Investigating order picking system adoption: a case-study-based approach

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1. Introduction

Order picking is the activity by which a small number of goods are retrieved from a warehousing system to satisfy a number of independent customer orders (Ashayeri and Goetschalckx 1989). The selection of a suitable order picking system (OPS) represents one of the key decisions for a company as it has a significant impact on both overall logistics costs and the service level provided to the customer. Indeed, numerous sources confirm that picking activity accounts for more than a half of the total warehousing cost (e.g. De Koster, Le-Duc, and Roodbergen 2007).

As highlighted by Dallari, Marchet, and Melacini (2009), the selection and design of an OPS is a very complex task, depending on several elements, such as products (e.g. number, size, value, packaging, inventory level and sales), customer orders (e.g. number, size and number of order lines), different types of functional areas (e.g. separate areas for fast-moving-product case picking versus slow-moving items), different combinations of equipment types (e.g. as far as slow-moving-product case picking is concerned, either a picker-to-part system or a miniload may be used), and operating policies for each functional area (e.g. pick by order or pick by item). Additionally, trends in the logistics industry reveal a progressive increase in complexity, due to market evolution, particularly because of globalisation, which has brought in new international

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competitors. Therefore, the market had to adapt to new customer requirements and regulations, coping with the increase in competitiveness, the progressive decrease in margin profits, and the need for offering high-quality value-added services to the customers. In this context, the key objectives that drive the OPS selection are maximising service level (e.g. De Koster, Le-Duc, and Roodbergen 2007) and reducing costs (e.g. Baker and Halim 2007).

A number of studies focusing on warehouse design, optimisation, and modelling have been found in the literature (e.g. Caron, Marchet, and Perego 2000; Baker 2006; Baker and Canessa 2009; Yu and De Koster 2009). Still, little empirical research has been performed so far on warehousing issues (e.g. Baker and Halim 2007), or on the type of OPS actually implemented.

An increasing number of automated OPS have been observed over time, often accompanied by the adoption of information and communication technology (ICT) systems to support material handling and picking operations (Hou, Wu, and Wu 2009), in order to reduce picking times, costs, and errors. In some cases, a partial automation may also be detected (e.g. Ackerman 1990). It is the case of those warehouses in which a combination of both conventional (i.e. manual) solutions and automated systems coexist and are adopted to handle stock keeping units (SKUs) with different features/requirements.

However, challenges and barriers may arise, especially with respect to the adoption of automated (or partially automated) OPS. As highlighted by Hackman et al. (2001), the most common hurdles faced by company management are high investment costs and the risk of interrupting warehouse operations during the implementation period. Further constraints may also be considered, e.g. related to building or zoning constraints enacted by local authorities as well as the attainment of safety standards. Nevertheless, companies seem more and more intetested in evaluating the implementation of automated (or partially automated) OPS to support their business, gradually overcoming the reluctance that has prevented them from adopting OPS in the past.

Building on previous research, the aim of this paper is (i) to investigate the state of the art in the adoption of OPS and (ii) to provide a broad empirical analysis based on a cross-section of 40 Italian distribution or factory warehouses. Specifically, the main purpose is to offer insights into the type of OPS adopted, the automation level, and the main ICT systems in place to support picking activities.

The paper is organised as follows. The next section presents the literature review. Section 3 provides the methodology, and Section 4 illustrates the findings of the analysis. In the final section, the main results are summarised and discussed, and areas for further development are identified.

2. Literature review

2.1. *Classification of OPS*

A variety of OPS can be found in warehouses. A number of papers addressing the issue of classifying the different OPS types are found in the literature. An example of OPS classification is provided by Van den Berg (1999). The author categorises OPS into three main clusters, namely picker-to-product, product-to-picker, and picker-less systems. More recently, Dallari, Marchet, and Melacini (2009) developed another classification method, where OPS are classified accordingly with four main drivers: who picks the goods (i.e. humans versus machines), who moves within the picking area (i.e. pickers versus goods), if conveyors are used to connect each picking zone, and the picking policy employed (i.e. pick by order versus pick by item). Five main types of OPS were identified: (i) picker-to-parts, (ii) parts-to-picker, (iii) pick-to-box, (iv) pick-and-sort, and (v) completely automated picking. The automation level increases ranging from picker-to-parts system to completely automated picking OPS. This classification method has also been acknowleged in subsequent publications (e.g. Melacini, Perotti, and Tumino 2011; Hanson, Medbo, and Medbo 2012), and its terminology has been adopted in this paper, as well.

According to this latter classification, picker-to-parts systems represent a significant majority of picking systems in warehouses, as attested by De Koster, Le-Duc, and Roodbergen (2007). Pickers walk or drive along the aisles to pick items, completing a single order or a batch of multiple orders, depending on the order picking policy. There are two main types of picker-to-parts systems, namely low- and high-level picking (e.g. Caron, Marchet, and Perego 1998; Hwang and Oh 2004). In low-level OPS, items are picked from picking locations (e.g. racks, gravity flow racks and bins) while travelling along the aisles. The second one (also called man-on-board OPS) employs high storage racks and pickers access picking locations on board an order picking truck (e.g. Van den Berg and Zijm 1999; De Koster, Le-Duc, and Roodbergen 2007). The picking area is usually separated from the storage area; this allows the retrieval of customer orders to take place in a smaller area than the storage area. Despite its relevance in industrial contexts, studies on picker-to-parts systems tend to be less prevalent in the literature than studies on parts-to-picker systems (De Koster, Le-Duc, and Roodbergen 2007; Melacini, Perotti, and Tumino 2011), as these latter are more complex (De Koster, Le-Duc, and Roodbergen 2007).

In parts-to-picker systems an automated device brings unit loads from the storage area to the picking stations (also called picking bays), where the pickers select the required amount of each item. Afterwards, the unit loads, if not empty, are conveyed back to the storage area. Potential equipment types used in the storage area are carousels, modular vertical lift modules, miniloads (e.g. Andriansyah et al. 2010), automated storage and retrieval systems (AS/RS), as reported by Frazelle (1996) and Van den Berg and Zijm (1999), and automated vehicle storage and retrieval systems (AVS/RS), as attested by Marchet et al. (2013). The advantage of this type of OPS lies in a picking cost reduction (i.e. in terms of labour hours and space required) with respect to picker-to-parts systems. However, the risk of creating bottlenecks in feeding the picking bays are high with this system, with a consequent reduction in picker utilisation and picking productivity. This OPS seems to be preferable at warehouses with small picking volumes and a large number of items to be managed, as stated by Dallari, Marchet, and Melacini (2009).

Pick-to-box systems (also known as ‘pick-and-pass’ OPS) divide the picking area into zones, each of which is assigned to one or more pickers. All the picking zones are connected by a conveyor on which boxes filled up with picked items are placed, with each of them corresponding (partially or completely) to a customer order. Customer orders are sequentially picked zone by zone (De Koster and Le-Duc 2005), and boxes are eventually sorted according to their destination. The costs and complexity of these OPS are related to workload balancing among the multiple picking zones (Dallari, Marchet, and Melacini 2009). This solution seems to be preferable where there are a significant number of small-sized items, medium-size flows, and small order size. Despite the importance of the pick-and-pass system in industrial contexts, research on these systems is not extensive as for other OPS, as was also observed by Melacini, Perotti, and Tumino (2011).

As far as pick-and-sort systems are concerned, operators in the picking area retrieve the required amount of each single item resulting from the batching of multiple customer orders and put it on a takeaway conveyor connecting the forward area with the sorting area. The conveyor operates in a closed loop with automatic divert mechanisms and accumulation lanes (e.g. a tilt-tray or cross-belt sorting conveyor). A computerised system then determines the destination bay for each item; each destination bay is dedicated to an individual customer order (Dallari, Marchet, and Melacini 2009; Marchet, Melacini, and Perotti 2011). Pick-and-sort systems typically work in picking waves, where all the orders in a picking wave are completely sorted before the following picking wave is released. As a consequence, the batch size is consistently high for this OPS (i.e. at least 20 customer orders per picking wave).

Completely automated picking systems are suitable for high-speed retrieval activities. Completely automated picking systems typically include automatic dispensers (A-frame or V-frame) and robots, which are usually connected to the other areas by means of automatic conveyors (Van den Berg 1999; Van den Berg and Zijm 1999; Baker and Halim 2007). Such systems are adopted more rarely than other OPS, because of high investment costs and the specificity of the contexts in which they may be suitable, and therefore there is limited information in the literature on these topics (Dallari, Marchet, and Melacini 2009).

Finally, as far as drivers of OPS selection are concerned, different decision-making parameters have been detected in the literature. For instance, according to the study by Dallari, Marchet, and Melacini (2009), the number of order lines picked per day along with the number of items and the average order size are the key parameters considered in the OPS selection.

2.2. *Automation in warehouses*

Automation in warehouses refers to both material handling solutions and ICT-based devices. According to Hou, Wu, and Wu (2009), due to the development and popularity of information and automation technologies, the logistics industry has gradually implemented automation or semi-automation to support picking operations. Expenditure on warehouse automation has increased steadily in Europe (e.g. Frost & Sullivan 2001) and this trend is reflected globally by figures showing that sales have increased by an average of 5% per year for the period 2003–2005, as highlighted by Baker and Canessa (2009). More recent data seem to confirm this trend (e.g. Wang, Zhang, and He 2009; Baker and Sleeman 2011).

Based on the research by Baker and Halim (2007), the main reasons for automating are coping with growth in the business, reducing operational costs, and increasing the service level provided to the customer. Among the benefits derived from the implementation of automated (or partially automated) OPS, the reduction in picking errors is mentioned in the literature, as reported by Brynzér and Johansson (1995), as well as operational costs.

However, some conflicting findings have been reported on the actual effectiveness of warehouse automation in terms of both responsiveness and cost, as observed by Baker and Halim (2007). Some concerns have also emerged related to warehouse automation, namely the risk of interrupting warehouse operations in the event of system failures, the loss of flexibility in the long term, and a decrease of customer service level in the short term (e.g. within the start-up phase), as observed by Hackman et al. (2001).

As far as information technologies are concerned, a number of ICT-based applications are currently available to support picking activities. Examples include pick-to-light systems, voice picking, and radio frequency identification (RFID), which complement the conventional systems based on simple paper picking lists or barcode reading. Electronic paperless pick-to-light systems are mainly used in pick-and-pass OPS. Pick-to-light systems help enhance productivity (up to 50%), decrease picking errors and simplify personnel training, thus reducing operational costs. As far as voice picking is concerned, the primary advantage is that pickers are hands-free – which is particularly useful if there are heavy products to be handled – and eyes-free, supported by headsets with an attached microphone. According to several sources (e.g. Modern Material Handling 2013), a considerable rise in productivity (i.e. 10–15%) may be achieved thanks to this system. Finally, RFID tools lead to a considerable reduction in picking errors, as mentioned by Chow et al. (2006) and Vijayaraman and Osyk (2006).

In summary, the literature highlights the potential of automation, although still little evidence has been reported on the actual implementation of automation in warehouses, and specifically in OPS.

3. Research methodology

As the research was exploratory in nature, qualitative methods were deemed to be most appropriate (Eisenhardt 1989) and the multiple-case study was selected as the primary methodology.

The research method was composed of two main steps (Figure 1). In the preliminary phase, distinctive OPS features were analysed. This analysis also included the investigation of the main ICT systems currently available for supporting warehousing and picking activities. The methodology adopted within this phase was primarily a review of the literature and secondary sources (e.g. reports and information from material handling providers). Subsequently, 40 case studies were carried out with companies involved in warehousing and picking activities in different industry sectors (e.g. food, pharmaceuticals and consumer electronics). The unit of analysis was the company warehouse. All of the companies involved in the study had recently engaged in a redesign of their warehousing procedures and eventually adopted at least one OPS in their warehouse(s). The aim of this phase was to record the types of OPS, the implementation process (i.e. motivations and barriers to adoption), and the current level of adoption of ICT systems to support picking activites in each examined warehouse.

3.1. *Case study selection*

As recommended in multiple case experiments (e.g. Eisenhardt 1989; Yin 2003), the choice of the case studies was aimed at achieving both theoretical replication and literal replication in order to support the generalisation of our results.

To investigate the adoption of the different OPS types, 40 warehouse facilities were considered for the purposes of the present study. All the companies whose warehouse(s) were analysed generate revenues of over 10 million euros each and are all based in Italy with at least one warehouse in the country. The sample intentionally includes different industry sectors (e.g. pharmaceuticals, cosmetics, fashion and apparel, food and beverage, consumer electronics, industrial components and machinery). All the examined warehouses had recently implemented internal redesign processes (i.e. from 1999 up to 2011) with the aim of improv-ing the efficiency and effectiveness of operations, with a particular emphasis on picking activities. We considered only recently redesigned warehouses because a change in business requirements could reduce OPS effectiveness in older warehouses, according to Dallari, Marchet, and Melacini (2009).

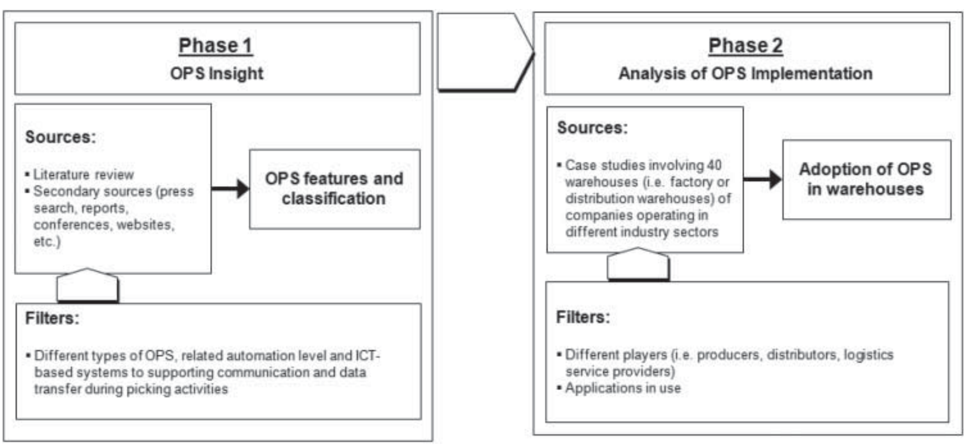

Figure 1. Research methodology.

The 40 warehouses investigated in our research include representative examples of OPS redesign in the country, notably characterised by small- and medium-sized companies.

3.2. *Data collection and analysis*

Semi-structured interviews were conducted with executives (i.e. managing directors, logistics managers, and operations managers) from each of the 40 warehouses.

Two different versions of the questionnaire were prepared. Participants received a short external version prior to the interview, whereas a more detailed, internal version was designed to support the interviewers. The questionnaire was based on the literature and organised into six main sections: interviewee and company details, description of the supply chain and warehouse processes, details of the OPS implemented, related ICT systems that support warehouse procedures (if applicable), implementation process (i.e. motivations and barriers) of OPS adoption, and the impact of the OPS on the order picking process. In addition to the interviews, complementary information was also gathered by means of secondary sources (e.g. company websites or internal documents).

This methodology included iterative, multiple-stage data collection (Lincoln and Guba 1985). As such, the questionnaire was slightly modified based on the results of earlier interviews. Each formal interview lasted between 60 and 120 minutes and was audiotaped. In most cases, an on-site visit to the warehouse was performed. A written transcription of each interview was produced for possible future analysis. In addition to the interviews, complementary information was also gathered by means of secondary sources (e.g. company websites or reports). After each interview had been completed, detailed case study reports were prepared and then reviewed by the interviewees. Finally, a short extract from each case study was reported in relevant Italian logistics practitioner journals (i.e. *Logistica* or *Euromerci*), which periodically publish brief articles on recently built warehouses, along with a brief description of their main features.

The data collected were analysed on two levels: within-case analysis and cross-case analysis. Within-case analysis involved detailed case study write-ups for each case. They were fundamental to the development of insights into each case, as they helped to address the challenge of analysing a large volume of data (Eisenhardt 1989). The written case descriptions were essential for demon-strating the reliability of the research. Each case analysis contained a detailed company profile, a description of the supply chain and warehouse processes, the details of the OPS implemented, the related ICT systems that support warehouse procedures (if applicable), and the impact of the OPS on the process. This process made it possible to identify the unique features of each case.

A cross-case analysis was then conducted to synthesise the information obtained from the case studies. The purpose is to force the investigation to go beyond initial impressions (Eisenhardt 1989). Also, cross-case analysis increases the probability of capturing novel findings that may exist in the data.

Table 1 summarises some information about the companies whose warehouse(s) were analysed in the case studies.

3.3. *Validity and reliability of the methodology*

Validity and reliability are particularly important for case-based research (Ellram 1996; Yin 2003). External validity reflects how accurately the results represent the phenomenon studied, estab-lishing the generalisability of the results (Yin 2003). In this study, the generalisability was enhanced, as recommended by Yin (2003), by including multiple in-depth case studies repre-senting different players (i.e. producers, distributors, and logistics service providers) and the diverse OPS and technologies adopted. The term 'construct validity' refers to the establishment of the appropriate operational measures for the concepts studied. According to Yin (2003), one way

Table 1. Companies involved in the case studies

Company	Industry	Company type: Producer	Company type: Distributor	Company type: Logistics service provider	No. of warehouses examined	Warehouse type(s)
Ambrovit S.r.l.	Industrial Components and Machinery		X		1	Distribution warehouse
Avon Products, Inc.	Cosmetics		X		1	Distribution warehouse
Company operating in the medical industry	Industrial Components and Machinery	X	X		1	Distribution warehouse
BSL S.p.A. (Geodis Group)	Fashion and Apparel			X	1	Distribution warehouse
C.D. Verte S.p.A.	Videogames and Accessories		X		1	Distribution warehouse
Caleffi S.p.A.	Industrial Components and Machinery	X			1	Factory warehouse
Cef (Cooperativa Esercenti Farmacia s.c.r.l.)	Pharmaceuticals		X		1	Distribution warehouse
Ceva Logistics	Fashion and Apparel			X	1	Distribution warehouse
	Publishing			X	1	Distribution warehouse
Comet S.p.A.	Consumer Electronics		X		1	Distribution warehouse
Decathlon S.r.l. (Oxylane Group)	Sportswear and Accessories		X		1	Distribution warehouse
Eral S.r.l. (Linea Light Group.)	Industrial Components and Machinery	X	X		1	Distribution warehouse
EuroSpin Italia S.p.A.	Food and Beverage		X		1	Distribution warehouse
Fincoma S.r.l.	Industrial Components and Machinery		X		1	Distribution warehouse
Fonderia Boccacci S.p.A.	Industrial Components and Machinery	X			1	Factory warehouse
GameStop Corporation	Videogames and Accessories		X		1	Distribution warehouse
Giacomini S.p.A.	Industrial Components and Machinery	X			1	Factory warehouse
Granarolo S.p.A.	Food and Beverage	X			1	Factory warehouse
Grandi Molini Italiani (Coriano Veronese)	Food and Beverage	X	X		1	Factory warehouse
Grandi Molini Italiani (Porto Marghera)	Food and Beverage	X			1	Factory warehouse
Künzi S.p.A.	Home and Outdoor Accessories		X		1	Distribution warehouse
MGM Mondo del Vino S.r.l.	Food and Beverage	X			1	Factory warehouse
Neologistica S.r.l.	Pharmaceuticals			X	1	Distribution warehouse
Norbert Dentressangle	Fashion and Apparel			X	1	Distribution warehouse

(*Continued*)

Table 1. Continued

Company	Industry	Company type: Producer	Distributor	Logistics service provider	No. of warehouses examined	Warehouse type(s)
Novartis Vaccines and Diagnostics S.r.l.	Pharmaceuticals	X			1	Factory warehouse
Novellini S.p.A.	Industrial Components and Machinery	X			1	Factory warehouse
Oleificio Zucchi S.p.A.	Food and Beverage	X			1	Factory warehouse
Panificio San Francesco	Food and Beverage	X			1	Factory warehouse
Perfetti van Melle S.p.A.	Food and Beverage		X		1	Distribution warehouse
Piquadro S.p.A.	Fashion and Apparel		X		1	Distribution warehouse
Polo S.p.A.	Food and Beverage		X		1	Distribution warehouse
Rancilio S.p.A.	Industrial Components and Machinery	X			1	Factory warehouse
Safar Società Cooperativa Arl.	Pharmaceuticals		X		1	Distribution warehouse
SGM Distribuzione S.r.l. (EXpert International Group)	Consumer Electronics		X		1	Distribution warehouse
Sirman S.p.A.	Industrial Components and Machinery	X	X		1	Factory warehouse
SIT S.p.A.	Industrial Components and Machinery		X		1	Distribution warehouse
Thun S.p.A.	Home Decoration		X		1	Distribution warehouse
Trasporti Lanzi S.r.l.	Industrial Components and Machinery			X	1	Distribution warehouse
Unico S.p.A.	Pharmaceuticals		X		2	Distribution warehouse
Unifarm S.p.A.	Pharmaceuticals		X		1	Distribution warehouse

to deal with construct validity is to return the case study reports to the informants for verification. Therefore, company managers reviewed all case descriptions prior to the cross-case analysis stage. Multiple sources of evidence (e.g. internal documents describing the project and information from the material handlling provider(s) who implemented the OPS) were also used during the study to improve construct validity (Auramo, Kauremaa, and Tanskanen 2005).

The second issue in the quality of the research design – i.e. reliability – involves the repeatability of the experiment and whether replication is possible and will achieve the same results. Therefore, pilot interviews were used to refine the research content and procedure prior to each data collection phase. Moreover, participants received a copy of the external version of the questionnaire prior to the interview, so they had prior knowledge of the questions and the type of documentation required. To further substantiate the reliability of the research, a case study database was established which included a copy of the complete interview guide for each case and a detailed summary of the write-up (Yin 2003; Auramo, Kauremaa, and Tanskanen 2005).

4. Results and discussion

On the basis of the literature review, the following areas were investigated:

- automation level and ICT adoption to support warehousing and picking activities;
- adoption level of the various OPS;
- implementation process, i.e. motivations and barriers to adoption, and impacts following adoption.

Tables 2 and 3, respectively, summarise the findings of the empirical analysis in terms of the number of OPS adopted and details regarding the types of OPS identified. In Figure 2, non-confidential data have been plotted to show the use of the different OPS based on the company operational context (i.e. picking volume and number of SKUs). The representation has been split into two graphs to enhance its readability.

The findings of the analysis are presented as follows.

4.1. *Overlook on the OPS automation level and ICT adoption*

Looking at the OPS automation level, the case study analysis revealed that half of the warehouses examined still use conventional (i.e. manual) OPS, which is consistent with De Koster, Le-Duc, and Roodbergen (2007). However, a general shift towards automation has been observed with respect to the past: the interviewed companies declared to have recently adopted automated (or partially automated) OPS in place of their former fully manual solutions. This result is consistent with the literature (e.g. Hou, Wu, and Wu 2009). As stated above, note that the analysis intentionally focused on warehouses that have recently underwent a process redesign: in all the cases examined, the warehouse reconfiguration was characterised by the adoption of more automated solutions than were previously in place.

According to Baker and Halim (2007), there are diverging opinions with regard to the role of automation in reducing operational times and costs within the warehouse. For the cases examined in this study, the choice of automation is guided by both economic reasons related to the operational context (i.e. labour cost increase) and the search for higher effectiveness (i.e. service level increase).

Besides, warehouse automation is also often associated with concerns related to system flexibility. Traditionally, flexibility has been characterised by two main dimensions: (i) with reference to the variability of picking volumes in a year (e.g. seasonality); (ii) with reference to potential 'structural' changes that may occur in terms of volumes and SKUs to be handled over time. From

Table 2. Number and types of OPS identified (note that the total exceeds 40 because of multiple OPS within the same warehouse).

Type of OPS	No. of OPS
Picker-to-parts	20
Pick-to-box	7
Pick-and-sort	3
Parts-to-picker	21
Completely automated picking	9

Table 3. Details of OPS in place (note that ‘n.a.’ refers to confidential data).

				OPS adopted				
Company	Industry	No. of SKUs	Picking volume (no. of order lines/day)	Picker-to-parts	Parts-to-picker	Pick-to-box	Pick-and-sort	Completely automated picking
Ambrovit S.r.l.	Industrial Components and Machinery	10,000	1200	X	X			
Avon Products, Inc.	Cosmetics	10,000	120,000			X		
Company operating in the medical industry	Industrial Components and Machinery	700,000	60		X			
BSL S.p.A. (Geodis Group)	Fashion and Apparel	52,000	2500	X				
C.D. Verte S.p.A.	Videogames and Accessories	n.a.	n.a.					X
Caleffi S.p.A.	Industrial Components and Machinery	4,000	n.a.		X			
Cef (Cooperativa Esercenti Farmacia s.c.r.l.)	Pharmaceuticals	40,000	65,000			X		X
Ceva Logistics	Fashion and Apparel	40,000	n.a.	X				
	Publishing	62,000	n.a.	X		X		
Comet S.p.A.	Consumer Electronics	20,000	5000	X				
Decathlon S.r.l. (Oxylane Group)	Sportswear and Accessories	40,000	35,000	X			X	
Eral S.r.l. (Linea Light Group.)	Industrial Components and Machinery	80,000	144	X	X			
EuroSpin Italia S.p.A.	Food	n.a.	48,000	X				
Fincoma S.r.l.	Industrial Components and Machinery	15,000	640		X			
Fonderia Boccacci S.p.A.	Industrial Components and Machinery	n.a.	n.a.					X
GameStop Corporation	Videogames and Accessories	4400	n.a.	X		X		
Giacomini S.p.A.	Industrial Components and Machinery	n.a.	n.a.					X
Granarolo S.p.A.	Food	40	n.a.		X			
Grandi Molini Italiani (Coriano Veronese)	Food	80	n.a.		X			
Grandi Molini Italiani (Porto Marghera)	Food	n.a.	n.a.		X			
Künzi S.p.A.	Home and Outdoor Accessories	4000	750	X	X			
MGM Mondo del Vino S.r.l.	Food	500	n.a.		X			

Neologistica S.r.l.	Pharmaceuticals	n.a.	n.a.	X	X			
Norbert Dentressangle	Fashion and Apparel	n.a.	n.a.	X	X		X	
Novartis Vaccines and Diagnostics S.r.l.	Pharmaceuticals	n.a	n.a.		X			
Novellini S.p.A.	Industrial Components and Machinery	50	n.a.		X			X
Oleificio Zucchi S.p.A.	Food	350	120	X				
Panificio San Francesco	Food	5	n.a.		X			
Perfetti van Melle S.p.A.	Food	n.a.	600		X			
Piquadro S.p.A.	Fashion and Apparel	10,000	n.a.	X	X			
Polo S.p.A.	Food	3000	n.a.		X			X
Rancilio S.p.A.	Industrial Components and Machinery	n.a.	n.a.	X	X			
Safar Società Cooperativa Arl.	Pharmaceuticals	60,000	40,000			X		X
SGM Distribuzione S.r.l. (Expert International Group)	Consumer Electronics	5000	8000	X				
Sirman S.p.A.	Industrial Components and Machinery	2800	n.a.		X			
SIT S.p.A.	Industrial Components and Machinery	15,000	650	X	X			
Thun S.p.A.	Home Decoration	10,000	n.a.				X	
Trasporti Lanzi S.r.l.	Industrial Components and Machinery	n.a.	n.a.	X				
Unico S.p.A.	Pharmaceuticals	65,000	n.a.	X		X		X
Unifarm S.p.A.	Pharmaceuticals	50,000	42,000	X		X		X

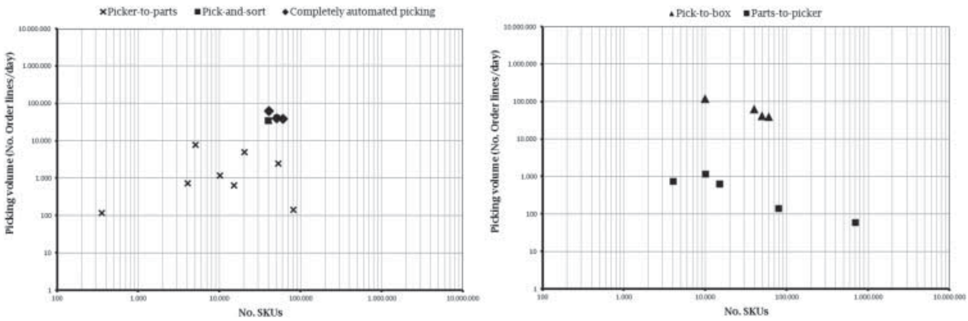

Figure 2. OPS matrix (case studies with non-confidential data).

the first viewpoint, automated picking solution are typically ‘rigid’, as they are generally designed starting from specific project data (e.g. in terms of picking volumes to be handled). An exception is provided by autonomous vehicle storage and retrieval systems (AVS/RS) where the number of vehicles may be increased (or reduced) as a function of the picking volumes. From the second viewpoint (i.e. potential ‘structural’ changes), an additional extra-capacity may be considered for potential future expansion when designing automated solutions. However, this latter solution appears to be ‘rigid’ in case of a decrease of picking volumes over time. Focusing on the examined cross-section of warehouses, in most cases the choice of automation is related to solutions with the aim of assuring a high degree of flexibility in terms of system ‘adaptability’ in the event of poten-tial new business requirements (e.g. structural changes in picking volumes or number of SKUs). This is often achieved by implementing systems that may easily be expanded or adapted based on an evolving operational context. For example, Eral S.r.l. implemented a two-aisle miniload and has plans to further expand this solution with two additional aisles in the event of a future increase in business.

Looking at ICT adoption for picking and warehousing operations, the case study results show that the techniques that enhance picking productivity (i.e. manual or automated) are routing optimisation algorithms, item allocation policies, and retrieval policies. These are normally man-aged by one or more ICT systems. For instance, Warehouse Management Systems are generally widespread, with the aim of coordinating and optimising picking activities, tracking customer orders, and managing inventories. Pick-to-light (e.g. Ceva – publishing industry, Thun, Avon), put-to-light (e.g. BSL – Geodis Group, CEF, Unifarm), and voice picking systems (e.g. Decathlon, Thun) were also identified. As far as item identification is concerned, the use of barcode scan-ners is ubiquitous (i.e. used in all the warehouses considered). Conversely the implementation of RFID technology - widely acknowledged in the literature as particularly evolved and flexible - still appears to be at an early stage. These results differ from those in other countries where a number of large- or medium-sized companies have adopted this technology, as shown by Chow et al.(2006). However, in recent years the implementation of RFID has not met the early expectations. According to White, Johnson, and Wilson (2008), the degree of adoption is still low (i.e. 14%).

Focusing on data transmission, a steady abandonment of paper picking lists has generally been experienced, substituted by a number of ICT-based technologies. The most common system is radio frequency (i.e. 81% of the warehouses investigated), whereas the use of simple paper picking lists or cable is limited (9.7% and 6.5%, respectively).

4.2. *Adoption level of the various OPS*

Empirical results are generally consistent with the findings of Dallari, Marchet, and Melacini (2009), where picker-to-parts and parts-to-picker systems are normally adopted in case of a low picking volume (i.e. lower than 10,000 order lines per day) and, as far as picker-to-parts system are concerned, a limited number of SKUs. When picking volumes and the number of SKUs increases, other OPS are also adopted. The case studies show that, in line with De Koster, Le-Duc, and Roodbergen (2007), half of the examined warehouses still adopt conventional picker-to-parts systems although a number of different OPS are in service. However, following warehousing process redesign an increase in the number of parts-to-picker systems was also noted. One of the reasons for this choice is related to the overall increase in the number of SKUs at the warehouses. In this context, parts-to-picker systems allow to achieve higher picking productivity, generally accompanied by a reduction in the number of required operators with respect to parts-to-picker solutions. Six companies (i.e. 15% of the examined set) are planning to reduce the percentage of their operations handled manually by picker-to-parts systems and adopt partially automated parts-to-picker systems, e.g. with AS/RS (i.e. in 7 warehouses). These partially automated solutions mainly consist of AS/RS or miniloads with one or more automated cranes, and they have been adopted in different industry sectors. For instance, Granarolo has implemented an AS/RS parts-to-picker system for chilled products (i.e. yoghurt), whereas Ambrovit, Caleffi, Sirman, and SIT are examples where parts-to-picker OPS were implemented in the industrial components and machinery sector. Automation in frozen-product contexts was also observed (i.e. Polo).

The literature review confirmed that there are still a limited number of studies on pick-to-box and pick-and-sort systems, as previously observed by Marchet, Melacini, and Perotti (2011) and Melacini, Perotti, and Tumino (2011). As far as the examined companies are concerned, these OPS were present at 7 and 3 large distribution warehouses (i.e. floor area $\geq 10,000$ square metres), respectively. According to Dallari, Marchet, and Melacini (2009), pick-to-box as well as pick-and-sort systems have been observed where there are high picking volumes (i.e. from 10,000 to 100,000 order lines per day for the examined warehouses), small-sized customer orders, and a large number of SKUs (i.e. from 10,000 to 100,000), as illustrated in Figure 2. Pick-to-box systems are particularly valuable thanks to their flexibility with respect to pickers' workload, which may be adapted or re-balanced when required. It should be noted that in the 11 warehouses with pick-to-box and pick-and-sort systems, other OPS are also used. Specifi-cally, seven have also implemented picker-to-parts systems, one has a parts-to-picker system, and five have automated picking solutions as well. Where both pick-to-box and picker-to-parts systems are concurrently present, picker-to-parts systems are used for items that are not suit-able for pick-to-box and pick-and-sort systems (e.g. bulky, heavy, and fragile, with low picking volume). An example of a warehouse where both pick-and-sort and parts-to-picker systems are concurrently used is provided by Norbert Dentressangle (i.e. warehouse for fashion products). After receiving, goods (i.e. 70% of the overall inbound flow) are subject to deconsolidation, then sorted by means of a cross-belt pick-and-sort system, and eventually stored into a miniload with three aisles and three cranes. They are finally retrieved and consolidated into multi-product pallets.

Finally, the literature review revealed that completely automated OPS are little widespread because of high investment costs and the specific contexts in which they may be appropriate (Baker and Halim 2007); therefore, very few studies are available on this topic. The empirical analysis showed that 9 warehouses (i.e. 22.5% of the total sample) have adopted this type of OPS, mainly using A-frame dispensers or robots. In some contexts, the selection of highly automated OPS seems very common, thus to compete in specific industries such as medical or pharmaceutical products. These contexts are characterised by high-value, small-sized, not fragile, standard-shaped items and have constraints on delivery times and accuracy. The case studies examined showed the presence of highly automated OPS in this industry (e.g. distributors such as CEF, Unico, and Unifarm), where most of the companies have adopted one (or more) A-frame dispenser(s) for high-volume item picking. This result is consistent with the scientific literature (e.g. Van den Berg and Zijm 1999; Dallari, Marchet, and Melacini 2009).

Finally, the adoption of other completely automated OPS (i.e. robots) is limited in the warehouses examined, due to the high investment costs and the specificity of the contexts in which they may be suitable. An interesting example of complete automation is C.D.Verte (videogames and accessories) where the warehouse has a one-aisle miniload. All the storage and retrieval transac-tions from/to the miniload are performed by means of an automated material handling device (i.e. a 'shuttle') that connects the miniload to two automated picking stations where robots perform the picking activities. The solution is completed by an automated end line for labelling and ship-ping. Elsewhere, companies generally tend to perform picking activities either manually (such as by means of conventional picker-to-parts systems and fork lift trucks or commissioners, i.e. high-level order picking trucks) or supported by partial automation (e.g. parts-to-picker systems with miniload or AS/RS, or pick-to-box systems).

4.3. *Implementation process: motivations and hurdles to OPS adoption*

The empirical results seem to confirm and build on previous literature (e.g. Baker and Halim 2007) dealing with motivations leading to automated OPS adoption. The foremost reasons for OPS adoption are coping with the company business growth and increasing company competitiveness, mainly by means of improving efficiency (e.g. operational cost reduction and space optimisation) and increasing the customer service level (e.g. higher picking accuracy and shorter delivery response times). Other major motivations are related to regulatory or operational constraints (e.g. reduction in the required delivery response time and drastic changes in handled volumes and number of SKUs), striving for warehouse optimisation (e.g. personnel reduction and picking error decrease), and, finally, the search for higher personnel safety and comfort.

ICT-based systems are typically implemented alongside OPS to improve item traceability in different areas of the warehouse, increase process monitoring (e.g. by means of metrics and indicators to be continually monitored), improve picking times and accuracy, and reduce picking errors - which are traditionally associated with highly manual operations. These results are consistent with previous studies (e.g. Brynzér and Johansson 1995; Poon et al. 2009).

The empirical analysis revealed a number of barriers and challenges related to the adoption of automated (or partially automated) OPS. First, in some cases companies are put off by significant investment costs and are concerned that the planning and start-up costs for new solutions are too high with respect to the potential savings in operational costs. In some other cases, according to Baker and Halim (2007), one of the barriers is the concern at some companies about losing flexibility in the long term. This concern has been identified particularly in operational contexts with high variability (e.g. in terms of number of daily order lines to be picked and inventory levels). In those cases the implementation of automated solutions tends to be difficult, as it gets complicated and expensive to assure system 'adaptability' in the event of potential new business requirements.

In addition, some concerns about the implementation phase have been pointed out (e.g. long start-up times and related problems). These include concerns about downtime during the start-up phase and, specifically, companies fear a potential reduction in service level in the medium or short term, as found previously in the literature (e.g. Hackman et al. 2001; Baker and Halim 2007). A further barrier preventing automated (or partially automated) OPS adoption is system reliability: there are concerns that unexpected problems or system malfunctions may hinder daily operations. Moreover, a certain reluctance to change has been observed in one or more company business units. Many of the above-mentioned hurdles might be avoided or at least mitigated by promoting information sharing and carefully programming the OPS start-up phase.

5. Conclusions and further research

The study builds on the existing literature (e.g. Baker and Halim 2007; Dallari, Marchet, and Melacini 2009) and contributes to the warehouse automation research stream. The decision to conduct a study on such a topic is based on multiple reasons. First, picking activities have a key role in warehousing operations in terms of both costs and service level – still, companies often perceive difficulties in identifying the suitable OPS based on the specific context they operate in. Second, despite its importance, warehouse automation has been little investigated so far and has been mainly tackled in general terms in previous literature.

Based on these premises, the aim of this paper was to investigate the state of the art in the adoption of OPS and provide a broad empirical analysis by examining a cross-section of 40 warehouses located in Italy. The results emerged from the study were discussed and compared to the scientific literature on this topic.

Overall, the research shows a substantial interest towards the implementation of automated solutions and ICT applications supporting picking activities, in line with Hou, Wu, and Wu (2009). This is reflected by the number of automated solutions that companies have recently implemented with respect to the fully manual solutions used in the past. The main purpose of automated OPS essentially lies in speeding up the processes and reducing picking errors traditionally associated with high conventional manual solutions. A particular attention has been also highlighted towards flexibility, mainly in terms of system 'adaptability' to respond to potential changes in the business environment (e.g. changes in picking volumes or number of SKUs). Focusing on automation in terms of ICT-based devices, the main reasons towards implementation essentially lie in increasing picking process efficiency and effectiveness.

Some key highlights have also emerged concerning the use of the different OPS. In warehouses with a low picking volume and small order size, conventional picker-to-parts systems are still widespread, although several companies have declared to have recently shifted to parts-to-picker systems because of an increase in the number of SKUs. Pick-to-box and pick-and-sort systems are relatively common in various industry sectors with a large number of SKUs, high picking volume, and small order size. Finally, some types of fully automated OPS are frequently adopted in specific industry sectors, but are often hampered by investment costs elsewhere.

Looking at the OPS adoption process, the main motivations leading to automated OPS are related to improvements in efficiency (e.g. cost reduction and space optimisation) and effectiveness (e.g. better picking accuracy and shorter delivery response times). As for the barriers and challenges that currently hamper the adoption of automated OPS, they are mainly related to investment costs, difficulties in the implementation process, and concerns about a loss of flexibility.

This study has some limitations that should be mentioned. First, the case study design was necessarily biased towards companies willing to discuss and share information openly. Since data were collected through interviews, the information used in the evaluation could be biased by interviewees' perceptions. Second, results in terms of OPS adoption are necessarily related to both energy costs and personnel costs and strictly depend on the company operating context (for instance, the Italian context is generally characterised by relatively high labour flexibility and low labour costs). Third, the implementation of a certain OPS does not necessarily imply its suitability. To this extent, it might be useful to develop tools for assessing the actual effectiveness of the implemented picking solutions varying the specific context requirements (e.g. country and company operating environment).

However, the results provide an interesting insight into OPS adoption and pave the way for further research in OPS investigation. A key element that has emerged lies in system flexibility. From this perspective, it might be useful to better investigate how and when the different OPS may contribute in terms of flexibility. Finally, the environmental dimension has been generally disre-garded when deciding OPS adoption, mostly because of a lack of appropriate tools and metrics.

In this regard, additional research may be recommended to adequately include this perspective in the analysis.

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