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A review of research trends in order batching, sequencing and picker routing problems

Revisión de las tendencias de investigación en los problemas de conformación de lotes, secuenciación y ruteo del picking

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Content

ABSTRACT:
This paper provides a discussion about order batching, sequencing and picker routing problems in order to identify research trends and gaps to meet real conditions of warehouses operations. Main approaches to order picking operations, problem settings, function objectives, and solution methods implemented in the literature are exposed. The future research trends focus on the importance of considering due dates, multi-objective approaches, dynamic arrivals of customer orders, multiple pickers, congestion and picker blocking, and 3D warehouse layouts with multiple blocks.
Keywords Order picking; Literature review; Warehouse management

RESUMEN:
Este artículo es presenta una discusión sobre los problemas de conformación de lotes, secuenciación y ruteo del picking. Con el fin de identificar brechas y tendencias de investigación se describen los principales enfoques en la preparación de pedidos, la configuración de los problemas, funciones objetivo y métodos de solución implementados. Las tendencias de investigaciones se enfocan en la inclusión de fechas de entregas, enfoques multiobjetivos, problemas dinámicos, múltiples operarios, congestión y bloqueo de operarios, y almacenes 3D con múltiples bloques.
Palabras clave: Preparación de pedidos; revisión de literatura; gestión de almacenes

1. Introduction

Warehouses are essential components for supply chain management and logistics (Cheng, Chen, Chen, & Yoo, 2015), because they are responsible for linking suppliers, production plants and distribution systems, storing products and recovering them in order to meet customer orders due dates (Ballestín, Pérez, Lino, Quintanilla, & Valls, 2013; Chen, Huang, Chen, & Wu, 2005; Henn, 2015; Karásek, 2013). This situation makes that the performance of operations in warehouses and distribution centers affects customer service, logistics costs, and efficiency of the entire supply chain (Ballestín et al., 2013; Chen, Cheng, Chen, & Chan, 2015; Karásek, 2013; Koch & Wäscher, 2016), up to the point at which warehousing can represent about 20% of the supply chain costs (Rubrico, Ota, Tamura, Akiyoshi, & Higashi, 2004).

Because of this, optimize storage operations and make them faster and adaptive has become a priority of vital importance (Albareda-Sambola, Alonso-Ayuso, Molina, & De Blas, 2009; Cergibozan & Tasan, 2016), since a small improvement in the efficiency of these operations can generate significant savings in costs and products movement (Centeno & Sundaram, 2004; Chen et al., 2005; Chen & Wu, 2005). The main operations that define a warehouse flow are receiving, put-away, storage, receipt of orders, order picking, sorting, packaging and shipment (Ballestín et al., 2013; Bartholdi & Hackman, 2014; Lee, Chang, Shim, & Cho, 2015; Tompkins, White, Bozer, & Tanchoco, 2010), being the order picking the most repetitive and labor intensive operation (Cheng et al., 2015; Henn, Koch, & Wäscher, 2012; Tompkins et al., 2010) generating 50-70% of operating costs (Bartholdi & Hackman, 2014; Chen et al., 2015; De Koster, Le-Duc, & Roodbergen, 2007; Kulak, Sahin, & Taner, 2012; Pan & Wu, 2012; Rubrico, Higashi, Tamura, & Ota, 2011). Order picking is responsible for recovering a specified amount of products from its storage location to meet customer orders (internal or external), while workers walk or drive a material-handling device through the warehouse (Albareda-Sambola et al., 2009; Bustillo, Menéndez, Pardo, & Duarte, 2015; Henn & Wäscher, 2012; Koch & Wäscher, 2016).

However, despite attempts to automate picking operations, manual order picking systems are the most commonly implemented in practice (Pan & Wu, 2012), involving human operators at large scale (Henn & Schmid, 2013; Henn, 2012). This is explained to some extent by the flexibility and autonomy offered by human operators, achieving the goals set in the operation, avoiding collisions, deadlocks and blockages with other agents (Lee et al., 2015; Rubrico et al., 2004), and also explained by the low labor costs in countries or regions where automation storage systems are not economically viable. In manual-order-picking systems, the picker-to-parts picking is the most widely used method, where operators must travel through the aisles of a warehouse retrieving stored products in shelves to fulfill a customer order (Bozer & Kile, 2008; Dallari, Marchet, & Melacini, 2009).

Due to that, responsiveness is a crucial success factor for companies, and order picking is a routine operation, any improvement on product movement can represent significant savings for a warehouse system (Hsu, Chen, & Chen, 2005). In this sense, grouping effectively customer orders into picking orders, sequencing them and determining the routes for the order pickers are pivotal to enhance order picking from an operative level (Albareda-Sambola et al., 2009; Koch & Wäscher, 2016; René De Koster, Roodbergen, & Voorden, 1999). In order to optimize the picking process, many studies have focused on creating policies and methods to solve problems related to the order batching, sequencing and router picking (Henn & Wäscher, 2012; Henn, 2012; Kulak et al., 2012; Pan & Wu, 2012). These problems have been tackled jointly in previous studies to provide a comprehensive solution to order picking (Chen et al., 2015; Cheng et al., 2015; Kulak et al., 2012; Scholz, Schubert and Wäscher, 2017; Tsai, Liou, & Huang, 2008; Valle, Beasley, & da Cunha, 2017; Won & Olafsson, 2005), fulfilling a certain objective function to reduce operative costs (Cheng et al., 2015; Henn, 2012; Hsieh & Huang, 2011; Hsu et al., 2005; Kulak et al., 2012; Rubrico, Higashi, Tamura, Nikaido, & Ota, 2009), and enhance customer service (Ballestín et al., 2013; Chen et al., 2015; Henn & Schmid, 2013; Henn, 2015).

Recent researches suggest capturing complexities of the real environment of a warehouse system, including the complexities involved in real life applications and providing fast and competitive solutions (Cergibozan & Tasan, 2016; Davarzani & Norrman, 2015). This has meant that new approaches and models have been proposed in the last decade for the order batching, sequencing and picker routing, therefore, several literature reviews have addressed these issues. These literature reviews have been presented by authors such as Gu, Goetschalckx and McGinnis (2007), Dukic and Oluic (2007), De Koster et al. (2007), Henn et al. (2010), Henn et al. (2012), Karásek (2013), Ong and Joseph (2014), Ma and Zhao (2014), and Cergibozan and Tasan (2016).

These literature reviews have focused mainly on the solution methods with heuristics, metaheuristics, exact solutions and other methodologies. However, it is necessary to highlight other issues that have not been discussed enough in previous review articles, such as the availability of information (online problem), warehouse layout and configuration, number of pickers, objective functions, due dates consideration, the joint order batching, sequencing and picker routing problem, and research opportunities suggested by several authors. These topics allow formulating models and solution approaches that fit the real environments of warehouses and distribution centers, and are discussed in this article.

For this very reason, we aim to present a discussion about the joint order batching, sequencing and picker routing problem in order to identify research trends and gaps in the order picking operations, exposing and describing the main approaches for the order picking problem, problem settings, function objectives, and solution methods implemented in the literature. The remainder of this work is organized as follows. Section 2, introduces the order picking system, detailing in order batching, sequencing and picker routing operations. Section 3, describes the order picking models and assumptions found in the literature review. Section 4, highlights future trends and research opportunities identified in literature, and Section 5, gives the main conclusions about future works to generate new knowledge for the order-picking problem.

2. Order picking operations

To understand the scope of the order picking operation, it can be divided into order batching, sequencing and picker routing operations, which will be explained below.

2.1. Order Batching

Order batching groups multiple customer orders in a picking order to be retrieved in a single tour (Henn et al., 2012; Henn & Schmid, 2013; De Koster et al., 2007) and the grouping criteria may depend on the common items among customer orders, due dates of customer orders, items localization and proximity in the warehouse, among others (Albareda-Sambola et al., 2009; Bustillo et al., 2015). Order batching can generate greater efficiency and productivity than single-order picking (Chen & Wu, 2005), and is very important in manual picking systems because combining several customer orders into individual picking orders reduce the total number of tours, total travel distance or total travel time (Chen & Shen, 2016; Hsu et al., 2005; Koch & Wäscher, 2016; De Koster et al., 2007).

2.2. Batch Sequencing

Once customer orders are assigned to picking orders (batches), batch sequencing determines the order in which batches are programmed, released and processed in the picking line (Azadnia, Taheri, Ghadimi, Mat Saman, & Wong, 2013; Bustillo et al., 2015; Henn & Schmid, 2013; Hong, Johnson, & Peters, 2016), and how to allocate these orders to pickers (operators), complying due time requirements, and minimizing tardiness and earliness of customer orders (Azadnia et al., 2013; Chen et al., 2015; Henn & Schmid, 2013; Henn, 2015; Tsai et al., 2008).

2.3. Picker Routing

Picker routing is a traditional traveling salesman problem (TSP) (Cheng et al., 2015; Hsieh & Huang, 2011), that plans the way in which pickers complete picking operations following the shortest path to minimize the travel distance and travel time (Bustillo et al., 2015), generating a tour or sequence to retrieve all the items of a batch, starting and finishing at the depot (Bustillo et al., 2015; Henn & Wäscher, 2012; Hsieh & Huang, 2011). Researchers are paying attention to generate an appropriate sequencing picking, because this is one of the crucial factors in achieving high picking efficiency (Moeller, 2011).

2.4. Joint Order Batching, Sequencing and Routing problem

In recent years, the order batching, sequencing and picker routing problems have been addressed jointly due to order selection influences picker routing, and slight modifications in the batches lead to significant changes in the total time consumed to collect them (Albareda-Sambola et al., 2009; Cheng et al., 2015). Therefore, the travel time can be reduced more than 35% considering batching, sequencing and routing decisions together (De Koster et al., 1999).

In the case of the order batching and sequencing problem, it has been addressed by authors like Henn and Schmid (2013), Henn (2015), and Zhang, Wang, Chan and Ruan (2017). Further advances have been proposed by authors like Won and Olafsson (2005), Tsai et al. (2008), Kulak et al. (2012), Grosse et al. (2014), Matusiak et al. (2014), Cheng et al. (2015), Chen et al. (2015), Lin, Kang, Hou and Cheng (2016), Li, Huang and Dai (2017), Scholz and Wäscher (2017) and Scholz et al. (2017). These authors addressed the joint order batching, sequencing and routing problem, justifying that the selection of orders to form batches and the batches sequence influence the picking routes distance as well as the compliance of due dates. Because order batching and sequencing directly impact the tardiness and earliness of customer orders, and routing determines the picking sequence within each batch (Chen et al., 2015), these problems must be solved jointly, which represents a challenge to develop quick and effective solutions to problems adapted to the reality of warehouses (Kulak et al., 2012; Scholz et al., 2017).

3. Models and problem settings

In the characterization of the order picking problems addressed in the literature, key elements influence the efficiency of the picking process. Elements such as objective functions, due dates, warehouse distribution (layout), availability of information, number of agents and metaheuristics solution methods are explained in this section.

3.1. Objective functions

Warehouses and distribution centers are interested in finding the most economical way to pick customer orders, which involves minimizing the operation costs, and implies the reduction of the travel distance or travel time (Chen et al., 2005; Hsu et al., 2005). In this regard, most studios focus on reducing the total traveled distance (Bozer & Kile, 2008; Chen et al., 2005; Chen & Wu, 2005; Cheng et al., 2015; Henn et al., 2012; Hsieh & Huang, 2011; Hsu et al., 2005; Koch & Wäscher, 2016; Kulak et al., 2012), transport and search time, and throughput time (Albareda-Sambola et al., 2009; Cheng et al., 2015; Gademann & van de Velde, 2005; Gómez, Giraldo, & Campo, 2016; Henn, 2012; Hong et al., 2016; Xu, Liu, Li, & Dong, 2014). However, in the reality of warehouses and distribution centers, customer orders should to be delivered in specific periods of time to avoid tardiness or earliness in production and distribution systems (Bustillo et al., 2015; Gademann, van den Berg, & van der Hoff, 2001; Henn et al., 2012), which results in dissatisfaction of customer expectations, as well as penalties to the warehouse (Azadnia et al., 2013; Chen et al., 2015). For this reason, tardiness and earliness of orders have begun to be studied by several authors (Azadnia et al., 2013; Bustillo et al., 2015; Chen et al., 2015; Henn & Schmid, 2013; Tsai et al., 2008), to the point of being considered as important as operating costs (Gu et al., 2007), and be required for future research (Cergibozan & Tasan, 2016).

Other objective functions have focused on minimizing the lead-time for batches (Gademann et al., 2001), and on minimizing picking costs by reducing the number of batches (Hsu et al., 2005). The order picking problems found in the literature generally cover only one of the abovementioned objectives, except some studies that involve two or more objectives such as minimizing operative costs and tardiness (Tsai et al., 2008; Zhang, Wang, & Huang, 2016), or minimizing earliness and tardiness (Henn et al., 2012; Tsai et al., 2008).

3.2. Consideration of due dates

In order to include customer service as a performance measure in objective functions, it is necessary to consider due dates for customer orders (Chen et al., 2015). To the best of our knowledge, the researches involving tardiness on their objective functions for order batching, sequencing and picker routing problems, are considering due dates as fixed points in time (Zhang, Wang, & Huang, 2016). In real word cases, customers expect to receive their orders within a specific time range (Cergibozan & Tasan, 2016), which is why due dates can be expressed through time windows (Sebastian Henn et al., 2010), as in the case of scheduling problems (Gerstl & Mosheiov, 2013; Itoh & Ishii, 1999; Kuo & Cheng, 2013; Lam & Cai, 2000; Pan, Ruiz, & Alfaro-Fernández, 2017).

3.3. Warehouse configuration (Layout)

The total travel distance and therefore the picking time depends in part on the layout of the warehouse (Hsu et al., 2005), which in almost all the order picking models is considered as a rectangular single-block layout warehouse. These layouts consist of multiple parallel aisles of equal length, connected by cross-aisles at the front and the back of the warehouse (Azadnia et al., 2013; Bustillo et al., 2015; Chen et al., 2015; Cheng et al., 2015; Hong, Johnson, & Peters, 2012; Koch & Wäscher, 2016). Few studies have considered real conditions for warehouses of great dimension that include a multiple-block warehouse separated by several cross-aisles or a double-block warehouse with three cross-aisles (Chen, Wei, & Wang, 2017; Li et al., 2017; Pan & Wu, 2009; Scholz et al., 2017; Valle et al., 2017). Other warehouse layouts like flying-V warehouse and fishbone warehouse, U-shaped layouts have been in the literature (Glock & Grosse, 2012; Pohl, Meller, & Gue, 2009), however, that kind of layout have not yet been widely implemented in real warehouses, so they will not be discussed in this research.

Regarding with horizontal and vertical movements in a warehouse, warehouse layouts are indicated as 2D or 3D (Cergibozan & Tasan, 2016). Under a 2D warehouse environment, it is supposed that items are located in a forward picking area, so the warehouse storage space is arranged as a low-level picker-to-part system (Albareda-Sambola et al., 2009; Bozer & Kile, 2008; Bustillo et al., 2015; Chen et al., 2015; Cheng et al., 2015). Under a 3D warehouse environment, items can be located at high storage levels (Azadnia et al., 2013; Hsu et al., 2005; Li et al., 2017; Won & Olafsson, 2005), such as in many warehouses where pickers must reach different storage levels to retrieve the items of a picking order.

3.4. Information availability

In order picking problems, the proposed models can be static (off-line) if it is assumed that all customer orders are available at the beginning of the planning period (Koch & Wäscher, 2016; Van Nieuwenhuyse & de Koster, 2009). In real warehouses, customer orders are dynamic (on-line) because they become available, can be modified o canceled over time (Cergibozan & Tasan, 2016; Henn & Schmid, 2013; Sebastian Henn, 2012; Yu & de Koster, 2009). In these cases, time window batching can be carried out as variable time window batching or fixed time window batching (Chen et al., 2017; Van Nieuwenhuyse & de Koster, 2009; Zhang et al., 2016).

3.5. Multiple pickers

Another condition that has been added to order picking optimization models is the existence of congestion and waiting time in picking operations due to the presence of multiple pickers in a warehouse zone (Ballestín et al., 2013; Chen et al., 2017; Gue & Meller, 2009; Hong et al., 2016; Pan & Wu, 2012; Rubrico et al., 2009). Thus, blocking must be included in batching and sequencing decisions (Hong et al., 2016), taking into account that the number of pickers may equal the number of batches provided to be processed simultaneously (Hsu et al., 2005).

3.6. Metaheuristics solution methods

The order-batching problem is recognized to be NP-hard (Gademann & van de Velde, 2005), for this reason, it is extremely difficult to obtain optimal solutions for large-scale problems within a tolerable computation time (Hsu et al., 2005; Scholz et al., 2017; Valle et al., 2017). Obtaining the exact solutions for order batching problems is very difficult and time-consuming (Chen et al., 2005; De Koster et al., 2007), and it is only solvable in polynomial time if each batch does not contain more than two orders (Gademann & van de Velde, 2005). For the picker routing as the number of locations to be visited increases, the solution time to obtain the optimal solution becomes intractable (Chen et al., 2015). Therefore, realistically sized problems cannot be solved in a reasonable amount of time (Albareda-Sambola et al., 2009).

Both order batching and picker routing are NP-hard problems (Cheng et al., 2015), thus the joint order batching, sequencing and picker routing problem can be proven as a NP-Hard problem (Chen et al., 2015; Cheng et al., 2015; Gademann & van de Velde, 2005). To overcome these drawbacks, some heuristics (rule-based algorithms, seed and saving methods) have been proposed to solve the order batching problem (Albareda-Sambola et al., 2009; Chen et al., 2005; Hsu et al., 2005; Koch & Wäscher, 2016), as well as data mining, association rules and cluster analysis (Azadnia et al., 2013; Chen et al., 2005; Chen & Wu, 2005; Hwang & Kim, 2005). To solve the picker routing problem basic and practical strategies such as traversal or s-shape, largest gap, middle point and combined routing policies have been used by different authors (Albareda-Sambola et al., 2009; Bozer & Kile, 2008; Bustillo et al., 2015; Chen et al., 2005; Hsu et al., 2005; Koch & Wäscher, 2016).

In real picking environments, fast and high quality solutions (pseudo-optimal) must be provided (Albareda-Sambola et al., 2009; Cergibozan & Tasan, 2016; Gu et al., 2007; Henn & Wäscher, 2012), and due to the complex and combinatorial nature of an integrated picking problem, it is essential to develop effective and efficient metaheuristic approaches. Metaheuristics have proven to be promising methods for order picking problems, for which it is found in the literature the use of Genetic Algorithms (GA) (Azadnia et al., 2013; Chen & Shen, 2016; Chen et al., 2015; Hsu et al., 2005; Koch & Wäscher, 2016; Mutingi & Mbohwa, 2017; Tsai et al., 2008), Particle Swarm Optimization (PSO) (Cheng et al., 2015; Gómez-Montoya, Correa-Espinal, & Hernández-Vahos, 2016), Ant Colony Optimization (ACO) (Chen et al., 2015; Cheng et al., 2015; Henn et al., 2010), Tabu Search (TS) (Cortés, Gómez-Montoya, Muñuzuri, & Correa-Espinal, 2017; Henn & Wäscher, 2012; Kulak et al., 2012; Öncan, 2015; Rubrico et al., 2004), Hill Climber (HC) (Henn & Schmid, 2013; Henn & Wäscher, 2012), Simulated Annealing (SA) (Vandani, Dolati, & Bashiri, 2013), Iterated Local Search (ILS) (Henn & Schmid, 2013; Henn et al., 2010; Öncan, 2015), Variable Neighborhood Search (VNS) and Variable Neighborhood Descent (VND) (Albareda-Sambola et al., 2009; Bustillo et al., 2015; Menéndez, Pardo, Alonso-Ayuso, Molina, & Duarte, 2017; Menéndez, Pardo, Duarte, Alonso-Ayuso, & Molina, 2015; Scholz et al., 2017), and other local search metaheuristics (Gómez et al., 2016; Henn et al., 2010; Henn, 2015; Koch & Wäscher, 2016).

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4. Future trends and research opportunities

Based on the abovementioned information and the suggestions made by several authors about future research trends, Table 1 shows that new model proposals and solutions for the order-picking problem should consider due dates, multiples objectives, dynamic customer orders, multiple pickers, real warehouse configurations, joint problems and fast solution approaches.

Table 1
Future research trends for the order picking optimization problem

Research trends	Description
Due dates	Incorporate due dates of the orders due to the priorities of the customers that have to be fulfilled at a certain time (Albareda-Sambola et al., 2009; Cergibozan & Tasan, 2016; Henn et al., 2012; Koch & Wäscher, 2016; Scholz et al., 2017).
Multi-objective	The creation of a multiple objective model considering the due date of each order (Cheng et al., 2015; Gu et al., 2007).
Dynamic (Online)	Dynamic contexts considering the continuous arrival of customer orders and constantly incorporating new information about the operating environments (Azadnia et al., 2013; Gu et al., 2007; Henn et al., 2012; Koch & Wäscher, 2016; Moons, Ramaekers, Caris, & Arda, 2017).
Multiple Pickers	Consider the multiple pickers to facilitate the multi-objective model (Chen et al., 2015), and the avoidance of congestions in narrow picking aisles (Koch & Wäscher, 2016; Scholz et al., 2017).
Warehouse configuration	Investigate the impact of different warehouse layouts: two block warehouses, non-standard warehouses, 3D layouts (Cergibozan & Tasan, 2016; Henn, 2012; Koch & Wäscher, 2016).
Joint Problem	Integration of order picking with other planning issues in order to deal simultaneously with order batching, sequencing and picker routing (Cergibozan & Tasan, 2016; Gu et al., 2007; Koch & Wäscher, 2016; Moons et al., 2017).
Fast Solution Approaches	Reducing the computational time using powerful heuristics and computers (Bozer & Kile, 2008; Cergibozan & Tasan, 2016; Hsu et al., 2005), as well as simple, intuitive, and reliable solutions (Gu et al., 2007; Valle et al., 2017).

In addition to these trends shown in Table 1, it is also suggested to take into consideration space capacity constraints (Chen & Wu, 2005), order splitting to improve warehousing efficiency (Tsai et al., 2008), stochastic optimization problems (De Koster et al., 2007), and models adjusted to the complex reality of competitive warehouses (Davarzani & Norrman, 2015).

5. Conclusions

Through a literature review, it was identified the main approaches solving the order picking problem, including order batching, batch sequencing a router picking problems. According to the future works and research trends suggested by several authors, these problems must be solved jointly considering realistic conditions of warehouses and distribution centers in order to meet the customers’ needs and the profitability of the warehouse operation.

Among the realistic conditions of actual warehouses can be mentioned the incorporation of due dates of customer orders, due dates with time windows, multi-objective approaches, dynamic arrivals of customer orders to the warehouse, multiple pickers, congestion and pickers blocking, warehouse layouts with multiple blocks and 3D movements.

Therefore, it is suggested for future researches to consider a joint order batching, sequencing and picker routing problem, considering 3D movements and multiple pickers within a multi-block warehouse. Likewise, it is recommended to tackle an online joint problem considering congestion within a multi-block warehouse. Both cases should operate in order to minimize simultaneously the total travel distance (or picking time), and the tardiness of customers' orders.

Finally, these new challenges must be solved with metaheuristics or another fast solution approaches in order to obtain high-quality solutions in short times, as required in real warehouses and distribution centers.

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