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# Trends in order picking: a 2007–2022 review of the literature

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**ABSTRACT**

A literature review on the order picking process in warehouses is presented for delineating the trends in time of research topics in this field. A total of 269 journal papers published between 2007 and 2022 were retrieved from Scopus. After a methodological classification, descriptive analyses were performed on authors, journals, subject area and top publishing countries. Bibliometric tools were used to map the topics covered by the reviewed studies, categorise them and determine possible relationships. Papers' contents were evaluated in terms of eight categories, including five typical issues of order picking systems, plus three aspects dealing with the characteristics of the application. Insights about the extent to which these aspects have been covered in the literature are derived; relationships between the various aspects of the picking process are also delineated. Suggestions for future research activities are finally deducted, offering researchers and practitioners strong bases for works on order picking systems.

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**KEYWORDS**

Order picking; literature review; research trends; bibliometric analyses

## 1. Introduction

Order picking is the process of retrieving goods from specific storage locations to meet customer orders and usually contributes to more than 55% of the total warehouse cost (J. Zhang, X. Zhang, et al., 2021b). This is especially true for manual picker-to-parts systems, in which the pickers walk through aisles, search and pick items and bring them to a depot for consolidation (Aerts et al., 2021).

To improve the order picking process, researchers have usually focused on its economic efficiency (de Koster et al., 2007). Indeed, the traditional goal of planning approaches to the picking problem consists in decreasing the time required for completing a single order or a set of orders or, more in general, the minimization of the travel distance (Schenone et al., 2020; Zuñiga et al., 2020). Besides this well-known aim, in the last years, additional aspects have been introduced by researchers when investigating order picking systems. A recently emerged topic is the optimization of the ergonomic conditions of order pickers (Al-Araidah et al., 2020). The rationale for evaluating this aspect is that the picking process typically includes

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manual tasks, so that an accurate planning of the ergonomic conditions can improve the pickers' health and safety, thus reducing the risk of injuries or disorders (M. Zhang, Winkelhaus et al., 2021). Also, demographic changes imply that people live longer, while also growing older, with obvious consequences on labour capabilities. As a second aspect, the recent (and somehow still actual) COVID-19 pandemic has changed consumers' attitudes and behaviours towards the usage of technological tools, involving a tremendous development of some sectors, such as the e-commerce field (Abbu et al., 2021). Some authors have also argued that the attitude towards the usage of digital technologies will continue in time (Alderighi, 2021), suggesting a pivotal role of e-commerce in the next years. Because of the wide number of single items managed in e-commerce warehouses, order picking will certainly cover a crucial role in this sector; hence, researchers have started investigating the performance of picking in e-commerce warehouses, with the aim to minimize the errors made (Villarreal-Zapata et al., 2020).

These brief considerations, besides confirming the relevance of order picking systems in practice, suggest a transition in the focus of scientific research on order picking from the key design issues traditionally evaluated to some emerging aspects. With the aim to explore the trends in the research on order picking and to highlight the recently emerged interests, this study conducts a detailed literature review on order picking systems using a combination of descriptive analyses and bibliometric techniques on a sample of over 260 studies published from 2007 to 2022. The starting point of the selected time span was chosen taking into account the previous review by de Koster et al. (2007). Although this is not the only available review paper on order picking (cf. Section 2.2), it was taken as a reference because the analysis made is similar to ours: indeed, the study classified the literature on the basis of the typical issues of order picking system design, which are also referred to in the present study, using a sample of 140 papers published up to 2006. Instead, the duration of the time span (16 years) is typical of scientometric studies, and in particular, it is wide enough to delineate the evolution in time of research interests.

From the outcomes from the literature review, the present study delineates the trends in the research on order picking systems, highlighting the themes that have been more or less studied, and thus suggests an agenda for future research in this field. These aspects are expressively evaluated:

(i) Warehouse layout and structure
(ii) Picking processes, storage allocation policies and routing policies
(iii) Problem constraints
(iv) Outcomes observed, in terms of output and performance indexes
(v) Industrial sectors

The article consists of five sections. The next section reviews the relevant literature, to highlight the contribution of this study compared to the published papers. Section 3 details the research methodology used in this review. A qualitative/quantitative analysis of the content of the papers reviewed and the relating results are extensively reported in Section 4. Discussion and conclusions regarding the contributions made by this study are formalised in Section 5, highlighting the main limitations, and suggesting future research directions.

## 2. Literature review

The literature on order picking is very wide. In line with the aim of this study, this section recalls the aspects traditionally investigated in order picking studies and discusses previous reviews on order picking.

### 2.1. Traditional design issues of order picking

Research on order picking has originally focused on the efficiency of the process, in the lightof the fact that order picking is the most labour-intensive and costly activity of a warehouse. To achieve this aim, the literature has deepened some key design aspects, namely the optimization of the warehouse layout, the efficient assignment of items to storage locations, the batching of orders and the optimal routing of order pickers in the warehouse (de Koster et al., 2007; Masae et al., 2020). Indeed, the order picking design involves many interrelated decisions that affect the final cost of the process (Yener & Yazgan, 2019).

Warehouse layout planning defines the configuration of the warehouse, including the number of aisles and cross-aisles (Franzke et al., 2017). Caron et al. (2000) claimed that the warehouse layout had an effect of more than 60% on the total picking travelling distance. If the warehouse uses low-level storage racks, items can be picked directly from the racks without requiring vertical movements, while in case of high-level racks, vertical movements may be necessary as well (Masae et al., 2020). An important aspect of the warehouse layout is also the location of the input/output (I/O) depot, i.e. the place where pickers deposit the items they have retrieved from the warehouse locations. The I/O depot is also the place where pickers receive instructions on the orders they need to pick in their next picking trip (Ho & Tseng, 2006). Warehouses around the world can have various layouts, such as conventional or non-conventional. The conventional (rectangular) layout is characterized by the arrangement of parallel aisles, orthogonal to the walls. On the contrary, there are some non-conventional layouts such as fishbone, U-shaped and flying-V. A fishbone layout has two diagonal cross-aisles, and the aisles in the lower zones are perpendicular to the aisles in the upper zones (Cardona et al., 2015). A U-shaped layout, instead, has the central aisle that is arranged in form of a U put upside down, and a front cross-aisle connects the central aisles to the depot (Henn et al., 2013). Finally, in a flying-V design, the middle aisle extends from the depot point to the left and right of most pick aisles in a V-shape (Çelk & Süral, 2014).

Storage assignment policies address the assignment of products to storage locations in a warehouse. The literature discusses three typical storage allocation strategies: random storage assignment; dedicated storage assignment, where items are assigned to shelf locations based on the item characteristics (e.g. size, weight or usage rate), and class-based storage, where the warehouse is divided into zones according to item characteristics, with storage allocation in each zone being random (Masae et al., 2020a).

The picker routing problem, instead, can be described as determining the sequences in which items are to be collected in the picking tour to minimize the travel time/distance. The solution approaches for the picker routing can be distinguished into exact, heuristic and meta-heuristic algorithms (J. Zhang, X. Zhang, et al., 2021b). No matter if simple heuristics or optimal procedures are used, the goal of routing policies is to minimize the distance travelled by the picker. Optimal procedures offer the best solution but may result in confusing routes. A recent review by Masae et al. (2020) has expressively evaluated the order picker routing, concluding that there are only few papers that have proposed exact algorithms for solving the order picker routing problem in non-conventional warehouses. Heuristics often yield near-optimal solutions while being easy to use and to be learnt by pickers (Petersen & Aase, 2004). Examples of these routings include the S-shape, the midpoint and the largest gap heuristics. Meta-heuristic algorithms, instead, are powerful techniques applicable generally to a large variety of problems. A meta-heuristic algorithm is an iterative procedure that guides and modifies the operations of subordinate heuristics by combining intelligently different concepts for exploring and exploiting the search space (El-Sherbeny, 2010). Examples include genetic algorithms (GAs), ant colony optimization (ACO), particle swarm optimization (PSO) or tabu search (TS).

To increase space utilization for order picking warehouses, the so-called 'narrow' warehouses are commonly employed, and the usage of 'ultra-narrow' aisles has been introduced recently to the same end (F. Chen et al., 2019). Narrow/ultra-narrow aisle warehouses have one major disadvantage, however, as aisles in such warehouses are usually too small to allow order pickers to overtake each other. The consequence is that in narrow aisle warehouses, order pickers working in the same zone may block each other. Picker blocking or picker congestion can result in longer travel times due to idle, waiting times or stops and ultimately reduce the efficiency of the process (Franzke et al., 2017). The number of stops in each tour can also be determined by the available capacity of the picking device, as well as by the capacity requirements of the items to be picked. For the definition of the capacity of the picking device, various criteria have been suggested in the literature. For example, the capacity can be expressed in terms of the maximum number of orders (Le Duc & de Koster, 2007) or items (Bozer & Kile, 2008; Henn et al., 2010, 2012). The bucket brigade concept that originated from general assembly-line operations, instead, is a well-known solution to a fixed zone approach. Employing a 'bucket brigade' order picking strategy relocates the human labour to balance the workload per worker (Hong et al., 2016).

### 2.2. Previous reviews on order picking

The first review paper on order picking is the well-known study by de Koster et al. (2007). Being a pioneering study, the aim of this paper was to provide a comprehensive description of the order picking process in its various design aspects, including warehouse layout, storage assignment, order batching/zoning and routing. Similar considerations hold true for the study by Gu et al. (2007), who have presented and classified various problems of warehouse design, including (but not limited to) picking activities. After these studies, subsequent reviews have in general targeted specific aspects of order picking (e.g. Cergibozan & Tasan, 2019; Gong & de Koster, 2011), or evaluated individual planning problems, at the same time concluding that many planning problems are not independent on one another.

To be more precise, Hassini (2009) has focused on the design problems affecting the optimal storage and order picking of carousels. A similar work has been carried out by Litvak and Vlasiou (2010), who have reviewed the performance measures and design approaches to carousel systems, thus discussing picking issues that are typical of those systems. Lodree et al. (2009) were the first authors to introduce human factors into warehouse problems; although inspired by the order picking process, as declared by the authors themselves, this study has not expressly targeted this activity, taking instead the more general perspective of task sequencing by minimizing the risk and maximizing the productivity of workers. The ergonomic issues in picking were deepened later, in the reviews by Grosse et al. (2015) and Grosse et al. (2017). Recently, De Lombaert et al. (2022) have proposed a toolset of five modelling constructs, obtained by varying work rates, quantitative physical state indicators, stochastic worker behaviour and work execution, subjective worker experience and judgement and socio-demographic worker differentiations, and it is suitable to be used for humanising order picking planning problems.

Recent review studies as well have typically targeted a specific design issue of order picking. Reyes et al. (2019) have presented a systematic literature review (SLR) on the storage location assignment problem, in which 71 representative papers published between 2005 and 2017 were classified according to the methods of solution, performance measures and restrictions or considerations. Cergibozan and Tasan (2019) have proposed a review of order batching mechanisms; the same theme has been approached by Cano et al. (2018), incorporating also considerations about sequencing and picker routing. Masae et al. (2020) have presented the results of a systematic review of research on order picking routing. In particular, the authors have identified order picker routing policies in a systematic search of the literature and then have developed a conceptual framework for categorising the various policies. Fragapane et al. (2021) have identified and classified research related to the planning and control of autonomous mobile robots (AMRs) in intralogistics. The authors have provided an exhaustive literature review that highlights how technological advancements in AMRs can affect planning and control decisions. Jaghbeer et al. (2020) have proposed a review of automated order picking systems, in the light of the developments of the e-commerce channel. Boysen et al. (2019) have analysed warehousing systems that are well suited for the special requirements of online retailers in the B2C segment from an operational research perspective. Winkelhaus et al. (2021) have conceptualised order picking 4.0 (OP 4.0), considering substitutive and supportive technologies. Based on a conceptual background, the authors have developed a framework for OP 4.0 as a socio-technical system.

The current view of researchers is that order picking operations need to be optimized by solving a wide range of interdependent problems; on the contrary, optimizing design problems sequentially would probably lead to suboptimal performance. In line with this consideration, the recent review by van Gils, Ramaekers, Braekers, et al. (2018) has tried to investigate a combination of multiple order picking planning problems. The 61 studies reviewed were classified by the authors in terms of the approach, performance measure and relationships between the design issues addressed. A similar perspective has been taken by Keshavarz et al. (2021), who reviewed 92 studies on order picking, classifying a combination of tactical and operational problems (e.g. cost, equipment, warehousing, allocation, routing, batching, sequencing and tardiness). Vanheusden, et al. (2022) have performed a state-of-the-art of existing literature in order to identify, classify and analyse practical factors in order picking planning.

The study at hand adds knowledge to reviews on order picking cited just above, in that it takes into account a greater number of papers (>260) published across a time span of

16 years, which is wide enough for clearly delineating the trends in the research on order picking and highlighting the topics emerged in the recent literature. Also, the analyses made will consider both the traditional design factors of order picking systems and a comprehensive set of additional aspects that allow the research on picking to be described in detail.

## 3. Methodology

To evaluate the state-of-the-art of order picking, an SLR was carried out. SLRs aim to search, appraise, synthetize and analyse all the studies relevant for a specific field of research (Hamja et al., 2019; Palmarini et al., 2018). Moreover, a contextualized literature review helps create or improve our knowledge of 'for whom', 'in what circumstances' and 'when' certain phenomena can be observed (Durach et al., 2021). This kind of review was selected because it allowed us to construct and understand specific theoretical concepts, obtain the information needed to construct a set of relevant bibliographical references, analyse the results at a quantitative and qualitative level, as well as suggest future research directions on the subject (Seuring et al., 2005). The methodology adopted to conduct the SLR consisted of the following three steps: (1) creation of the sample of papers; (2) data collection and (3) data analysis (Liao et al., 2017).

### *3.1. Sample creation and papers classification*

The inclusion criteria of any SLR have to be clearly specified, with the purpose of correctly selecting the studies to be reviewed and make the selection process replicable. The Scopus database (http://www.scopus.com/) was used to search for the relevant literature, to ensure that all pertinent papers are included. In terms of criteria, we have only included the following review articles:

(1) those in English and published in international journals;
(2) those expressly focusing on order picking in warehouses; and
(3) those published between 2007 and 2022 (included).

First, the keywords to be used in the query were defined. To retrieve a comprehensive set of papers, the search query was built by combining the 'OR' operator in 'Article title' between each of the following three terms: 'order picking', 'picker routing' and 'picking order'. The type of document was set as 'article'. Figure 1 illustrates the procedure followed.

As can be seen from Figure 1, the query generated a total of 755 papers (numbers effective 31 December 2022). By applying the first and third inclusion criteria, the original number of manuscripts was reduced to 316 papers written in English and published in international journals in the selected time span. The full text of all these documents was retrieved and examined in detail to ensure that they met the second inclusion criterion. This screening led to further 47 papers to be excluded from the analysis because of their limited relevance to order picking or the unusual or very specific context (see Table 1 for the full list of papers retrieved and examined). As an example of the excluded papers, Füßler et al.

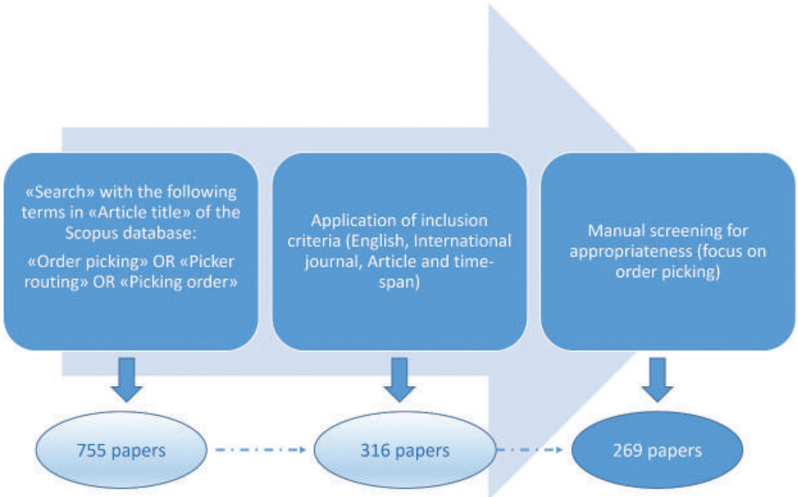



**Figure 1.** Scheme of the query and relating results.

(2019) have investigated picking activities in a cafeteria with the purpose of finding a sequence of customers and scheduling the service for the waiter; this context is very different from traditional warehouses, which justifies the exclusion of the study.

The resulting 269 papers were retained and included in the SLR. For classification purpose, the paper type was also determined, based on a direct analysis of the full text; more precisely, papers were categorised into one or more[1] of the following categories:

(a) Simulation paper, which provides simulations in an industrial context (van Gils, Ramaekers, Caris, et al., 2018);
(b) Case study, which presents one or more order picking applications to real contexts (Maestrini et al., 2017);
(c) Analytic paper, which presents a mathematical model to solve an order picking problem (van Gils, Ramaekers, Caris, et al., 2018);
(d) Conceptual paper, which identifies order picking research problems and proposes some conceptual or theoretical solutions, but without any direct application (Bartolini et al., 2019).

Despite the query was limited to 'articles', a small set of eight papers was found to be more similar to review papers,[2] as particularly detailed in the analysis and consolidation of findings and knowledge from publications, which is typical of reviews (Durach et al., 2021). For completeness, they have been highlighted with an asterisk in Table 1.

The final sample of papers along with the corresponding classification is proposed in Table 1.

**Table 1.** Full list of papers retrieved and analysed (note: * denotes papers with similarities with review studies).

| Reference | Included (Y/N) | Classification | | | |
|---|---|---|---|---|---|
| | | Simulation paper | Case study | Analytic paper | Conceptual paper |
| Accorsi et al. (2012) | Y | | x | | |
| Aerts et al. (2021) | Y | x | | x | |
| Aitziane et al. (2021) | N | | | | |
| Al-Araidah et al. (2017) | N | | | | |
| Al-Araidah et al. (2020) | Y | x | x | x | |
| Aldarondo and Bozer (2022) | N | | | | |
| Alipour et al. (2020) | Y | | | x | |
| Altarazi and Ammouri (2018) | Y | x | | | |
| Andriansyah et al. (2011) | Y | x | | | x |
| Andriansyah et al. (2014) | N | | | | |
| Ardjmand et al. (2020) | Y | x | x | x | |
| Ardjmand et al. (2021) | Y | x | x | x | |
| Ardjmand et al. (2019) | Y | | | x | |
| Ardjmand et al. (2018) | Y | x | | x | |
| Artal-Sevil et al. (2017) | N | | | | |
| Atashi Khoei et al. (2022) | Y | x | | x | |
| Atchade Adelomou et al. (2021) | N | | | | |
| Atmaca and Ozturk (2013) | Y | | | x | |
| Azizpour et al. (2022) | N | | | | |
| Bahrami et al. (2017) | Y | x | | | |
| Bahrami et al. (2019) | Y | x | x | | |
| Bal et al. (2022) | Y | | x | | x |
| Bansal and Roy (2021) | Y | x | x | x | |
| Battini et al. (2015) | Y | | x | x | |
| Battini et al. (2017) | Y | | | | x |
| Battini et al. (2017) | Y | | x | x | |
| Battini et al. (2016) | Y | x | x | x | |
| Beroule et al. (2017) | Y | x | | x | |
| Bindi et al. (2009) | Y | | x | x | x |
| Bloss (2013) | N | | | | |
| Bódis and Botzheim (2018) | Y | x | | | |
| Bottani et al. (2012) | Y | x | x | | |
| Bottani and Vignali (2019) | Y | x | x | | |
| Boysen et al. (2017) | Y | x | | x | |
| Boysen et al. (2020) | Y | x | | x | x |
| Boywitz et al. (2019) | Y | x | x | x | |
| Bozer and Aldarondo (2018) | Y | x | | | |
| Bozer and Kile (2008) | Y | | | x | |
| Briant et al. (2020) | Y | x | x | x | |
| Bukchin et al. (2012) | Y | | | x | |
| Burinskiene (2010) | Y | x | | | |
| Burinskienė et al. (2018) | Y | x | x | | |
| Calzavara et al. (2016) | Y | | | x | |
| Calzavara et al. (2017) | Y | | | x | |
| Calzavara, Glock, et al. (2019) | Y | | x | x | |
| Calzavara et al. (2018) | Y | x | | | x |

(*Continued*)

**Table 1.** (Continued).

| Reference | Included (Y/N) | Classification: Simulation paper | Case study | Analytic paper | Conceptual paper |
|---|---|---|---|---|---|
| Calzavara, Sgarbossa, et al. (2019) | Y | | x | x | |
| Cano (2020)* | Y | | | x | |
| Cano et al. (2018) | N | | | | |
| Cano et al. (2020) | Y | | | x | |
| Cano et al. (2022) | Y | x | | x | |
| Çelik and Süral (2016) | Y | x | | x | |
| Çelik and Süral (2019) | Y | | | x | |
| Çelk and Süral (2014) | Y | | | x | |
| Chabot et al. (2018) | Y | x | | x | |
| Chabot et al. (2017) | Y | x | x | x | |
| Chackelson et al. (2013) | Y | x | x | | |
| Chan and Chan (2011) | Y | | x | | |
| Chandra and Natalia (2021) | Y | x | | x | |
| Charkhgard and Savelsbergh (2015) | Y | x | x | | |
| C. -M. Chen et al. (2010) | Y | x | | | |
| F. Chen et al. (2013) | Y | x | | x | |
| F. Chen et al. (2016) | Y | x | | | |
| Y. Chen et al. (2022) | Y | x | x | x | |
| R. -C. Chen and Lin (2020) | Y | x | x | x | |
| Cheng et al. (2015) | Y | x | | x | |
| Choy et al. (2017) | Y | x | x | | x |
| Chuang et al. (2014) | Y | | x | | |
| Cierniak-emerych et al. (2021) | Y | | x | | x |
| Claeys et al. (2016) | Y | | | x | |
| da Piedade et al. (2016) | Y | x | | | |
| Dallari et al. (2009) | Y | | x | | x |
| Damayanti et al. (2022) | Y | x | x | x | |
| Dauod and Won (2022) | N | | | | |
| de Koster et al. (2007)* | Y | | | | x |
| De Lombaert et al. (2022) | Y | | | | x |
| de Vries et al. (2016) | Y | | x | | |
| de Vries et al. (2015) | Y | | | x | |
| Dickinson (2016) | N | | | | |
| Diefenbach et al. (2022) | Y | x | | x | |
| Diefenbach and Glock (2019) | Y | | | x | |
| Djurdjević et al. (2022)* | Y | x | x | | |
| Dmytrów (2022) | Y | x | | x | |
| Dukić et al. (2010) | N | | | | |
| Dukic and Oluic (2007) | Y | x | | | |
| Dukic et al. (2015) | Y | x | | x | |
| Düzgit et al. (2021) | N | | | | |
| D'haen et al. (2022) | Y | x | x | x | |
| Eisenstein (2008) | Y | x | | | |
| Elbert et al. (2018) | Y | | x | | |
| Elbert and Müller (2017) | Y | x | | x | |
| Elbert, Franzke, Glock et al. (2017) | Y | x | | | |

(*Continued*)

**Table 1.** (Continued).

| Reference | Included (Y/N) | Classification: Simulation paper | Case study | Analytic paper | Conceptual paper |
|---|---|---|---|---|---|
| Ellinger and Hompel (2012) | N | | | | |
| Fang and An (2020) | Y | | x | | x |
| Farhadi Sartangi et al. (2022) | Y | x | x | x | |
| Fibrianto &Hong (2019) | Y | x | | x | |
| Foroughi et al. (2021) | Y | x | | x | |
| Fumi et al. (2013) | Y | x | | | |
| Füßler and Boysen (2017)* | Y | | | x | |
| Füßler et al. (2019) | N | | | | |
| Gajšek et al. (2021b) | Y | x | x | | x |
| Gajšek et al. (2022) | Y | x | x | x | |
| Gajšek et al. (2021a) | Y | x | x | | |
| Giannikas et al. (2017) | Y | x | x | | |
| Glock and Grosse (2012) | Y | x | | | |
| Glock et al. (2019) | Y | x | x | x | |
| Glock, Grosse, Elbert et al. (2017) | Y | | x | | x |
| Goeke and Schneider (2021) | Y | x | x | x | |
| Gong and de Koster (2008) | Y | x | | x | |
| Grosse et al. (2016) | Y | | | | x |
| Grosse and Glock (2013) | Y | | x | x | |
| Grosse and Glock (2015)* | Y | | x | x | |
| Grosse et al. (2014) | Y | x | | x | |
| Grosse et al. (2013) | Y | | | x | |
| Grosse et al. (2015) | Y | | | | x |
| Grosse et al. (2017) | Y | | | | x |
| Gu et al. (2010) | Y | x | | x | |
| Guo et al. (2011) | N | | | | |
| Habazin et al. (2017) | Y | | x | | |
| Hanson et al. (2018) | Y | | x | | x |
| Haouassi et al. (2022) | Y | x | | x | |
| Hara et al. (2020) | Y | | x | x | |
| Heßler and Irnich (2022) | N | | | | |
| Henn (2012) | Y | x | | x | |
| Henn et al. (2010) | Y | x | | x | |
| Henn and Schmid (2013) | Y | | x | x | |
| Henn and Schmid (2013) | Y | x | | x | |
| Henn and Wäscher (2012) | Y | x | | x | |
| Ho and Lin (2017) | Y | x | | | x |
| Ho et al. (2008) | Y | x | | | |
| Hong (2018) | Y | x | | x | |
| Hong (2019) | Y | x | | x | |
| Hong et al. (2012) | Y | x | | x | |
| Hong et al. (2013) | Y | x | | x | |
| Hong et al. (2015) | Y | x | | x | |
| Hong et al. (2016) | Y | x | | | x |
| Hong and Kim (2017) | Y | x | | | |
| Hong and Kim (2018) | N | | | | |

(*Continued*)

**Table 1.** (Continued).

| Reference | Included (Y/N) | Classification: Simulation paper | Case study | Analytic paper | Conceptual paper |
|---|---|---|---|---|---|
| Hossein Nia Shavaki and Jolai (2020) | Y | x | x | x | |
| Hsieh and Huang (2011) | Y | x | | | |
| Hu et al. (2009) | Y | x | x | x | |
| Huang et al. (2018) | Y | x | x | x | |
| Hulett and Damodaran (2019) | N | | | | |
| Isler et al. (2016) | Y | x | | x | |
| Jaghbeer et al. (2020) | Y | | | | x |
| Jharkharia and Das (2019) | N | | | | |
| Jiang et al. (2020) | Y | x | x | x | |
| Kajiwara et al. (2019) | N | | | | |
| Kang (2021) | Y | x | x | x | |
| Kašparová and Dyntar (2021) | Y | x | | x | |
| Keung et al. (2022) | Y | x | x | | |
| Khachatryan and McGinnis (2014) | Y | x | | x | |
| Khojasteh and Son (2016) | Y | | | x | |
| Khojasteh-Ghamari and Son (2008) | Y | | | x | |
| Kim et al. (2019) | Y | x | x | | |
| Klein-Theyer et al. (2016) | Y | | x | | |
| Klodawski et al. (2018) | Y | x | | x | |
| Klumpp and Loske (2021) | Y | x | | x | |
| Koo (2009) | Y | x | | | x |
| Kostrzewski (2020) | Y | x | | x | |
| Kostrzewski et al. (2020) | Y | x | | x | |
| Kovac and Djurdjevic (2020) | Y | x | x | x | |
| Kübler et al. (2020) | Y | x | x | x | |
| Kulak et al. (2012) | Y | | | x | |
| Kuo et al. (2016) | Y | | | x | |
| Lam et al. (2014) | Y | | | x | |
| Latif and Shin (2020) | Y | | x | | x |
| H. -Y. Lee and Murray (2019) | Y | | | x | |
| I. Lee et al. (2020) | Y | x | x | x | |
| J. Lee et al. (2020) | N | | | | |
| S. -D. Lee and Kuo (2008) | Y | x | | | |
| Lenoble et al. (2020) | N | | | | |
| J. Li et al. (2017) | Y | x | | x | |
| Y. Li et al. (2021) | Y | x | x | x | |
| Lind et al. (2020) | Y | | x | | x |
| Liu et al. (2011) | N | | | | |
| Lolli et al. (2022) | Y | x | x | x | |
| Lorenc and Burinskiene (2021) | Y | | x | x | |
| Loske (2022) | Y | | | x | |
| Löffler et al. (2022) | Y | x | | x | |
| Lu, McFarlane, Giannikas, & Y. Zhang (2016) | Y | x | x | x | |
| Madani et al. (2020) | N | | | | |
| Manzini et al. (2019) | Y | | x | x | |
| Manzini et al. (2007) | Y | | | x | |

(*Continued*)

**Table 1.** (Continued).

| Reference | Included (Y/N) | Classification: Simulation paper | Case study | Analytic paper | Conceptual paper |
|---|---|---|---|---|---|
| Marchet, et al. (2011) | Y | | x | x | |
| Marchet et al. (2015)* | Y | | x | | |
| Marzialia et al. (2022) | N | | | | |
| Masae, Glock, & Vichitkunakorn (2020b) | Y | | x | x | x |
| Masae, Glock, & Vichitkunakorn (2020a) | N | | | | |
| Masae et al. (2021) | Y | x | | x | |
| Mejri et al. (2022) | Y | x | | x | |
| Melacini et al. (2011) | Y | | x | x | |
| Miguel et al. (2022) | Y | x | | x | |
| Mohring et al. (2020) | Y | x | | x | x |
| Moons et al. (2019) | Y | | | x | |
| Moons et al. (2018) | Y | x | | x | |
| Mou (2022) | Y | x | | x | |
| Mowrey and Parikh (2014) | Y | x | | x | |
| Muter and Öncan (2022) | N | | | | |
| Nagda et al. (2019) | Y | | | | x |
| Oh et al. (2021) | N | | | | |
| Oláh et al. (2020) | N | | | | |
| Ozden et al. (2021a) | Y | x | | x | |
| Ozden et al. (2021b) | Y | x | | x | |
| Öztürkoğlu and Hoser (2019) | Y | x | | x | |
| Öztürkoglu and Hoser (2019) | Y | x | | | |
| Pan et al. (2012) | Y | | | x | |
| Pan and Wu (2009) | Y | | | x | |
| Pan and Wu (2012) | Y | x | | x | |
| Pansart et al. (2018) | Y | x | x | x | |
| Parikh and Meller (2008) | Y | | | x | |
| Parikh and Meller (2009) | Y | x | | x | |
| Parikh and Meller (2010a) | Y | x | | x | |
| Parikh and Meller (2010b) | Y | x | | x | |
| Poon et al. (2009) | Y | | x | x | |
| Pugliese et al. (2022) | Y | x | x | x | |
| Purba et al. (2018) | Y | | x | | |
| Quader and Castillo-Villar (2018) | Y | x | | x | |
| Ramaekers et al. (2018) | Y | x | | | |
| Rammelmeier et al. (2012) | N | | | | |
| Ran et al. (2020) | Y | | x | x | |
| Rao and Adil (2013) | Y | x | | x | |
| Rasmi et al. (2022) | Y | x | | x | |
| Redmer (2020) | Y | x | | x | |
| Reif and Günthner (2009) | Y | | x | | x |
| Renaud and Ruiz (2008) | Y | x | x | | |
| Revillot-Narváez et al. (2020) | Y | x | x | x | |
| Rijal et al. (2021) | Y | x | x | x | |
| Rim and Park (2008) | Y | | | x | |
| Rojanapitoon and Teeravaraprug (2018) | Y | x | | x | |

(*Continued*)

**Table 1.** (Continued).

| Reference | Included (Y/N) | Classification: Simulation paper | Case study | Analytic paper | Conceptual paper |
|---|---|---|---|---|---|
| Roodbergen et al. (2008) | Y | x | | x | |
| Saylam et al. (2022) | Y | x | | x | |
| Scholz et al. (2016) | Y | x | | x | |
| Scholz and Wäscher (2017) | Y | x | x | x | |
| Scholz and Wäscher (2017) | Y | | | x | |
| Schrotenboer et al. (2017) | Y | x | | x | |
| Schubert et al. (2018) | Y | | | x | |
| Shekari Ashgzari and Gue (2021) | Y | x | | x | |
| Schubert et al. (2021) | Y | x | x | x | |
| Schwerdfeger and Boysen (2017)* | Y | x | | x | |
| Sgarbossa et al. (2019) | Y | x | | x | |
| Sgarbossa et al. (2022) | Y | x | x | | x |
| Shen et al. (2011) | N | | | | |
| Shetty et al. (2020) | Y | x | x | x | |
| Shiau et al. (2021) | N | | | | |
| Shouman et al. (2007) | Y | x | | | x |
| Silva et al. (2020) | Y | x | x | x | |
| Soyaslan et al. (2017) | Y | | x | x | |
| Srinivas and Yu (2022) | Y | x | | x | |
| Stinson and Wehking (2012) | N | | | | |
| Stinson and Wehking (2016) | Y | x | | | |
| T. -S. Su and Hwang (2017) | N | | | | |
| Y. Su et al. (2022) | Y | x | | x | |
| Sundram et al. (2019) | N | | | | |
| Tajima et al. (2020) | Y | x | | x | |
| Taljanovic and Salihbegovic (2010) | N | | | | |
| Tappia et al. (2019) | Y | x | | x | |
| Theys et al. (2010) | Y | | | x | |
| Trindade et al. (2021a) | Y | x | x | x | |
| Trindade et al. (2021b) | Y | x | x | x | |
| Urzúa et al. (2019) | Y | x | x | | |
| Valle et al. (2017) | Y | x | | x | |
| van der Gaast and Weidinger (2022) | Y | x | | | |
| van Gils et al. (2019) | Y | x | x | | |
| van Gils, et al. (2018) | Y | x | x | | |
| van Gils et al. (2017) | Y | | x | x | |
| Vanheusden, et al. (2022) | N | | | | |
| Vanheusden et al. (2020) | Y | x | x | x | |
| Vazquez-Noguerol et al. (2020) | N | | | | |
| Vazquez-Noguerol et al. (2022) | N | | | | |
| Venkitasubramony and Adil (2017) | Y | | | x | |
| Villarreal-Zapata et al. (2020) | Y | | | | x |
| Walter et al. (2013) | Y | | | x | |
| Wan and Liu (2022) | Y | x | x | x | |
| M. Wang et al. (2020) | Y | x | x | x | |
| X. Wang et al. (2013) | Y | x | | x | |

(*Continued*)

**Table 1.** (Continued).

| Reference | Included (Y/N) | Classification: Simulation paper | Case study | Analytic paper | Conceptual paper |
|---|---|---|---|---|---|
| X. -Z. Wang et al. (2013) | Y | x | | x | |
| Webster et al. (2012) | Y | x | | x | |
| Weichert et al. (2014) | N | | | | |
| Weidinger (2018) | Y | x | | | |
| Weidinger et al. (2019) | Y | x | | | |
| Winkelhaus et al. (2021) | Y | | | | x |
| Winkelhaus et al. (2018) | Y | x | | | |
| Winkelhaus et al. (2022) | Y | x | x | | |
| W. Wu et al. (2020) | Y | | x | x | |
| Y. Wu and Wu (2014) | N | | | | |
| Y. Wu and Zhang (2008) | N | | | | |
| Y. Wu et al. (2017) | Y | x | | x | |
| Z. -H. Wu et al. (2020) | Y | x | | x | |
| M. -F. Yang (2008) | Y | x | | | |
| D. Yang et al. (2022) | Y | x | x | x | |
| J. Yang et al. (2021) | Y | | x | x | |
| Yousefi Nejad Attari, Ebadi Torkayesh, Malmir, & Neyshabouri Jami (2021) | Y | x | x | x | |
| Yu and de Koster (2008) | Y | x | x | | |
| Yu and de Koster (2010) | Y | x | | x | |
| Yu and de Koster (2009) | Y | x | x | x | |
| X. Zhang et al. (2022) | N | | | | |
| K. Zhang and Gao (2022) | Y | x | | x | |
| J. Zhang et al. (2019) | Y | | | x | |
| Zhang et al. (2022) | Y | x | | x | |
| Y. Zhang (2016) | Y | x | x | x | |
| J. Zhang et al. (2021a) | Y | x | x | x | |
| J. Zhang et al. (2021b)* | Y | x | x | x | |
| S. Zhang et al. (2022) | Y | x | | x | |
| J. Zhang et al. (2022) | Y | x | x | x | |
| Y. Zhuang et al. (2022) | Y | | | x | x |
| Zhao et al. (2019) | Y | | x | x | |
| Zhou et al. (2010) | N | | | | |
| Zhu, J., Guo, J., Zhou, L., & Zhang, H. (2016) | N | | | | |
| Zhu et al. (2011) | N | | | | |
| Z. Zhuang et al. (2021) | Y | x | | x | |
| Y. Zhuang et al. (2022) | Y | x | x | x | |
| Ziółkowski and Lęgas (2019) | Y | | | x | |
| Zivanic et al. (2019) | Y | x | | | |
| Žulj et al. (2018) | Y | x | | x | |
| Zuñiga et al. (2020) | Y | x | x | x | |

### 3.2. Data collection

For each paper in the final sample, eight further categories of data were collected and recorded in a structured database[3]; some of the data were retrieved directly from the Scopus database, while other ones were deduced from an analysis of the paper full text.

(1) *Paper metadata*. The first category includes the metadata of the papers, such as title, authors, year of publication, country, source title, keywords and number of citations; these data were directly taken from Scopus using the ‘export’ function.
(2) *Warehouse characteristics*. The second class of data includes the details related to the warehouse characteristics:
   (a) layout (i.e. rectangular, fishbone, U-shaped and flying-V) and
   (b) structure (e.g. presence of cross-aisles, depot location, shape factor and narrow aisles).
(3) *Picking process*. The next class of data includes specific characteristics of the picking process, namely:
   (a) picking type (high vs. low level, manual vs. automated);
   (b) picking strategy (order picking, batch picking or zone picking);
(4) *Storage allocation* policies, i.e. random, class-based, correlated or other;
(5) *Routing policies*, i.e. heuristic, meta-heuristic or exact;
(6) *Problem constraints* (e.g. picker capacity, congestion, and bucket brigade);
(7) *Application context*. This category describes the context of application of the study, which typically include the industry field (for instance, manufacturing, food, automotive, health care, retail, etc.);
(8) *Results*. The last class of information describes the results obtained in the reviewed paper. These results were classified as follows:
   (a) output type (process improvement, process optimization or comparative results); and
   (b) Key Performance Indicators (KPIs) measured.

Most of the options listed in the previous classes of data are not mutually exclusive. For example, it is always possible that a study takes into account more warehouse layouts in the attempt to make a comparison of the results obtained with different warehouse configurations. These situations will obviously result in the document to be classified into more categories. At the same time, it is also possible that a paper is not classified into one of the above classes, if the relating aspect has not been treated in the manuscript.

### 3.3. Papers analysis

The data collected on the sample of papers were analysed applying both qualitative and quantitative methods, as detailed in the subsections below.

#### 3.3.1. Descriptive statistics

The paper metadata were used to make some preliminary qualitative analyses, in the form of descriptive statistics on the sample of studies. These analyses, carried out using the basic functions of Microsoft Excel™, aim at delineating the trend of research on order picking over time, as well as the distribution of the papers among the various journals and countries. Relating outcomes are described in Section 4.1.

#### 3.3.2. Citation analysis

Citation analysis is a 'quantitative-oriented' bibliometric tool, typically used to determine the most influential articles on a subject, to illustrate the connections between papers in a literature sample and to identify works that have been pivotal for shaping a specific research field (Masae et al., 2020). Such an analysis was made on the sample of studies reviewed, using again the papers metadata elaborated in Microsoft Excel™, to gain insights into how an author's work is positioned in relation to others and indicate how a research field is evolving, as well as to determine the most influential papers in the field of order picking. Relating outcomes are proposed in Section 4.2.

#### 3.3.3. Keyword analysis

Keywords or research terms are important tools in any research area, as they help researchers have access to papers, books and works related to their field of expertise (Amini et al., 2021). Indeed, keywords are deliberately selected or created by authors themselves, with the aim to (correctly) express the main subject of their papers (L. Yang et al., 2018). In scientometrics, author keywords are recognised to reflect research topics (J. Zhang et al., 2016), and in particular, they are regarded as 'unique' topics inside a wider evolving theme (K. Li & Yan, 2019).

Following the approach by Fadlalla and Amani (2015), a keyword analysis was applied for mapping the topics covered by the published articles and their classification into well-established ('core'), intermittent, phantom/emerging or trendy topics. To this end, the analysis evaluates the *frequency* of usage of the keywords of a sample of papers and their *persistence*: the former reflects the number of occurrences of a keyword, while the latter represents the continuity of a given concept over time and is measured as the number of years since a concept was first introduced as a keyword (Bigliardi et al., 2021). Results are presented and discussed in Section 4.3.

#### 3.3.4. Content analysis

The last set of analyses was made using the eight categories of data listed in Section 3.2, which were mapped across the various studies reviewed to deepen the specific contents of each paper. Cross-analyses, supported by Statistical Package for the Social Science (SPSS) release 27, were made where appropriate to identify possible relationships between the various categories. Results are detailed in Section 4.3.

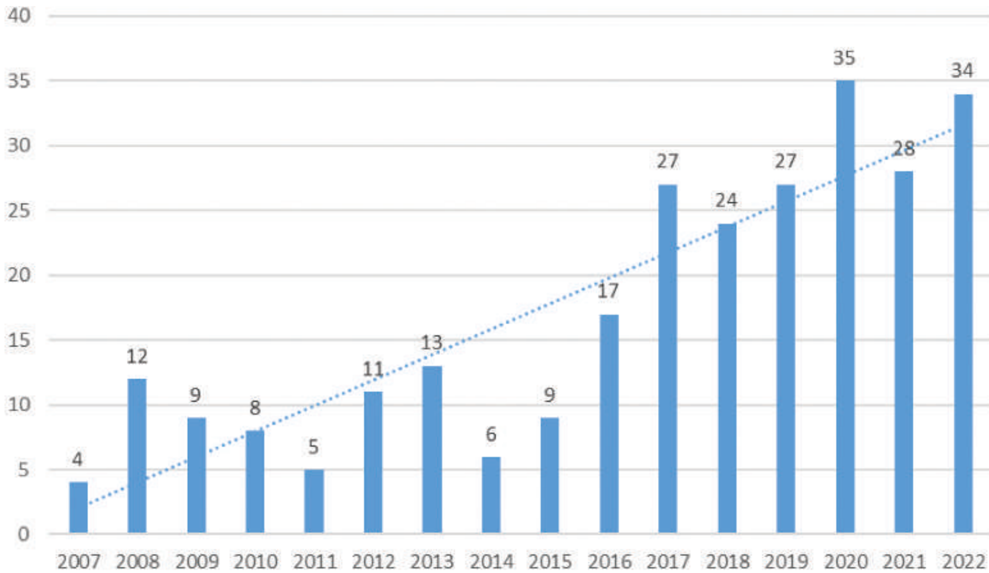



**Figure 2.** Trend of the number of papers per year.

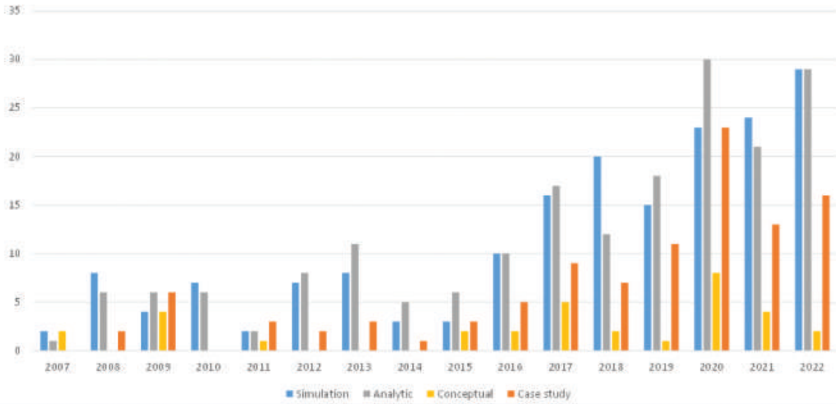
## 4. Review results

### *4.1. Descriptive statistics*

In this section, some key results from the descriptive analyses of the sample of papers are discussed. Figure 2 presents the distribution of the articles reviewed by the year of publication.

From 2007 until 2015, an average of 8–9 studies per year were published. As can be seen from Figure 2, in 2016 the number of studies per year started increasing, reaching 27 articles in 2017, 24 in 2018, 27 in 2019, 35 in 2020, 28 in 2021 and 34 in 2022. Taking into account the fact that the query made was quite general in nature, the resulting distribution of the papers highlights an increase in time of the number of papers about order picking, suggesting a stable and continuous focus on this subject during the last years.

Figure 3 details the distribution of papers as a function of the type of study. We recall that the papers reviewed could be classified into more than one category; this is for instance the case for studies that make use of combined approaches, hybrid models or, more simply, various techniques. Hence, Figure 3 takes into consideration the total number of applications of each method within the sample of papers reviewed. Having said that, analytic studies emerged as the most frequent type of study (188 papers), followed by simulation methods (181). Simulation models are generally recognised as suitable tools for providing an effective representation of order picking systems, and compared to analytical models, they allow for the evaluation and testing of a wide set of policies, even in combination (van Gils, Ramaekers, Caris, et al., 2018). Nonetheless, it is interesting to note that 130 articles (48.33% of the sample) adopted simulation coupled with analytic approaches, suggesting that the combined usage of these techniques enhances the effectiveness of the analysis.




| Study type | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Simulation | 2 | 8 | 4 | 7 | 2 | 7 | 8 | 3 | 3 | 10 | 16 | 20 | 15 | 23 | 24 | 29 | 181 |
| Case study | | 2 | 6 | | 3 | 2 | 3 | 1 | 3 | 5 | 9 | 7 | 11 | 23 | 13 | 16 | 104 |
| Analytic | 1 | 6 | 6 | 6 | 2 | 8 | 11 | 5 | 6 | 10 | 17 | 12 | 18 | 30 | 21 | 29 | 188 |
| Conceptual | 2 | | 4 | | 1 | | | | 2 | 2 | 5 | 2 | 1 | 8 | 4 | 2 | 33 |

**Figure 3.** Paper distribution by research methodology applied.

Many papers (104 out of 269, 38.66%) have proposed a case study, referring to a real context in which the study was made, or the solution proposed was tested; this outcome confirms the relevance of order picking in real industrial systems, as also highlighted by many authors (e.g. de Koster et al., 2007; Melacini et al., 2011). It can also be seen from Figure 3 that case studies have become more popular in recent years; such outcome could suggest that recent research has focused on solving picking problems in real contexts, probably, because of the increased implementation and usage of order picking systems. Overall, research on order picking seems to privilege practical over theoretical approaches.

The remaining category (conceptual papers) includes a significantly lower number of studies. The recalled study by de Koster et al. (2007) has targeted the general context of order picking systems. Other studies have focused on more specific topics, such as the level of adoption of order picking systems (Marchet et al., 2015), human factors and ergonomic issues (Elbert et al., 2017; Grosse et al., 2015, 2017) and, more recently, the automation of order picking systems (Jaghbeer et al., 2020). Grosse et al. (2016) have discussed the relevance of human factors in order picking and have developed a methodological approach for the use of qualitative interviewing to study the interaction between order picking design and human factors. The objective of Battini et al. (2017) study, instead, is to define how to study fatigue and recovery time in order picking systems. The main focus is the understanding of which instrument can be used for this kind of analysis and what are the steps to be taken for the improvement of picking efficiency through the analysis of fatigue accumulation of the operators.

The 269 papers reviewed have been published on a total of 97 different journals. Table 2 shows the key academic journals in which the articles were published, limited to the sources that published at least five papers to be more effective. This table is useful for identifying the most influential journals in the area of order picking systems.

The *International Journal of Production Research* stands at the top by publishing the highest number of papers (34 papers out of 269, 12.64% of the sample). Moreover, papers have appeared on this journal with a good continuity: in 3 years only, there were no

**Table 2.** Trend of publications on order picking by journals.

| | Publication year | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Journal title | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
| International Journal of Production Research | 0 | 2 | 1 | 1 | 0 | 1 | 1 | 0 | 2 | 1 | 8 | 2 | 6 | 5 | 0 | 4 | 34 |
| European Journal of Operational Research | 1 | 0 | 1 | 2 | 0 | 3 | 1 | 1 | 0 | 3 | 5 | 0 | 4 | 1 | 0 | 3 | 25 |
| Computers and Industrial Engineering | 0 | 2 | 1 | 0 | 0 | 1 | 3 | 0 | 0 | 1 | 3 | 1 | 3 | 4 | 1 | 2 | 22 |
| International Journal of Production Economics | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 4 | 0 | 1 | 2 | 1 | 0 | 1 | 1 | 11 |
| IFAC-PapersOnLine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 3 | 0 | 0 | 0 | 0 | 10 |
| IIE Transactions (Institute of Industrial Engineers) | 0 | 3 | 1 | 1 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| International Journal of Advanced Manufacturing Technology | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 1 | 1 | 0 | 1 | 9 |
| Computers and Operations Research | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 2 | 1 | 8 |
| Expert Systems with Applications | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 5 |
| Flexible Services and Manufacturing Journal | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 5 |
| Mathematical Problems in Engineering | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 5 |
| Naval Research Logistics | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 5 |

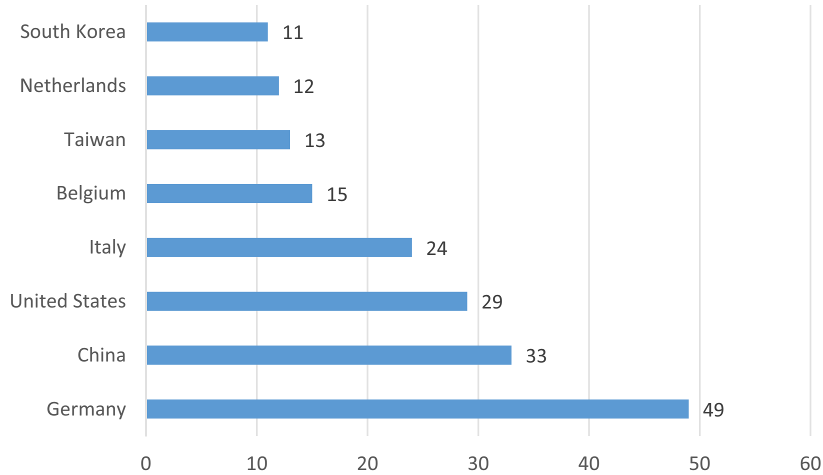



**Figure 4.** Geographic distribution of the studies reviewed.

publications about order picking published on the *International Journal of Production Research*. Similar considerations hold true for the *European Journal of Operational Research*, which is the second ranked journal in terms of publications (25 papers, 9.29% of the sample), and for *Computer & Industrial Engineering*, the third ranked journal with 22 publications (8.18% of the sample). Overall, the top three sources encompass 30.11% of all the selected studies: this suggests that there is a restricted group of journals which is recognised by the authors working in the field of order picking as a suitable outlet for their research. These journals are also well established and top sources in their subject areas.

Countries with the highest number of order picking research are shown in Figure 4 in ascending order of the relating number of publications. To determine the country of the study, if conflicts existed, the nationality of the first author was taken as reference, which is a common approach in review studies (Bottani & Vignali, 2019; Gao et al., 2017).

Germany by itself contributed 18.22% of the studies on picking (49 papers). China held the second position by publishing 33 papers. The third and fourth ranked countries are United States and Italy with 29 and 24 studies, respectively. From a practical point of view, the relevance of the order picking problem in these countries could be justified in the light of the fact that Germany, China, the US and Italy are all characterized by a quite high cost of manpower, which plays a very important role in order picking (Daniels et al., 1998). The top four countries, overall, account for 50.19% of the total papers.

Figure 5 outlines the top contributing authors along with the number of their papers.

In total, 551 different authors contributed to the order picking literature, resulting in an average of 3.14 authors per paper. Out of 269 papers, only 16 have a single author, 68 articles have two authors, 91 papers have three authors and 64 papers have four different authors. Also, the majority of authors ($433 \approx 78.6\%$) published one paper only. Leveraging the facts that multiple papers are typically necessary for a researcher to exert a high academic impact in a given field (Hou et al., 2020) and that co-author networks tend to increase across a scholar's career (S. Lee & Bozeman, 2005), we could argue that most of the authors analysed are relatively new to the order picking area. One

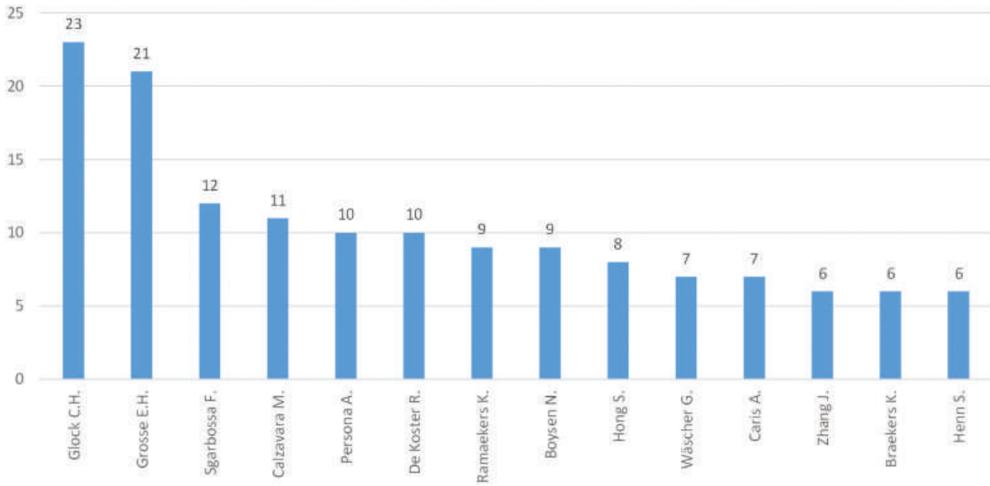



**Figure 5.** Top authors and the number of articles.

hundred-eighteen authors (21.4%) published instead more than one study, and, among them, Glock dominates the ranking with 23 published papers, followed by Grosse, Sgarbossa and Calzavara with 21, 12 and 11 papers each, respectively.

### *4.2. Citation analysis*

Citation analysis was made on the sample of papers reviewed, and related results are presented in Table 3. The left part of the table shows the 10 most-cited publications overall, while the right part ranks the papers in descending order of the number of citations per year. This latter parameter was computed as the raw citation counts of the paper (directly retrieved from Scopus) divided by the number of years elapsed from the publication of the paper to the time of data extraction (end of 2022).

The papers with highest absolute number of citations are de Koster et al. (2007) (1212 citations), Grosse et al. (2015) (226 citations) and Poon et al. (2009) (223 citations). We recall that the former study owns some characteristics typical of review papers, which, by nature, tend to be more cited than original research articles; this is probably the reason for the very high number of citations, more than four times higher than the second ranked paper. This latter is instead an original research article that has proposed the usage of radio frequency identification (RFID) for order picking management in warehouses. It is reasonable to argue that the popularity of RFID and its potential for being used in logistics have contributed to the impact of this paper. Time normalisation of citations based on calendar years confirms the popularity of the two papers by de Koster et al. (2007) and Poon et al. (2009), which hold the top and fifth positions, respectively, in the ranking by citations per year. In this respect, it should be mentioned that the number of citations per year, although recognised as a suitable index for comparing articles, could generate inconsistent results for recent papers, as it takes a few years for an article to gain a foothold in science and at least 2–3 years for it to become successful (Ioannidis et al., 2016). In our sample, this is reflected by the lower number of citations per year of papers

**Table 3.** Top-cited publications.

| # | Reference | Citations | # | Reference | Citations per year (up to 2022) |
|---|---|---|---|---|---|
| 1 | (de Koster et al., 2007) | 1212 | 1 | (de Koster et al., 2007) | 75.75 |
| 2 | (Grosse et al., 2015) | 226 | 2 | (Grosse et al., 2015) | 28.25 |
| 3 | (Poon et al., 2009) | 223 | 3 | (Grosse et al., 2017) | 24.00 |
| 4 | (Grosse et al., 2017) | 144 | 4 | (Scholz et al., 2017) | 16.67 |
| 5 | (Theys et al., 2010) | 138 | 5 | (Poon et al., 2009) | 15.93 |
| 6 | (Chan & Chan, 2011) | 131 | 6 | (Lu et al., 2016) | 14.00 |
| 7 | (Henn & Wäscher, 2012) | 112 | 7 | (J. Zhang et al., 2019) | 13.00 |
| 8 | (Kulak et al., 2012) | 112 | 8 | (Kim et al., 2019) | 12.75 |
| 9 | (Henn, 2012) | 109 | 9 | (J. Li et al., 2017) | 12.50 |
| 10 | (Yu & de Koster, 2009) | 102 | 10 | (Valle et al., 2017) | 11.83 |

published since 2017, whose popularity, therefore, cannot be fully evaluated at the time of writing.

### 4.3. Keyword analysis

Among the 269 studies reviewed, 260 (96.65%) papers have author keywords, which accounted for 545 different terms in total. It should be mentioned that the keyword 'order picking' was excluded from the analysis because it was originally used to make the search query on the Scopus database. A preliminary analysis revealed that authors often use slightly different keywords to express a similar (or the same) concept. This is the case for 'RFID'/'radio frequency identification' or 'simulation'/'simulations'. We consequently screened manually the various keywords and grouped them into the same semantic area. Moreover, to be more effective, the analysis was focused on keywords whose frequency is at least 2, i.e. 133 selected keywords. For the purpose of this study, the persistence was calculated taking into account the first appearance of a keyword.

By correlating the persistence of the keywords with their frequency, we obtained the outcomes in Figure 6. This graph is divided into quarters using one horizontal and one vertical lines as separators. For the persistence, the horizontal line is set at persistence = 8, corresponding to half of the time span covered in the review. As far as frequency is concerned, the median value (i.e. frequency = 3) was taken as the threshold. According to the quadrant they finally belong to, keywords were categorised into four groups:

(1) Well-known research topics (39), with high frequency and high persistence
(2) Intermittent research topics (32), with low frequency and high persistence
(3) Emergent research topics (51), with low frequency and low persistence
(4) Trendy research topics (11), with high frequency and low persistence

Most of the well-established research topics describe very general concepts, and therefore, they are likely to be mentioned with a higher frequency by researchers. As shown in Figure 6, 'warehousing', 'order batching', 'warehouse management', 'routing', 'storage assignment', 'human factor', 'logistics', 'simulation', 'warehouse' and 'ergonomics' belong to these topics. These keywords cover most of the traditional picking themes, which indeed have been widely addressed in the literature. Among routing applications,

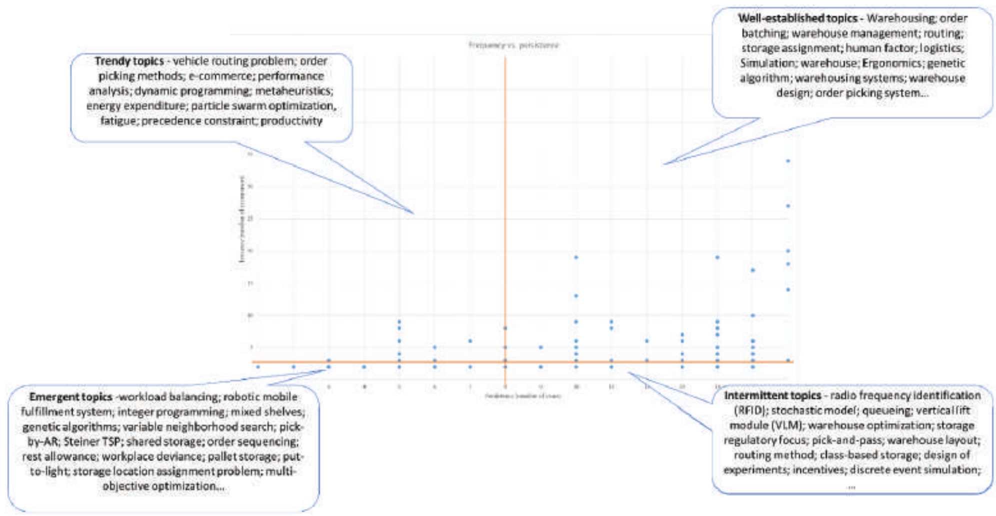



**Figure 6.** Persistence vs. frequency of the keywords.

Weidinger (2018) has investigated the picker routing problem in a rectangular scattered storage warehouse, which differs from classical picker routing problems by being a combined selection and routing problem. Similarly, Masae et al. (2020a) have developed an optimal order picker routing policy for the Chevron warehouse using a dynamic programming procedure.

An example of intermittent topic is ‘Markov chain’; some of its applications have been mentioned by Mohring et al. (2020), who depicted the order picking system with levelled order release, or by Bukchin et al. (2012), who set an optimal decision-making policy. As shown in Figure 6, other keywords in the quadrant of intermittent concepts refer to ‘radio frequency identification (RFID)’, ‘stochastic model’, ‘queueing’, ‘vertical lift module’ (VLM), ‘warehouse optimization’, ‘storage regulatory focus’, ‘pick-and-pass’, ‘warehouse layout’, ‘multi-picker operations’ and ‘fuzzy logic’. RFID technology has been treated in three studies, namely Poon et al. (2009), X. Wang et al. (2013) and Choy et al. (2017). The former authors have adopted RFID technology to facilitate the collection and sharing of data in a warehouse. Tests were performed for evaluating the reading performance of both active and passive RFID apparatus. Similarly, Choy et al. (2017) have proposed an RFID-based decision support system for storage assignment in a warehouse. Looking at multi-picker operations, Pan and Wu (2012) have presented an approximation method based on closed queueing network by using the self-correcting approximation technique algorithm to evaluate the throughput time of an order picking system with multiple pickers and aisle congestion considerations for different routing policies. An interesting application of fuzzy logic technique is provided by Lam et al. (2014) for dividing the receiving orders into batches and prioritise the batch-handling sequence for picking.

Emerging research topics either include very specific concepts or refer to a particular process/policy, which is likely to be mentioned with lower frequency by researchers. These concepts include the specific methodologies applied in some studies (e.g. integer programming, genetics algorithms, variable neighbourhood search or multi-objective optimization) or general topics relating to an order picking system (robotic mobile fulfilment system, mixed shelves, pick-by-AR, shared storage, put-to-light and pallet storage).

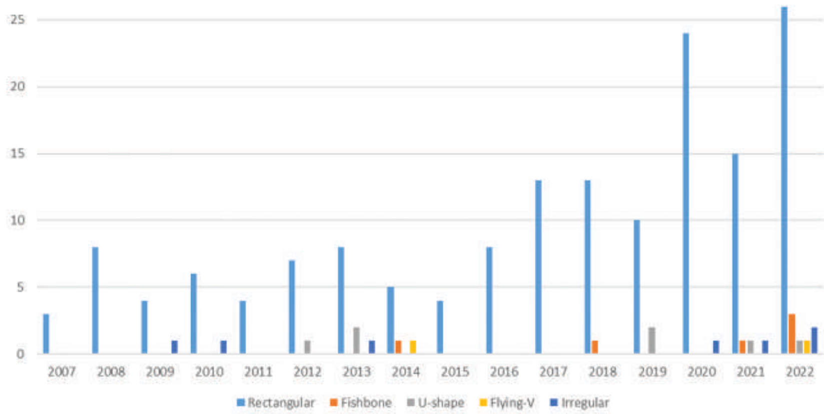
Among trendy topics, we found few (11) keywords, namely 'vehicle routing problem', 'order picking methods', 'e-commerce', 'performance analysis', 'dynamic programming', 'meta-heuristics', 'energy expenditure', 'PSO', 'fatigue', 'precedence constraint' and 'productivity'. Cheng et al. (2015) have proposed an efficient hybrid algorithm for solving the joint batch picking and picker routing problem to determine the batch size, order allocation in a batch and the travelling distance. The core of this hybrid algorithm consists in the PSO and the ACO algorithms. Studies dealing with fatigue have been developed by Battini et al. (2017), Winkelhaus et al. (2018), Calzavara et al. (2018), Zhao et al. (2019) and Al-Araidah et al. (2020). Among them, Battini et al. (2017) have discussed how to determine fatigue and recovery time in order picking systems. The focus was on the understanding of the appropriate tool to be used for this kind of analysis and of the steps to be taken for the improvement of picking efficiency through the analysis of the fatigue accumulated by the operators.

## 4.4. Content analysis

### 4.4.1. Warehouse layout and structure

From the analysis of the papers, it emerged that 99 studies do not precisely mention the warehouse layout, suggesting that this was not the primary focus of the study. The remaining 170 papers (63.2% of the sample) instead refer to one or more warehouse layouts.

Figure 7 shows an analysis of the trend in time of the studies. As shown in Figure 7, the conventional (rectangular) layout is by far the most popular configuration analysed by authors and has always been widespread in the literature, being also the only layout considered in the first studies on order picking. Overall, 158 articles have evaluated the conventional layout. The remaining layout types are significantly less studied in the literature and have been studied somehow discontinuously; moreover, they have attracted the attention of researchers more recently compared to the conventional layout. This could be due either to the greatest difficulty in modelling layouts other than the rectangular one or to the lower relevance these layouts have in practice compared to the rectangular shape. Overall, 17 papers only have considered non-conventional layouts, either individually or in combination[4] with other layouts. To be more precise, looking at the individual layout analyses, the U-shaped layout has been treated in five studies (i.e. Diefenbach & Glock, 2019; Glock & Grosse, 2012; Glock et al., 2019; Grosse & Glock, 2013; Henn et al., 2013); also, five papers have studied the fishbone layout, while four studies have evaluated irregular warehouse layouts: three circular layouts (Hong et al., 2013; Parikh & Meller, 2009, 2010a) and one Chevron (Masae et al., 2020a). More in detail, Altarazi and Ammouri (2018) have proposed a concurrent simulation-based design of experiments approach for the design of manual order picking warehouses. Four different warehouse layouts have been investigated: the conventional one-block layout, a two-block layout (i.e. a warehouse with one cross-aisle), the horizontal layout and the fishbone layout. The authors found that the horizontal layout is to be preferred




| Warehouse shape | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rectangular | 3 | 8 | 4 | 6 | 4 | 7 | 8 | 5 | 4 | 8 | 13 | 13 | 10 | 24 | 15 | 26 | 158 |
| Fishbone | | | | | | | | 1 | | | | 1 | | | 1 | 3 | 6 |
| U-shape | | | | | | 1 | 2 | | | | | | 2 | | 1 | 1 | 7 |
| Flying-V | | | | | | | | 1 | | | | | | | | 1 | 2 |
| Irregular | | | 1 | 1 | | | 1 | | | | | | | 1 | 1 | 2 | 7 |

**Figure 7.** Warehouse layout vs. publication year.

compared to all other studied layouts. On the contrary, Çelk and Süral (2014) have demonstrated that the multi-item order picking problem can be solved in polynomial time for both fishbone and flying-V layouts. In their study, these two layouts are compared with the conventional parallel-aisle design under the case of multi-item pick lists. In addition, the fact that the flying-V layout has never been studied individually could suggest that research is mainly devoted to exploring this layout as alternative to more conventional ones, thus further supporting the previous consideration about the still limited relevance of this unconventional layout in practice.

As far as the warehouse structure is concerned, the key elements taken into account in this review are the presence of cross-aisles, the depot location, the warehouse shape factor and the presence of narrow aisles. Each study reviewed was first screened to check whether these aspects were evaluated, and, if so, which specific warehouse configuration was examined.

Figure 8 depicts the trend in time of the studies that have evaluated the presence of cross-aisles in the warehouse structure. A general consideration from the outcomes in Figure 8 is that most of the studies on order picking have not taken into account the presence of cross-aisles in the warehouse; overall, this aspect has been analysed in 62 of the 269 studies reviewed (23.05%).

The reason for the limited number of studies is that it is undoubtedly challenging to model the picking process in a warehouse that also include cross-aisles because of the increased complexity of the routing problem, which cannot always be solved in polynomial time. From a practical point of view, cross-aisles divide the warehouse into blocks and offer greater flexibility in the routing of pickers; as a result, shorter travel distances are typically generated. However, this positive effect could be nullified if the number of cross-aisles becomes excessive, as in that case, the cross-aisles themselves have to be crossed to reach the items to be picked, increasing the length

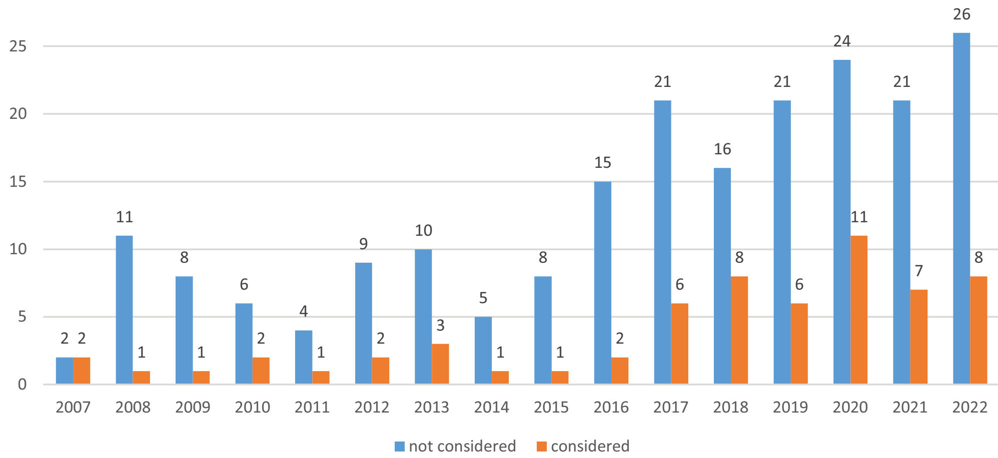



**Figure 8.** Cross-aisle vs. publication year.

of the picking tour (Bottani, Volpi, et al., 2019). This is why various researchers have focused on determining the optimal number and position of cross-aisles in the warehouse (e.g. Öztürkoğlu & Hoser, 2019). The difficulty in modelling the picking tour and solving the routing problem in warehouses with cross-aisles is confirmed by the outcomes proposed in Figure 9, which relates the presence of cross-aisles with the warehouse layout. Indeed, what emerges from this figure is that unconventional layouts are rarely associated to cross-aisles, which, on the contrary, are more frequently considered when referring to rectangular warehouses.

A further consideration is that the theme of cross-aisle is somehow more popular among the studies published in the last years (from 2017 onwards); having stated just above that is it challenging to solve the routing problem in polynomial time, it could be conjectured that the increased computational power available today might help researchers approach this problem. In this respect, the recent literature also suggests possible relationships between picking and Industry 4.0 (e.g. Winkelhaus et al., 2021).

The presence of narrow aisles in a warehouse is a further important point of its structure and is relevant to the order picking process because congestion between pickers can originate from this system configuration (Klodawski et al., 2018). In numerical terms, as shown in Figure 10, this aspect was studied in 36 (13.38%) of the 269 articles reviewed, while 233 articles have neglected it. The topic has also been studied quite discontinuously: although the first studies date back to 2007, the number of papers per year that evaluated warehouses with narrow aisles is quite limited; the only exception is the presence of five papers in 2018, but overall, this aspect has not gained success in the literature. The interest towards the analysis of narrow aisles seems to stem from the industrial practice: indeed, recent studies on the topic (e.g. F. Chen et al., 2019) state that narrow aisles represent a relatively new features of warehouses, observed at sites of big retailers and online retailers. From a scientific perspective, as mentioned, the key issue of narrow aisles is the possibility of congestions; in line with this, mathematical models and heuristic and exact methods have been proposed by researchers to take into account congestions and solve them (Chabot et al., 2018; Pan & Wu, 2012).

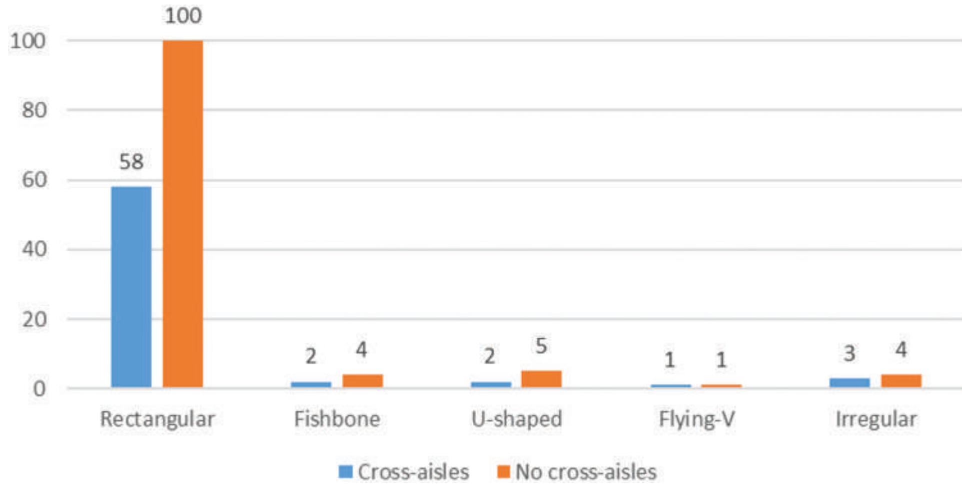
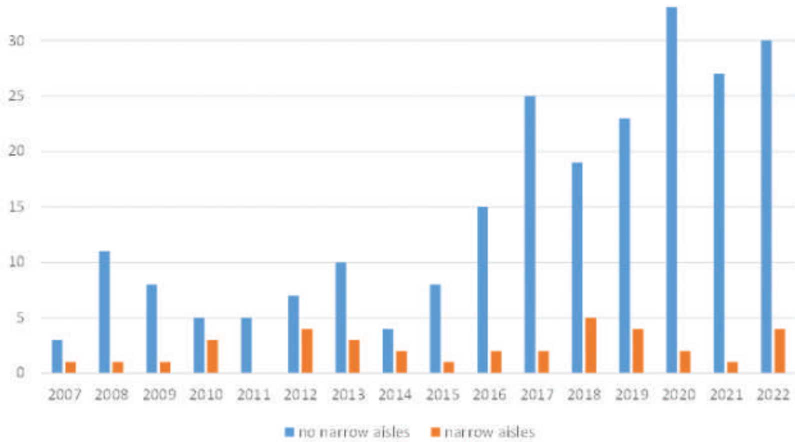



**Figure 9.** Correlation between cross-aisle and warehouse layout.

As shown in Figure 11, a further consideration is that most of the available studies on narrow aisles have focused, once again, on the rectangular warehouses, which are easier to be modelled compared to unconventional layouts. Interestingly, irregular warehouses are all characterised by narrow aisles, which probably are the features that actually make these layouts irregular.

Figure 12 presents the trend in time of the studies that have evaluated the depot location in the warehouse structure. As shown in Figure 12, 113 studies out of 269 (42.01%) have expressly taken into account this aspect in the analyses made, for example by varying the warehouse configuration and setting different possible locations for the depot. Examples of these studies are Beroule et al. (2017), Khachatryan and McGinnis (2014) or C. -M. Chen et al. (2010). Looking at the picking process, it is evident that the position of the depot affects the total length of the picking tour, as the picker is forced to start from a given point in the warehouse and come back to the same point once he/she has completed the tour. In line with this consideration, some studies have also attempted to optimize the position of the depot taking into account the routing policy applied (e.g. Roodbergen & Vis, 2006). Once again, recent studies have more frequently considered the depot location, compared to the older ones, highlighting an increasing interest towards this topic. As it could be reasonable to expect, the warehouse configuration typically taken into account when evaluating the depot location is the rectangular one (Figure 13).

In a similar way, the shape factor, i.e. the ratio between the width and the depth of the warehouse (Petersen, 1997), affects the picking tour because it modifies the geometry of the warehouse itself. As shown in Figure 14, this aspect has been almost neglected in the scientific literature: only 14 studies out of 269 (≈5%) have expressly evaluated it, which means, for instance, that various warehouse configurations were tested (e.g. Chabot et al., 2017). A possible explanation for the very limited number of studies on this topic is that most of the studies relating to order picking targets real contexts, in which the warehouse is already available and owns a precise structure; hence, testing alternative shape factors is




| Narrow aisles | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Totale |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| no narrow aisles | 3 | 11 | 8 | 5 | 5 | 7 | 10 | 4 | 8 | 15 | 25 | 19 | 23 | 33 | 27 | 30 | 233 |
| narrow aisles | 1 | 1 | 1 | 3 | 0 | 4 | 3 | 2 | 1 | 2 | 2 | 5 | 4 | 2 | 1 | 4 | 36 |

**Figure 10.** Narrow aisle vs. publication year.

unfeasible (or at least useless). On the contrary, such testing could be more effective if made at the design stage of the warehouse, to determine its best configuration (Bottani, Montanari, et al., 2019).

### *4.4.2. Picking process*

In this section, the main results derived from an analysis of the characteristics of the order picking process are presented.

Overall, data about the picking level is available in 199 studies of the sample analysed (73.98%); the trend in time of the studies focusing on this topic is presented in Figure 15. According to the findings, low-level picking is by far the most used picking solution (60.81% of the studies), followed by high-level picking (30.65%). It is interesting to note that in 8.54% of the papers, both levels of picking are evaluated, resulting in a combination of solutions. This is for example the case for Calzavara et al. (2016), who have evaluated ergonomics indicators of order picking activities under various scenarios, namely (1) picking from full pallets at ground level (low-level picking); (2) picking from half pallets at ground level (low-level picking) and (3) picking from half pallets on the upper rank of the shelf (high-level picking). To be more precise, the authors have developed a mathematical model for the ergonomics analysis of picking activities and have discussed the risk factors related to musculoskeletal disorders associated with the specific picking system.

Looking at the level of automation of picking systems, the relating aspects are discussed in 246 studies (91.45% of the sample). Figure 16 presents the frequency of usage of the different picking types in time. As can be seen from this figure, the picking type most commonly investigated in the literature is manual picking (76.42%), followed by the automated picking (14.63%). Indeed, humans and human work remain important factors in many real picking processes, and manual picking represents the most common

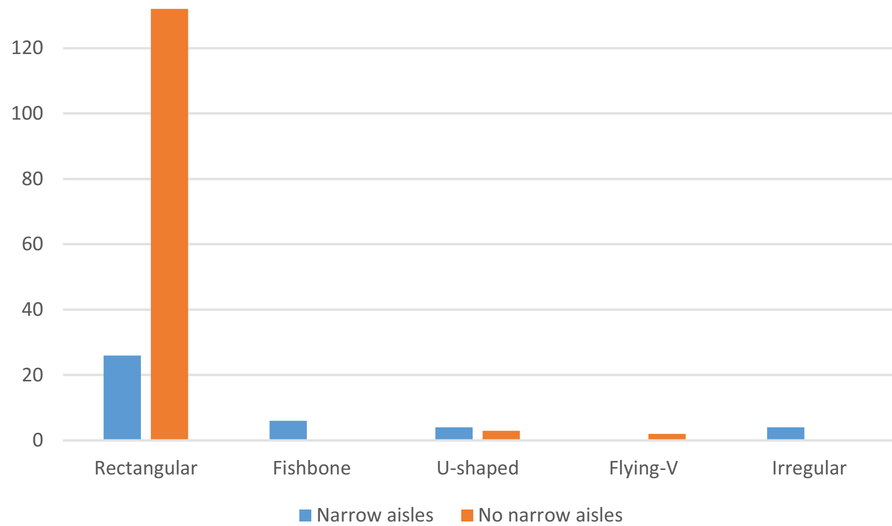
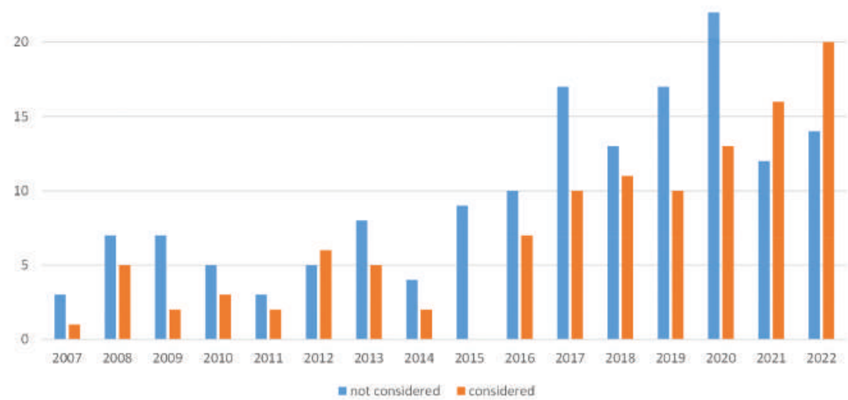



**Figure 11.** Correlation between narrow aisle and warehouse layout.




| Depot location | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| not considered | 3 | 7 | 7 | 5 | 3 | 5 | 8 | 4 | 9 | 10 | 17 | 13 | 17 | 22 | 12 | 14 | 156 |
| considered | 1 | 5 | 2 | 3 | 2 | 6 | 5 | 2 | 0 | 7 | 10 | 11 | 10 | 13 | 16 | 20 | 113 |

**Figure 12.** Depot location vs. publication year.

approach to order preparation in warehouses and distribution centres (Grosse et al., 2017). At the same time, however, businesses are today forced to implement automated solutions at various levels, especially in picking, which is the highest labour-intensive process of a warehouse. In line with these considerations, automated picking processes are more popular in recent studies (from 2016 onwards) and have gained sufficient continuity in the last years. At the same time, it is interesting to note that in 8.94% of the papers, both types of picking (manual and automated) are investigated, with an increase in recent years. Cano et al. (2020) have introduced for the first time a study of several mathematical programming models for solving the joint order batching/picker routing problem (JOBPRP) and the joint order batching, sequencing and routing problem

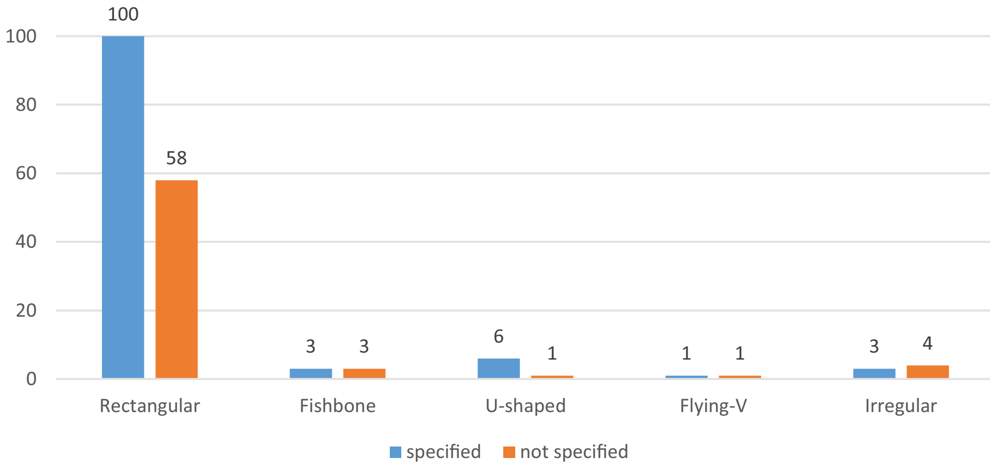
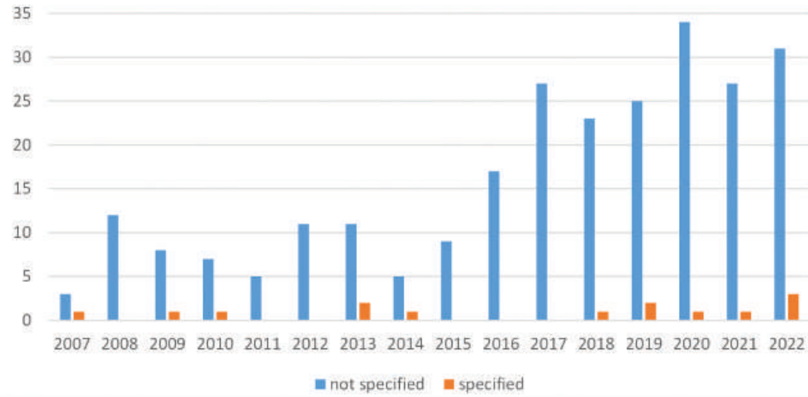



**Figure 13.** Correlation between depot location and warehouse layout.

(JOBSRP) in manual order picking systems, considering the real warehouse environments of distribution centres. The authors have presented various formulations of the travel distance and travel time between picking positions in low-level vs. high-level picker-to-parts systems and single-block vs. multiple-block warehouses. Instead, Khojasteh and Son (2016) have addressed an order picking problem in a multi-aisle automated warehouse, in which a single storage/retrieval (S/R) machine performs storage and retrieval operations. The objective was to minimize the total time travelled by the S/R machine to complete the retrieval process of customer orders in the shortest time. da Piedade et al. (2016) have presented a modelling and simulation approach for evaluating alternative material handling systems. The approach is based on the combination of IDEF-SIM (Integrated Definition Methods – Simulation) technique, along with an implementation using commercial simulation software packages. Two different material handling settings were proposed and compared, the first one comprising a human-based system and the second one an automation-based system.

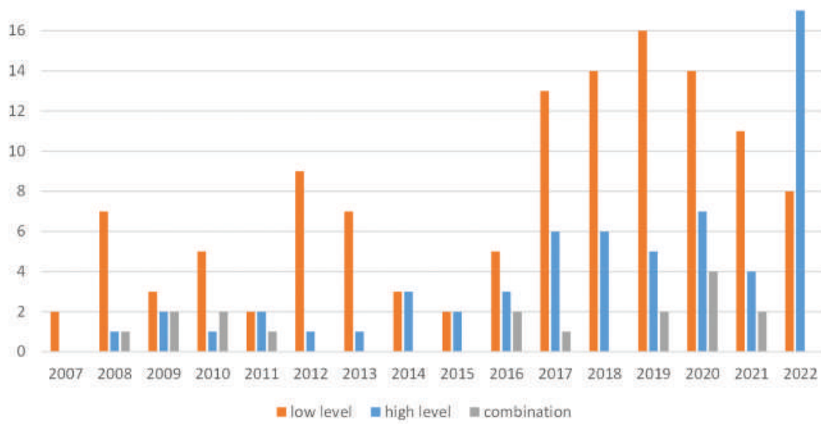
About 10 studies focus on a particular manual order picking system called the 'bucket brigade'. Bucket brigade order picking is an essential function of distribution centre operations. The bucket brigade's workload balancing characteristic ultimately leads to high productivity, even though order picking frequently encounters operational disruptions, mostly because of fluctuating demand (Hong, 2019). Among these studies, Hong et al. (2015) have modelled and quantified picker blocking in bucket brigade order picking systems. The authors showed that bucket brigade order picking experiences picker blocking when there is a workload imbalance per pick face. Also, they derived a closed-form solution to quantify the level of blocking for two extreme walk speed cases. The bucket brigade system has also been applied in combination with zone picking strategies (Koo, 2009), or batch picking (Fibrianto & Hong, 2019), and with random allocation policies (Webster et al., 2012).

Besides order picking, in which a worker picks all the items for a single order on each tour, other strategies are discussed in the literature, such as batch picking, in which a




| Shape factor | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| not specified | 3 | 12 | 8 | 7 | 5 | 11 | 11 | 5 | 9 | 17 | 27 | 23 | 25 | 34 | 27 | 31 | 255 |
| specified | 1 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 2 | 1 | 1 | 3 | 14 |

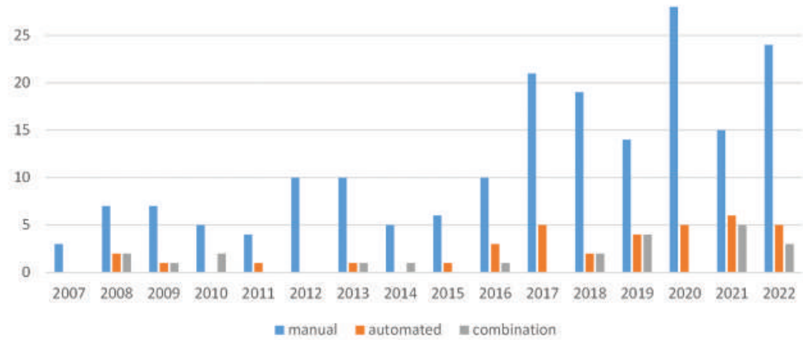
**Figure 14.** Warehouse shape factor vs. publication year.




| Picking level | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| low level | 2 | 7 | 3 | 5 | 2 | 9 | 7 | 3 | 2 | 5 | 13 | 14 | 16 | 14 | 11 | 8 | 121 |
| high level | 0 | 1 | 2 | 1 | 2 | 1 | 1 | 3 | 2 | 3 | 6 | 6 | 5 | 7 | 4 | 17 | 61 |
| combination | 0 | 1 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 2 | 1 | 0 | 2 | 4 | 2 | 0 | 17 |

**Figure 15.** Picking level vs. publication year.

worker collects items for several orders on each tour, and zone picking, in which the order picking area is zoned. In each zone, an order picker is responsible for picking from a specific part of the warehouse (Gue et al., 2006; Van Der Gaast et al., 2020). Figure 17 shows the trend in time of the picking strategy applied. The detailed description of the picking strategy (order picking vs. batch picking vs. zone picking) is available in 253 studies out of 269 analysed (94.05%). As the query made for retrieving the sample of papers focused expressly on order picking – in line with the scope of the work – this strategy is obviously the most recurring one in numerical terms, with 153 studies (56.88% of the sample). At the same time, however, it is interesting to note that the remaining strategies have been studied as well, even if the primary focus of the papers reviewed was




| Picking automation | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| manual | 3 | 7 | 7 | 5 | 4 | 10 | 10 | 5 | 6 | 10 | 21 | 19 | 14 | 28 | 15 | 24 | 188 |
| automated | 0 | 2 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 3 | 5 | 2 | 4 | 5 | 6 | 5 | 36 |
| combination | 0 | 2 | 1 | 2 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 2 | 4 | 0 | 5 | 3 | 22 |

**Figure 16.** Picking automation vs. publication year.

order picking. Batch picking, for instance, has been studied in 45 papers, approximately half of which published since 2017. One of the reasons for this outcome is that batch picking represents a strategy typically applied in e-commerce distribution centres, which need to handle thousands of orders in a short time (P. Yang et al., 2020). As recalled earlier, a recent driver for the increase in e-commerce transactions was the COVID-19 pandemic, whose effect on the consumer's behaviour is expected to last in time. Hence, it could be argued that the batch picking strategy will be even more used in the next years.

In contrast, the less common picking strategy is the zone picking (26 articles), quite scattered across the time span of analysis. As a stand-alone strategy, zone picking has been discussed in 10 articles only (3.95%), while in the remaining ones (16 papers), it is always compared with other strategies. More in detail, Kuo et al. (2016) have proposed an application of meta-heuristic algorithms, namely PSO and GAs, for item assignment in the synchronized zoning system. The experimental results showed that PSO and GAs can perform better than the existing algorithms. Y. Wu et al. (2017) have developed a model for finding merging sequences with minimum order fulfilment time considering a zone automated order fulfilment system with a number of zones linked by a main conveyor. Experimental tests showed that the solution presented by the authors can reduce the order fulfilment time by approximately 5% with both empirical and simulated data. X. Wang et al. (2013) have proposed an information system framework of the real-time synchronized zone order picking (R-SZOP) for balancing pickers' workload by using RFID technologies. The results proved the feasibility of the R-SZOP system in practice.

### 4.4.3. *Storage allocation policies*

Out of the 269 studies reviewed, 143 papers (53.16%) have addressed the theme of allocation policies, with the frequencies shown in Figure 18.

In general terms, allocation rules attempt to provide an effective way of locating products, with the final goal to improve the efficiency of the picking process. Random storage, i.e. the allocation policy in which the location for each item can be selected randomly from all eligible empty locations, is the most common strategy in the literature, with 61 studies addressing this policy. From a practical perspective, this outcome reflects

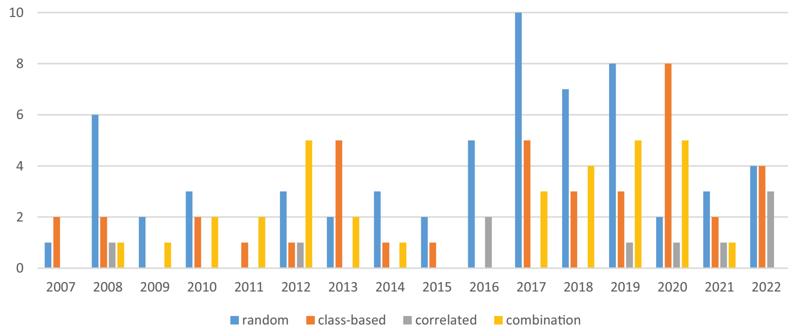

| Picking strategy | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| order picking | 2 | 6 | 3 | 7 | 2 | 6 | 11 | 2 | 3 | 11 | 14 | 12 | 15 | 19 | 20 | 20 | 153 |
| batch picking | 1 | 4 | 2 | 0 | 2 | 5 | 1 | 2 | 2 | 2 | 5 | 4 | 5 | 8 | 0 | 2 | 45 |
| zone picking | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 2 | 1 | 1 | 0 | 1 | 0 | 10 |
| combination | 0 | 2 | 2 | 1 | 0 | 0 | 0 | 1 | 3 | 3 | 5 | 4 | 3 | 2 | 7 | 12 | 45 |

**Figure 17.** Picking strategy vs. publication year.

the wide usage of random storage in real scenarios, due to its simplicity, better utilization of the available picking locations, as well as to the fact that it requires less storage capacity compared to other methods (Petersen & Schmenner, 1999). Indeed, the interest towards random storage is quite stable during the years. Among recent studies dealing with this policy, Al-Araidah et al. (2020) have presented a Monte Carlo simulation model to estimate the average rate of energy expenditure and fatigue allowance in manual order picking systems with high demand rates. Replicates of 10,000 orders with random order size and random location of items are used. Results highlight a significant impact of body mass and walking speed on the productivity and rate of energy expenditure.

From a scientific point of view, research has demonstrated that in general, allocation policies other than the random one have potential to significantly reduce the travel time (Jarvis & McDowell, 1991; Petersen & Schmenner, 1999). The class-based storage policy, in particular, assigns items to a number of different classes on the basis of various possible criteria, an example of which is the cube-per-order index (Mirzaei et al., 2021). Other classification criteria also exist, such as turnover-based storage classes (van Gils, Ramaekers, Braekers, et al., 2018), popularity of the item over its life cycle (Manzini et al., 2015) or density-turnover index (Hwang, Yong, & Cha, 2003). The typical number of classes ranges from 2 to 5 (Rao & Adil, 2013). An increase in the picking performance, in terms of length of the picking tour, has been generally observed when using class-based storage compared to random storage. In line with this, class-based turns out to be the second most popular allocation strategy in the literature, with 40 studies addressing this topic. The interest is also increasing in time, as recent (≥2017) studies have focused the attention on this topic, with a peak in 2020 (8 studies).

A limitation of class-based allocation policies is that they neglect the possible affinity between two products in historical orders, i.e. the fact that two products could appear as ‘correlated’ in customer orders, being ordered together. ‘Correlated’ assignment policies are expected to capture this aspect: according to these logics, items often picked together should be allocated close to each other, to reduce the travel time of pickers (Frazele & Sharp, 1989). Research on these policies, however, is still limited: 10 papers only were found to focus expressly on correlated assignment logics (e.g. Y. Zhang, 2016; Accorsi et




| Storage allocation policy | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 202 2 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| random | 1 | 6 | 2 | 3 | 0 | 3 | 2 | 3 | 2 | 5 | 10 | 7 | 8 | 2 | 3 | 4 | 61 |
| class-based | 2 | 2 | 0 | 2 | 1 | 1 | 5 | 1 | 1 | 0 | 5 | 3 | 3 | 8 | 2 | 4 | 40 |
| correlated | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 0 | 0 | 1 | 1 | 1 | 3 | 10 |
| combination | 0 | 1 | 1 | 2 | 2 | 5 | 2 | 1 | 0 | 0 | 3 | 4 | 5 | 5 | 1 | 0 | 32 |

**Figure 18.** Storage allocation policy vs. publication year.

al., 2012; Calzavara, Glock, et al., 2019 or Zhang Y., Y. Zhang, 2016), which emerge as the least used strategies, on which the literature is limited.

Moreover, it is interesting to note that 32 studies (11.9% of the sample) have proposed a combination/comparison of more allocation policies; an increase in the number of combined studies can also be observed in the last years. Bindi et al. (2009) have developed, tested and compared a set of different storage allocation rules based on the application of an innovative similarity coefficient coupled with clustering techniques. This study pays particular attention to the comparative analysis of the performance of distinct similarity indices, storage assignment strategies (e.g. random, class-based and correlated) and assignment rules.

In most articles where item allocation policies are considered, the typical aim is to minimise the travel distance and retrieval time. However, ergonomic aspects are taken into account in some studies. Among them, Battini et al. (2016) have modelled and analysed the integration of human energy expenditure, as a key aspect of ergonomics, into the storage assignment problem. The authors applied a bi-objective approach that takes into consideration both the total order picking time and the ergonomic aspects. Calzavara et al. (2017) have developed economic and ergonomic performance measures for the case where orders are picked from pallets, half-pallets and half-pallets equipped with a pull-out system. A comprehensive analysis of the different rack layouts showed that there are opportunities to replace the traditional pallet storage system by half-pallets with a pull-out system on the lower rank to improve both ergonomic and economic performance values. Finally, Glock et al. (2019) have proposed an integrated model that supports the planning of order picking operations and pallet rotations taking into account both the time required for completing a set of orders and the spinal load of the order picker, with consequent risk of injuries. The results of a numerical experiment indicated that selective rotation of pallets may reduce both order picking time and the workload on the order picker, leading to a quicker and less risky order picking process.

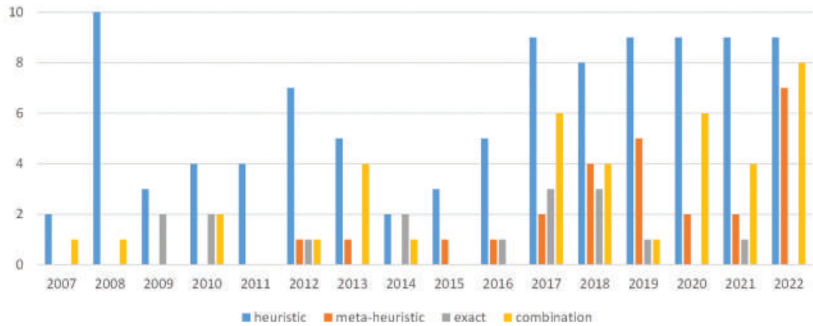
#### 4.4.4. Routing policies

Among the 269 articles reviewed, 179 studies investigated the various routing policies existing in the literature (66.54%); Figure 19 displays the share of routing methods across the years.

As can be seen from the outcomes, more than two-thirds of the studies reviewed have made use of heuristic (54.75%) or meta-heuristic (14.53%) approaches for routing order pickers. This result is in line with the review by Masae et al. (2020), who found that heuristic algorithms are the most widely used approaches in the routing field, followed by meta-heuristic algorithms. Indeed, the problem of routing order pickers in a warehouse is a special case of the travelling salesman problem (TSP), which is recognised as a NP-hard problem in operation research (Theys et al., 2010). The exact solution of this problem cannot always be determined in polynomial time; this somehow contrasts with the fact that picker routing is an operational decision, which need to be made almost in real time (Bottani et al., 2012). In the attempt to combine these antithetical needs, the general aim of research on routing policies is to find optimal or near-optimal solutions for minimizing the travel distance of pickers, using relatively fast methods, such as heuristic and meta-heuristic approaches. Also, the number of papers focusing on these approaches has increased in the last years, showing that research on heuristic or meta-heuristic algorithms is still actual.

Routing and storage allocation policies have been frequently evaluated in conjunction, showing a general relationship between storage and routing planning problems (Manzini et al., 2007; Theys et al., 2010). In Table 4, a cross-analysis has thus been made to relate the routing algorithm with the storage allocation policy. The outcomes show that heuristic algorithms have been proposed in conjunction with all storage assignment policies, with a prevalence of random storage (24 studies). Meta-heuristic algorithms have instead been proposed in conjunction with random and class-based storage policies. Neither exact nor meta-heuristic algorithms, instead, are available for correlated storage policy environments.

Among the studies that coupled random allocation strategies with heuristic routing policies, Shouman et al. (2007) have addressed the problem of routing methods in warehouses with multiple cross-aisles. In particular, the authors have developed two new *ad hoc* heuristics, called block-aisle1 and block-aisle2, with the aim of decreasing the total time spent in the order picking process. The order size and locations were randomly selected. J. Zhang et al. (2018) have studied the online order fulfilment scheduling problem in B2C economic companies. The authors have modelled the problem as an online scheduling problem of order picking and multizone delivery with limited vehicle capacity. In this paper, the S-shape strategy is used to define the picking route and the random storage is chosen. The final goal is to minimize the makespan and the total delivery cost. Looking at meta-heuristic routing policies coupled with random allocation, Zhao et al. (2019) have presented a work–rest schedule model for the picker-to-parts system. Two objectives are proposed that include minimization of the picking time and of the picking error rate. The authors have used a GA to solve a multi-objective optimization problem in which goods are stored randomly in static shelves. In addition, a case study is developed to check the model effectiveness and confirm the opportunity of taking into account the human factor in picking systems.




| Routing | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| heuristic | 2 | 10 | 3 | 4 | 4 | 7 | 5 | 2 | 3 | 5 | 9 | 8 | 9 | 9 | 9 | 9 | 98 |
| meta-heuristic | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 2 | 4 | 5 | 2 | 2 | 7 | 26 |
| exact | 0 | 0 | 2 | 2 | 0 | 1 | 0 | 2 | 0 | 1 | 3 | 3 | 1 | 0 | 1 | 0 | 16 |
| combination | 1 | 1 | 0 | 2 | 0 | 1 | 4 | 1 | 0 | 0 | 6 | 4 | 1 | 6 | 4 | 8 | 39 |

**Figure 19.** Routing policies vs. publication year.

From the review of the literature, it is also evident that a relationship exists between the routing algorithm, the warehouse layout and the number of blocks. In Table 5, a further cross-analysis was thus made to relate routing policies and warehouse structure.

Overall, 140 papers out of the 269 in the sample have expressly related the routing policy to a specific warehouse layout. Moreover, it can be seen from this table that most of the available algorithms have targeted the rectangular warehouse layout (126 papers out of 140); a peak of 74 papers has proposed heuristic algorithms in rectangular warehouses. Also, almost all the exact algorithms (10 papers out of 11) have been developed for rectangular warehouses, probably in the light of the easier representation of the picking tour in these warehouses compared to non-traditional ones. For U-shaped, flying-V and other unconventional layouts, no exact algorithms are available in the literature. It is also immediate to observe that if the warehouse structure is more complex in terms of the number of blocks (i.e. if it owns cross-aisles), solving exactly the routing problem becomes significantly more difficult, with less algorithms available and limited to the rectangular layout.

Among the studies that analysed rectangular layouts with heuristic routing policies, Hsieh and Huang (2011) have developed and verified by simulation experiments, two new batch construction heuristics called k-means batching (KMB) and self-organization map batching (SOMB) in a rectangular warehouse. Both batching strategies show a preferment of superior performance in total travel distance and average picking vehicle utility, and, from a computational point of view, even a conspicuous improvement in total CPU running time. Y. Zhang (2016) has instead developed a correlated storage assignment strategy (CSAS) to reduce the travel distance in the picker-to-parts order picking system for a conventional rectangular single-block warehouse. Consequently, various heuristic algorithms of the CSAS are developed and tested.

Related to the picking process and relating design problems is the software tool that the authors can use to solve the problem. In this respect, Figure 20 shows the usage of software tools across the studies reviewed, paying particular attention to analytic and simulation studies. To be more effective, the representation is limited to those software tools that were used at least three times. As the figure shows, CPLEX and Matlab are the

**Table 4.** Cross-analysis of routing algorithms and allocation policies.

| | Routing policies | | | | |
|---|---|---|---|---|---|
| Storage allocation policy | Heuristic | Meta-heuristic | Exact | Combination | Total |
| Random | 24 | 6 | 9 | 11 | 50 |
| Class-based | 20 | 6 | 1 | 9 | 36 |
| Correlated | 5 | 0 | 0 | 2 | 7 |
| Combination | 20 | 0 | 1 | 6 | 27 |
| Total | 69 | 12 | 11 | 28 | 120 |

**Table 5.** Cross-analysis of routing algorithms and warehouse characteristics.

| | | Routing policy | | | | |
|---|---|---|---|---|---|---|
| Warehouse characteristics | | Heuristic | Meta-heuristic | Exact | Combination | Total |
| Rectangular | No cross-aisles | 49 | 10 | 5 | 17 | **81** |
| | With cross-aisles | 25 | 4 | 5 | 11 | **45** |
| | *Subtotal* | *74* | *14* | *10* | *28* | *126* |
| Fishbone | No cross-aisles | 1 | 0 | 0 | 0 | **1** |
| | With cross-aisles | 0 | 0 | 0 | 0 | **0** |
| | *Subtotal* | *1* | *0* | *0* | *0* | *1* |
| U-shaped | No cross-aisles | 2 | 1 | 0 | 2 | **5** |
| | With cross-aisles | 0 | 0 | 0 | 0 | **0** |
| | *Subtotal* | *2* | *1* | *0* | *0* | *5* |
| Flying-V | No cross-aisles | 0 | 0 | 0 | 0 | **0** |
| | With cross-aisles | 0 | 0 | 0 | 0 | **0** |
| | *Subtotal* | *0* | *0* | *0* | *0* | *0* |
| Irregular | No cross-aisles | 2 | 0 | 0 | 0 | **2** |
| | With cross-aisles | 0 | 0 | 0 | 1 | **1** |
| | *Subtotal* | *2* | *0* | *0* | *1* | *3* |
| Combined | No cross-aisles | 1 | 0 | 1 | 0 | **2** |
| | With cross-aisles | 0 | 0 | 0 | 3 | **3** |
| | *Subtotal* | 1 | 0 | 1 | 3 | **5** |
| Total | No cross-aisles | *55* | *11* | *6* | *19* | *91* |
| | With cross-aisles | *25* | *4* | *5* | *15* | *49* |
| | Total | 80 | 15 | 11 | 34 | 140 |

most used software packages, with 30 and 23 applications, respectively. The usage of CPLEX is typical of analytic problems, in line with the capabilities of this software package, or to mixed analytic/simulation studies; Matlab, instead, seems to be exploited mainly for simulation purposes or, again, in mixed analytic/simulation studies.

#### *4.4.5. Problem constraints*

In this section, the main results in terms of constraints evaluated are presented. Among the 269 reviewed articles, 99 studies (36.80%) have taken into account various constraints, whose frequency is shown in Figure 21.

As it is easy to observe from Figure 21, the capacity of pickers, in terms of the number of items that a picker can handle in a tour (Ardjmand et al., 2020), is the problem constraint most frequently evaluated in research articles (62 out of 99 papers). This aspect

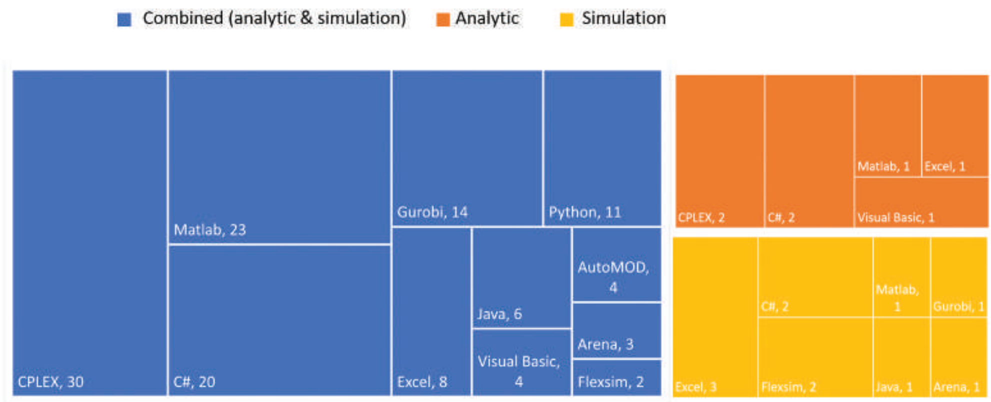
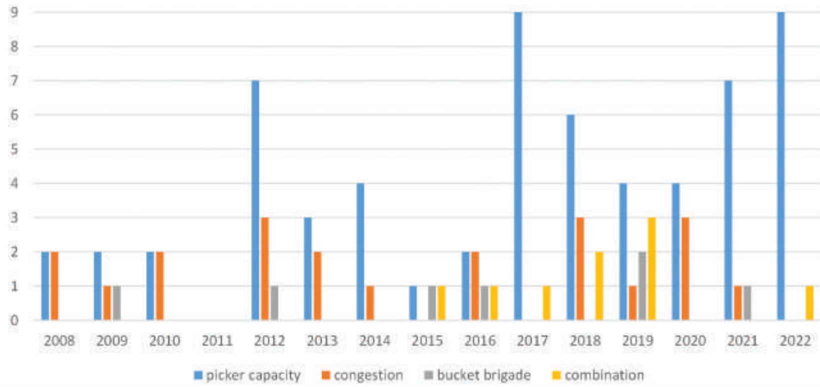



**Figure 20.** Software vs. solution approach.

is probably the most relevant in practice too, as in real operating environments, orders must be assigned to pickers with sufficient capacity or, alternatively, the picking tour should be revised in the light of the picker capacity (Ardjmand et al., 2019). Twenty-one papers have instead analysed issues relating to the congestion of pickers and almost always have dealt with the case of narrow aisle warehouses (16 out of the 21 studies). Earlier in the manuscript, it has been recalled that narrow aisles are typical features recently observed at sites of big retailers and online retailers; in line with the newness of this feature, most of the studies on narrow aisles appeared in the recent literature. Seven papers only have instead focused on bucket brigade order picking. This latter represents a flexible response of pickers to the operational variation in order picking (Hong, 2019). Studies on this topic are somehow discontinuous in literature, probably, because of the limited potential for applying this solution in practice; indeed, bucket brigade is well suited for some order picking systems only (i.e. flow-rack order picking system). The remaining eight studies have considered a combination of multiple constraints. To be more precise, the capacity constraint has been typically associated to congestion considerations (Bahrami et al., 2017; Moons et al., 2018; Tappia et al., 2019; van Gils et al., 2019). In turn, congestion issues have been evaluated in conjunction with the bucket brigade scenario by Hong (2018, 2019). One study only (i.e. Hong et al., 2016) has taken into account the whole set of three constraints.

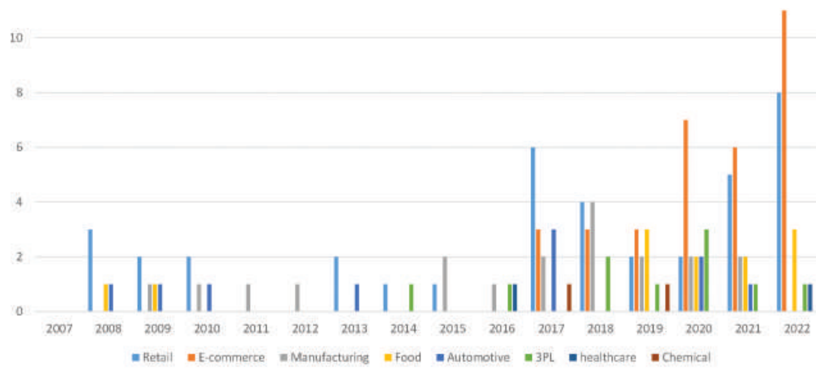
#### *4.4.6. Application context*

The industrial sectors in which the case studies were carried out are shown in Figure 22. As a first consideration, many papers (162) did not present a case study, thus preventing the possibility of identifying an industrial sector in which the research was carried out. These papers could be in the form of a laboratory experiment or a simulation study. In 16 cases, the application involved multiple industrial sectors, resulting in the paper to be categorised into multiple fields. This is for instance the case for Gu et al. (2010), who have proposed a branch-and-bound algorithm to solve the forward–reverse allocation problem in an office product warehouse and in a tyre warehouse. Glock, Grosse, Elbert et al. (2017) have applied their proposed approach to various industrial sectors simultaneously: manufacturing, automotive, retail and chemical. J. Zhang et al. (2019) have studied the online integrated order picking and




| Constraints | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Picker capacity | 2 | 2 | 2 | 0 | 7 | 3 | 4 | 1 | 2 | 9 | 6 | 4 | 4 | 7 | 9 | 62 |
| Congestion | 2 | 1 | 2 | 0 | 3 | 2 | 1 | 0 | 2 | 0 | 3 | 1 | 3 | 1 | 0 | 21 |
| Bucket brigade | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 0 | 1 | 0 | 7 |
| combination | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 2 | 3 | 0 | 0 | 1 | 9 |

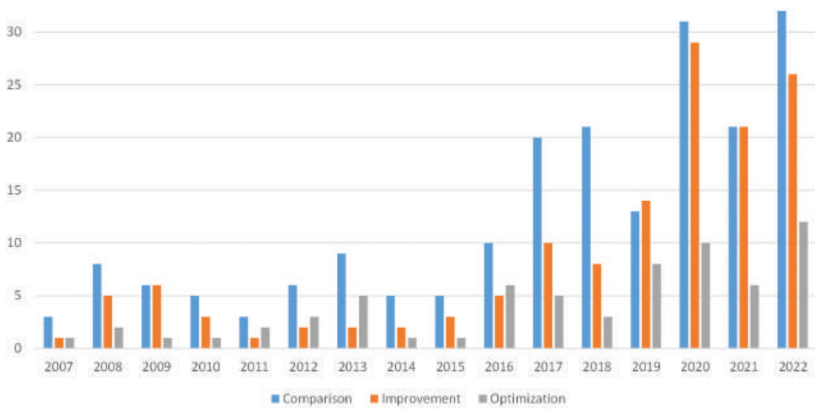
**Figure 21.** Problem constraints vs. publication year.




| Industrial sector | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Retail | | 3 | 2 | 2 | | | 2 | 1 | 1 | | 6 | 4 | 2 | 2 | 5 | 8 | 38 |
| E-commerce | | | | | | | | | | | 3 | 3 | 3 | 7 | 6 | 11 | 33 |
| Manufacturing | | | 1 | 1 | 1 | 1 | | | 2 | 1 | 2 | 4 | 2 | 2 | 2 | | 19 |
| Food | | 1 | 1 | | | | | | | | | | 3 | 2 | 2 | 3 | 12 |
| Automotive | | 1 | 1 | 1 | | | 1 | | | | 3 | | | 2 | 1 | | 10 |
| 3PL | | | | | | | | 1 | | 1 | | 2 | 1 | 3 | 1 | 1 | 10 |
| healthcare | | | | | | | | | | 1 | | | | | | 1 | 2 |
| Chemical | | | | | | | | | | | 1 | | 1 | | | | 2 |

**Figure 22.** Industrial sectors vs. publication year.

delivery problem for an online-to-offline community supermarket, and order pickers' learning effects were considered to better plan the integrated problem. Manzini et al. (2019) have introduced a practice-ready systematic methodology for the management of storage assignments and allocation decisions as well as an assessment of the resulting performance in an order picking system. The analysis targeted a real-world case study and addressed a third-party provider warehouse operating in the beverage sector responsible for serving hundreds of canteens, restaurants, and bars in Italy. Briant et al. (2020) have presented an exponential linear programming formulation to tackle the joint order batching and picker routing problem. The methodology proposed by these authors was applied to two distinct industrial scenarios, Foodmart




| Output type | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Comparison | 3 | 8 | 6 | 5 | 3 | 6 | 9 | 5 | 5 | 10 | 20 | 21 | 13 | 31 | 21 | 32 | 198 |
| Improvement | 1 | 5 | 6 | 3 | 1 | 2 | 2 | 2 | 3 | 5 | 10 | 8 | 14 | 29 | 21 | 26 | 138 |
| Optimization | 1 | 2 | 1 | 1 | 2 | 3 | 5 | 1 | 1 | 6 | 5 | 3 | 8 | 10 | 6 | 12 | 67 |

**Figure 23.** Output type.

and HappyChic; the former originates from online grocery shopping, while the latter is a French company specialized in men clothes.

As far as the specific sectors are concerned, retailing is by far the most popular field in which order picking research has been carried out, with 38 papers, followed by e-commerce and manufacturing, with 33 and 19 papers, respectively. Also, the retailing and manufacturing sectors have been studied with good continuity, while papers addressing picking problems in the e-commerce field started being published in 2017, thus confirming the increased importance of this field in recent years.

#### *4.4.7. Results*

*4.4.7.1. Output type.* The outputs returned by the studies reviewed are shown in Figure 23. We recall that the outputs were categorised as process improvement, process optimization and comparative results and that these categories are not mutually exclusive, as a paper can obviously report both comparative analyses and an improvement of the process. As Figure 23 shows, the comparison of scenarios is very frequent in order picking studies, with 198 out of 269 papers (≈70% of the sample) proposing results in this form. Results in terms of process improvement are achieved in a relevant number of studies as well (138 papers, 51.3% of the sample). Process optimization is reported in 67 studies (24.91% of the sample); this is probably a consequence of the objective difficulties in obtaining the global optimal result of the problem investigated (e.g. in the case of routing problems). Looking at the trend, all categories of outputs have been studied with good continuity in time, suggesting that research on order picking has always been approached with a view on quantitative outcomes, intended for the optimization of the process. Also, all categories experienced an increase in recent years, thus indicating that researchers are always seeking for the optimal design of the picking system.

For a deeper investigation of these aspects, in Tables 6 and 7, a cross-analysis was made to combine the output type with two key design issues of picking systems, i.e.

**Table 6.** Cross-analysis of routing algorithm vs. output type.

| | Routing algorithm | | | | |
|---|---|---|---|---|---|
| *Output type* | Heuristic | Meta-heuristic | Exact | Combination | Total |
| Improvement | 46 | 8 | 8 | 19 | **81** |
| Optimization | 20 | 7 | 5 | 7 | **39** |
| Combined (improvement/optimization) | 2 | 4 | 0 | 3 | **9** |
| Comparison of scenarios | 71 | 22 | 8 | 34 | **135** |

**Table 7.** Cross-analysis of storage allocation policies vs. output type.

| | Storage allocation policy | | | | |
|---|---|---|---|---|---|
| *Output type* | Random | Class-based | Correlated | Combination | Total |
| Improvement | 27 | 17 | 5 | 15 | **64** |
| Optimization | 14 | 8 | 3 | 2 | **27** |
| Combined (improvement/optimization) | 1 | 4 | 1 | 1 | **7** |
| Comparison of scenarios | 47 | 31 | 8 | 27 | **113** |

routing algorithms and storage allocation policy. The cross-analysis for routing algorithms carried out in Table 6 shows that most of the outcomes were reported when studying heuristic algorithms and that comparative results and improvements are the most frequent categories of outcomes reported.

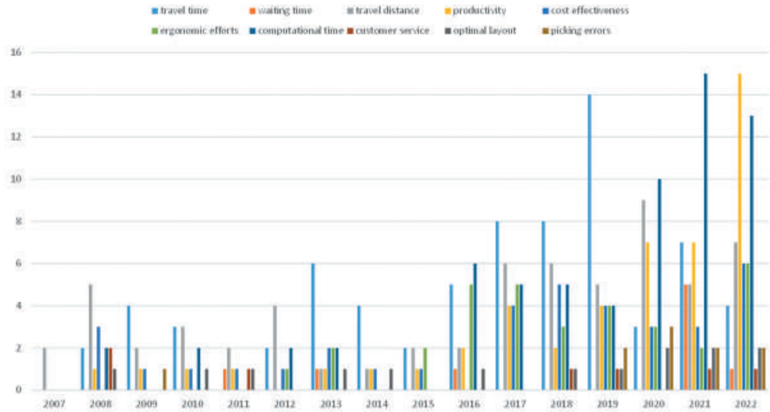
Looking instead at the relationship between storage allocation policies and output type, as shown in Table 7, outcomes first confirm that the random policy has been more investigated compared to the remaining policies and that most of the studies are comparative in nature. Similar considerations hold true for the class-based policy. It is also interesting to observe that optimization studies have been proposed for all policies, with a prevalence for the random one, but with some studies also targeting more complex policies such as the class-based or the correlated one.

*4.4.7.2. KPIs measured.* The full list of KPIs evaluated in the sample of studies is proposed in Figure 24.

For classification purpose, the KPIs found in the papers reviewed were divided into five classes, namely:

(1) *Technical KPIs*, whose aim is to evaluate the operational aspects of the picking process
(2) *Efficiency KPIs*, focusing on productivity of the process
(3) *Ergonomic KPIs*, whose aim is to evaluate the efforts made by the picker during the process
(4) *Computational KPIs*, which express the speed in executing the computer program or algorithm
(5) *Other KPIs*, which group performance indexes not falling into the above categories

In numerical terms, technical KPIs are the most frequent category of performance indexes evaluated in order picking systems and appeared in 186 studies (69.14% of the




| KPI category | Detailed KPI | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technical KPIs | travel time | | 2 | 4 | 3 | | 2 | 6 | 4 | 2 | 5 | 8 | 8 | 14 | 3 | 7 | 4 | **72** |
| | waiting time | | | | | 1 | | 1 | | | 1 | | | | | 5 | 1 | **9** |
| | travel distance | 2 | 5 | 2 | 3 | 2 | 4 | 1 | 1 | 2 | 2 | 6 | 6 | 5 | 9 | 5 | 7 | **62** |
| | combination | 1 | 2 | 1 | | 1 | 5 | 2 | 1 | 1 | 4 | 5 | 3 | 4 | 9 | 1 | 3 | **43** |
| | ***Total*** | ***3*** | ***9*** | ***7*** | ***6*** | ***4*** | ***11*** | ***10*** | ***6*** | ***5*** | ***12*** | ***19*** | ***17*** | ***23*** | ***21*** | ***18*** | ***15*** | ***186*** |
| Efficiency KPIs | productivity | | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | 2 | 4 | 2 | 4 | 7 | 7 | 15 | **48** |
| | cost effectiveness | | 3 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | | 4 | 5 | 4 | 3 | 3 | 6 | **36** |
| | combination | | 1 | 2 | | | | | | 1 | | | | 1 | 1 | 2 | 1 | **9** |
| | ***Total*** | ***0*** | ***5*** | ***4*** | ***2*** | ***2*** | ***1*** | ***3*** | ***2*** | ***3*** | ***2*** | ***8*** | ***7*** | ***9*** | ***11*** | ***12*** | ***22*** | ***93*** |
| Ergonomic KPIs | ergonomic efforts | | | | | | 1 | 2 | | 2 | 5 | 5 | 3 | 4 | 3 | 2 | 6 | **33** |
| | ***Total*** | ***0*** | ***0*** | ***0*** | ***0*** | ***0*** | ***1*** | ***2*** | ***0*** | ***2*** | ***5*** | ***5*** | ***3*** | ***4*** | ***3*** | ***2*** | ***6*** | ***33*** |
| Computational efforts | computational time | | 2 | | 2 | | 2 | 2 | | | 6 | 5 | 5 | 4 | 10 | 15 | 13 | **66** |
| | ***Total*** | ***0*** | ***2*** | ***0*** | ***2*** | ***0*** | ***2*** | ***2*** | ***0*** | ***0*** | ***6*** | ***5*** | ***5*** | ***4*** | ***10*** | ***15*** | ***13*** | ***66*** |
| Other KPIs | customer service | | 2 | | | 1 | | | | | | | 1 | 1 | | 1 | 1 | **7** |
| | optimal layout | | 1 | | 1 | 1 | | 1 | 1 | | 1 | | 1 | 1 | 2 | 2 | 2 | **14** |
| | picking errors | | | 1 | | | | | | | | | | 2 | 3 | 2 | 2 | **10** |
| | combination | | | | | | | | | | | | | | | | 1 | **1** |
| | ***Total*** | ***0*** | ***3*** | ***1*** | ***1*** | ***2*** | ***0*** | ***1*** | ***1*** | ***0*** | ***1*** | ***0*** | ***2*** | ***4*** | ***5*** | ***5*** | ***6*** | ***32*** |

**Figure 24.** KPIs measured vs. publication year.

sample). Within this category, specific KPIs evaluated are the travel time, travel distance and waiting time. The most analysed technical KPI is travel time, with 72 papers (38.71%), while the waiting time is the less studied. In practical terms, the travel distance can be seen as equivalent to the travel time, as this latter is typically a linear function of the distance covered by the picker in the tour. Among the studies that evaluated the travel time, X. -Z. Wang et al. (2013) have addressed the order picking problem in a material handling system consisting of multiple carousels and one picker. The objective was to find the optimal picking sequence that minimizes the travel time. Ho and Lin (2017) have instead studied the problems caused by the fixed-sequence-route constraint in a sequential zone-picking line by proposing a new zone-picking network that offers routing flexibility to orders. In this study, the authors have proposed and studied 13 tote-dispatching rules. Among them, there is the minimum travel time dispatching rule. Various studies have simultaneously evaluated travel time and travel distance, which is a logical combination; among these studies, Hu et al. (2009) have proposed the middle cross-aisle model based on the perspective of warehouse layouts of mobile-automated storage/retrieval system. They found that both travel distance and time could be reduced significantly by reducing the huge rack row and making rack row movements more efficient and safer. Shetty et al. (2020) have addressed the problem of routing optimization for order picking in a warehouse to minimize the travel time and distance. In particular, the authors proposed an easy-to-implement vehicle routing-based approach in conjunction with the distance matrix for determining the optimal route of order pickers. The waiting time, which is rarely investigated in the literature, is often associated to congestion constraints and is used to mitigate picker blocking in manual picking systems (Hong et al., 2015), especially in warehouses with narrow aisles (F. Chen et al., 2013, 2016, 2019; Hong et al., 2013).

The second most studied category of KPIs refers to the efficiency of the picking process (93 studies, 50.0%), either in terms of productivity of the picker or of cost of the process. To be more precise, from Table 8 it can be seen that productivity has been evaluated in 48 studies, while cost-effectiveness in 36, resulting in 51.61% of the studies aimed at improving its productivity and 38.71% aimed at optimising the system's cost. In addition, 9.68% of the articles has evaluated both aspects. Among those studies that aim at reducing the system's cost, Parikh and Meller (2008) have focused on the issue of selecting between a batch picking and a zone picking strategy. For this problem, the authors proposed a model to estimate the cost of both types of picking strategy. Atmaca and Ozturk (2013) have instead built a mathematical model that minimizes the cost of holding stocks for an AS/RS system. The authors have obtained the optimal solution as they limited the analysis to a problem with a small solution space.

As mentioned earlier in the manuscript, ergonomic issues in picking activities are not marginal, as picking is often carried out manually by human operators and rarely automated; this review itself has highlighted a small percentage (14.63%) of studies that evaluated automated picking. Therefore, when analysing an order picking system, the efforts made by the pickers and the ergonomic working conditions are to be taken into account. Awareness about the relevance of these aspects has emerged only recently in the literature on order picking systems: overall, 33 studies have addressed this point, and 30 of these studies were published since 2015. Among these, van Gils et al. (2017) have introduced workload forecasting in a warehouse context, in particular a zone picking warehouse. The objective of this study is to present time series forecasting models that perform well in a zone picking warehouse. Lind et al. (2020) have evaluated the short-term effect of real-time vibrotactile feedback on postural exposure using a smart work wear system for work-posture intervention in a simulated industrial order picking system.

The computational performance, in terms of computational time, has been evaluated in 66 studies only (≈25% of the sample). This outcome is somehow surprising. Indeed, many authors have highlighted that the computational complexity of the picking (in particular, routing) problem increases rapidly with warehouse size and the number of items in the picking list (Theys et al., 2010), which emphasises the relevance of this aspect. Also, results of this review have confirmed that heuristic and meta-heuristic algorithms are by far the most applied tools for determining the picking route. The rationale behind the usage of a heuristic or meta-heuristic approach is typically the possibility of determining a good (not always optimal) solution in a relatively short time, which, once again, substantiates the importance of evaluating the computational time. Hence, it is strange to see that most of the studies have neglected a detailed evaluation of the computational performance. Looking at the studies that evaluated the computational performance, Gu et al. (2010) have developed a branch-and-bound algorithm based on outer approximation to optimally solve the forward–reverse allocation problem. Computational results demonstrate that the proposed optimal algorithm, although requiring more computation effort than best heuristic algorithm, is fast enough to solve practical problems. Kulak et al. (2012) have proposed two innovative cluster-based TS algorithms to solve the order batching and picker routing problems jointly for

**Table 8.** Cross-analysis of KPI measured vs. routing algorithm.

| | | *Routing algorithm* | | | | |
|---|---|---|---|---|---|---|
| | Detailed KPI | Heuristic | Meta-heuristic | Exact | Combination | *Total* |
| Technical KPIs | Travel time | 28 | 6 | 5 | 6 | **45** |
| | Waiting time | 3 | 1 | 0 | 2 | **6** |
| | Travel distance | 32 | 7 | 4 | 16 | **59** |
| | Combination | 13 | 2 | 4 | 11 | **30** |
| *Total* | | *76* | *16* | *13* | *35* | *140* |
| Efficiency KPIs | Productivity | 18 | 4 | 2 | 5 | **29** |
| | Cost-effectiveness | 15 | 8 | 4 | 2 | **29** |
| | Combination | 5 | 0 | 1 | 1 | **7** |
| *Total* | | *38* | *12* | *7* | *8* | *65* |
| Ergonomic KPIs | Ergonomic efforts | 9 | 4 | 1 | 2 | **16** |
| *Total* | | *9* | *4* | *1* | *2* | *16* |
| Computational efforts | Computational time | 21 | 11 | 5 | 18 | **55** |
| *Total* | | *21* | *11* | *5* | *18* | *55* |
| Other KPIs | Customer service | 3 | 2 | 1 | 0 | **6** |
| | Optimal layout | 7 | 1 | 0 | 1 | **9** |
| | Picking errors | 3 | 1 | 0 | 0 | **4** |
| *Total* | | *13* | *4* | *1* | *1* | *19* |

multiple cross-aisle warehouse systems. Weidinger et al. (2019) have defined the resulting picker routing problem in mixed-shelves warehouses and have provided efficient solution methods.

The last category (*other KPIs*) includes additional KPIs, not strictly falling into the remaining classes. Within this category, three relevant KPIs have been identified from the studies reviewed, such as customer service aspects, layout optimization and picking errors. Both customer service and picking errors are rarely investigated in the literature (7 and 10 studies, respectively). Customer service is typically evaluated in terms of the order fulfilment time (Urzúa et al., 2019), possibility of satisfying late orders (Moons et al., 2018), average throughput time (Melacini et al., 2011) or higher on-time service completion (Gong & de Koster, 2008). Layout optimization has instead been addressed in 14 studies. For example, Roodbergen et al. (2008) have presented a model that minimizes the travel distances of pickers by identifying an appropriate layout structure consisting of one or more blocks of parallel aisles.

Some cross-analyses were made to relate the KPIs evaluated in the paper:

- to the routing algorithm applied in the study and
- to the research methodology.

The first cross-analysis confirms that the computational effort is not always evaluated by the authors even in studies that proposed heuristic or meta-heuristic routing algorithms (Table 9); on the contrary, the percentage of studies in which that performance is evaluated is quite low (21.43% for heuristic algorithms and 42.3% for meta-heuristic algorithms, respectively). Conversely, technical KPIs, such as either the travel time or travel distance, are evaluated with respect to any kind of routing algorithm.

From the correlation of the performance indexes with the research methodology, some considerations can be made about the methodological tools that enable the evaluation of specific KPIs. The outcomes (Table 9) show that regardless of the particular methodology, technical KPIs have almost always been evaluated by authors; reversing the reasoning, all research tools can be primarily intended to measure technical KPIs. The combination of various research methodologies contributes to the evaluation of more KPIs, falling into different classes (e.g. the technical, efficiency and other categories).

Among the studies that coupled simulation with the evaluation of technical KPIs, Bahrami et al. (2017) have tested and analysed the effect of different routing methods as well as order sequencing and storage strategies executed under different batching methods on low-level picker-to-parts picking performance. The authors have carried out extensive simulations of the order batching process to evaluate the performance of warehouse picking activities in terms of total distance travelled by operators, collisions between multiple pickers and order lead times (affected by congestion). Looking at efficiency KPIs coupled with simulation models, Ramaekers et al. (2018) have estimated the additional cost of allowing customers to choose a preferred delivery time window using the integrated order picking vehicle routing problem. An experimental design was set up by the authors to investigate this service cost under varying circumstances depending on customer characteristics (clustered in an urban region or dispersed in a rural setting), time window characteristics (allowed time window width) and operator size (number of orders to schedule). Based on the results of the simulations, the authors conclude that the investigated factors have a significant impact on the additional cost of allowing customers select a delivery time window. Only one study (C. -M. Chen et al., 2010) has evaluated secondary KPIs (i.e. optimal layout) using simulation; these authors have developed a novel framework to evaluate the full performance of order picking systems with different combinations of storage and order picking policies. To be more precise, the authors have used data envelopment analysis to evaluate the performance of different policy combinations through the Monte Carlo simulation.

## 5. Discussion and conclusions

Order picking is the single most expensive activity in warehouse management. Without tackling order picking successfully and efficiently, it is almost impossible for any business to have an efficient logistics system (Sankalp et al., 2019). With the aim of deepening the picking problem, we carried out a detailed analysis of order picking in warehouses, using bibliometric tools on a sample of 269 journal papers published from 2007 to 2022. These studies were classified into conceptual papers (33), case studies (104), simulation papers (181) and analytic papers (138). Probably because of the larger sample of papers analysed, this preliminary classification turns out to be not fully aligned with the results of van Gils, Ramaekers, Caris, et al. (2018), who have instead found that simulation studies form the largest category of research papers about picking. Conversely, in the review of van Gils, Ramaekers, Caris, et al. (2018), analytical models appear to be significantly less considered as possible approaches to order picking planning problems.

The whole sample of papers reviewed was analysed through descriptive statistics about the year of publication, geographic origin of the study, influential authors and journals. Then, citations and keywords analyses were carried out to delineate the main topics

**Table 9.** Cross-analysis of KPI measured vs. research methodology applied.

| | | *Paper type* | | | | | |
|---|---|---|---|---|---|---|---|
| | Detailed KPI | Simulation | Case study | Analytic | Conceptual | Combination | *Total* |
| Technical KPIs | Travel time | 7 | 3 | 8 | 1 | 53 | **72** |
| | Waiting time | 1 | 0 | 0 | 0 | 8 | **9** |
| | Travel distance | 12 | 1 | 9 | 0 | 40 | **62** |
| | Combination | 2 | 2 | 5 | 0 | 34 | **43** |
| *Total* | | *22* | *6* | *22* | *1* | *135* | **186** |
| Efficiency KPIs | Productivity | 5 | 3 | 3 | 0 | 37 | **48** |
| | Cost-effectiveness | 4 | 0 | 8 | 0 | 24 | **36** |
| | Combination | 0 | 0 | 3 | 0 | 6 | **9** |
| *Total* | | *9* | *3* | *14* | *0* | *67* | *93* |
| Ergonomic KPIs | Ergonomic efforts | 3 | 2 | 3 | 2 | 23 | **33** |
| *Total* | | *3* | *2* | *3* | *2* | *23* | *33* |
| Computational efforts | Computational time | 3 | 0 | 6 | 0 | **57** | **66** |
| *Total* | | *3* | *0* | *6* | *0* | *57* | *66* |
| Other KPIs | Customer service | 1 | 0 | 0 | 0 | 6 | **7** |
| | Optimal layout | 2 | 0 | 0 | 0 | 12 | **14** |
| | Picking errors | 0 | 0 | 0 | 0 | 10 | **10** |
| *Total* | | *3* | *0* | *0* | *0* | *28* | *31* |

covered and their level of investigation in the scientific community. Finally, the contents of the papers were mapped on the basis of eigth categories of data, including both the typical isses of order picking design (e.g. warehouse layout and structure, picking process, storage allocation policies and routing policies) and additional aspects, such as the problem constraints, application contexts, results presented and KPIs measured.

An analysis of the outcomes obtained allowed to derive insights and considerations about the extent to which these aspects have been covered in the literature, the relating trend in time, the level of maturity reached and the relationships between the various aspects of the picking process. In terms of popularity of the order picking topic, some countries (e.g. Germany, China, U.S.A and Italy) seem to pay particular attention to this problem, probably in the light of the high cost of labour in these countries and corresponding need to optimize (manual) warehouse activities. There is also a group of (well) established authors in the field of picking, with a number of articles ranging from 6 to 23.

A summary of the specific topics treated in the literature and of their trend in time is proposed in Table 10; the last columns of the table highlight the recent interest towards these topics, evaluated on the basis of the percentage of studies that targeted each topic in the last years (from 2017 onwards).

From a scientific point of view, a general consideration is that the interest towards the order picking process in the warehouse context has increased over time, as highlighted by the growing number of papers focusing on order picking even in recent times. This is confirmed by the trends: looking at Table 10, it can be observed that for most of the topics analysed in this paper (26), there is a progressive increase in the interest of researchers, meaning that order picking is still an important area of research; however, for two of these topics (highlighted in the table), the interest seems to be less evident in the last years.

**Table 10.** Summary of the topics and relating trend.

| Picking problem | | Item | Number of studies | % of studies | Trend | Number of studies since 2017 | % of studies since 2017 | Recent interest |
|---|---|---|---|---|---|---|---|---|
| Warehouse characteristics | *Layout* | Rectangular | 158 | 58.74% | Increasing | 88 | 55.7% | x |
| | | Fishbone | 6 | 2.23% | No trend* | 5 | 83.3% | x |
| | | U-shaped | 7 | 2.60% | No trend* | 4 | 57.1% | x |
| | | Flying-V | 2 | 0.74% | No trend* | 1 | 50.0% | |
| | | Irregular | 7 | 2.60% | No trend* | 4 | 57.1% | x |
| | *Structure* | Cross-aisles | 62 | 23.05% | Increasing | 40 | 64.5% | x |
| | | Depot location | 113 | 42.01% | Increasing | 70 | 61.9% | x |
| | | Shape factor | 14 | 5.20% | No trend* | 8 | 57.1% | x |
| | | Narrow aisles | 36 | 13.38% | Constant | 16 | 44.4% | |
| Picking process | *Picking level* | High level | 61 | 22.68% | Increasing | 39 | 63.9% | x |
| | | Low level | 121 | 44.98% | Increasing** | 63 | 52.1% | x |
| | | Combination | 17 | 6.32% | Constant | 8 | 47.1% | |
| | *Picking automation* | Manual | 188 | 69.89% | Increasing** | 100 | 53.2% | x |
| | | Automated | 36 | 13.38% | Increasing | 22 | 61.1% | x |
| | | Combination | 22 | 8.18% | Increasing | 14 | 63.6% | x |
| | *Picking strategy* | Order picking | 153 | 56.88% | Increasing | 86 | 56.2% | x |
| | | Order batching | 45 | 16.73% | No trend | 19 | 42.2% | |
| | | Zone picking | 10 | 3.72% | No trend* | 3 | 30.0% | |
| | | Combination | 45 | 16.73% | Increasing | 28 | 62.2% | x |
| Storage allocation policy | | Random | 61 | 22.68% | Constant | 24 | 39.3% | |
| | | Class-based | 40 | 14.87% | Increasing** | 20 | 50.0% | |
| | | Correlated | 10 | 3.72% | No trend* | 6 | 60.0% | x |
| | | Combination | 32 | 11.90% | No trend | 15 | 46.9% | |
| Routing policy | | Heuristic | 98 | 36.43% | Constant | 44 | 44.9% | |
| | | Meta-heuristic | 26 | 9.67% | Increasing | 20 | 76.9% | x |
| | | Exact | 16 | 5.95% | Constant | 5 | 31.3% | |
| | | Combination | 39 | 14.50% | Increasing | 23 | 59.0% | x |

(*Continued*)

**Table 10.** (Continued).

| Picking problem | | Item | Number of studies | % of studies | Trend | Number of studies since 2017 | % of studies since 2017 | Recent interest |
|---|---|---|---|---|---|---|---|---|
| Problem constraint | | Picker capacity | 62 | 23.05% | Increasing | 30 | 48.4% | |
| | | Congestion | 21 | 7.81% | Constant | 8 | 38.1% | |
| | | Bucket brigade | 7 | 2.60% | No trend* | 3 | 42.9% | |
| | | Combination | 9 | 3.35% | No trend* | 6 | 66.7% | x |
| Industrial context | | Retail | 38 | 14.13% | Increasing | 21 | 55.3% | x |
| | | e-Commerce | 33 | 12.27% | Increasing | 30 | 90.9% | x |
| | | Manufacturing | 19 | 7.06% | Constant | 10 | 52.6% | x |
| | | Food | 12 | 4.46% | No trend* | 10 | 83.3% | x |
| | | Automotive | 10 | 3.72% | No trend* | 3 | 30.0% | |
| | | 3PL | 10 | 3.72% | No trend* | 8 | 80.0% | x |
| | | Health care | 2 | 0.74% | No trend* | 1 | 50.0% | |
| | | Chemical | 2 | 0.74% | No trend* | 1 | 50.0% | |
| Results | *Output type* | Process improvement | 138 | 51.30% | Increasing | 98 | 71.0% | x |
| | | Process optimization | 67 | 24.91% | Increasing | 39 | 58.2% | x |
| | | Comparative results | 198 | 73.61% | Increasing | 118 | 59.6% | x |
| | *Technical KPIs* | Travel time | 72 | 26.77% | increasing | 36 | 50.0% | |
| | | Waiting time | 9 | 3.35% | No trend* | 6 | 66.7% | x |
| | | Travel distance | 62 | 23.05% | Increasing | 32 | 51.6% | x |
| | *Efficiency KPIs* | Productivity | 48 | 17.84% | Increasing | 35 | 72.9% | x |
| | | Cost-effectiveness | 36 | 13.38% | Increasing | 21 | 58.3% | x |
| | *Ergonomic KPIs* | Ergonomic efforts | 33 | 12.27% | Increasing | 18 | 54.5% | x |
| | *Computational KPI* | Computational time | 66 | 24.54% | Increasing | 47 | 71.2% | x |
| | *Other KPIs* | Customer service | 7 | 2.60% | No trend* | 4 | 57.1% | x |
| | | Optimal layout | 14 | 5.20% | No trend* | 8 | 57.1% | x |
| | | Picking errors | 10 | 3.72% | No trend* | 9 | 90.0% | X |

Note: * number of entries insufficient for determining a trend; ** trends less evident in the last years.

Recalling the points listed in the introduction section, some closing considerations on the outcomes and some suggestions for future research activities can be delineated.

(i) *Warehouse layout and structure*. Most of the studies reviewed (≈59%) have targeted conventional warehouses, which is the possible consequence of their high degree of space utilization. On the contrary, less of 8% (overall) of the papers has addressed the order picking problem in non-conventional warehouses. Because of the limited number of studies that targeted non-conventional warehouses, no trends can be delineated. Nonetheless, it can be observed that the interest towards these unconventional layouts has emerged in recent times. On the contrary, studies targeting the presence of cross-aisles and the analysis of the depot location have increased in time. These aspects are important to highlight, as they represent picking design problems that have been not so explored in the literature, probably, because of the higher complexity or the limits in the computational capacity available. It could be argued that the current availability of enhanced computational capacity is helping researchers analyse more complex picking problems or more complex warehouse configurations. It is, therefore, recommended to address these less explored topics (non-conventional layouts and cross-aisle layouts) in future research activities.

(ii) *Picking processes, storage allocation policies and routing policies*. The most investigated picking method is low-level picking; high-level picking is significantly less explored, although it has emerged as a topic of interest in recent times. The most popular picking type is instead manual picking; again, the remaining two types have been less explored in the literature but are attracting the recent interest of researchers. Moreover, it was found that the most studied issue (discussed in 179 articles) is picker routing, and on the contrary, bucket brigade received a very limited attention (7 papers), followed by picker congestion (21 studies); this latter topic, by the way, is to be evaluated together with narrow-aisle layouts, which, in turn, are not so explored in literature. Keshavarz et al. (2021) obtained a similar outcome, as they also found that the most studied order picking problem is routing. In most of the articles reviewed, random allocation of items is considered; this topic has received a constant attention in time, meaning that random allocation is a typical strategy, always of scientific and practical interest. However, it is worth mentioning that the interest towards other allocation policies, such as class-based and correlated storage, has increased in time; correlated storage is also more widely explored in recent papers. Besides the already recalled enhanced computational capacity of modern Information and Communication Technologies (ICT) tools, which makes class-based and correlated storage policies easier to model, it is likely that these policies are being increasingly implemented in practice, which probably also stimulates the scientific interest. Overall, however, the number of studies targeting either correlated or class-based storage is still limited and would benefit from additional research activities. We also found that the algorithms employed for solving the order picking routing problem differ in terms of accuracy and computational complexity. Heuristics have enjoyed the highest popularity in the literature, and they represent a quite mature field (constant trend); exact algorithms have received less attention, but again, the development of exact algorithms for picker routing is a quite mature topic (constant trend), on which future research or additional optimization approaches do not seem to be strictly required. Obviously, in some cases or layout types, the computational complexity of exact algorithms becomes excessive and, consequently, the development of an exact algorithm is not feasible, which forces the authors to shift towards meta-heuristic approaches. Indeed, the interest towards meta-heuristic algorithms has increased in time; it could be conjectured that the always higher computational efficiency of the available ICT is stimulating the researchers towards the development of new algorithms expressively designed for picker routing or to the implementation of more complex algorithms to the picking area; this is somehow demonstrated by the high quota of recent studies making use of meta-heuristic algorithms. As far as the picking process is concerned, manual activities are by far the most popular in the literature, which is consonant with the traditional nature of order picking. Automated picking is significantly less explored, but it is interesting to observe that the attention towards this topic is increasing and that sufficient continuity has been reached in the last years. It could be conjectured that automated picking will gain a progressive importance in the order picking literature, both as a consequence of the implementation of Industry 4.0 solutions in industry and also because of the COVID-19 pandemic, as automation has sometimes been used by companies to reduce the presence of personnel at work, with the purpose of reducing the spread of the virus. Relationships between these aspects (i.e. COVID-19, automated picking and Industry 4.0) represent interesting topics for future research activities.

(iii) *Problem constraints*. The picker capacity is the topic, which, although analysed in a moderate number of studies, seems to be neglected in early studies by researchers. In contrast, it is gradually beginning to be investigated in recent years. As far as the remaining problem constraints, it has been already mentioned that congestion issues have been explored in a limited number of studies only; the trend of these studies is almost stable in time. Bucket brigade, instead, is still at its early stage of study, and no trends can be highlighted. Future studies need to investigate this aspect of the picking process for gaining additional insights.

(iv) *Outcomes observed*. The technical KPIs with the highest frequency of usage is the travel time, followed by the travel distance; this is consonant with the general objective of picking studies, i.e. minimising the travel time of pickers. In terms of efficiency, the most used KPIs are instead the productivity and cost-effectiveness of the order picking system; both KPIs seem to be of particular interest in recent studies. On the contrary, despite the importance of human resources in the warehouse environment, as in the Keshavarz et al. (2021) and Masae et al. (2020) articles, a small number of studies at present have evaluated ergonomic aspects of picking; again, this topic is emerging in the recent literature. It is, nonetheless, interesting to note that, exception made for some KPIs which have not been explored to a significant level of detail (e.g. the 'other KPIs' category), the interest towards the evaluation of the order picking performance, in its various forms, has increased in time, and recent studies pay a particular attention to this aspect. This is the possible effect of the general perception of the inefficiency of order picking, primarily in economic terms, which makes the evaluation of performance particularly relevant. The attention towards the picker, demonstrated by the increased usage of ergonomic KPIs, also deserves attention, particularly in manual processes, and is expected to represent an interesting future line of research. The combination of various KPIs into a multi-objective optimization problem is suggested as an interesting future research direction. To this end, it is advisable to evaluate the effectiveness of order picking systems taking into account even less used indicators, such as picking errors or customer service, for a more comprehensive evaluation. Looking instead at the performance of the solution procedures used by researchers (e.g. for picker routing or items allocation), it is to be remarked that the computational time is rarely taken into account as a KPI (66 studies overall). This outcome sounds strange because of two reasons. First of all, it is evident that the computational effort is quite relevant for judging the practical usability of an algorithm and pondering its application in a real context. Indeed, most of the picking decisions (e.g. routing) are operational decisions, which need to be made in a very short time; a routing algorithm should therefore be able to provide a quick solution to the problem. As a second point, let us suppose that a researcher is willing to present a new algorithm for order pickers' routing. If this is the case, typically it has not to (merely) demonstrate that the algorithm performs well, as there are already numerous algorithms for picker routing; rather, the superiority of the new algorithm compared to other existing approaches must be demonstrated. Obviously, the computational time is an important parameter to be evaluated to this end. Indeed, the recent literature seems to be more precise from this point of view, as the evaluation of the computational time is frequently included in the newer studies. Our suggestion to researchers, obviously, is to always include, where appropriate, the evaluation of the computational time in their study.

(v) *Industrial sectors*. Results of the review show that picking studies have targeted numerous industrial fields, but that, at the same time, most of them are emerging and of recent interest, while two fields only are showed increasing interest (retail and e-commerce). The most striking is e-commerce (more than 90% of the studies published since 2017), which was partially expected as a consequence of the changes in the consumers' behaviour in response to the COVID-19 pandemic. The importance of this sector is also likely to last in time, and thus e-commerce represents an interesting avenue for research on order picking.

As it is typical of review studies, this paper does not present fully 'new' research results by itself. Rather, scientific contributions come from (1) consolidating existing information from numerous studies on order picking systems and (2) delineating the (recent) trends of research in this field, at the same time highlighting the need for future research activities on the topic. As such, we are confident that this study could form the basis for further investigations in the area of order picking, possibly taking inspiration from the research directions delineated above.

The study has, of course, some limitations. A first aspect is the fact that the papers reviewed were taken from one scientific database only. Scopus includes a wide number of relevant journals, and this is expected to ensure high quality of the contents retrieved. However, journals that are not indexed in this database have not been retrieved or evaluated, resulting in possible losses of data. A similar consideration holds true for the publication language, which was limited to English, and for the paper type (set at peer-reviewed journal paper). Although this is a reasonable choice, these settings involve other study types (e.g. conference proceedings or book chapters) to be neglected and again could lead to some loss of relevant information. Finally, the usage of specific keywords in the query setting for sure allowed to select (relevant) papers, but other ones could have been excluded if the authors used different terms. Expanding the query, for example by including more keywords, could be a possible way for widening the analysis in future studies; this would certainly result in a larger pool of papers retrieved, which, therefore, could require a more careful screening or the usage of more structured approaches in mapping them (e.g. bibliometric and network analysis tools).

## Notes

1. This is typically the case for studies that have implemented multiple approaches (e.g. an analytic model followed by a simulated study).
2. We have not investigated the particular reason for this outcome, as it is out of scope for the present study; it is known, however, that classification errors in Scopus (and in any scientific database) could always occur. Highlighting the similarity of these studies to review papers, nonetheless, is relevant to our study, as reviews typically have higher figures compared to journal articles (e.g. more citations).
3. Available in the supplementary material in the form of a Microsoft Excel™ spreadsheet.
4. By ‘combination’, we refer to the situation in which more than one layout type is evaluated in the same article.

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## References

Abbu, H., Fleischmann, D., & Gopalakrishna, P. (2021). The digital transformation of the grocery business - briven by consumers, powered by technology, and accelerated by the COVID-19 pandemic. *Advances in Intelligent Systems and Computing*, *1367*, 329–339. https://doi.org/10.1007/978-3-030-72660-7_32

Accorsi, R., Manzini, R., & Bortolini, M. (2012). A hierarchical procedure for storage allocation and assignment within an order-picking system. A case study. *International Journal of Logistics: Research and Applications*, *15*(6), 351–364. https://doi.org/10.1080/13675567.2012.742877

Aerts, B., Cornelissens, T., & Sörensen, K. (2021). The joint order batching and picker routing problem: Modelled and solved as a clustered vehicle routing problem. *Computers & Operations Research*, *129*, 129. https://doi.org/10.1016/j.cor.2020.105168

Aitziane, A., Barra, A., & Bensassi, B. (2021). Sensitivity analysis modeling for the evaluation of the order picking process performance. *International Review of Automatic Control*, *14*(2), 76–84. https://doi.org/10.15866/ireaco.v14i2.20459

Al-Araidah, O., Dalalah, D., Azeez, M. -A., Khasawneh, M., & Khasawneh, M. T. (2017). A heuristic for clustering and picking small items considering safe reach of the order picker. *European Journal of Industrial Engineering*, *11*(2), 256–269. https://doi.org/10.1504/EJIE.2017.083256

Al-Araidah, O., Okudan-Kremer, G., Gunay, E., & Chu, C. -Y. (2020). A Monte Carlo simulation to estimate fatigue allowance for female order pickers in high traffic manual picking systems. *International Journal of Production Research*, *59*(15), 4711–4722. https://doi.org/10.1080/00207543.2020.1770357

Aldarondo, F., & Bozer, Y. (2022). Expected distances and alternative design configurations for automated guided vehicle-based order picking systems. *International Journal of Production Research*, *60*(4), 1298–1315. https://doi.org/10.1080/00207543.2020.1856438

Alderighi, M. (2021). Il post pandemia: l'effetto di lungo termine sulle attività economiche. *EyesReg*, *11*(3).

Alipour, M. Z., Zare Mehrjedrdi, Y., & Mostafaeipour, A. (2020). A rule-based heuristic algorithm for on-line order batching and scheduling in an order picking warehouse with multiple pickers. *RAIRO - Operations Research*, *54*(1), 101–117. https://doi.org/10.1051/ro/2018069

Altarazi, S., & Ammouri, M. (2018). Concurrent manual-order-picking warehouse design: A simulation-based design of experiments approach. *International Journal of Production Research*, *56*(23), 7103–7121. https://doi.org/10.1080/00207543.2017.1421780

Amini, H., Jabalameli, M., & Ramesht, M. (2021). Development of regional foresight studies between 2000 and 2019: An overview and co-citation analysis. *European Journal of Futures Research*, *9*(1). https://doi.org/10.1186/s40309-021-00170-7

Andriansyah, R., De Koning, W., Jordan, R., Etman, L., & Rooda, J. (2011). A process algebra based simulation model of a miniload-workstation order picking system. *Computers in Industry*, *62*(3), 292–300. https://doi.org/10.1016/j.compind.2010.09.005

Andriansyah, R., Etman, L., Adan, I., & Rooda, J. (2014). Design and analysis of an automated order-picking workstation. *Journal of Simulation*, *8*(2), 151–163. https://doi.org/10.1057/jos.2013.24

Ardjmand, E., Ghalehkhondabi, I., Young, W., II, Sadeghi, A., Weckman, G., & Shakeri, H. (2020). A hybrid artificial neural network, genetic algorithm and column generation heuristic for minimizing makespan in manual order picking operations. *Expert Systems with Applications*, *159*, 159. https://doi.org/10.1016/j.eswa.2020.113566

Ardjmand, E., Sanei Bajgiran, O., & Youssef, E. (2019). Using list-based simulated annealing and genetic algorithm for order batching and picker routing in put wall based picking systems. *Applied Soft Computing Journal*, *75*, 106–119. https://doi.org/10.1016/j.asoc.2018.11.019

Ardjmand, E., Shakeri, H., Singh, M., & Sanei Bajgiran, O. (2018). Minimizing order picking makespan with multiple pickers in a wave picking warehouse. *International Journal of Production Economics*, *206*, 169–183. https://doi.org/10.1016/j.ijpe.2018.10.001

Ardjmand, E., Singh, M., Shakeri, H., Tavasoli, A., & Young, W., II. (2021). Mitigating the risk of infection spread in manual order picking operations: A multi-objective approach. *Applied Soft Computing*, *100*, 106953. https://doi.org/10.1016/j.asoc.2020.106953

Artal-Sevil, J., Bernal-Agustín, J., Dufo-López, R., & Domínguez-Navarro, J. (2017). Forklifts, automated guided vehicles and horizontal order pickers in industrial environments. Energy management of an active hybrid power system based on batteries, PEM fuel cells and ultracapacitors. *Renewable Energy and Power Quality Journal*, *1*(15), 859–864. https://doi.org/10.24084/repqj15.497

Atashi Khoei, A., Süral, H., & Tural, M. (2022). Energy minimizing order picker forklift routing problem. *European Journal of Operational Research*, *307*(2), 604–626. https://doi.org/10.1016/j.ejor.2022.08.038

Atchade Adelomou, P., Alonso-Linaje, G., Albo-Canals, J., & Casado-Fauli, D. (2021). Qrobot: A quantum computing approach in mobile robot order picking and batching problem solver optimization. *Algorithms*, *14*(7), 194. https://doi.org/10.3390/a14070194

Atmaca, E., & Ozturk, A. (2013). Defining order picking policy: A storage assignment model and a simulated annealing solution in AS/RS systems. *Applied Mathematical Modelling*, *37*(7), 5069–5079. https://doi.org/10.1016/j.apm.2012.09.057

Azizpour, M., Namazypour, N., & Kirchheim, A. (2022). Synthetic data generation for robotic order picking. *Logistics Journal*, *2022*(11). https://doi.org/10.2195/lj_proc_azizpour_en_202211_01

Bahrami, B., Aghezzaf, E. -H., & Limere, V. (2017). Using simulation to analyze picker blocking in manual order picking systems. *Procedia Manufacturing*, *11*, 1798–1808. https://doi.org/10.1016/j.promfg.2017.07.317

Bahrami, B., Aghezzaf, E. -H., & Limère, V. (2019). Enhancing the order picking process through a new storage assignment strategy in forward-reserve area. *International Journal of Production Research*, *57*(21), 6593–6614. https://doi.org/10.1080/00207543.2019.1567953

Bal, M., Vermeerbergen, L., & Benders, J. (2022). Putting head-worn displays to use for order picking: A most-similar comparative case study. *The International Journal of Logistics Management*. https://doi.org/10.1108/IJLM-12-2021-0570

Bansal, V., & Roy, D. (2021). Stochastic modeling of multiline orders in integrated storage-order picking system. *Naval Research Logistics*, *68*(6), 810–836. https://doi.org/10.1002/nav.21978

Bartolini, M., Bottani, E., & Grosse, E. (2019). Green warehousing: Systematic literature review and bibliometric analysis. *Journal of Cleaner Production*, *226*, 242–258. https://doi.org/10.1016/j.jclepro.2019.04.055

Battini, D., Calzavara, M., Persona, A., & Sgarbossa, F. (2015). Order picking system design: The storage assignment and travel distance estimation (SA&TDE) joint method. *International Journal of Production Research*, *53*(4), 1077–1093. https://doi.org/10.1080/00207543.2014.944282

Battini, D., Calzavara, M., Persona, A., & Sgarbossa, F. (2017). Additional effort estimation due to ergonomic conditions in order picking systems. *International Journal of Production Research*, *55*(10), 2764–2774. https://doi.org/10.1080/00207543.2016.1190879

Battini, D., Calzavara, M. , Persona, A., Sgarbossa, F., & Visentin, V. (2017). Fatigue and recovery: Research opportunities in order picking systems. *IFAC-Papersonline*, *50*(1), 6882–6887. https://doi.org/10.1016/j.ifacol.2017.08.1211

Battini, D., Glock, C., Grosse, E., Persona, A., & Sgarbossa, F. (2016). Human energy expenditure in order picking storage assignment: A bi-objective method. *Computers & Industrial Engineering*, *94*, 147–157. https://doi.org/10.1016/j.cie.2016.01.020

Beroule, B., Grunder, O., Barakat, O., & Aujoulat, O. (2017). Order picking problem in a warehouse hospital pharmacy. *IFAC-Papersonline*, *50*(1), 5017–5022. https://doi.org/10.1016/j.ifacol.2017.08.910

Bigliardi, B., Casella, G., & Bottani, E. (2021). Industry 4.0 in the logistics field: A bibliometric analysis. *IET Collaborative Intelligent Manufacturing*, *3*(1), 4–12. https://doi.org/10.1049/cim2.12015

Bindi, F., Manzini, R., Pareschi, A., & Regattieri, A. (2009). Similarity-based storage allocation rules in an order picking system: An application to the food service industry. *International Journal of Logistics: Research and Applications*, *12*(4), 233–247. https://doi.org/10.1080/13675560903075943

Bloss, R. (2013). Ease of programming and sophisticated sensors see robots advancing in transport logistics, palletizing, order picking and assembly. *The Industrial Robot*, *40*(5), 420–424. https://doi.org/10.1108/IR-03-2013-335

Bódis, T., & Botzheim, J. (2018). Bacterial memetic algorithms for order picking routing problem with loading constraints. *Expert Systems with Applications*, *105*, 196–220. https://doi.org/10.1016/j.eswa.2018.03.043

Bottani, E., Cecconi, M. V. G., Vignali, G., & Montanari, R. (2012). Optimisation of storage allocation in order picking operations through a genetic algorithm. *International Journal of Logistics: Research and Applications*, *15*(2), 127–146. https://doi.org/10.1080/13675567.2012.694860

Bottani, E., Montanari, R., & Rinaldi, M. (2019). Development and testing of software tool for warehouse design and picking optimisation. *International Journal of Management and Decision Making*, *18*(2), 119–150. https://doi.org/10.1504/IJMDM.2019.098649

Bottani, E., & Vignali, G. (2019). Augmented reality technology in the manufacturing industry: A review of the last decade. *IISE Transactions*, *51*(3), 284–310. https://doi.org/10.1080/24725854.2018.1493244

Bottani, E., Volpi, A., & Montanari, R. (2019). Design and optimization of order picking systems: An integrated procedure and two case studies. *Computers & Industrial Engineering*, *137*, 137. https://doi.org/10.1016/j.cie.2019.106035

Boysen, N., Briskorn, D., & Emde, S. (2017). Sequencing of picking orders in mobile rack warehouses. *European Journal of Operational Research*, *259*(1), 293–307. https://doi.org/10.1016/j.ejor.2016.09.046

Boysen, N., De Koster, R., & Weidinger, F. (2019). Warehousing in the e-commerce era: A survey. *European Journal of Operational Research*, *277*(2), 396–411. https://doi.org/10.1016/j.ejor.2018.08.023

Boysen, N., Füßler, D., & Stephan, K. (2020). See the light: Optimization of put-to-light order picking systems. *Naval Research Logistics*, *67*(1), 3–20. https://doi.org/10.1002/nav.21883

Boywitz, D., Schwerdfeger, S., & Boysen, N. (2019). Sequencing of picking orders to facilitate the replenishment of A-Frame systems. *IISE Transactions*, *51*(4), 368–381. https://doi.org/10.1080/24725854.2018.1513672

Bozer, Y., & Aldarondo, F. (2018). A simulation-based comparison of two goods-to-person order picking systems in an online retail setting. *International Journal of Production Research*, *56*(11), 3838–3858. https://doi.org/10.1080/00207543.2018.1424364

Bozer, Y., & Kile, J. (2008). Order batching in walk-and-pick order picking systems. *International Journal of Production Research*, *46*(7), 1887–1909. https://doi.org/10.1080/00207540600920850

Briant, O., Cambazard, H., Cattaruzza, D., Catusse, N., Ladier, A. -L., & Ogier, M. (2020). An efficient and general approach for the joint order batching and picker routing problem. *European Journal of Operational Research*, *295*(2), 497–512. https://doi.org/10.1016/j.ejor.2020.01.059

Bukchin, Y., Khmelnitsky, E., & Yakuel, P. (2012). Optimizing a dynamic order-picking process. *European Journal of Operational Research*, *219*(2), 335–346. https://doi.org/10.1016/j.ejor.2011.12.041

Burinskiene, A. (2010). Order picking process at warehouses. *International Journal of Logistics Systems and Management*, *6*(2), 162–178. https://doi.org/10.1504/IJLSM.2010.030958

Burinskienė, A., Davidavičienė, V., Raudeliūnienė, J., & Meidutė-Kavaliauskienė, I. (2018). Simulation and order picking in a very-narrow-aisle warehouse. *Economic Research-Ekonomska Istrazivanja*, *31*(1), 1574–1589. https://doi.org/10.1080/1331677X.2018.1505532

Calzavara, M., Glock, C., Grosse, E., Persona, A., & Sgarbossa, F. (2016). Models for an ergonomic evaluation of order picking from different rack layouts. *IFAC-Papersonline*, *49*(12), 1715–1720. https://doi.org/10.1016/j.ifacol.2016.07.829

Calzavara, M., Glock, C., Grosse, E., Persona, A., & Sgarbossa, F. (2017). Analysis of economic and ergonomic performance measures of different rack layouts in an order picking warehouse. *Computers & Industrial Engineering*, *111*, 527–536. https://doi.org/10.1016/j.cie.2016.07.001
Calzavara, M., Glock, C., Grosse, E., & Sgarbossa, F. (2019). An integrated storage assignment method for manual order picking warehouses considering cost, workload and posture. *International Journal of Production Research*, *57*(8), 2392–2408. https://doi.org/10.1080/00207543.2018.1518609
Calzavara, M., Persona, A., Sgarbossa, F., & Visentin, V. (2018). A device to monitor fatigue level in order-picking. *Industrial Management and Data Systems*, *118*(4), 714–727. https://doi.org/10.1108/IMDS-05-2017-0182
Calzavara, M., Sgarbossa, F., & Persona, A. (2019). Vertical lift modules for small items order picking: An economic evaluation. *International Journal of Production Economics*, *210*, 199–210. https://doi.org/10.1016/j.ijpe.2019.01.012
Cano, J. (2020). Formulations for joint order picking problems in low-level picker-to-part systems. *Bulletin of Electrical Engineering and Informatics*, *9*(2), 834–842. https://doi.org/10.11591/eei.Q28v9i2.211
Cano, J., Correa-Espinal, A., & Gómez-Montoya, R. (2018). A review of research trends in order batching, sequencing and picker routing problems. *Espacios*, *39*(4).
Cano, J., Correa-Espinal, A., & Gómez-Montoya, R. (2020). Mathematical programming modeling for joint order batching, sequencing and picker routing problems in manual order picking systems. *Journal of King Saud University - Engineering Sciences*, *32*(3), 219–228. https://doi.org/10.1016/j.jksues.2019.02.004
Cano, J., Cortés, P., Muñuzuri, J., & Correa-Espinal, A. (2022). Solving the picker routing problem in multi-block high-level storage systems using metaheuristics. *Flexible Services and Manufacturing Journal*. https://doi.org/10.1007/s10696-022-09445-y
Cardona, L., Soto, D., Rivera, L., & Martínez, H. (2015). Detailed design of fishbone warehouse layouts with vertical travel. *International Journal of Production Economics*, *170*, 825–837. https://doi.org/10.1016/j.ijpe.2015.03.006
Caron, F., Marchet, G., & Perego, A. (2000). Optimal layout in low-level picker-to-part systems. *International Journal of Production Research*, *38*(1), 101–117. https://doi.org/10.1080/002075400189608
Çelik, M., & Süral, H. (2016). Order picking in a parallel-aisle warehouse with turn penalties. *International Journal of Production Research*, *54*(14), 4340–4355. https://doi.org/10.1080/00207543.2016.1154624
Çelik, M., & Süral, H. (2019). Order picking in parallel-aisle warehouses with multiple blocks: Complexity and a graph theory-based heuristic. *International Journal of Production Research*, *57*(3), 888–906. https://doi.org/10.1080/00207543.2018.1489154
Çelk, M., & Süral, H. (2014). Order picking under random and turnover-based storage policies in fishbone aisle warehouses. *IIE Transactions (Institute of Industrial Engineers)*, *46*(3), 283–300. https://doi.org/10.1080/0740817X.2013.768871
Cergibozan, Ç., & Tasan, A. (2019). Order batching operations: An overview of classification, solution techniques, and future research. *Journal of Intelligent Manufacturing*, *30*(1), 335–349. https://doi.org/10.1007/s10845-016-1248-4
Chabot, T., Coelho, L., Renaud, J., & Côté, J. -F. (2018). Mathematical model, heuristics and exact method for order picking in narrow aisles. *The Journal of the Operational Research Society*, *69*(8), 1242–1253. https://doi.org/10.1080/01605682.2017.1390532
Chabot, T., Lahyani, R., Coelho, L., & Renaud, J. (2017). Order picking problems under weight, fragility and category constraints. *International Journal of Production Research*, *55*(21), 6361–6379. https://doi.org/10.1080/00207543.2016.1251625
Chackelson, C., Errasti, A., Ciprés, D., & Lahoz, F. (2013). Evaluating order picking performance trade-offs by configuring main operating strategies in a retail distributor: A design of experiments approach. *International Journal of Production Research*, *51*(20), 6097–6109. https://doi.org/10.1080/00207543.2013.796421

Chan, F., & Chan, H. (2011). Improving the productivity of order picking of a manual-pick and multi-level rack distribution warehouse through the implementation of class-based storage. *Expert Systems with Applications*, *38*(3), 2686–2700. https://doi.org/10.1016/j.eswa.2010.08.058

Chandra, A., & Natalia, C. (2021). The study of depot position effect on travel distance in order picking problem. *Croatian Operational Research Review*, *12*(2), 189–198. https://doi.org/10.17535/CRORR.2021.0016

Charkhgard, H., & Savelsbergh, M. (2015). Efficient algorithms for travelling salesman problems arising in warehouse order picking. *ANZIAM Journal*, *57*(2), 166–174. https://doi.org/10.1017/S1446181115000140

Cheng, C. -Y., Chen, Y. -Y., Chen, T. -L., & Jung-Woon Yoo, J. (2015). Using a hybrid approach based on the particle swarm optimization and ant colony optimization to solve a joint order batching and picker routing problem. *International Journal of Production Economics*, *170*, 805–814. https://doi.org/10.1016/j.ijpe.2015.03.021

Chen, C. -M., Gong, Y., de Koster, R., & Van Nunen, J. (2010). A flexible evaluative framework for order picking systems. *Production and Operations Management*, *19*(1), 70–82. https://doi.org/10.1111/j.1937-5956.2009.01047.x

Chen, Y., Lan, H., Wang, C., Jia, X., & Sahoo, L. (2022). Integrated online order picking and vehicle routing of food cold chain with demand surge. *Mathematical Problems in Engineering*, *2022*, 1–14. https://doi.org/10.1155/2022/4485376

Chen, R. -C., & Lin, C. -Y. (2020). An efficient two-stage method for solving the order-picking problem. *The Journal of Supercomputing*, *76*(8), 6258–6279. https://doi.org/10.1007/s11227-019-02775-z

Chen, F., Wang, H., Qi, C., & Xie, Y. (2013). An ant colony optimization routing algorithm for two order pickers with congestion consideration. *Computers & Industrial Engineering*, *66*(1), 77–85. https://doi.org/10.1016/j.cie.2013.06.013

Chen, F., Wang, H., Xie, Y., & Qi, C. (2016). An ACO-based online routing method for multiple order pickers with congestion consideration in warehouse. *Journal of Intelligent Manufacturing*, *27*(2), 389–408. https://doi.org/10.1007/s10845-014-0871-1

Chen, F., Xu, G., & Wei, Y. (2019). Heuristic routing methods in multiple-block warehouses with ultra-narrow aisles and access restriction. *International Journal of Production Research*, *57*(1), 228–249. https://doi.org/10.1080/00207543.2018.1473657

Choy, K., Ho, G., & Lee, C. (2017). A RFID-based storage assignment system for enhancing the efficiency of order picking. *Journal of Intelligent Manufacturing*, *28*(1), 111–129. https://doi.org/10.1007/s10845-014-0965-9

Chuang, Y. -F., Chia, S. -H., & Wong, J. -Y. (2014). Enhancing order-picking efficiency through data mining and assignment approaches. *WSEAS Transactions on Business and Economics*, *11*(1), 52–64.

Cierniak-emerych, A., Golej, R., & Różycka, H. (2021). Working conditions and their importance for eliminating errors in the order picking process, using an E-commerce commercial enterprise as an example. *Sustainability*, *13*(23), 13374. https://doi.org/10.3390/su132313374

Claeys, D., Adan, I., & Boxma, O. (2016). Stochastic bounds for order flow times in parts-to-picker warehouses with remotely located order-picking workstations. *European Journal of Operational Research*, *254*(3), 895–906. https://doi.org/10.1016/j.ejor.2016.04.050

Dallari, F., Marchet, G., & Melacini, M. (2009). Design of order picking system. *International Journal of Advanced Manufacturing Technology*, *42*(1–2), 1–12. https://doi.org/10.1007/s00170-008-1571-9

Damayanti, D., Novitasari, N., Setyawan, E., & Muttaqin, P. (2022). Intelligent warehouse picking improvement model for e-logistics warehouse using single picker routing problem and wave picking. *International Journal on Informatics Visualization*, *6*(2), 418–426. https://doi.org/10.30630/joiv.6.2.1006

Daniels, R., Rummel, J., & Schantz, R. (1998). A model for warehouse order picking. *European Journal of Operational Research*, *105*(1), 1–17. https://doi.org/10.1016/S0377-2217(97)00043-X da Piedade, F., Campos, D., Frazzon, E., & Machado, R. (2016). On the application of modelling and simulation to compare human- and automation-based order-picking systems. *IFAC-Papersonline*, *49*(12), 1062–1067. https://doi.org/10.1016/j.ifacol.2016.07.583

Dauod, H., & Won, D. (2022). Real-time order picking planning framework for warehouses and distribution centres. *International Journal of Production Research*, *60*(18), 5468–5487. https://doi.org/10.1080/00207543.2021.1961037

de Koster, R., Le Duc, T., & Roodbergen, K. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*, *182*(2), 481–501. https://doi.org/10.1016/j.ejor.2006.07.009

De Lombaert, T., Braekers, K., De Koster, R., & Ramaekers, K. (2022). In pursuit of humanised order picking planning: Methodological review, literature classification and input from practice. *International Journal of Production Research*, 1–31. https://doi.org/10.1080/00207543.2022.2079437

de Vries, J., de Koster, R., & Stam, D. (2015). Making the right pick: Aligning order picking methods, incentive systems and regulatory focus to increase picking performance. *IFAC-Papersonline*, *48*(3), 585. https://doi.org/10.1016/j.ifacol.2015.06.144

de Vries, J., de Koster, R., & Stam, D. (2016). Aligning order picking methods, incentive systems, and regulatory focus to increase performance. *Production and Operations Management*, *25*(8), 1363–1376. https://doi.org/10.1111/poms.12547

D'haen, R., Braekers, K., & Ramaekers, K. (2022). Integrated scheduling of order picking operations under dynamic order arrivals. *International Journal of Production Research*, 1–22. https://doi.org/10.1080/00207543.2022.2078747

Dickinson, B. (2016). An idea conquers the world: 20 years of Rowa order picking automats [APOTHEKE UND MARKT: Eine Idee erobert die Welt: 20 Jahre Rowa Kommissionierautomaten]. *Deutsche Apotheker Zeitung*, *156*(26).

Diefenbach, H., Emde, S., Glock, C., & Grosse, E. (2022). New solution procedures for the order picker routing problem in U-shaped pick areas with a movable depot. *OR Spectrum*, *44*(2), 535–573. https://doi.org/10.1007/s00291-021-00663-8

Diefenbach, H., & Glock, C. (2019). Ergonomic and economic optimization of layout and item assignment of a U-shaped order picking zone. *Computers & Industrial Engineering*, *138*, 138. https://doi.org/10.1016/j.cie.2019.106094

Djurdjević, D., Bjelić, N., Popović, D., & Andrejić, M. (2022). A combined dynamic programming and simulation approach to the sizing of the low-level order-picking area. *Mathematics*, *10*(20), 3733. https://doi.org/10.3390/math10203733

Dmytrów, K. (2022). Analytical and simulation determination of order picking time in a low storage warehouse for shared storage systems. *Operations Research and Decisions*, *32*(2), 34–51. https://doi.org/10.37190/ord220203

Dukić, G., Česnik, V., & Opetuk, T. (2010). Order-picking methods and technologies for greener warehousing. *Strojarstvo*, *52*(1), 23–31.

Dukic, G., & Oluic, C. (2007). Order-picking methods: Improving order-picking efficiency. *International Journal of Logistics Systems and Management*, *3*(4), 451–460. https://doi.org/10.1504/IJLSM.2007.013214

Dukic, G., Opetuk, T., & Lerher, T. (2015). A throughput model for a dual-tray vertical lift module with a human order-picker. *International Journal of Production Economics*, *170*, 874–881. https://doi.org/10.1016/j.ijpe.2015.04.009

Durach, C. F., Kembro, J. H., & Wieland, A. (2021). How to advance theory through literature reviews in logistics and supply chain management. *International Journal of Physical Distribution & Logistics Management*, *51*(10), 1090–1107. https://doi.org/10.1108/IJPDLM-11-2020-0381

Düzgit, Z., Toy, A., & Saner, A. (2021). Performance comparison of meta-heuristics for the multiblock warehouse order picking problem. *International Journal of Industrial Engineering: Theory Applications and Practice*, *28*(1), 75–91.

Eisenstein, D. (2008). Analysis and optimal design of discrete order picking technologies along a line. *Naval Research Logistics*, *55*(4), 350–362. https://doi.org/10.1002/nav.20289

Elbert, R., Franzke, T., Glock, C., & Grosse, E. (2017). The effects of human behavior on the efficiency of routing policies in order picking: The case of route deviations. *Computers & Industrial Engineering*, *111*, 537–551. https://doi.org/10.1016/j.cie.2016.11.033
Elbert, R., Knigge, J. -K., & Sarnow, T. (2018). Transferability of order picking performance and training effects achieved in a virtual reality using head mounted devices. *IFAC-Papersonline*, *51* (11), 686–691. https://doi.org/10.1016/j.ifacol.2018.08.398
Elbert, R., & Müller, J. (2017). Manoeuvres in manual person-to-parts order picking systems: Is there a significant influence on travel time and metabolic rates? *IFAC-Papersonline*, *50*(1), 6894–6899. https://doi.org/10.1016/j.ifacol.2017.08.1213
Ellinger, M., & Hompel, M. (2012). Agent based planning model for the plan of concept for order picking systems [Agentenbasiertes planungsmodell für die grobplanung von kommissioniersystemen]. *Logistics Journal*, 1–10. https://doi.org/10.2195/lj_Proc_ellinger_de_201210_01
El-Sherbeny, N. (2010). Vehicle routing with time windows: An overviewof exact, heuristic and metaheuristic methods. *Journal of King Saud University*, *22*(3), 123–131. https://doi.org/10.1016/j.jksus.2010.03.002
Fadlalla, A., & Amani, F. (2015). A keyword-based organizing framework for ERP intellectual contributions. *Journal of Enterprise Information Management*, *28*(5), 637–657. https://doi.org/10.1108/JEIM-09-2014-0090
Fang, W., & An, Z. (2020). A scalable wearable AR system for manual order picking based on warehouse floor-related navigation. *International Journal of Advanced Manufacturing Technology*, *109*(7–8), 2023–2037. https://doi.org/10.1007/s00170-020-05771-3
Farhadi Sartangi, M., Husseinzadeh Kashan, A., Haleh, H., Kazemi, A., & Lotfi, R. (2022). A mixed integer linear formulation and a grouping league championship algorithm for a multiperiod-multitrip order picking system with product replenishment to minimize total tardiness. *Complexity*, *2022*, 1–24. https://doi.org/10.1155/2022/1382558
Fibrianto, H., & Hong, S. (2019). Dynamic order batching in bucket brigade order picking systems with consecutive batch windows and non-identical pickers. *International Journal of Production Research*, *57*(20), 6552–6568. https://doi.org/10.1080/00207543.2019.1567948
Foroughi, A., Boysen, N., Emde, S., & Schneider, M. (2021). High-density storage with mobile racks: Picker routing and product location. *The Journal of the Operational Research Society*, *72* (3), 535–553. https://doi.org/10.1080/01605682.2019.1700180
Fragapane, G., De Koster, R., Sgarbossa, F., & Strandhagen, J. O. (2021). Planning and control of autonomous mobile robots for intralogistics: Literature review and research agenda. *European Journal of Operational Research*, *294*(2), 405–426. https://doi.org/10.1016/j.ejor.2021.01.019
Franzke, T., Grosse, E., Glock, C., & Elbert, R. (2017). An investigation of the effects of storage assignment and picker routing on the occurrence of picker blocking in manual picker-to-parts warehouses. *The International Journal of Logistics Management*, *28*(3), 841–863. https://doi.org/10.1108/IJLM-04-2016-0095
Frazele, E., & Sharp, G. (1989). Correlated assignment strategy can improve any order-picking operation. *Industrial Engineering*, *21*, 33–37.
Fumi, A., Scarabotti, L., & Schiraldi, M. (2013). The effect of slot-code optimization in warehouse order picking. *International Journal of Engineering Business Management*, *5*(1), 1–10. https://doi.org/10.5772/56803
Füßler, D., & Boysen, N. (2017). Efficient order processing in an inverse order picking system. *Computers & Operations Research*, *88*, 150–160. https://doi.org/10.1016/j.cor.2017.07.005
Füßler, D., Fedtke, S., & Boysen, N. (2019). The cafeteria problem: Order sequencing and picker routing in on-the-line picking systems. *OR Spectrum*, *41*(3), 727–756. https://doi.org/10.1007/s00291-019-00553-0
Gajšek, B., Cajner, H., Butlewski, M., Opetuk, T., & Đukić, G. (2022). Bi-objective assignment model for lean order picking in a warehouse. *Tehnicki Vjesnik*, *29*(1), 293–300. https://doi.org/10.17559/TV-20201002103433
Gajšek, B., Dukic, G., Kovacic, M., & Brezocnik, M. (2021a). A multi-objective genetic algorithms approach for modelling of order picking. *International Journal of Simulation Modelling*, *20*(4), 719–729. https://doi.org/10.2507/IJSIMM20-4-582

Gajšek, B., Šinko, S., Kramberger, T., Butlewski, M., Özceylan, E., & Đukić, G. (2021b). Towards productive and ergonomic order picking: Multi-objective modeling approach. *Applied Sciences*, *11*(9), 4179. https://doi.org/10.3390/app11094179

Gao, D., Xu, Z., Ruan, Y., & Lu, H. (2017). From a systematic literature review to integrated definition for sustainable supply chain innovation (SSCI). *Journal of Cleaner Production*, *142*, 1518–1538. https://doi.org/10.1016/j.jclepro.2016.11.153

Giannikas, V., Lu, W., Robertson, B., & McFarlane, D. (2017). An interventionist strategy for warehouse order picking: Evidence from two case studies. *International Journal of Production Economics*, *189*, 63–76. https://doi.org/10.1016/j.ijpe.2017.04.002

Glock, C., & Grosse, E. (2012). Storage policies and order picking strategies in U-shaped order-picking sytems with a movable base. *International Journal of Production Research*, *50*(16), 4344–4357. https://doi.org/10.1080/00207543.2011.588621

Glock, C., Grosse, E., Abedinnia, H., & Emde, S. (2019). An integrated model to improve ergonomic and economic performance in order picking by rotating pallets. *European Journal of Operational Research*, *273*(2), 516–534. https://doi.org/10.1016/j.ejor.2018.08.015

Glock, C., Grosse, E., Elbert, R., & Franzke, T. (2017). Maverick picking: The impact of modifications in work schedules on manual order picking processes. *International Journal of Production Research*, *55*(21), 6344–6360. https://doi.org/10.1080/00207543.2016.1252862

Goeke, D., & Schneider, M. (2021). Modeling single-picker routing problems in classical and modern warehouses. *INFORMS Journal on Computing*, *33*(2), 436–451. https://doi.org/10.1287/ijoc.2020.1040

Gong, Y., & de Koster, R. (2008). A polling-based dynamic order picking system for online retailers. *IIE Transactions (Institute of Industrial Engineers)*, *40*(11), 1070–1082. https://doi.org/10.1080/07408170802167670

Gong, Y., & de Koster, R. (2011). A review on stochastic models and analysis of warehouse operations. *Logistics Research*, *3*(4), 191–205. https://doi.org/10.1007/s12159-011-0057-6

Grosse, E., Dixon, S., Neumann, W., & Glock, C. (2016). Using qualitative interviewing to examine human factors in warehouse order picking: Technical note. *International Journal of Logistics Systems and Management*, *23*(4), 499–518. https://doi.org/10.1504/IJLSM.2016.075211

Grosse, E., & Glock, C. (2013). An experimental investigation of learning effects in order picking systems. *Journal of Manufacturing Technology Management*, *24*(6), 850–872. https://doi.org/10.1108/JMTM-03-2012-0036

Grosse, E., & Glock, C. (2015). The effect of worker learning on manual order picking processes. *International Journal of Production Economics*, *170*, 882–890. https://doi.org/10.1016/j.ijpe.2014.12.018

Grosse, E., Glock, C., & Ballester-Ripoll, R. (2014). A simulated annealing approach for the joint order batching and order picker routing problem with weight restrictions. *International Journal of Operations and Quantitative Management*, *20*(2), 65–83.

Grosse, E., Glock, C., & Jaber, M. (2013). The effect of worker learning and forgetting on storage reassignment decisions in order picking systems. *Computers & Industrial Engineering*, *66*(4), 653–662. https://doi.org/10.1016/j.cie.2013.09.013

Grosse, E., Glock, C., Jaber, M., & Neumann, W. (2015). Incorporating human factors in order picking planning models: Framework and research opportunities. *International Journal of Production Research*, *53*(3), 695–717. https://doi.org/10.1080/00207543.2014.919424

Grosse, E., Glock, C., & Neumann, W. (2017). Human factors in order picking: A content analysis of the literature. *International Journal of Production Research*, *55*(5), 1260–1276. https://doi.org/10.1080/00207543.2016.1186296

Gue, K., Meller, R., & Skufca, J. (2006). The effects of pick density on order picking areas with narrow aisles. *IIE Transactions (Institute of Industrial Engineers)*, *38*(10), 859–868. https://doi.org/10.1080/07408170600809341

Gu, J., Goetschalckx, M., & McGinnis, L. (2007). Research on warehouse operation: A comprehensive review. *European Journal of Operational Research*, *177*(1), 1–21. https://doi.org/10.1016/j.ejor.2006.02.025

Gu, J., Goetschalckx, M., & McGinnis, L. (2010). Solving the forward-reserve allocation problem in warehouse order picking systems. *The Journal of the Operational Research Society*, *61*(6), 1013–1021. https://doi.org/10.1057/jors.2009.39
Guo, J., Zhu, J., Zhou, L., & Qu, Q. (2011). The study of sorted-storage return-type manual order picking based on M/G/1 random service system theory. *Journal of Computational Information Systems*, *7*(4), 1270–1277.
Habazin, J., Glasnović, A., & Bajor, I. (2017). Order picking process in warehouse: Case study of dairy industry in Croatia [Skladišni proces komisioniranja: Studija slučaja u mljekarskoj industriji u republici hrvatskoj]. *Promet - Traffic - Traffico*, *29*(1), 57–65. https://doi.org/10.7307/ptt.v29i1.2106
Hamja, A., Maalouf, M., & Hasle, P. (2019). The effect of lean on occupational health and safety and productivity in the garment industry–a literature review. *Production and Manufacturing Research*, *7*(1), 316–334. https://doi.org/10.1080/21693277.2019.1620652
Hanson, R., Medbo, L., & Johansson, M. (2018). Performance characteristics of robotic mobile fulfilment systems in order picking applications. *IFAC-Papersonline*, *51*(11), 1493–1498. https://doi.org/10.1016/j.ifacol.2018.08.290
Haouassi, M., Kergosien, Y., Mendoza, J., & Rousseau, L. -M. (2022). The integrated orderline batching, batch scheduling, and picker routing problem with multiple pickers: The benefits of splitting customer orders. *Flexible Services and Manufacturing Journal*, *34*(3), 614–645. https://doi.org/10.1007/s10696-021-09425-8
Hara, T., Li, Y., Ota, J., & Arai, T. (2020). Automatic risk assessment integrated with activity segmentation in the order picking process to support health management. *CIRP Annals*, *69*(1), 17–20. https://doi.org/10.1016/j.cirp.2020.04.011
Hassini, E. (2009). One-dimensional carousel storage problems: Applications, review and generalizations. *INFOR*, *47*(2), 81–92. https://doi.org/10.3138/infor.47.2.81
Henn, S. (2012). Algorithms for on-line order batching in an order picking warehouse. *Computers & Operations Research*, *39*(11), 2549–2563. https://doi.org/10.1016/j.cor.2011.12.019
Henn, S., Koch, S., Doerner, K., Strauss, C., & Wäscher, G. (2010). Metaheuristics for the order batching problem in manual order picking systems. *Business Research*, *3*(1), 82–105. https://doi.org/10.1007/BF03342717
Henn, S., Koch, S., Gerking, H., & Wäscher, G. (2013). A U-shaped layout for manual order-picking systems. *Logistics Research*, *6*(4), 245–261. https://doi.org/10.1007/s12159-013-0104-6
Henn, S., Koch, S., & Wäscher, G. (2012). Order batching in order picking warehouses: A survey of solution approaches. *TUT Press*. https://doi.org/10.1007/978-1-4471-2274-6_6
Henn, S., & Schmid, V. (2013). Metaheuristics for order batching and sequencing in manual order picking systems. *Computers & Industrial Engineering*, *66*(2), 338–351. https://doi.org/10.1016/j.cie.2013.07.003
Henn, S., & Wäscher, G. (2012). Tabu search heuristics for the order batching problem in manual order picking systems. *European Journal of Operational Research*, *222*(3), 484–494. https://doi.org/10.1016/j.ejor.2012.05.049
Heßler, K., & Irnich, S. (2022). A note on the linearity of Ratliff and Rosenthal's algorithm for optimal picker routing. *Operations Research Letters*, *50*(2), 155–159. https://doi.org/10.1016/j.orl.2022.01.014
Ho, Y. -C., & Lin, J. -W. (2017). Improving order-picking performance by converting a sequential zone-picking line into a zone-picking network. *Computers & Industrial Engineering*, *113*, 241–255. https://doi.org/10.1016/j.cie.2017.09.014
Hong, S. (2018). The effects of picker-oriented operational factors on hand-off delay in a bucket brigade order picking system. *OR Spectrum*, *40*(3), 781–808. https://doi.org/10.1007/s00291-018-0523-5
Hong, S. (2019). A performance evaluation of bucket brigade order picking systems: Analytical and simulation approaches. *Computers & Industrial Engineering*, *135*, 120–131. https://doi.org/10.1016/j.cie.2019.05.037

Hong, S., Johnson, A., & Peters, B. (2012). Batch picking in narrow-aisle order picking systems with consideration for picker blocking. *European Journal of Operational Research*, *221*(3), 557–570. https://doi.org/10.1016/j.ejor.2012.03.045
Hong, S., Johnson, A., & Peters, B. (2013). A note on picker blocking models in a parallel-aisle order picking system. *IIE Transactions (Institute of Industrial Engineers)*, *45*(12), 1345–1355. https://doi.org/10.1080/0740817X.2012.745204
Hong, S., Johnson, A., & Peters, B. (2015). Quantifying picker blocking in a bucket brigade order picking system. *International Journal of Production Economics*, *170*, 862–873. https://doi.org/10.1016/j.ijpe.2015.04.012
Hong, S., Johnson, A., & Peters, B. (2016). Order batching in a bucket brigade order picking system considering picker blocking. *Flexible Services and Manufacturing Journal*, *28*(3), 425–441. https://doi.org/10.1007/s10696-015-9223-5
Hong, S., & Kim, Y. (2017). A route-selecting order batching model with the S-shape routes in a parallel-aisle order picking system. *European Journal of Operational Research*, *257*(1), 185–196. https://doi.org/10.1016/j.ejor.2016.07.017
Hong, S., & Kim, Y. (2018). The effects of loosely coupled hand-off operations on bucket brigade order picking systems. *Industrial Engineering and Management Systems*, *17*(4), 745–756. https://doi.org/10.7232/iems.2018.17.4.745
Hossein Nia Shavaki, F., & Jolai, F. (2020). A rule-based heuristic algorithm for joint order batching and delivery planning of online retailers with multiple order pickers. *Applied Intelligence*, *51*(6), 3917–3935. https://doi.org/10.1007/s10489-020-01843-9
Ho, Y. -C., Su, T. -S., & Shi, Z. -B. (2008). Order-batching methods for an order-picking warehouse with two cross aisles. *Computers & Industrial Engineering*, *55*(2), 321–347. https://doi.org/10.1016/j.cie.2007.12.018
Ho, Y. -C., & Tseng, Y. -Y. (2006). A study on order-batching methods of order-picking in a distribution centre with two cross-aisles. *International Journal of Production Research*, *44*(17), 3391–3417. https://doi.org/10.1080/00207540600558015
Hou, J., Yang, X., Chen, C., & Glanzel, W. (2020). Measuring researchers' potential scholarly impact with structural variations: Four types of researchers in information science (1979–2018). *Plos One*, *15*(6), e0234347. https://doi.org/10.1371/journal.pone.0234347
Hsieh, L. -F., & Huang, Y. -C. (2011). New batch construction heuristics to optimise the performance of order picking systems. *International Journal of Production Economics*, *131*(2), 618–630. https://doi.org/10.1016/j.ijpe.2011.02.006
Huang, M., Guo, Q., Liu, J., & Huang, X. (2018). Mixed model assembly line scheduling approach to order picking problem in online supermarkets. *Sustainability*, *10*(11), 3931. https://doi.org/10.3390/su10113931
Hu, K. -Y., Chang, T. -H., Fu, H. -P., & Yeh, H. (2009). Improvement order picking in mobile storage systems with a middle cross aisle. *International Journal of Production Research*, *47*(4), 1089–1104. https://doi.org/10.1080/00207540801905452
Hulett, M., & Damodaran, P. (2019). Analytical approximations to predict order picking times at a warehouse. *International Journal of Industrial and Systems Engineering*, *33*(2), 141–161. https://doi.org/10.1504/IJISE.2019.102468
Hwang, H., Oh, Y. H., & Cha, C. N. (2003). A stock location rule for a low level picker-to-part system. *Engineering Optimization*, *35*(3), 285–295. https://doi.org/10.1080/0305215031000136172
Ioannidis, J., Boyack, K., & Wouters, P. (2016). Citation Metrics: A primer on how (not) to normalize. *PLoS Biology*, *14*(9), e1002542. https://doi.org/10.1371/journal.pbio.1002542
Isler, C., Righetto, G., & Morabito, R. (2016). Optimizing the order picking of a scholar and office supplies warehouse. *International Journal of Advanced Manufacturing Technology*, *87*(5–8), 2327–2336. https://doi.org/10.1007/s00170-016-8625-1
Jaghbeer, Y., Hanson, R., & Johansson, M. (2020). Automated order picking systems and the links between design and performance: A systematic literature review. *International Journal of Production Research*, *58*(15), 1–17. https://doi.org/10.1080/00207543.2020.1788734

Jarvis, J. M., & McDowell, E. D. (1991). Optimal Product Layout in an Order Picking Warehouse. *IIE Transactions*, *23*, 93–102. https://doi.org/10.1080/07408179108963844

Jharkharia, S., & Das, C. (2019). Vehicle routing analyses with integrated order picking and delivery problem under carbon cap and trade policy. *Management Research Review*, *43*(2), 223–243. https://doi.org/10.1108/MRR-01-2019-0013

Jiang, W., Liu, J., Dong, Y., & Wang, L. (2020). Assignment of duplicate storage locations in distribution centres to minimise walking distance in order picking. *International Journal of Production Research*, *59*(15), 4457–4471. https://doi.org/10.1080/00207543.2020.1766714

Kajiwara, Y., Shimauchi, T., & Kimura, H. (2019). Predicting emotion and engagement of workers in order picking based on behavior and pulse waves acquired by wearable devices. *Sensors*, *19*(1), 165. https://doi.org/10.3390/s19010165

Kang, C. (2021). An order picking algorithm for vertically stacked and top-retrieval storage systems. *ICIC Express Letters*, *15*(9), 991–997. https://doi.org/10.24507/icicel.15.09.991

Kašparová, P., & Dyntar, J. (2021). Effective designing of order picking systems using dynamic simulation. *Acta Informatica Pragensia*, *10*(1), 108–120. https://doi.org/10.18267/J.AIP.149

Keshavarz, A., Jaafari, D., Khalaj, M., & Dokouhaki, P. (2021). A survey of the literature on order-picking systems by combining planning problems. *Applied Sciences*, *11*(22), 10641. https://doi.org/10.3390/app112210641

Keung, K., Lee, C., & Ji, P. (2022). Industrial internet of things-driven storage location assignment and order picking in a resource synchronization and sharing-based robotic mobile fulfillment system. *Advanced Engineering Informatics*, *52*, 101540. https://doi.org/10.1016/j.aei.2022.101540

Khachatryan, M., & McGinnis, L. (2014). Picker travel time model for an order picking system with buffers. *IIE Transactions (Institute of Industrial Engineers)*, *46*(9), 894–904. https://doi.org/10.1080/0740817X.2013.823001

Khojasteh-Ghamari, Y., & Son, J. -D. (2008). Order picking problem in a multi-aisle automated warehouse served by a single storage/retrieval machine. *International Journal of Information and Management Sciences*, *19*(4), 651–665.

Khojasteh, Y., & Son, J. -D. (2016). A travel time model for order picking systems in automated warehouses. *International Journal of Advanced Manufacturing Technology*, *86*(5–8), 2219–2229. https://doi.org/10.1007/s00170-016-8340-y

Kim, S., Nussbaum, M., & Gabbard, J. (2019). Influences of augmented reality head-worn display type and user interface design on performance and usability in simulated warehouse order picking. *Applied Ergonomics*, *74*, 186–193. https://doi.org/10.1016/j.apergo.2018.08.026

Klein-Theyer, A., Horwath-Winter, J., Rabensteiner, D., Schwantzer, G., Wultsch, G., Aminfar, H., Boldin, I. (2016). The impact of visual guided order picking on ocular comfort, ocular surface and tear function. *Plos One*, *11*(6), e0157564. https://doi.org/10.1371/journal.pone.0157564

Klodawski, M., Jachimowski, R., Jacyna-Golda, I., & Izdebski, M. (2018). Simulation analysis of order picking efficiency with congestion situations. *International Journal of Simulation Modelling*, *17*(3), 431–443. https://doi.org/10.2507/IJSIMM17(3)438

Klumpp, M., & Loske, D. (2021). Order picking and e-commerce: Introducing non-parametric efficiency measurement for sustainable retail logistics. *Journal of Theoretical and Applied Electronic Commerce Research*, *16*(4), 846–858. https://doi.org/10.3390/jtaer16040048

Koo, P. -H. (2009). The use of bucket brigades in zone order picking systems. *OR Spectrum*, *31*(4), 759–774. https://doi.org/10.1007/s00291-008-0131-x

Kostrzewski, M. (2020). Sensitivity analysis of selected parameters in the order picking process simulation model, with randomly generated orders. *Entropy*, *22*(4), 423. https://doi.org/10.3390/E22040423

Kostrzewski, M., Gnap, J., Varjan, P., & Likos, M. (2020). Application of simulation methods for study on availability of one-aisle machine order picking process. *Communications - Scientific Letters of the University of Zilina*, *22*(2), 107–114. https://doi.org/10.26552/com.C.2020.2.107-114

Kovac, M., & Djurdjevic, D. (2020). Optimization of order-picking systems through tactical and operational decision making. *International Journal of Simulation Modelling*, *19*(1), 89–99. https://doi.org/10.2507/IJSIMM19-1-505

Kübler, P., Glock, C., & Bauernhansl, T. (2020). A new iterative method for solving the joint dynamic storage location assignment, order batching and picker routing problem in manual picker-to-parts warehouses. *Computers & Industrial Engineering*, *147*, 147. https://doi.org/10.1016/j.cie.2020.106645

Kulak, O., Sahin, Y., & Taner, M. (2012). Joint order batching and picker routing in single and multiple-cross-aisle warehouses using cluster-based tabu search algorithms. *Flexible Services and Manufacturing Journal*, *24*(1), 52–80. https://doi.org/10.1007/s10696-011-9101-8

Kuo, R., Kuo, P., Chen, Y., & Zulvia, F. (2016). Application of metaheuristics-based clustering algorithm to item assignment in a synchronized zone order picking system. *Applied Soft Computing Journal*, *46*, 143–150. https://doi.org/10.1016/j.asoc.2016.03.012

Lam, C., Choy, K., Ho, G., & Lee, C. (2014). An order-picking operations system for managing the batching activities in a warehouse. *International Journal of Systems Science*, *45*(6), 1283–1295. https://doi.org/10.1080/00207721.2012.761461

Latif, U., & Shin, S. (2020). OP-MR: The implementation of order picking based on mixed reality in a smart warehouse. *The Visual Computer*, *36*(7), 1491–1500. https://doi.org/10.1007/s00371-019-01745-z

Le Duc, T., & de Koster, R. (2007). Travel time estimation and order batching in a 2-block warehouse. *European Journal of Operational Research*, *176*(1), 374–388. https://doi.org/10.1016/j.ejor.2005.03.052

Lee, S., & Bozeman, B. (2005). The impact of research collaboration on scientific productivity. *Social Studies of Science*, *35*(5), 673–702. https://doi.org/10.1177/0306312705052359

Lee, J., Chang, Y., & Karwowski, W. (2020). Assessment of working postures and physical loading in advanced order picking tasks: A case study of human interaction with automated warehouse goods-to-picker systems. *Work*, *67*(4), 855–866. https://doi.org/10.3233/WOR-203337

Lee, I., Chung, S., & Yoon, S. (2020). Two-stage storage assignment to minimize travel time and congestion for warehouse order picking operations. *Computers & Industrial Engineering*, *139*, 139. https://doi.org/10.1016/j.cie.2019.106129

Lee, S. -D., & Kuo, Y. -C. (2008). Exact and inexact solution procedures for the order picking in an automated carousal conveyor. *International Journal of Production Research*, *46*(16), 4619–4636. https://doi.org/10.1080/00207540601166990

Lee, H. -Y., & Murray, C. (2019). Robotics in order picking: Evaluating warehouse layouts for pick, place, and transport vehicle routing systems. *International Journal of Production Research*, *57*(18), 5821–5841. https://doi.org/10.1080/00207543.2018.1552031

Lenoble, N., Hammami, R., & Frein, Y. (2020). Fixed and rolling batching for order picking from multiple carousels. *Production Planning & Control*, *32*(8), 652–669. https://doi.org/10.1080/09537287.2020.1751326

Liao, Y., Deschamps, F., Loures, E., & Ramos, L. (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research*, *55*(12), 3609–3629. https://doi.org/10.1080/00207543.2017.1308576

Li, J., Huang, R., & Dai, J. (2017). Joint optimisation of order batching and picker routing in the online retailer's warehouse in China. *International Journal of Production Research*, *55*(2), 447–461. https://doi.org/10.1080/00207543.2016.1187313

Li, Y., Méndez-Mediavilla, F., Temponi, C., Kim, J., & Jimenez, J. (2021). A heuristic storage location assignment based on frequent itemset classes to improve order picking operations. *Applied Sciences*, *11*(4), 1–15. https://doi.org/10.3390/app11041839

Lind, C., Yang, L., Abtahi, F., Hanson, L., Lindecrantz, K., Lu, K., Eklund, J. (2020). Reducing postural load in order picking through a smart workwear system using real-time vibrotactile feedback. *Applied Ergonomics*, *89*, 89. https://doi.org/10.1016/j.apergo.2020.103188

Litvak, N., & Vlasiou, M. (2010). A survey on performance analysis of warehouse carousel systems. *Statistica Neerlandica*, *64*(4), 401–447. https://doi.org/10.1111/j.1467-9574.2010.00454.x

Liu, P., Wu, Y., Zhou, C., & Xu, N. (2011). Fluid-based slotting optimization for automated order picking system with multiple dispenser types. *Chinese Journal of Mechanical Engineering*, *24*(4), 529–538. https://doi.org/10.3901/CJME.2011.04.529

Li, K., & Yan, E. (2019). Are NIH-funded publications fulfilling the proposed research? An examination of concept-matchedness between NIH research grants and their supported publications. *Journal of Informetrics*, *13*(1), 226–237. https://doi.org/10.1016/j.joi.2019.01.001

Lodree, E., Jr., Geiger, C., & Jiang, X. (2009). Taxonomy for integrating scheduling theory and human factors: Review and research opportunities. *International Journal of Industrial Ergonomics*, *39*(1), 39–51. https://doi.org/10.1016/j.ergon.2008.05.001

Löffler, M., Boysen, N., & Schneider, M. (2022). Picker Routing in AGV-Assisted Order Picking Systems. *INFORMS Journal on Computing*, *34*(1), 440–462. https://doi.org/10.1287/ijoc.2021.1060

Lolli, F., Lodi, F., Giberti, C., Coruzzolo, A., Marinello, S., & Gul, M. (2022). Order picking systems: a queue model for dimensioning the storage capacity, the crew of pickers, and the AGV Fleet. *Mathematical Problems in Engineering*, *2022*, 1–15. https://doi.org/10.1155/2022/6318659

Lorenc, A., & Burinskiene, A. (2021). Improve the orders picking in eCommerce by using WMS data and BigData analysis. *FME Transactions*, *49*(1), 233–243. https://doi.org/10.5937/FME2101233L

Loske, D. (2022). Empirical evidence on human learning and work characteristics in the transition to automated order picking. *Journal of Business Logistics*, *43*(3), 302–342. https://doi.org/10.1111/jbl.12300

Lu, W., McFarlane, D., Giannikas, V., & Zhang, Q. (2016). An algorithm for dynamic order-picking in warehouse operations. *European Journal of Operational Research*, *248*(1), 107–122. https://doi.org/10.1016/j.ejor.2015.06.074

Madani, A., Batta, R., & Karwan, M. (2020). The balancing traveling salesman problem: Application to warehouse order picking. *TOP*, *29*(2), 442–469. https://doi.org/10.1007/s11750-020-00557-y

Maestrini, V., Luzzini, D., Maccarrone, P., & Caniato, F. (2017). Supply chain performance measurement systems: A systematic review and research agenda. *International Journal of Production Economics*, *183*, 299–315. https://doi.org/10.1016/j.ijpe.2016.11.005

Manzini, R., Accorsi, R., Baruffaldi, G., Santi, D. T., & Tufano, A. (2019). Performance assessment in order picking systems: A visual double cross-analysis. *International Journal of Advanced Manufacturing Technology*, *101*(5–8), 1927–1938. https://doi.org/10.1007/s00170-018-2967-9

Manzini, R., Accorsi, R., Gamberi, M., & Penazzi, S. (2015). Modeling class-based storage assignment over life cycle picking patterns. *International Journal of Production Economics*, *170*, 790–800. https://doi.org/10.1016/j.ijpe.2015.06.026

Manzini, R., Gamberi, M., Persona, A., & Regattieri, A. (2007). Design of a class based storage picker to product order picking system. *International Journal of Advanced Manufacturing Technology*, *32*(7–8), 811–821. https://doi.org/10.1007/s00170-005-0377-2

Marchet, G., Melacini, M., & Perotti, S. (2011). A model for design and performance estimation of pick-and-sort order picking systems. *Journal of Manufacturing Technology Management*, *22*(2), 261–282.

Marchet, G., Melacini, M., & Perotti, S. (2015). Investigating order picking system adoption: A case-study-based approach. *International Journal of Logistics: Research and Applications*, *18*(1), 82–98. https://doi.org/10.1080/13675567.2014.945400

Marzialia, M., Rossit, D., & Toncovicha, A. (2022). Order picking and loading-dock arrival punctuality performance indicators for supply chain management: A case study. *Engineering Management in Production and Services*, *14*(1), 26–37. https://doi.org/10.2478/emj-2022-0003

Masae, M., Glock, C., & Grosse, E. (2020). Order picker routing in warehouses: A systematic literature review. *International Journal of Production Economics*, *224*, 224. https://doi.org/10.1016/j.ijpe.2019.107564

Masae, M., Glock, C., & Vichitkunakorn, P. (2020a). Optimal order picker routing in a conventional warehouse with two blocks and arbitrary starting and ending points of a tour.

*International Journal of Production Research*, *58*(17), 5337–5358. https://doi.org/10.1080/00207543.2020.1724342

Masae, M., Glock, C., & Vichitkunakorn, P. (2020b). Optimal order picker routing in the Chevron warehouse. *IISE Transactions*, *52*(6), 665–687. https://doi.org/10.1080/24725854.2019.1660833

Masae, M., Glock, C., & Vichitkunakorn, P. (2021). A method for efficiently routing order pickers in the leaf warehouse. *International Journal of Production Economics*, *234*, 108069. https://doi.org/10.1016/j.ijpe.2021.108069

Mejri, E., Kelouwani, S., Dube, Y., Henao, N., & Agbossou, K. (2022). Energy efficient order picking routing for a pick support automated guided vehicle (Ps-AGV). *IEEE Access*, *10*, 108832–108847. https://doi.org/10.1109/ACCESS.2022.3212797

Melacini, M., Perotti, S., & Tumino, A. (2011). Development of a framework for pick-and-pass order picking system design. *International Journal of Advanced Manufacturing Technology*, *53*(9–12), 841–854. https://doi.org/10.1007/s00170-010-2881-2

Miguel, F., Frutos, M., Méndez, M., & Tohmé, F. (2022). Order batching and order picking with 3D positioning of the articles: Solution through a hybrid evolutionary algorithm. *Mathematical Biosciences and Engineering*, *19*(6), 5546–5563. https://doi.org/10.3934/mbe.2022259

Mirzaei, M., Zaerpour, N., & de Koster, R. (2021). The impact of integrated cluster-based storage allocation on parts-to-picker warehouse performance, Transportation Research Part E. *The Logistics and Transportation Review*, *146*.

Mohring, U., Baumann, M., & Furmans, K. (2020). Discrete-time analysis of levelled order release and staffing in order picking systems. *Logistics Research*, *13*(1), 1–20. https://doi.org/10.23773/2020_9

Moons, S., Braekers, K., Ramaekers, K., Caris, A., & Arda, Y. (2019). The value of integrating order picking and vehicle routing decisions in a B2C e-commerce environment. *International Journal of Production Research*, *57*(20), 6405–6423. https://doi.org/10.1080/00207543.2019.1566668

Moons, S., Ramaekers, K., Caris, A., & Arda, Y. (2018). Integration of order picking and vehicle routing in a B2C e-commerce context. *Flexible Services and Manufacturing Journal*, *30*(4), 813–843. https://doi.org/10.1007/s10696-017-9287-5

Mou, S. (2022). Integrated order picking and multi-skilled picker scheduling in omni-channel retail stores. *Mathematics*, *10*(9), 1484. https://doi.org/10.3390/math10091484

Mowrey, C., & Parikh, P. (2014). Mixed-width aisle configurations for order picking in distribution centers. *European Journal of Operational Research*, *232*(1), 87–97. https://doi.org/10.1016/j.ejor.2013.07.002

Muter, İ., & Öncan, T. (2022). Order batching and picker scheduling in warehouse order picking. *IISE Transactions*, *54*(5), 435–447. https://doi.org/10.1080/24725854.2021.1925178

Nagda, M., Sinha, S., & Poovammal, E. (2019). An augmented reality assisted order picking system using IoT. *International Journal of Recent Technology and Engineering*, *8*(3), 744–749. https://doi.org/10.35940/ijrte.C3991.098319

Oh, S. -C., Min, H., & Ahn, Y. -H. (2021). A comparative analysis of discrete and batch picking and the identification of factors influencing order picking efficiency. *International Journal of Industrial Engineering: Theory Applications and Practice*, *28*(3), 354–368.

Oláh, J., Lakner, Z., & Popp, J. (2020). An integrated approach to order picking systems in warehouses. *International Journal of Logistics Systems and Management*, *35*(1), 50–71. https://doi.org/10.1504/IJLSM.2020.103867

Ozden, S., Smith, A., & Gue, K. (2021a). A computational software system to design order picking warehouses. *Computers & Operations Research*, *132*, 105311. https://doi.org/10.1016/j.cor.2021.105311

Ozden, S., Smith, A., & Gue, K. (2021b). A novel approach for modeling order picking paths. *Naval Research Logistics*, *68*(4), 471–484. https://doi.org/10.1002/nav.21966

Öztürkoglu, Ö., & Hoser, D. (2019). An evaluation of order-picking tour efficiency in two-block warehouses. *Operations and Supply Chain Management*, *12*(2), 74–87. https://doi.org/10.31387/oscm0370225

Öztürkoğlu, Ö., & Hoser, D. (2019). A discrete cross aisle design model for order-picking warehouses. *European Journal of Operational Research*, *275*(2), 411–430. https://doi.org/10.1016/j.ejor.2018.11.037
Palmarini, R., Erkoyuncu, J., Roy, R. T., & Torabmostaedi, H. (2018). A systematic review of augmented reality applications in maintenance. *Robotics and Computer-Integrated Manufacturing*, *49*, 215–228. https://doi.org/10.1016/j.rcim.2017.06.002
Pansart, L., Catusse, N., & Cambazard, H. (2018). Exact algorithms for the order picking problem. *Computers & Operations Research*, *100*, 117–127. https://doi.org/10.1016/j.cor.2018.07.002
Pan, J. -H., Shih, P. -H., & Wu, M. -H. (2012). Storage assignment problem with travel distance and blocking considerations for a picker-to-part order picking system. *Computers & Industrial Engineering*, *62*(2), 527–535. https://doi.org/10.1016/j.cie.2011.11.001
Pan, J. -H., & Wu, M. -H. (2009). A study of storage assignment problem for an order picking line in a pick-and-pass warehousing system. *Computers & Industrial Engineering*, *57*(1), 261–268. https://doi.org/10.1016/j.cie.2008.11.026
Pan, J. -H., & Wu, M. -H. (2012). Throughput analysis for order picking system with multiple pickers and aisle congestion considerations. *Computers & Operations Research*, *39*(7), 1661–1672. https://doi.org/10.1016/j.cor.2011.09.022
Parikh, P., & Meller, R. (2008). Selecting between batch and zone order picking strategies in a distribution center. *Transportation Research Part E: Logistics and Transportation Review*, *44*(5), 696–719. https://doi.org/10.1016/j.tre.2007.03.002
Parikh, P., & Meller, R. (2009). Estimating picker blocking in wide-aisle order picking system. *IIE Transactions (Institute of Industrial Engineers)*, *41*(3), 232–246. https://doi.org/10.1080/07408170802108518
Parikh, P., & Meller, R. (2010a). A note on worker blocking in narrow-aisle order picking systems when pick time is non-deterministic. *IIE Transactions (Institute of Industrial Engineers)*, *42*(6), 392–404. https://doi.org/10.1080/07408170903171043
Parikh, P., & Meller, R. (2010b). A travel-time model for a person-onboard order picking system. *European Journal of Operational Research*, *200*(2), 385–394. https://doi.org/10.1016/j.ejor.2008.12.031
Petersen, C., II. (1997). An evaluation of order picking routing policies. *International Journal of Operations & Production Management*, *17*(11), 1098–1111. https://doi.org/10.1108/01443579710177860
Petersen, C., & Aase, G. (2004). A comparison of picking, storage, and routing policies in manual order picking. *International Journal of Production Economics*, *92*(1), 11–19. https://doi.org/10.1016/j.ijpe.2003.09.006
Petersen, C., II, & Schmenner, R. (1999). An evaluation of routing and volume-based storage policies in an order picking operation. *Decision Sciences*, *30*(2), 481–501. https://doi.org/10.1111/j.1540-5915.1999.tb01619.x
Poon, T., Choy, K., Chow, H., Lau, H., Chan, F., & Ho, K. (2009). A RFID case-based logistics resource management system for managing order-picking operations in warehouses. *Expert Systems with Applications*, *36*(4), 8277–8301. https://doi.org/10.1016/j.eswa.2008.10.011
Pugliese, G., Chou, X., Loske, D., Klumpp, M., & Montemanni, R. (2022). AMR-assisted order picking: models for picker-to-parts systems in a two-blocks warehouse. *Algorithms*, *15*(11), 413. https://doi.org/10.3390/a15110413
Purba, H.H., Mukhlisin, & Aisyah, S. (2018). Productivity improvement picking order by appropriate method, value stream mapping analysis, and storage design: A case study in automotive part center. *Management and Production Engineering Review*, *9*(1), 71–81. https://doi.org/10.24425/119402
Quader, S., & Castillo-Villar, K. (2018). Design of an enhanced multi-aisle order-picking system considering storage assignments and routing heuristics. *Robotics and Computer-Integrated Manufacturing*, *50*, 13–29. https://doi.org/10.1016/j.rcim.2015.12.009
Ramaekers, K., Caris, A., Moons, S., & van Gils, T. (2018). Using an integrated order picking-vehicle routing problem to study the impact of delivery time windows in e-commerce. *European Transport Research Review*, *10*(2). https://doi.org/10.1186/s12544-018-0333-5

Rammelmeier, T., Galka, S., & Günthner, W. (2012). Error prevention in manual order picking [fehlervermeidung in der kommissionierung]. *Logistics Journal*, *2012*, 1–8. https://doi.org/10.2195/lj_Proc_rammelmeier_de_201210_01
Ran, W., Liu, S., & Zhang, Z. (2020). A polling-based dynamic order-picking system considering priority orders. *Complexity*, *2020*, 1–15. https://doi.org/10.1155/2020/4595316
Rao, S., & Adil, G. (2013). Optimal class boundaries, number of aisles, and pick list size for low-level order picking systems. *IIE Transactions (Institute of Industrial Engineers)*, *45*(12), 1309–1321. https://doi.org/10.1080/0740817X.2013.772691
Rasmi, S., Wang, Y., & Charkhgard, H. (2022). Wave order picking under the mixed-shelves storage strategy: A solution method and advantages. *Computers & Operations Research*, *137*, 105556. https://doi.org/10.1016/j.cor.2021.105556
Redmer, A. (2020). Analysis of the length of order-picking paths determined using the S–shape method. *Logforum*, *16*(1), 33–46. https://doi.org/10.17270/J.LOG.2020.379
Reif, R., & Günthner, W. (2009). Pick-by-vision: Augmented reality supported order picking. *The Visual Computer*, *25*(5–7), 461–467. https://doi.org/10.1007/s00371-009-0348-y
Renaud, J., & Ruiz, A. (2008). Improving product location and order picking activities in a distribution centre. *The Journal of the Operational Research Society*, *59*(12), 1603–1613. https://doi.org/10.1057/palgrave.jors.2602514
Revillot-Narváez, D., Pérez-Galarce, F., & Álvarez-Miranda, E. (2020). Optimising the storage assignment and order-picking for the compact drive-in storage system. *International Journal of Production Research*, *58*(22), 6949–6969. https://doi.org/10.1080/00207543.2019.1687951
Reyes, J. J. R., Solano-Charris, E. L., & Montoya-Torres, J. R. (2019). The storage location assignment problem: A literature review. *International Journal of Industrial Engineering Computations*, *10*(2), 199–224. https://doi.org/10.5267/j.ijiec.2018.8.001
Rijal, A., Bijvank, M., Goel, A., & de Koster, R. (2021). Workforce scheduling with order-picking assignments in distribution facilities. *Transportation Science*, *55*(3), 725–746. https://doi.org/10.1287/trsc.2020.1029
Rim, S. -C., & Park, I. -S. (2008). Order picking plan to maximize the order fill rate. *Computers & Industrial Engineering*, *55*(3), 557–566. https://doi.org/10.1016/j.cie.2008.01.012
Rojanapitoon, T., & Teeravaraprug, J. (2018). A computer simulation for economical order picker routing when considering travel distance and vehicle energy consumption. *International Journal of Engineering and Technology (UAE)*, *7*(2), 33–37. https://doi.org/10.14419/ijet.v7i2.28.12878
Roodbergen, K., Sharp, G., & Vis, I. (2008). Designing the layout structure of manual order picking areas in warehouses. *IIE Transactions (Institute of Industrial Engineers)*, *40*(11), 1032–1045. https://doi.org/10.1080/07408170802167639
Roodbergen, K., & Vis, I. (2006). A model for warehouse layout. *IIE Transactions (Institute of Industrial Engineers)*, *38*(10), 799–811. https://doi.org/10.1080/07408170500494566
Sankalp, S., Mayank, K., & Poovammal, E. (2019). Order picking: A survey of methods and problems. *International Journal of Psychosocial Rehabilitation*, *24*(1), 1876–1885. https://doi.org/10.37200/IJPR/V24I1/PR200290
Saylam, S., Çelik, M., & Süral, H. (2022). The min–max order picking problem in synchronised dynamic zone-picking systems. *International Journal of Production Research*, *61*(7), 2086–2104. https://doi.org/10.1080/00207543.2022.2058433
Schenone, M., Mangano, G., Grimaldi, S., & Cagliano, A. C. (2020). An approach for computing AS/R systems travel times in a class-based storage configuration. *Production and Manufacturing Research*, *8*(1), 273–290. https://doi.org/10.1080/21693277.2020.1781703
Scholz, A., Henn, S., Stuhlmann, M., & Wäscher, G. (2016). A new mathematical programming formulation for the single-picker routing problem. *European Journal of Operational Research*, *253*(1), 68–84. https://doi.org/10.1016/j.ejor.2016.02.018
Scholz, A., Schubert, D., & Wäscher, G. (2017). Order picking with multiple pickers and due dates – Simultaneous solution of order batching, batch assignment and sequencing, and picker routing problems. *European Journal of Operational Research*, *263*(2), 461–478. https://doi.org/10.1016/j.ejor.2017.04.038

Scholz, A., & Wäscher, G. (2017). Order batching and picker routing in manual order picking systems: The benefits of integrated routing. *Central European Journal of Operations Research*, *25*(2), 491–520. https://doi.org/10.1007/s10100-017-0467-x

Schrotenboer, A., Wruck, S., Roodbergen, K., Veenstra, M., & Dijkstra, A. (2017). Order picker routing with product returns and interaction delays. *International Journal of Production Research*, *55*(21), 6394–6406. https://doi.org/10.1080/00207543.2016.1206982

Schubert, D., Kuhn, H., & Holzapfel, A. (2021). Same-day deliveries in omnichannel retail: Integrated order picking and vehicle routing with vehicle-site dependencies. *Naval Research Logistics*, *68*(6), 721–744. https://doi.org/10.1002/nav.21954

Schubert, D., Scholz, A., & Wäscher, G. (2018). Integrated order picking and vehicle routing with due dates. *OR Spectrum*, *40*(4), 1109–1139. https://doi.org/10.1007/s00291-018-0517-3

Schwerdfeger, S., & Boysen, N. (2017). Order picking along a crane-supplied pick face: The SKU switching problem. *European Journal of Operational Research*, *260*(2), 534–545. https://doi.org/10.1016/j.ejor.2016.12.037

Seuring, S., Müller, M., Westhaus, M., & Morana, R. (2005). Conducting a Literature Review — the Example of Sustainability in Supply Chains. *Research Methodologies in Supply Chain Management*, 91–106. https://doi.org/10.1007/3-7908-1636-1_7

Sgarbossa, F., Calzavara, M., & Persona, A. (2019). Throughput models for a dual-bay VLM order picking system under different configurations. *Industrial Management and Data Systems*, *119*(6), 1268–1288. https://doi.org/10.1108/IMDS-11-2018-0518

Sgarbossa, F., Glock, C., Grosse, E., Calzavara, M., & de Koster, R. (2022). The impact of monetary incentives and regulatory focus on worker productivity and learning in order picking. *International Journal of Operations & Production Management*, *42*(11), 1793–1816. https://doi.org/10.1108/IJOPM-11-2021-0730

Shekari Ashgzari, M., & Gue, K. (2021). A puzzle-based material handling system for order picking. *International Transactions in Operational Research*, *28*(4), 1821–1846. https://doi.org/10.1111/itor.12886

Shen, C., Wu, Y., & Zhou, C. (2011). Selecting between sequential zoning and simultaneous zoning for picker-to-parts order picking system based on order cluster and genetic algorithm. *Chinese Journal of Mechanical Engineering*, *24*(5), 820–828. https://doi.org/10.3901/CJME.2011.05.820

Shetty, N., Sah, B., & Chung, S. (2020). Route optimization for warehouse order picking operations via vehicle routing and simulation. *SN Applied Sciences*, *2*(2). https://doi.org/10.1007/s42452-020-2076-x

Shiau, J. -Y., Huang, M. -K., Chou, S. -W., & Liao, T. -C. (2021). A delivery oriented order picking policy with batching for a randomised storage warehouse. *International Journal of Logistics Systems and Management*, *40*(4), 443–465. https://doi.org/10.1504/IJLSM.2021.120490

Shouman, M., Khater, M., & Boushaala, A. (2007). Comparisons of order picking routing methods for warehouses with multiple cross aisles. *AEJ - Alexandria Engineering Journal*, *46*(3), 261–272.

Silva, A., Coelho, L., Darvish, M., & Renaud, J. (2020). Integrating storage location and order picking problems in warehouse planning. *Transportation Research Part E: Logistics and Transportation Review*, *140*, 140. https://doi.org/10.1016/j.tre.2020.102003

Soyaslan, M., Kozkurt, C., & Fenercioglu, A. (2017). A new truck based order picking model for automated storage and retrieval system (AS/RS). *Journal of Engineering Research*, *5*(4), 169–194.

Srinivas, S., & Yu, S. (2022). Collaborative order picking with multiple pickers and robots: Integrated approach for order batching, sequencing and picker-robot routing. *International Journal of Production Economics*, *254*, 108634. https://doi.org/10.1016/j.ijpe.2022.108634

Stinson, M., & Wehking, K. -H. (2012). Performance assessment and optimization in manual order picking [Leistungsbewertung und -optimierung in der manuellen kommissionierung]. *Logistics Journal*, *2012*, 1–7. https://doi.org/10.2195/lj_Proc_stinson_de_201210_01

Stinson, M., & Wehking, K. -H. (2016). Experimental analysis of manual order picking processes in a learning warehouse [Experimentelle analyse von manuellen kommissionierprozessen im lernlager]. *Logistics Journal*, *2016*. https://doi.org/10.2195/lj_Proc_stinson_en_201610_01

Su, T. -S., & Hwang, M. -H. (2017). An efficient order-picking route planning based on a fuzzy set method with a multiple-aisle in a distribution center. *Procedia Manufacturing*, *11*, 1856–1862. https://doi.org/10.1016/j.promfg.2017.07.323

Su, Y., Li, M., Zhu, X., & Li, C. (2022). Steiner TSP based on aisle as a unit for order picking. *Computers & Industrial Engineering*, *168*, 108026. https://doi.org/10.1016/j.cie.2022.108026

Sundram, V., Ibrahim, I., Esa, M., & Azly, N. (2019). The issues in order picking and packaging in a leading pharmaceutical company in Malaysia. *International Journal of Supply Chain Management*, *8*(6), 1055–1061.

Tajima, E., Suzuki, M., Ishigaki, A., Hamada, M., & Kawai, W. (2020). Effect of picker congestion on travel time in an order picking operation. *Journal of Advanced Mechanical Design, Systems and Manufacturing*, *14*(5). https://doi.org/10.1299/jamdsm.2020jamdsm0072

Taljanovic, K., & Salihbegovic, A. (2010). New strategies in the order picking process. *Journal of Computational Methods in Sciences and Engineering*, *10*(s2), 163–175. https://doi.org/10.3233/JCM-2010-0276

Tappia, E., Roy, D., Melacini, M., & de Koster, R. (2019). Integrated storage-order picking systems: Technology, performance models, and design insights. *European Journal of Operational Research*, *274*(3), 947–965. https://doi.org/10.1016/j.ejor.2018.10.048

Theys, C., Bräysy, O., Dullaert, W., & Raa, B. (2010). Using a TSP heuristic for routing order pickers in warehouses. *European Journal of Operational Research*, *200*(3), 755–763. https://doi.org/10.1016/j.ejor.2009.01.036

Trindade, M., Sousa, P., & Moreira, M. (2021a). Defining a storage-assignment strategy for precedence-constrained order picking. *Operations Research and Decisions*, *31*(2), 147–160. https://doi.org/10.37190/ord210207

Trindade, M., Sousa, P., & Moreira, M. (2021b). Improving order-picking operations with precedence constraints through efficient storage location assignment: Evidence from a retail company. *University Porto Journal of Engineering*, *7*(3), 34–52. https://doi.org/10.24840/2183-6493_007.003_0004

Urzúa, M., Mendoza, A., & González, A.O. (2019). Evaluating the impact of order picking strategies on the order fulfilment time: A simulation study. *Acta Logistica*, *6*(4), 103–114. https://doi.org/10.22306/al.v6i4.129

Valle, C., Beasley, J., & da Cunha, A. (2017). Optimally solving the joint order batching and picker routing problem. *European Journal of Operational Research*, *262*(3), 817–834. https://doi.org/10.1016/j.ejor.2017.03.069

Van Der Gaast, J., De Koster, R., Adan, I., & Resing, J. (2020). Capacity analysis of sequential zone picking systems. *Operations Research*, *68*(1), 161–179. https://doi.org/10.1287/OPRE.2019.1885

van der Gaast, J., & Weidinger, F. (2022). A deep learning approach for the selection of an order picking system. *European Journal of Operational Research*, *302*(2), 530–543. https://doi.org/10.1016/j.ejor.2022.01.006

van Gils, T., Caris, A., Ramaekers, K., Braekers, K., & de Koster, R. (2019). Designing efficient order picking systems: The effect of real-life features on the relationship among planning problems. *Transportation Research Part E: Logistics and Transportation Review*, *125*, 47–73. https://doi.org/10.1016/j.tre.2019.02.010

van Gils, T., Ramaekers, K., Braekers, K., Depaire, B., & Caris, A. (2018). Increasing order picking efficiency by integrating storage, batching, zone picking, and routing policy decisions. *International Journal of Production Economics*, *197*, 243–261. https://doi.org/10.1016/j.ijpe.2017.11.021

van Gils, T., Ramaekers, K., Caris, A., & Cools, M. (2017). The use of time series forecasting in zone order picking systems to predict order pickers' workload. *International Journal of Production Research*, *55*(21), 6380–6393. https://doi.org/10.1080/00207543.2016.1216659

van Gils, T., Ramaekers, K., Caris, A., & de Koster, R. (2018). Designing efficient order picking systems by combining planning problems: State-of-the-art classification and review. *European Journal of Operational Research*, *267*(1), 1–15. https://doi.org/10.1016/j.ejor.2017.09.002

Vanheusden, S., van Gils, T., Braekers, K., Ramaekers, K., & Caris, A. (2022). Analysing the effectiveness of workload balancing measures in order picking operations. *International Journal of Production Research*, *60*(7), 2126–2150. https://doi.org/10.1080/00207543.2021.1884307

Vanheusden, S., van Gils, T., Caris, A., Ramaekers, K., & Braekers, K. (2020). Operational workload balancing in manual order picking. *Computers & Industrial Engineering*, *141*, 141. https://doi.org/10.1016/j.cie.2020.106269

Vanheusden, S., van Gils, T., Ramaekers, K., Cornelissens, T., & Caris, A. (2022). Practical factors in order picking planning: State-of-the-art classification and review. *International Journal of Production Research*, *61*(6), 1–25. https://doi.org/10.1080/00207543.2022.2053223

Vazquez-Noguerol, M., Comesaña-Benavides, J., Poler, R., & Prado-Prado, J. (2020). An optimisation approach for the e-grocery order picking and delivery problem. *Central European Journal of Operations Research*, *30*(3), 961–990. https://doi.org/10.1007/s10100-020-00710-9

Vazquez-Noguerol, M., Riveiro-Sanromán, S., Portela-Caramés, I., & Prado-Prado, J. (2022). Analyzing store features for online order picking in grocery retailing: An experimental study. *International Journal of Production Management and Engineering*, *10*(2), 183–193. https://doi.org/10.4995/ijpme.2022.17207

Venkitasubramony, R., & Adil, G. (2017). Design of an order-picking warehouse factoring vertical travel and space sharing. *International Journal of Advanced Manufacturing Technology*, *91*(5–8), 1921–1934. https://doi.org/10.1007/s00170-016-9879-3

Villarreal-Zapata, G., Salais-Fierro, T., & Saucedo-Martínez, J. (2020). Intelligent system for selection of order picking technologies. *Wireless Networks*, *26*(8), 5809–5816. https://doi.org/10.1007/s11276-020-02262-x

Walter, R., Boysen, N., & Scholl, A. (2013). The discrete forward-reserve problem - Allocating space, selecting products, and area sizing in forward order picking. *European Journal of Operational Research*, *229*(3), 585–594. https://doi.org/10.1016/j.ejor.2013.02.047

Wang, X. -Z., Wang, G. -Q., & Li, X. -C. (2013). Order picking optimization in carousels storage system. *Mathematical Problems in Engineering*, *2013*, 1–8. https://doi.org/10.1155/2013/692701

Wang, M., Zhang, R. -Q., & Fan, K. (2020). Improving order-picking operation through efficient storage location assignment: A new approach. *Computers & Industrial Engineering*, *139*, 139. https://doi.org/10.1016/j.cie.2019.106186

Wang, X., Zhang, J., & Shang, H. (2013). A real-time synchronized zone order picking system for balancing pickers' workload. *ICIC Express Letters, Part B: Applications*, *4*(5), 1495–1502.

Wan, Y., & Liu, Y. (2022). Integrating optimized fishbone warehouse layout, storage location assignment and picker routing. *IAENG International Journal of Computer Science*, *49*(3).

Webster, S., Ruben, R., & Yang, K. -K. (2012). Impact of storage assignment decisions on a bucket brigade order picking line. *Production and Operations Management*, *21*(2), 276–290. https://doi.org/10.1111/j.1937-5956.2011.01267.x

Weichert, F., Böckenkamp, A., Prasse, C., Timm, C., Rudak, B., Hölscher, K., & Ten Hompel, M. (2014). Towards sensor-actuator coupling in an automated order picking system by detecting sealed seams on pouch packed goods. *Journal of Sensor and Actuator Networks*, *3*(4), 245–273. https://doi.org/10.3390/jsan3040245

Weidinger, F. (2018). Picker routing in rectangular mixed shelves warehouses. *Computers & Operations Research*, *95*, 139–150. https://doi.org/10.1016/j.cor.2018.03.012

Weidinger, F., Boysen, N., & Schneider, M. (2019). Picker routing in the mixed-shelves warehouses of e-commerce retailers. *European Journal of Operational Research*, *274*(2), 501–515. https://doi.org/10.1016/j.ejor.2018.10.021

Winkelhaus, S., Grosse, E., & Morana, S. (2021). Towards a conceptualisation of Order Picking 4.0. *Computers & Industrial Engineering*, *159*, 159. https://doi.org/10.1016/j.cie.2021.107511

Winkelhaus, S., Sgarbossa, F., Calzavara, M., & Grosse, E. (2018). The effects of human fatigue on learning in order picking: An explorative experimental investigation. *IFAC-Papersonline*, *51*(11), 832–837. https://doi.org/10.1016/j.ifacol.2018.08.442

Winkelhaus, S., Zhang, M., Grosse, E., & Glock, C. (2022). Hybrid order picking: A simulation model of a joint manual and autonomous order picking system. *Computers & Industrial Engineering*, *167*, 107981. https://doi.org/10.1016/j.cie.2022.107981

Wu, Z. -H., Chen, H. -J., & Yang, J. -J. (2020). Optimization of order-picking problems by intelligent optimization algorithm. In *Mathematical Problems in Engineering* (Vol. 2020). https://doi.org/10.1155/2020/6352539

Wu, W., de Koster, R., & Yu, Y. (2020). Forward-reserve storage strategies with order picking: When do they pay off? *IISE Transactions*, *52*(9), 961–976. https://doi.org/10.1080/24725854.2019.1699979

Wu, Y., & Wu, Y. (2014). Taboo search algorithm for item assignment in synchronized zone automated order picking system. *Chinese Journal of Mechanical Engineering*, *27*(4), 860–866. https://doi.org/10.3901/CJME.2014.0430.084

Wu, Y., & Zhang, Y. (2008). Order-picking optimization for automated picking system with parallel dispensers. *Chinese Journal of Mechanical Engineering*, *21*(6), 25–29. https://doi.org/10.3901/CJME.2008.06.025

Wu, Y., Zhou, C., Wu, Y., & Kong, X. (2017). Zone merge sequencing in an automated order picking system. *International Journal of Production Research*, *55*(21), 6500–6515. https://doi.org/10.1080/00207543.2016.1264641

Yang, M. -F. (2008). Using simulation to object-oriented order picking system. *Information Technology Journal*, *7*(1), 224–227. https://doi.org/10.3923/itj.2008.224.227

Yang, L., Li, K., & Huang, H. (2018). A new network model for extracting text keywords. *Scientometrics*, *116*(1), 339–361. https://doi.org/10.1007/s11192-018-2743-5

Yang, D., Liu, S., & Zhang, Z. (2022). An asymmetric polling-based optimization model in a dynamic order picking system. *Symmetry*, *14*(11), 2283. https://doi.org/10.3390/sym14112283

Yang, P., Zhao, Z., & Guo, H. (2020). Order batch picking optimization under different storage scenarios for e-commerce warehouses. *Transportation Research Part E: Logistics and Transportation Review*, *136*, 136. https://doi.org/10.1016/j.tre.2020.101897

Yang, J., Zhou, L., Liu, H., & Wang, Y. (2021). Hybrid genetic algorithm-based optimisation of the batch order picking in a dense mobile rack warehouse. *Plos One*, *16*(4), e0249543. https://doi.org/10.1371/journal.pone.0249543

Yener, F., & Yazgan, H. (2019). Optimal warehouse design: Literature review and case study application. *Computers & Industrial Engineering*, *129*, 1–13. https://doi.org/10.1016/j.cie.2019.01.006

Yousefi Nejad Attari, M., Ebadi Torkayesh, A., Malmir, B., & Neyshabouri Jami, E. (2021). Robust possibilistic programming for joint order batching and picker routing problem in warehouse management. *International Journal of Production Research*, *59*(14), 4434–4452. https://doi.org/10.1080/00207543.2020.1766712

Yu, M., & de Koster, R. (2008). Performance approximation and design of pick-and-pass order picking systems. *IIE Transactions (Institute of Industrial Engineers)*, *40*(11), 1054–1069. https://doi.org/10.1080/07408170802167613

Yu, M., & de Koster, R. (2009). The impact of order batching and picking area zoning on order picking system performance. *European Journal of Operational Research*, *198*(2), 480–490. https://doi.org/10.1016/j.ejor.2008.09.011

Yu, M., & de Koster, R. (2010). Enhancing performance in order picking processes by dynamic storage systems. *International Journal of Production Research*, *48*(16), 4785–4806. https://doi.org/10.1080/00207540903055693

Zhang, Y. (2016). Correlated storage assignment strategy to reduce travel distance in order picking. *IFAC-Papersonline*, *49*(2), 30–35. https://doi.org/10.1016/j.ifacol.2016.03.006

Zhang, X., de Vries, J., de Koster, R., & Liu, C. (2022). Fast and faultless? Quantity and quality feedback in order picking. *Production and Operations Management*, *31*(4), 1536–1559. https://doi.org/10.1111/poms.13630

Zhang, K., & Gao, C. (2022). Improved formulations of the joint order batching and picker routing problem. *International Journal of Production Research*, 1–24. https://doi.org/10.1080/00207543.2022.2149872

Zhang, J., Liu, F., Tang, J., & Li, Y. (2019). The online integrated order picking and delivery considering pickers' learning effects for an O2O community supermarket. *Transportation*

*Research Part E: Logistics and Transportation Review*, *123*, 180–199. https://doi.org/10.1016/j.tre.2019.01.013
Zhang, J., Wang, S., He, W., Li, J., Cao, Z., Wei, B., & Wang, M. (2022). Material kitting in selective assembly: A manual order picking system based on augmented reality. *International Journal of Advanced Manufacturing Technology*, *123*(1–2), 675–686. https://doi.org/10.1007/s00170-022-10188-1
Zhang, J., Wang, X., & Huang, K. (2018). On-line scheduling of order picking and delivery with multiple zones and limited vehicle capacity. *Omega*, *79*, 104–115. https://doi.org/10.1016/j.omega.2017.08.004
Zhang, M., Winkelhaus, S., & Grosse, E. (2021). Evaluation of human workload in a hybrid order picking system. *IFAC-Papersonline*, *54*(1), 458–463. https://doi.org/10.1016/j.ifacol.2021.08.053
Zhang, J., Yu, Q., Zheng, F., Long, C., Lu, Z., & Duan, Z. (2016). Comparing keywords plus of WOS and author keywords: A case study of patient adherence research. *Journal of the Association for Information Science and Technology*, *67*(4), 967–972. https://doi.org/10.1002/asi.23437
Zhang, J., Zhang, Y., & Zhang, X. (2021a). The study of joint order batching and picker routing problem with food and nonfood category constraint in online-to-offline grocery store. *International Transactions in Operational Research*, *28*(5), 2440–2463. https://doi.org/10.1111/itor.12926
Zhang, J., Zhang, X., Zhang, Y. (2021b). A study on online scheduling problem of integrated order picking and delivery with multizone vehicle routing method for online-to-offline supermarket. *Mathematical Problems in Engineering*, *2021*, 1–9. https://doi.org/10.1155/2021/6673079
Zhang, S., Zhuge, D., Tan, Z., & Zhen, L. (2022). Order picking optimization in a robotic mobile fulfillment system. *Expert Systems with Applications*, *209*, 118338. https://doi.org/10.1016/j.eswa.2022.118338
Zhao, X., Liu, N., Zhao, S., Wu, J., Zhang, K., & Zhang, R. (2019). Research on the work-rest scheduling in the manual order picking systems to consider human factors. *Journal of Systems Science and Systems Engineering*, *28*(3), 344–355. https://doi.org/10.1007/s11518-019-5407-y
Zhou, L., Zhu, J., & Guo, J. (2010). Stochastic model of sorted-storage return-type manual order picking route. *Journal of Beijing Institute of Technology*, *19*, 97–102.
Zhuang, Z., Huang, Z., Sun, Y., & Qin, W. (2021). Optimization for cooperative task planning of heterogeneous multi-robot systems in an order picking warehouse. *Engineering Optimization*, *53*(10), 1715–1732. https://doi.org/10.1080/0305215X.2020.1821198
Zhuang, Y., Zhou, Y., Yuan, Y., Hu, X., & Hassini, E. (2022). Order picking optimization with rack-moving mobile robots and multiple workstations. *European Journal of Operational Research*, *300*(2), 527–544. https://doi.org/10.1016/j.ejor.2021.08.003
Zhu, J., Guo, J., Zhou, L., & Zhang, H. (2016). Study on the improvement of the additional distance for sorted-storage S-type manual order picking. *Journal of Computational and Theoretical Nanoscience*, *13*(4), 2639–2644. https://doi.org/10.1166/jctn.2016.4631
Zhu, J., Zhou, L., & Guo, J. (2011). The study of random-storage return-type manual order picking based on M/G/1 random service system theory. *Journal of Computational Information Systems*, *7*(1), 265–272.
Ziółkowski, J., & Lęgas, A. (2019). Benefitting from the problem of allocation in the optimisation of the order picking process [Wykorzystanie problemu przydziału w optymalizacji procesu kompletacji]. *Journal of Konbin*, *49*(2), 397–420. https://doi.org/10.2478/jok-2019-0042
Zivanic, D., Zelic, A., Lalic, B., Simeunovic, N., & Szabo, L. (2019). Improving the order picking efficiency by optimising the orders' sequence. *International Journal of Simulation Modelling*, *18*(1), 125–137. https://doi.org/10.2507/IJSIMM18(1)469
Žulj, I., Glock, C., Grosse, E., & Schneider, M. (2018). Picker routing and storage-assignment strategies for precedence-constrained order picking. *Computers & Industrial Engineering*, *123*, 338–347. https://doi.org/10.1016/j.cie.2018.06.015
Zuñiga, J., Martínez, J., Fierro, T., & Saucedo, J. (2020). Optimization of the storage location assignment and the picker-routing problem by using mathematical programming. *Applied Sciences*, *10*(2), 534. https://doi.org/10.3390/app10020534