developed a mixed-integer programming formulation for the OBP based on S shape, return, and midpoint routing strategies in his research and suggests the Repetitive Local Search Algorithm with Tabu Threshold to solve the problem. The proposed algorithm gives highly effective performance ranges, both in terms of accuracy and efficiency, according to the results stated in the study [69]. Scholz and Wascher (2017) also improve an iterated local search algorithm for the OBPRP in another study. After the solution is applied, they claim that the results are obtained using the algorithm compared to the solution that was made without using the algorithm [70].

Cheng et al. (2015) propose a hybrid algorithm for the OBPRP in their study, using algorithms for particle swarm optimization and ant colony optimization. The authors use the particle swarm optimization algorithm to achieve the minimum travel distance necessary for order batching, while also applying the ant colony optimization algorithm to real data to find the most effective way to organize each batch. Findings from this study report that the hybrid algorithm is more efficient in terms of both solution consistency and computational efficiency compared to the known optimal solution and applications available [71]. Lin et al. (2016) advance an optimization algorithm for the OBPRP by particle swarm. It is mentioned as a result of the analysis that this solution method applied to real data yields quality results according to correct parameter values [72]. Li et al. (2017) develop an integrated OBSQP integer programming formulation that minimizes total travel time and proposes a colony optimization algorithm developed with a local search to solve this problem. It has been applied to real data in Chinese retail, and the results show that the proposed common optimization algorithm has potential benefits in different order sizes and order structures [73]. In a study by Hojaghani et al. (2019), a new nonlinear mathematical model for the OOBP was promoted in a zone picking strategy, and this problem was solved using artificial bee colony and ant colony optimization algorithms using real data. In the analysis, it was reported that the findings show improved performance with a small decrease in the response time of the average customer orders compared to the results ofa study by Zhang et al.'s work [74]. At the same time, the ant colony algorithm performs better than the artificial bee colony algorithm [75].

There are a number of studies in the literature in which the tabu search algorithm is used for the OBP. Henn and Wascher (2012) improve two algorithms for the OBP, namely the tabu search and attribute-based hill climber algorithms that are capable of minimizing the picking distance for each route. The results of the proposed methods were compared with the methods in the literature, and it was shown that these methods are superior to current methods, as they enable more efficient work in practices in warehouses [76]. Zhao and Yang (2017) suggest a tabu search algorithm for the OBP in their study. The problem was solved with the data proposed from a real e-commerce company's warehouse, with the proposed algorithm, and it was stated that the proposed algorithm could greatly improve the efficiency of order picking compared to the results of current operations [77]. Kulak et al. (2012) propose a seed algorithm based on tabu search and clustering for the OBPRP and solve the problem using two different types of algorithms [78].

The OBP and Picker Routing Problem (PRP) are solved separately by Matusiak et al. (2014) using heuristics. The proposed solution entails the introduction of restricted priority grouping (for example, putting heavy goods under a container) for the OBP. In their study, the authors propose the simulated annealing algorithm for the OBP, and the A* algorithm introduced by Hart et al. for PRP [79,80]. Nicolas et al. (2018) examine the OBP automated collection systems. The authors design a simulated annealing approach to solve the problem, intending to reduce the time needed to pick orders, and they solve the problem on the data of two separate companies using the proposed algorithm [81].

Hojaghani et al. (2019) in another study, enhanced an OOBP model, which aims to reduce the total amount of idle times per picker operator block and the cumulative order return time, and solve this model with a teaching-learning-based optimization algorithm for blocky and blockless warehouse types. Based on the results obtained, it is reported that the warehouse blocking program has a major impact on the reduction of the warehouse orders return time and idle time [82].

Heuristic Methods

Although not as much as metaheuristic algorithms, heuristic algorithms are also used for the solution of the OBP. Heuristic solutions have been previously applied for a solution for the OBP. The first is a study by Hwang and Lee (1988) who develop a clustering algorithm in the OBP that aims to reduce travel time [83]. After this, Elsayed and Unal (1989) improve heuristic algorithms designed to reduce the travel time on the OBP [22]. In another research study, Gibson and Sharp (1992) suggest a heuristic algorithm for the OBP and tackle the issue with their stock assignment policies in mind [14]. Pan and Liu (1995) study batching algorithms, which consists of four seed select rules and four order addition rules as comparative. Additionally, the authors compare algorithm efficiency with three sizes of shape, picker capacity, and stock assignment policy factors [18].

Rosenwein (1996) proposes an algorithm that would use different distance measurements to select the order for the OBP [21]. Koster et al. (1999) contrast the saving algorithms, the First-Come-First-Served algorithm with the seed algorithm. The authors claimed as a result of the analysis that the seed algorithm methods have the best results with the high-capacity picker and the S-shaped routing methods, while the savings algorithms do better with the low-capacity picker and the largest gap routing method [17].

Won and Olafsson (2005) enhance a model for the OBP and develop two heuristic algorithms for this model's solution, the object of which is to reduce the weighted average of total aggregate picking time and batch waiting time [84]. Zhang et al. (2016) examine the subject of the integrated online Order Batching and Scheduling (OBSP) problem. The authors suggest a solution based on new laws, by constructing a mathematical model. The approaches describe which instructions are urgent and can be issued immediately, and which can be met later [85]. Hong et al. (2017) explore the issue of the OBP with the S shape routing strategy. In solving the problem, a set of routes is specified for S-shape routes, and the most appropriate route is generated for batches from the predefined S-shape routes when splitting the orders into lots. The authors propose a model to minimize the total distances of the picker routes by selecting a route for the OBP [86]. Pferschy and Schauer (2018) offer a heuristic algorithm for the OBPRP in their study. The writers apply this new algorithm to data from real-life [87]. Bue et al. (2019) research an advanced OBPRP regarding a textile company's real details. General features of the problem under analysis are as follows: orders should be divided into multiple boxes; and boxes should be divided into pickers with a certain hierarchy in the collection field. A two-step heuristic algorithm is proposed to solve large-scale problems with ease [88]. Aboelfotoh et al. (2019) advance a statistical model for the OBP. The authors suggest a heuristic algorithm for larger-scale model solutions [89]. Alipour et al. (2020) build a mathematical model for the OOBP in their research and create a rule-based heuristic algorithm for their solution [90].

3.3. Simulation*:*

There are a few studies in the literature that use simulation models for the OBP solution. The first of these is a studiy by Elsayed et al. (1993) whinch examines the OBSQP, for orders to be delivered on time. In the study, to reduce early and delay penalties was aimed in the Automated Storage / Retrieval Systems warehouse [91]. Another study by Le-Duc and Koster (2007) solve the OBP by simulation procedure, assuming the orders come with a Poisson cycle to the warehouse and use the intuition of the S-shape to route order pickers. The findings show that this method offers a high degree of precision [92]. Following this, Yu and De Koster (2009) develop a model based on queuing theory to examine the impact of order batching in order picking on the average order over time. In the order picking method, the average processing time of a random order is obtained in light of the details. The authors claim that the findings obtained in the study from a real application and simulation provide reasonable precision, and that order picking systems can be easily implemented in the design and selection process because the proposed method is simple and fast [93]. Pan et al. (2011) suggest an empirical model method based on probability and queuing theory in order picking framework to evaluate order batching and picking on average order delivery time. They also note that the resulting model can be conveniently implemented during the order picking systems design and selection process [94]. With optimization and simulation, Zuniga et al. (2015) build a hybrid algorithm for the OBP in their research. The optimization algorithm generates the initial solution of certain deterministic parameters that feed the model of simulation [95].

Data mining:

Data mining has been used in recent years for the OBP solution. The first study using data mining is a study by Chen and Wu (2005) who develop an approach based on data mining and 0-1 integer programming. Based on 0-1 integer programming, this solution approach aims to increase the relationship between commands within each group [96]. Hwang and Kim (2005) analyze the issue of the OBP in terms of overall travel time and several s generated batches and develop an algorithm focused on cluster analysis. Within this algorithm, S shape, return, and midpoint heuristics are utilized as routing strategy. This algorithm, developed by the authors, is compared with the algorithms in the literature, and it is stated that the algorithm is superior when the number of orders is greater than tewnty, and the seed algorithm is superior when the number of orders is less than tewnty [97]. Ho et al. (2006) develop grouping approaches that take seed order selection rules and order addition rules for the OBP. By addressing the rules usng two separate routing strategies, they find the solutions by ANOVA [15]. In another study by Ho et al. (2008) analysis, the utility of the fourteen seed order selection rules and order addition rules is investigated in conjunction with previous research. Similarly, the findings are analyzed via ANOVA to find the most powerful combination of rules [98].

FINDINGS

A number of the studies in the literature examine the bullwhip impact of the supply chain order batching process [99,100]. Though certain studies don't propose a solution to the OBP, all leverage the development of a mathematical model or the distribution of a solution process in which parameters are recommended [101,102]. Nevertheless, the order batching process is considered a problem in many literature articles, and this question is investigated from different angles in order that an approach might be developed and a solution ultimately found.

Within the framework of the resource analysis, research has been carried out wherein studies utilize the problem approach by recognizing the order batching process as an issue, and offer a solution method included in the study. As such, sixty-eight studies were reviewed without any restriction based on years, as can be seen in appendix. Such reviews can be described by category as follows:

General Information:

Years worked in the general field of knowledge are analyzed. As seen in Figure 4, 14% of the studies analyzed are from 2017, with the study distribution ranging from 1969 to 2020. Since 2017, 12% of the works are from 2019.

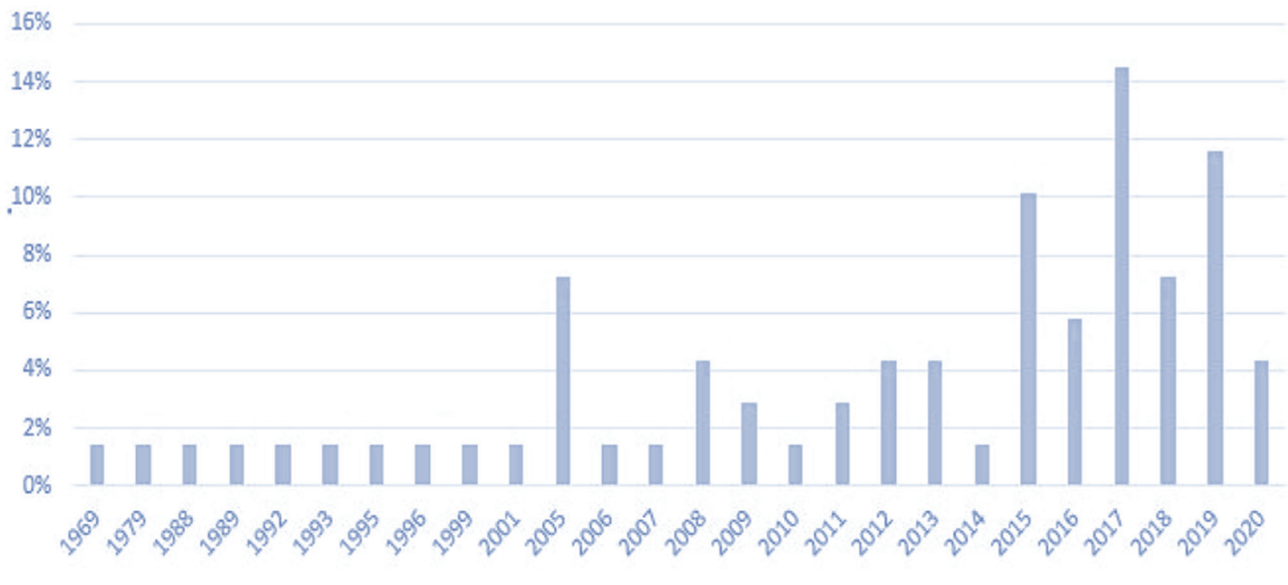

Figure 4 Working distribution by years.

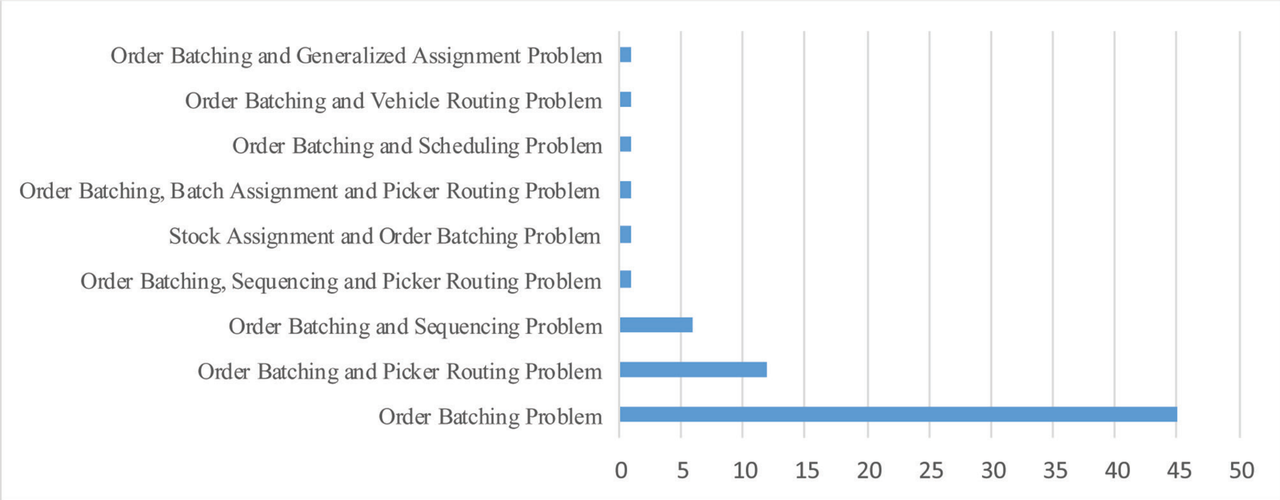

Figure 5 Problem structures in the studies.

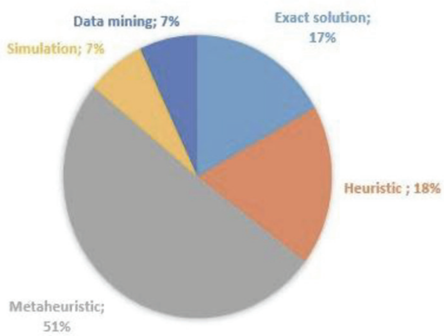

Figure 6 Working rates according to solution methods.

Therefore, 2017 has the largest number of studies, and the year with the second-highest number of studies, within the framework of the studies examined, is 2019.

Problem Type:

The problem type is actually divided into two categories. Firstly; it is related to the sub-problems involved in the problem. This category is as expressed in Figure 5; the most reviewed number of studies relating to the OBP with 65 %. Next, 17% of these studies belong the OBPRP that combine the order grouping problem and the routing problem. In this way, most studies on the OBP in the literature are those in which only the OBP is discussed. Secondly; in the structural classification of order, grouped as either static or dynamic, 9% of the examined studies are dynamic and 91% are static. SGP studies with dynamic structure are referred to as Dynamic OBP (Online Order Batching Problem-OOBP) in the literature. Dynamic studies start in 2012 and have been increasing recently.

Solution Method:

As can be seen in Figure 6, concerning these tests, 51% of the studies are solved by metaheuristic algorithms, 18% by heuristic algorithms, 17% by specific methods, 7% by simulation, and the remaining 7% by data mining solution methods. It should be noted in this sense that most metaheuristic algorithms are used within the framework of the studies being analyzed. If the metaheuristic algorithms are analysed, it can be seen that the most widely-used algorithms are neighborhood search algorithms and genetic algorithms.

The Data Considered:

It is of interest to determine whether the data used in the application type use tests is real data (case study). Based on actual evidence, 25% of the studies are completed, while true statistics have not been included in the remaining 75% of the reports.

Warehouse Structure:

In the warehouse structure segment, where single-block warehouses are evaluated for the warehouse systems listed in the studies, 45% of the studies were conducted in single-block warehouses, 29% were conducted in multiple-block warehouses, and 3% were conducted in single-block and multiple-block warehouses. In the remaining 23% of the studies, the warehouse layout is not defined. Therefore, it can be claimed that the studies presented in the literature are less applicable to multi-block structure warehouses.

CONCLUSIONS

The OBP has received much attention from researchers in recent years. Until now, this problem has been considered as a whole with different problems or it has been studied alone, with different solution methods, in different warehouse layouts, with different data structures.

The aim of this study is to provide the researchers with a general analysis for studies using the OBP. In accordance with this purpose in this study, a detailed literature research has been conducted on the OBP, which is a component of Order Picking Process. After an explanation of the subject, relevant studies were analyzed. A classification has been made based on a specific method and the studies have been examined according to this classification. As a result of this analysis, it has emerged that the OBP is an up-to-date and vibrant topic. In this increasing work, the PRP is the most-studied subject in the OBP literature. These two problems are handled as a problem and various solution methods are developed for their solution. In the literature there are fewer studies on the OOBP. When the solution methods of these studies are examined, it is shown that metaheuristic methods are the most commonly-used, and that data analysis methods and modeling are the least-commonly used. Furthermore, data usage is critical for studies. The use of real data is important for a study to be applied to a real-life problem. Although the OBP is a real-life problem the number of studies using real data is minimal in the scheme of literature research.

Warehouse structure is an important factor that affects the solution of the OBP. Therefore, while examining the studies, it is necessary to analyze warehouse structure. According to this analysis; in warehouses with multiple-block systems, OBP research is less when the warehouse structure in the researched studies is examined.

The literature review show that since there are few studies in which the OBP and out-of-warehouse processes are integrated, therefore; this is a gap in the field. The OBP should be considered together with out-of-warehouse processes in order to reduce supply chain costs more efficiently.

This study has certain limitations. Studies containing 'Order Batching' in their title, addressing order batching as a problem and the propose-solution method, were examined. Therefore, future researchers can contribute to this research by expanding their scope to integrate order batching into warehouse management systems. At the same time, they can perform analysis for the solution of the OBP (for example, parameter analysis in metaheuristic usage) by improving the dimension of this study. Future research could further investigate other problems integrated with the OBP. In particular, because the OOBP is a problem type more suitable to real life, it has become the most trending subject of recent times.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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APPENDIX

Study	Problem Type		Solution Method	The Data Considered	Warehouse Structure	Objective
[35]	OBP	Static	Integer programming	Hypothetic	-*	Minimizing the total distance
[36]	OBP	Static	Mixed integer programming	Hypothetic	-*	Minimizing the total time
[23]	OBP	Static	Hierarchical clustering algorithm	Hypothetic	-*	Minimizing the total distance
[22]	OBP	Static	Equal, Small and large, Maxsav, CWright algorithms	Hypothetic	-*	Minimizing the total navigation time
[14]	OBP	Static	2-dimensional spacefilling curve, Sequential minimal distance algorithms	Hypothetic	Single block	Minimizing the total distance
[91]	OBSQP	Static	Simulation	Hypothetic	-*	Minimizing early and delay penalties of orders
[18]	OBP	Static	Seed, Small and large algorithm	Hypothetic	-*	Minimizing the travel distance of the collector
[21]	OBP	Static	Order batching heuristic, Gibson-Sharp heuristic	Hypothetic	Single block	Minimizing the total navigation time
[17]	OBP	Static	Seed, Clarke and Right, Equal, First come first served algorithms	Hypothetic	Single block	Minimizing the total navigation time
[38]	OBP	Static	Branch and bound algorithm	Hypothetic	Single block	Minimizing the maximum delivery time of any of the groups
[8]	OBP	Static	Branch and price algorithm, recurring descent algorithm	Hypothetic	Single block	Minimizing the total distance
[47]	OBP	Static	Genetic algorithm	Hypothetic	Single block	Minimizing the travel distance
[96]	OBP	Static	Data mining	Hypothetic	Single block	Maximizing the link between orders in the group
[97]	OBP	Static	Batching algorithm based on cluster analysis	Hypothetic	-*	Minimizing the travel distance of the collector
[84]	OBP	Static	Sequential order batching and picking, Joint order batching and picking algorithms	Hypothetic	-*	Minimizing the weighted average of the total collection time of the groups and waiting time of the orders in the group
[15]	OBP	Static	Data mining	Hypothetic	Single block	Minimizing total order picking distance
[92]	OBP	Static	Simulation	Hypothetic	Multiple block	Minimizing the total time
[40]	OBP	Static	Mixed integer programming and heuristic	Hypothetic	Single block	Minimizing the total distance
[98]	OBP	Static	Data mining	Hypothetic	Single block	Minimizing total order picking distance
[41]	OBP	Static	Mixed integer programming-Lagrange relaxation	Real data	-*	Minimizing the total cost
[56]	OBP	Static	Variable neighbourhood search	Hypothetic	Single block	Minimizing the total distance
[93]	OBP	Static	Queue modelling	Real data	Multiple block	Reaching the average production time of a random order

[66]	OBP	Static	Iteration local search-Ant colony optimization	Hypothetic	Single block	Minimizing the total length of the entire lap
[42]	OBP	Static	Mixed integer programming	Real data	-*	Minimize all costs, including assignment cost, stock holding cost, and penalty cost
[76]	OBP	Static	Behaviour based hill climbing-Tabu search	Hypothetic	Multiple block	Minimizing the total distances of the picker routes
[67]	OBP	Dynamic	Iteration local search-Clarke and Wright-First in first services	Hypothetic	Single block	Minimizing the maximum completion times of orders
[78]	OBPRP	Static	Seed algorithm and tabu search based on clustering	Hypothetic	Single block-multiple block	Minimizing the total travel distances of all tours and groups
[48]	OBP	Static	Genetic algorithm	Hypothetic	Single block	Minimizing the total distances of the collector routes
[51]	OBP	Static	Genetic algorithm – data mining	Hypothetic	Multiple block	Minimizing the total delays of customer orders
[68]	OBSQP	Static	Iterated local search-Feature based hill climbing algorithm	Hypothetic	Single block	Minimizing the total delays of customer orders
[80]	OBPRP	Static	Simulated annealing-A*	Real data	Multiple block	Minimizing the total routing costs of the groups
[43]	OBP	Static	Mixed integer programming - Column generation	Hypothetic	Single block	Minimizing the total distance of collectors
[52]	OBSQPRP	Static	Hybrid genetic algorithm and ant colony optimization algorithm	Hypothetic	Single block	Minimizing the total delays of customer orders
[71]	OBPRP	Static	Particle swarm optimization-Ant colony optimization	Real data	Single block	Minimizing the total distance
[69]	OBP	Static	Iterated local search algorithm	Hypothetic	Single block	Minimizing the total distances of the collector routes
[57]	OBSQP	Static	Variable neighbourhood descent and neighbourhood search algorithm	Hypothetic	Single block	Minimizing the total delays of customer orders
[95]	OBP	Static	Optimization-Simulation	Hypothetic	Single block	Minimizing the total travel distance
[53]	OBP	Static	Genetic algorithm	Hypothetic	-*	Minimizing the number of groups and balancing the workforce
[44]	OBPRP	Static	Integer programming-branch and cut algorithm	Hypothetic	Multiple block	Minimizing the total distance
[72]	OBPRP	Static	Particle swarm optimization	Real data	Multiple block	Minimizing the travel distance
[54]	OBP	Static	Genetic algorithm	Hypothetic	Single block	Minimizing the total length of all laps
[85]	OBSP	Dynamic	Seed, Urgentseed, Clark and Wright, Urgent Clark and Wright algorithms	Hypothetic	Single block	Minimizing service time and maximizing the number of orders delivered

[45]	OBPRP	Static	Mixed integer programming	Real data	Multiple block	Minimizing the total distance
[103]	OBP	Static	Variable neighbourhood search	Hypothetic	Single block	Minimizing the total distance
[73]	OBPRP	Static	local search algorithm	Real data	Multiple block	Minimizing the travel distance
[86]	OBP	Static	the S-shape route-packing based batching procedure algorithm	Hypothetic	Single block	Minimizing the total distances of the collector routes
[59]	OBBAPRP	Static	Variable neighbourhood descent algorithm	Hypothetic	Multiple block	Minimize total delays
[64]	OBGAP	Static	Adaptive large neighbourhood search	Real data	Multiple block	Minimizing the time required to collect all orders
[55]	OBP	Static	Genetic algorithm	Hypothetic	Single block	Minimizing the distance required to collect all orders
[58]	OBSQP	Static	Variable neighbourhood search	Hypothetic	-*	Minimizing the total delays of customer orders
[70]	OBPRP	Static	Iteration local search	Hypothetic	Multiple block	Minimizing the total distance
[77]	OBP	Static	Tabu search	Real data	Multiple block	Minimizing the total length of all laps
[65]	OBP	Static	Adaptive large neighbourhood search and tabu search	Hypothetic	Single block	Minimizing the total length of all routes
[60]	SAOBP	Static	Variable neighbourhood search	Hypothetic	Multiple block	Maximize product similarity in all pods and minimize pod visits
[81]	OBP	Static	Simulated annealing	Real data	Multiple block	Minimizing the time required to collect all orders
[88]	OBPRP	Static	Heuristic algorithm based on a double split procedure	Real data	Multiple block	Minimizing the total distance
[87]	OBPRP	Static	Heuristic algorithm based on a fairly general graph model	Real data	-*	Minimizing the total length of the entire lap
[75]	OBP	Dynamic	Teaching-learning based optimization algorithm	Hypothetic	Single block-multiple block	Minimize the total amount of idle times per block of the pickup operator and the maximum return time of orders
[75]	OBP	Dynamic	Artificial bee colony algorithm -Ant colony algorithm	Hypothetic	Multiple block	Minimize the total amount of idle times per block of the pickup operator and the maximum return time of orders
[104]	OBP	Static	Genetic algorithm	Hypothetic	-*	Minimizing the total length of all laps
[49]	OBSQP	Static	Genetic algorithm	Hypothetic	Multiple block	Minimizing the total distances of the collector routes

[62]	OBP	Dynamic	Variable neighbourhood search	Hypothetic	Single block	Minimizing the time required to collect all orders
[50]	OBPRP	Static	Genetic algorithm – Simulated annealing	Hypothetic	-*	Minimizing the total travel distance
[89]	OBP	Static	Order batching heuristic	Real data	Single block	Minimizing the total travel distance
[61]	OBP	Static	Variable neighbourhood search	Real data	Single block	Maximizing your savings distance
[46]	OBPRP	Static	Linear programming-Column generation	Real data	Multiple block	Minimizing the total distances of the collector routes
[90]	OBP	Dynamic	Rule based heuristic algorithm	Hypothetic	Single block	Minimizing the time required to collect all orders
[63]	OBVRP	Static	Adaptive large neighbourhood search	Real data	Multiple block	Minimizing the total delay times of all orders

*No information was given about the warehouse structure.