Int J Adv Manuf Technol (2009) 42:1–12
DOI 10.1007/s00170-008-1571-9

ORIGINAL ARTICLE

Design of order picking system

Fabrizio Dallari · Gino Marchet · Marco Melacini

Received: 31 July 2007 / Accepted: 14 May 2008 / Published online: 17 June 2008
© Springer-Verlag London Limited 2008

Abstract Numerous design and cost parameters, combined with an endless variety of equipment types, make it difficult to choose the right order picking system (OPS). The purpose of this study is to develop a methodology to support warehouse designers in choosing the most suitable OPS. By developing a new OPS classification, we carried out an in-depth survey on over 68 distribution centres that have been recently built in Italy. The results of the critical analysis allowed developing a design methodology to choose the most suitable OPS. This methodology has been integrated in the structured procedure for OPS design, developed by Yoon and Sharp (*IIE Trans* 28:379–389, 1996). Finally, a numerical case study is presented to illustrate the application of the proposed design methodology.

Keywords Order picking · Automation · Warehousing · Survey · Case study

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 [1]. Picking activity is achieving more and more a crucial role in supply chain management, both from the production system point of view (i.e. the supply of assembly stations with assembly kits) and from the point of view of the physical distribution activities (i.e. customer order fulfilment). In fact, this activity, highly labour intensive, deeply impacts on both overall logistic costs and the service level provided to the customer. In many cases, costs related to the order picking activity impact for more than a half of the total warehousing cost [2, 3].

The relevance and the complexity of the topic induced material handling system providers to increase their product range and, at the same time, stimulated researchers to develop numerous policies to increase optimise order picking system (OPS) performances [4]. At present, most of OPSs are designed on the basis of insights, experience and, sometimes, on a detailed simulation. There exists a need for a design methodology that requires, at least in the OPS selection phase, fewer detailed data and shorter time-to-design [5].

In the literature, there are many policies to improve order picking productivity (e.g. sequencing, batching and sorting and items allocation in the forward area) and to design the forward area [6–12]. These studies are referred to a certain picking system. However, even though warehouse design is a key activity in logistics systems modelling, OPS design has not been frequently studied in literature [5]. Most of the research focuses on a specific OPS or a given design issue, while overall design procedures and global optimisation models for order picking are still lacking [3]. The most considerable studies to propose a structured methodology for OPS design can be found in the papers by Georgia Tech University researchers [5, 13, 14]. Yoon and Sharp [14] presented an original structured procedure for OPS design, based on iterative top–down decomposition and bottom–up modification. That procedure reflects the most common modus operandi of OPS designers by analysing the solutions

F. Dallari
Logistic Research Center, Carlo Cattaneo University—LIUC, Castellanza, Italy

G. Marchet · M. Melacini (✉)
Department of Management, Economics and Industrial Engineering, Politecnico di Milano,
Milan, Italy
e-mail: marco.melacini@polimi.it

for each functional area, called subsystem, followed by a reconciliation.

In this paper, we resume the design procedure for OPS proposed by Yoon and Sharp [14]. The aim is to integrate their design procedure by developing a new design methodology to support warehouse designer in the initial phase, when characteristics of each OPS subsystem have to be defined. To this extent, we start by pointing out the main aspects of the methodology proposed by Yoon and Sharp (Section 2). Then, we propose a reclassification of OPS (Section 3), and finally, we present the results of an empirical analysis on the OPS application fields, carried out on a sample of over 68 Italian warehouses (Section 4). On the basis of the critical analysis of empirical results and starting from the decisional process proposed by Yoon and Sharp, we propose a new design methodology for OPS (Section 5). Finally (Section 6), a numerical case study is presented to illustrate the proposed design methodology, followed by a discussion on conclusions and further research (Section 7).

2 Review of order picking system design

The design of OPS is a very complex task, depending on several elements: 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. a case pick area for fast moving products and another for slow moving ones), different combination of equipment types (e.g. within case picking area for slow moving products, we could use a picker-to-part system or a miniload) and operating policies for each functional area (e.g. pick by order or pick by item).

The most comprehensive work on designing OPS can be considered the one by Yoon and Sharp [14], which developed a cognitive procedure based on a top–down decomposition and a bottom–up modification (Fig. 1).

Hereafter, the main elements of the proposed procedure are reported, outlining the most critical aspects to further identify potential improvements.

They subdivide the design process in three main phases: input stage, selection stage and evaluation stage. In the input stage, a few managerial considerations (e.g. budget and project life), operational constraints (e.g. total area available, ceiling height and number of shifts) and transaction data on customer order and products are taken into account. Moving from this first stage, the specification of overall OPS structure (e.g. number of subsystems) and the requirements of each subsystem (e.g. flow in terms of pallets, cases or items, number of stock keeping units and suborders) are derived.

In the selection stage, the designer has to choose the features of each subsystem with reference to equipment type

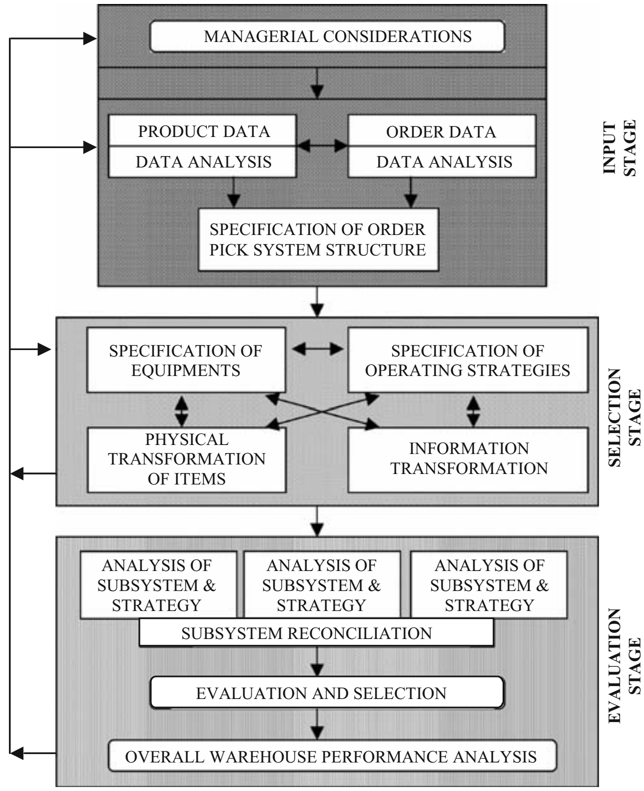


Fig. 1 Procedure for OPS design [14]

(e.g. gravity flow rack and order picker trucks) and operating policies (e.g. storage and retrieval rules). This analysis is accompanied by the definition of physical transformation of items and by the study of information transformation.

In the final evaluation stage, there is quantitative and qualitative reconciliation of the different subsystems. This may lead to a further selection and specification.

In the above procedure, the steps inside the selection stage might be more deeply defined. In particular, the process leading to the identification of the specific solutions to be examined is not clear. From one side, the warehouse designers are always concerned with the risk of missing potentially interesting alternatives. From the other, there is the risk to be forced to generate a considerable number of alternatives, consequently increasing time and costs of this phase. The higher the detail level of the description (e.g. storage and routing rules), the higher the aforementioned risk. To illustrate this, the case study presented in another work by Yoon and Sharp [13] can be considered. The case study presents a numerical example to illustrate the above described procedure for OPS design. In this paper, they identify and evaluate a few alternatives for each subsystem, for a total of seven different alternatives. Notwithstanding the seven alternatives have been examined analytically and not through simulation, there is a remarkable processing time. Furthermore, there is no evidence of the reasons that lead to the selection of those OPS alternatives.

Definitely, the identification of alternative OPS is one of the most critical phases of the overall design process, as it requires to solve the trade-off between the completeness and the cost of the analysis (i.e. from identifying all possible alternatives to examining only one). In this sense, further on in this work, we will develop and propose an analysis on the application fields of OPSs. Secondly, in the proposed procedure, the size of the picking area (called also forward area) is assumed as a given value, connected with the stock cover. Conversely, in the literature, there are some studies [6, 7] showing that the size of the picking area can be derived from the optimisation of handling costs (known as the forward reserve problem).

3 Order picking system classification

A variety of OPSs can be found in warehouses. To better identify the application fields for each OPS, a new classification is proposed that focuses chiefly on the operational policy rather than on the specific equipment type adopted. Moving from the original classification proposed by Sharp [15], recently reviewed by De Koster et al. [3], we propose a classification of OPSs into five main groups (Fig. 2):

- "Picker-to-parts" system
- "Pick-to-box" system
- "Pick-and-sort" system
- "Parts-to-picker" system
- "Completely automated picking" system (e.g. robots or dispensers)

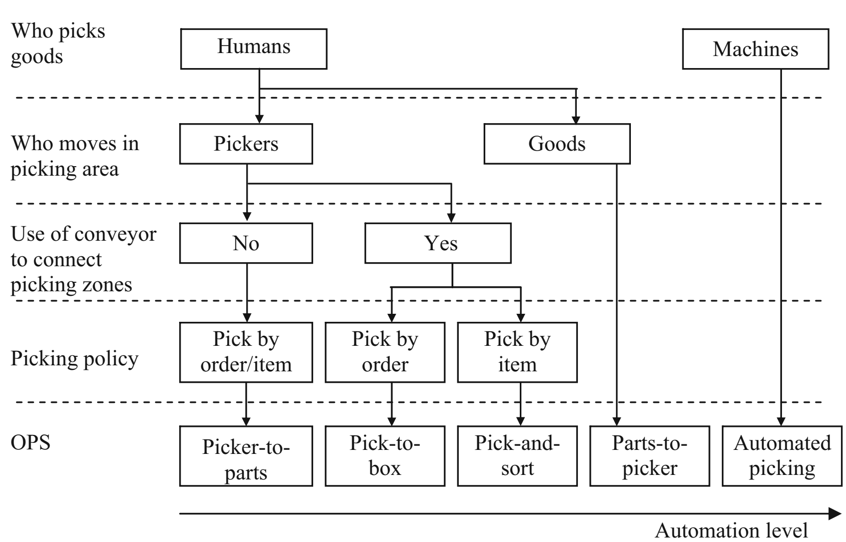
OPSs are classified accordingly with four main decisions: who picks goods (humans/machines), who moves in picking area (pickers/goods), if conveyors are used to connect each picking zone and which picking policy is employed (pick by order or by item). Automation level increases, ranging from the "picker-to-parts" system to the "completely automated picking" one. As stated above, the classification does not consider the single equipment type to be used but the operational policy. For instance, in the "parts-to-picker" system, it is possible to use both mini-loads [i.e. an automated storage and retrieval systems (AS/RS) designed for the storage and the order picking of small items, stored in modular storage drawers or bins] and modular vertical lift modules.

Each OPS will be briefly described on the basis of both the equipment components and the resource requirements (labour, space and capital). In the following sections of this paper, the "completely automated picking" system will not be considered, as it is employed in very limited contexts. Therefore, we will specifically focus on the remaining four OPS groups.

3.1 "Picker-to-parts" system

"Picker-to-parts" system represents the very large majority of picking systems in warehouses [3]. It can be considered as the basic system for the picking activity. In such system, 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. In the batch picking policy, the picked items are immediately sorted by the picker (sort-while-pick system). We can distinguish two types of picker-to-parts systems: low- and high-level picking [11, 16, 17]. In low-level order picking systems, items are picked from picking locations (e.g. racks, gravity flow racks and bins) while travelling along the aisles. The second, called also man-on-board OPS, employs high

Fig. 2 Classification of order picking systems



storage racks in which picking locations are visited by pickers on board of an order-pick truck. Picking area is usually separated from the storage area; this allows retrieving customer orders in a smaller area if compared to the storage one. In the "picker-to-parts" system, further optimisation can be carried out by means of routing algorithms, items allocation policies and paperless operations using radio frequency or voice picking devices. Therefore, the order picking productivity strongly depends on also the utilisation of the aforementioned optimisation drivers.

3.2 "Pick-to-box" system

"Pick-to-box" system (also known as "pick-and-pass" system) divides the picking area in zones, each of them 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, each of them corresponding (partially or completely) to a customer order ("order picking" policy). According to process sequence, zoning can be classified as progressive zoning: Customer orders are sequentially picked zone by zone [18]. Therefore, a line-end sorting per each order is not necessary, as the orders have already been prepared in boxes that will be sorted for their destination (e.g. carrier). The resulting advantages of separating the forward area in multiple picking zones mainly lay in the reduction of the overall picker travel time. The costs and complexity of these OPS are related to workload balancing among the multiple picking zones. This solution seems to be preferable in case of high number of small-sized items, medium-size flows and small order size. Indeed, an increase of the order size might determine a growing complexity in the management of the higher number of boxes flowing through the warehouse.

3.3 "Pick-and-sort" system

Operators in the picking area retrieve the amount of each single item resulting from the batching of multiple 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 refers to an individual customer order. A "pick-and-sort" system typically works with pick waves, where all of the orders in a pick wave are completely sorted before releasing the following pick wave. As a consequence within this OPS, the batch size is consistently high (i.e. at least 20 customer orders per pick wave). The takeaway conveyor is usually close to the aisles of the forward area so that each picker can operate in a small part of the forward area [18]. Concerning the picking activity, the productivity is higher than the one usually measured within "picker-to-parts" system, as the picking locations are visited less frequently[1], therefore reducing the pickers travel time. Such reduction is greater as far as the pickers operate in a small part of the forward area. When designing a "pick-and-sort" system, great attention must be paid on trade-offs between picking and packing efficiencies [19]. In addition, the larger trade-off between the capital costs involved with implementing an automated sorter and the labour saving it will reap must be carefully weighed. This solution seems to be preferable in case of high overlapping of order lines, a high outflow and absence of brittle products.

3.4 "Parts-to-picker" system

In "parts-to-picker" system, an automatic 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. Afterward, the unit loads, if not empty, are conveyed back to the storage area. Potential equipment types for storage area are: carousels, modular vertical lift modules, miniloads, and AS/RS [20, 21]. The advantage of this system derives from the picking cost reduction (i.e. in terms of labour hours and space required). Nevertheless, this system presents a high risk of creating bottlenecks in feeding the picking bays, reducing the picker's utilisation and then picking productivity. This OPS seems to be preferable in case of a large number of items and small outflow.

The aforementioned classification of OPSs into four groups, carried out with respect to different operating conditions, will be used in the next section to compare alternative application fields.

4 Empirical analysis of order picking systems

We analysed the most recent warehouses that have been built in Italy between 2002 and 2006 to identify the main drivers affecting the choice of an OPS. We considered only recent warehouses because a change in business requirements could reduce effectiveness in older warehouses.

We obtained data mainly from three relevant Italian logistics trade journals[2], which periodically publish a report on the warehouses lately built, along with a brief description of their main features. In case of lack of information, either the material handling providers or the company warehouse managers were interviewed. We collected data on 68

[1] Number of picks from a location is also function of the number of pick-waves.

[2] Logistica, Logistica Management, Il Giornale della Logistica

warehouse facilities, belonging to companies with revenues greater than 10 million euro, operating in different industries (i.e. consumer packaged goods, pharmaceutical, high tech and electronics, textile and apparel and mechanical). In this way, we avoided studying situations in which the investment in automated OPS would represent a too large part of the revenues.

A recent survey about warehouse organisation was recently performed by Warehousing Education and Research Council (WERC) resulting in about 120 cases investigated [22]. Considering that the 68 warehouses investigated in our research are among the best practice in the country, which is notably made of small- and medium-sized companies, we believed that sample is sufficient and unlikely extendable. The possibility that the cases investigated do not employ the optimal OPS is smoothed by sample size and relevance of the companies in their respective industry.

Each warehouse has been classified according to the following criteria:

- General information: company details, industry, start-up year, provider of material handling system and equipment
- OPS group: “picker-to-parts”, “pick-to-box”, “pick-and-sort” and “parts-to-picker”
- Material handling requirements:
  - Number of items
  - Picking rate
  - Outflow
  - Order size
  - Response time
  - Unit load (i.e. pallet, box, carton, tote and piece)
- Other storage needs (e.g. hazardous materials, perishable goods)

We did not include either economic nor environment constraints (i.e. payback time, discount rate and building dimensions) because they could be enablers or not, according to the specific context.

Collected data represent average values and not distributions, as it has been difficult to obtain data with higher detail level. Moreover, during the initial phase of OPS selection, average values allow having a good description of the system requirements; the following analysis in design process will lead to a more detailed picture.

We analysed the relationship between the four OPSs and the material handling requirements. When more than one OPS was identified in a warehouse, data were decomposed for each OPS. The most significant results emerged considering the relationship of the four OPSs with respect to two dimensions: the picking rate (expressed by order lines picked per day) and the number of items managed in the picking area. These material handling requirements have been considered in the literature as typical warehouse complexity factors [23].

The analysis has been developed with two detail levels to assess the relationship among OPSs and the aforementioned dimensions, considering:

- The whole sample of cases (aggregated analysis)
- A subset of cases according to customer order size (segmented analysis)

In the aggregated analysis, the 68 analysed warehouses have been included and plotted on a scatter diagram (Fig. 3), build considering the number of items on the x-axis and the picking volume (number of order lines per day) on the y-axis. Because of the high data concentration, the logarithmic scale has been used for both dimensions.

Fig. 3 Empirical analysis of investigated order picking systems

Statistical data analysis has been performed according to two different approaches:

– By studying the characteristics of the population, having inference on the examined sample, supposing an unknown variance [24]
– By assessing the use or not of one of the examined OPS through the logit model; that is to say, the computation of the probability of choosing one of the OPS (binary variable $Y = 1$) when changing material handling requirements [25]:

$$\mathrm{Prob}(Y = 1|X) = \frac{e^{X'\beta}}{1 + e^{X'\beta}} \tag{1}$$

where:

Y adoption of an OPS
X row vector of material handling requirements (daily order lines and number of items) that explain the choice of OPS
X' column vector of material handling requirements (daily order lines and number of items) that explain the choice of OPS
β set of parameters that reflect the impact of changes in X' on the probability

Statistical analysis has been made with Minitab 14.0. There are three main findings:

1. When the number of items is lower than 1,000, order picking follows a "picker-to-parts" approach anyway. With high significance (p value lower than 0.001), we can say this OPS is used when the number of items is lower than 1,000. As shown in Fig. 4, the probability to use this OPS is very high when number of items is lower than 1,000, although it is employed also when the number of items is higher than 1,000.
2. High incidence of "parts-to-picker" system can be observed in case of large number of items and quite small number of order lines per day. With high significance (p value equal to 0.000014), we can state that this OPS is used when the number of items is higher than 1,000. At the same time, this OPS does not fit when the number of order lines picked per day increases (Fig. 5). In fact, the higher number of items makes it critical to manage the picking area (in terms of space and handling activities) using a "picker-to-parts" system. Furthermore, there is a physical constraint to employ "parts-to-picker" system due to the resulting higher replenishment flow towards the picking bays.
3. "Pick-and-sort" and "pick-to-box" systems are found when both picking rate and number of items are high. We can assert with a high significance level that these two OPSs are used when the number of order lines per day is higher than 1,000 (p value equal to 0.000022) and the number of items is higher than 1,000 (p value equal to 0.00006).

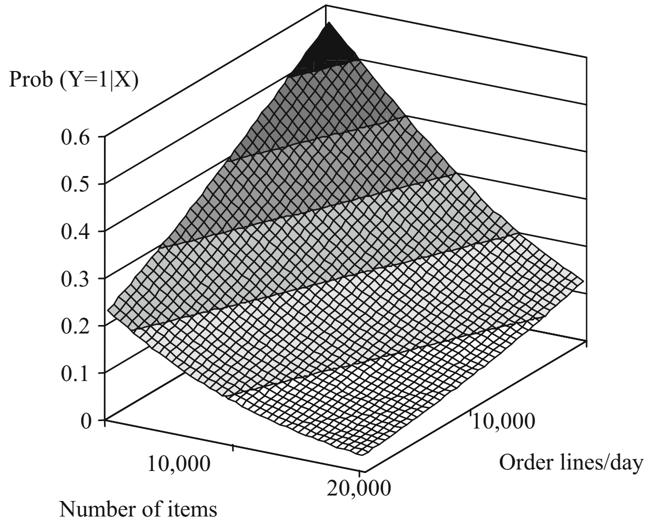


Fig. 4 Probability to use "picker-to-parts" system, varying number of daily order lines and number of items (β_0=0.26676, p value=0.545; β_1 (coefficient of the variable "number of items")=−0.00011, p value=0.029; β_2 (coefficient of the variable "order lines/day")=−0.00007, p value=0.203)

As far as the segmented analysis is concerned, we studied OPSs also with respect to the customer order size, expressed in terms of cubic volume. Two main order classes have been defined:

1. *Small orders*: when average order volume is lower than (or equal to) 0.5 m^3

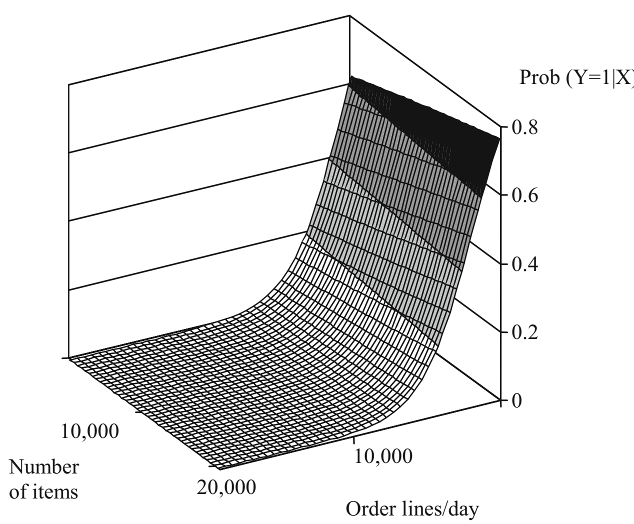


Fig. 5 Probability to use "parts-to-picker" system, varying number of daily order lines and number of items (β_0=−0.515, p value=0.26; β_1 (coefficient of the variable "number of items")=0.0000318, p value=0.127; β_2 (coefficient of the variable "order lines/day")=−0.0005867, p value=0.003)

2. *Large orders*: when average order volume is higher than 0.5 m^3

The threshold value of 0.5 m^3 approximately represents the half size of a palletised unit load. Indeed, given the same number of daily order lines, the higher the average order volume, the larger the outflows, consequently reducing the effectiveness of automated OPSs.

In performing the segmented analysis, we considered a sample composed of 48 warehouses out of 68: indeed, information for the remaining 20 cases was not available. Consequently, the resulting smaller number of cases prevents from supporting statistically some evidences of the analysis. The results of the study highlight (Figs. 6 and 7):

1. "Pick-to-box" system is used only when the average order size is lower than 0.5 m ^{3}. The occurrence of this OPS is high in those cases with small orders because this system is often implemented when one or few pieces are picked for each item and when there is a large number of items.
2. "Picker-to-parts" system is used either for small or large orders. In the latter case, this OPS occurs regardless the number of order lines picked per day and the number of items managed. In fact, a larger order size makes the implementation of optimising techniques easier (e.g. warehouses in the retail industry are mainly managed according to this OPS, along with "zone picking" policy).
3. "Parts-to-picker" system is used either for small or for large orders. The same percentage of occurrences was found with both large and small orders.

Both aggregated and segmented analysis highlight the relevance of the number of daily order lines and of the number of items as variables driving the choice of the most suitable OPS. By taking into account also the average order size, we are able to identify the application fields for OPSs, as shown in Figs. 6 and 7. These application fields are the result of the in-depth analysis of 68 recently built warehouses, validated by means of a focus group involving both logistics managers and material handling providers. The results of the analysis have been used to draw a taxonomy for OPS choice to be further evaluated in details in the project phase (see next section). The proposed taxonomy must be considered as a tool for identifying OPS groups, even though there are contexts where the choice of OPS is not so well defined, resulting in a overlapping of application fields. As far as the "pick-and-sort" system is concerned, it should be remarked that there are no statistical evidences on its right application field. Consequently, we will consider this OPS jointly with "pick-to-box".

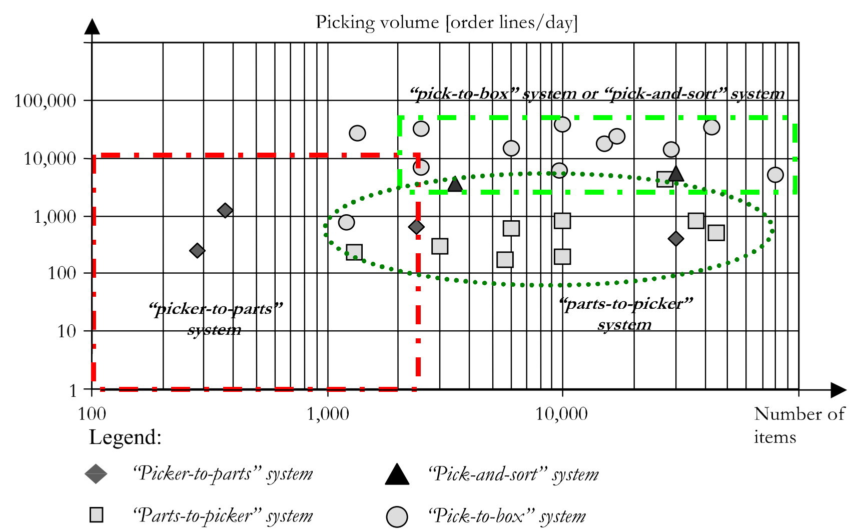
5 A methodology for order picking system design

Moving from the original procedure by Yoon and Sharp [14], we propose a new OPS design methodology composed by four stages (Fig. 8):

– Input stage
– Selection stage
– Evaluation stage
– Detail stage

As the input and the evaluation stages follow precisely in content what already proposed in [14], we will concentrate on the description of the stages that have been introduced or modified.

Fig. 6 OPS matrix, when order size is lower than 0.5 m^3



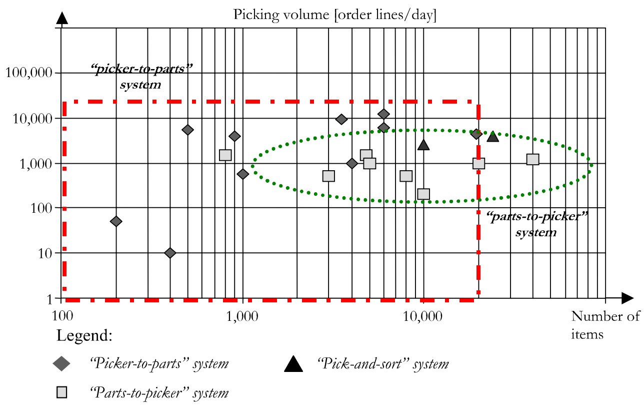


Fig. 7 OPS matrix, when order size is higher than 0.5 m^3

5.1 Selection stage

This stage must be carried out for each identified subsystem. It consists of three sequential steps, namely OPS identification, equipment type requirements and design of the forward area (e.g. size and number of pickers per shift). Even in this case it is theoretically possible that the result of an analysis leads to change the decisions previously made.

5.1.1 Identification of OPS

In the selection stage, the first step is to identify the most suitable OPS (“picker-to-parts”, “pick-to-box”, “pick-and-sort”, “parts-to-picker” and “completely automated picking” system) for the examined subsystem. The results coming from the in-field analysis have shown two different situations in OPS design, respectively for small and large size orders. In the first case (as shown in Fig. 6), it is suitable to use “pick-to-box” system and ”pick-and-sort” system for a large number of retrieval operations (order lines picked per day) and a large number of items. The difference between these OPS groups is mainly related to the number of managed items. Indeed, as the number of items increases, the “pick-and-sort” system is less performing than “pick-to-box” because of the reduced overlap among order lines. Furthermore, the “pick-to-box” system is more suitable for the retrieval of small items. Conversely, in case of relatively small number of order lines picked per day, it seems suitable to adopt a “picker-to-parts” system. This OPS represents an appropriate solution especially when the number of items is low (less than 1,000). The “parts-to-picker” system represents an intermediate option, as its application field is identified by a significant number of items (higher than 1,000) and a relatively small number of order lines (about 1,000–2,000 order lines per day).

The most suitable solution for large size orders in most cases seems to be the “picker-to-parts” system (Fig. 7). The higher the order size, the more significant the consequent advantage in adopting this system. In fact, as above-mentioned, a large order size allows to apply effectively optimisation techniques, such as the zone-picking policy. However, it could be necessary to use the “parts-to-picker” system in case of large number of items (higher than 1,000) and relatively small number of order lines (about 1,000–2,000 order lines per day).

Besides the aforementioned aspects, in this stage, other factors must be taken into account, which are harder to generalise, such as the unit labour cost and the risk attitude of the company (i.e. payback time). For instance, the “picker-to-parts” system is the most widespread system across logistics service providers operating in Italy, even when it is not the most suitable solution. The wide diffusion of this system is due to its remarkable operating flexibility, well fitting for the short average outsourcing contract

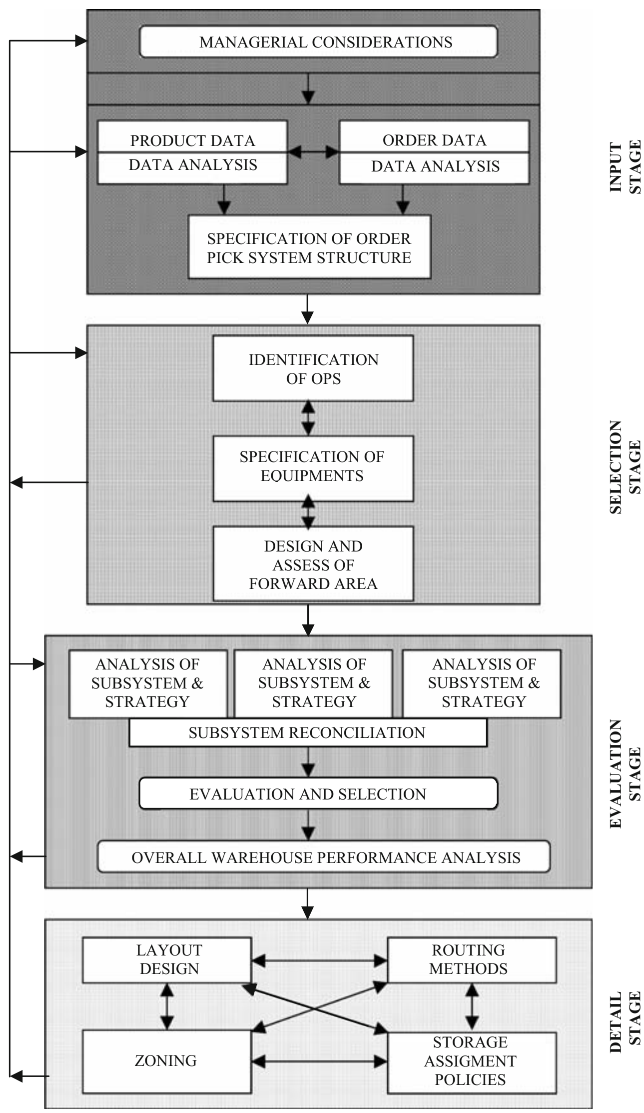


Fig. 8 OPS design methodology

Table 1 List of main managerial considerations and operational constraints for Company S

Consideration and constraints	
1. Economic constraints:	
1.1 Initial investment budget	About 4 million €
1.2 Annual budget	NA
1.3 System installation deadline	1 year
1.4 Project life	8 years
1.5 Depreciation methods	NA
1.6 Marginal tax rate	NA
1.7 Minimum attractive rate of return	NA
1.8 Payback period	3 years
2. Environmental constraints	
2.1 Total space available	12,000 m^2
2.2.Ceiling height	9 m
2.3 Building layout	rectangular
2.4 Noise restriction	NA
2.5 Fire hazard regulations	NA
3. System requirements	
3.1 Response time for orders	8 h
3.2 Number of orders per shift	1,000
3.3 Number of order lines per shift	10,000
4. Operational constraints	
4.1 Shift length	8 h
4.2 Number of shifts per day	1
4.3 Working days per year	250
4.4 Number of products groups	3
4.5 Number of order classes	1
4.6 Operator utilization factor	0.8

length. As these factors should have been already considered in the input stage, the purpose is now to choose the best solution among the feasible ones, on the basis of the design elements collected in the input stage.

5.1.2 Specification of equipments

Once the more suitable OPS group has been identified, it is possible to choose the specific equipment type. This choice has to consider, once again, the material handling requirements such as subsystem capacity and daily outflow to find the technical solution that better fits the problem. For example, once it has been understood that the solution might be a "parts-to-picker" system along with a pick by order policy, it will be possible to evaluate the use of a horizontal carousel or a miniload, by defining the basic characteristics for each solution (e.g. if a single or double shuttle miniload should be employed).

5.1.3 Design of the forward area

Once the OPS and the equipment type have been defined, it is necessary to evaluate the subsystem size (i.e. number and size of picking locations and size of forward area) and its performances (i.e. response time, picking rate and number of pickers). The evaluation of the picking area needs the resolution of the forward reserve problem, deciding the quantity of each item to be placed in the forward area, balancing additional replenishment efforts over extra pick effort savings [6, 7, 26]. To evaluate system performances, the analytical models found in literature could be used [10, 11, 13, 18, 27].

5.2 Detail stage

At the end of the evaluation stage, it is necessary to detail the characteristics of each subsystem, trying to optimise as much as possible the performances (detail stage). This requires an in-depth study of the aspects connected with layout design, storage and routing policies and zoning (e.g. zone size) in a context where the main characteristics of the system have already been defined. For example, when a low-level manual OPS is employed, layout design concerns the determination of the number of blocks and the number, length and width of aisles in each block [11]. Some decisions previously taken for the performance assessment may be refined (e.g. batch size and length of pick wave and number of zones) and the more operational issues of the OPS can be treated in detail (e.g. routing policies and replenishment policies). Evidently, these issues have been considered also in the previous phases but with a low-level detail. At this stage, the issues deriving from the previous stages can be further studied and refined starting from the viewpoint of system performance improvement. It is possible, although less likely, that the result of this optimisation process leads to outline new needs concerning the overall system framework. In this case, it will be necessary to come back and review, partially or wholly, the decisions made. To maximise the outcome of the detail design, it is necessary to consider the joint adoption of the aforementioned levers, due to the strict

Table 2 Item groups description

	Group number		
	1	2	3
Average product size (dm^3)	3	20	500
Number of sku	9,000	1,500	300
Number of order lines per shift	7,450	2,500	50
Quantity retrieved per order line	8	2	1
Group specification criteria	Product size	Product size	Product size

Table 3 Subsystem specifications

	Subsystem			
	1	1	2	3
Department (area)	Fast item pick	Item pick	Case pick	Case pick
Group number	1	1	2	3
OPS	Pick-to-box	Pick-to-box	Picker-to-parts	Picker-to-parts
Equipment	Flow racks	Flow racks	Pallet racks	Pallet racks
	Racks	Racks	Order picker trucks	Order picker trucks
	Conveyor	Conveyor	RF terminals	RF terminals
	“Pick to light” systems	RF terminals		
Operating strategy	Order picking and zoning	Order picking and zoning	Batch picking	Order picking

interdependency of their impact on order picking performance [3]. From an operational point of view, in this phase, with more precise edges, having recourse to simulation might turn out as being highly useful.

6 Case study

We present an application of the proposed OPS design methodology. Company S is a national distributor of office supplies (e.g. paper, pens, folders and toners). The company is planning to build a new OPS. In Table 1, we report a list of managerial considerations and operational constraints, according to the scheme proposed in [14]. We identified three product groups above all on the basis of their unit size (Table 2):

- Group 1: Small size items, generally picked by piece
- Group 2: Medium size items, generally picked by cartons
- Group 3: Bulky items

The average order size is generally less than 15 order lines and, as far as group 1 items are concerned, its volume is never higher than 0.05 m^3. Following the proposed taxonomy, when the customer order size is smaller than 0.5 m^3 (Fig. 6), we identified two alternatives: a “pick-to-box” system for group 1 items (9,000 items; 7,450 order lines/day) and a “picker-to-parts” system for both group 2 (1,500 items; 2,500 order lines/day) and group 3 items (300 items; 50 order lines/day).

6.1 Specification of equipments and OPS design for group 1 items

Following the forward reserve problem approach, we considered the daily flow of group 1 items in terms of cubic volume. The analysis showed the presence of a small number of items (about 500) with a significant outflow (higher than 1 m^3 per week) whereas the majority with a smaller one. For items with a significant outflow, we decided for picking locations on gravity flow racks, whereas shelves were chosen for the remaining items. Many of the items assigned to shelves have their overall stock assigned in this area, while for the remaining items, replenishment should be made from the reserve area. Secondly, the analysis on customer orders showed a considerable difference among items: 10% of items account for 70% of order lines. Thus, the introduction of a reduced area (formed by two picking aisles) has been decided, using “pick to light” technology instead of radio frequency terminals. The result of the OPS design is a 4,000 m^2 picking area, operated by 12 pickers.

6.2 Specification of equipments and OPS design for groups 2 and 3 items

Even in this case, we initially considered the volume flow of items. In this case, items are relatively homogeneous and the outflow for each item is higher than 1 m^3 per week. Therefore, a pallet storage location has been assigned to each item, coherently with the unit loads received in the warehouse too (single-item palletised unit loads). The assumed picking system is “picker-to-parts”: the first storage level (and occasionally the second one) is used as forward area, while the upper levels act as reserve area (generally the overall stock quantity per item is less than the

Table 4 Resources for each subsystem

Subsystem	Floor space(m^2)	Number of pickers (FTE)	Number of workers for replenishment (FTE)
1	4.000	12	2
2	6.000	4.5	1
3		0.5	/
Total	10.000	17	3

equivalent of 3 m^3). For group 3 items, order lines are retrieved following the order picking policy. Conversely, order lines are retrieved following a batch picking policy for group 2 items, which are commonly small/medium and characterised by a small order size. The adoption of a "pick by item" policy is also explained by the introduction of a sorter for group 1 items. The result of the decisions made is a 6,000 m^2 picking area, employing five pickers.

6.3 Evaluation and detail stage

After specifying the subsystems in each functional area, the next task is to reconcile the subsystems. Then, the overall performance analysis has to be conducted. The introduction of the sorter in the "pick-to-box" area guarantees the reconciliation of product flows. Currently, there is no need to exactly consolidate the customer order (this activity is postponed to the courier hub).

In Table 3, we summarise the main characteristics of each subsystem, while Table 4 shows the output in terms of used resources. To provide a synthetic illustration of this stage, we avoid including calculations pertaining to the detail stage, which has been carried out to define the operational features of warehouse functionality. The analysis focused on items allocation to picking locations so as to minimise travels and to balance workloads. The results of this stage confirmed the values obtained in previous stages.

The case study has shown how to apply the proposed OPS design methodology. Although the discussion has followed a top–down approach (from the input stage down to the detail stage), by means of the case study, we have been able to test the proposed taxonomy. The aim was to support warehouse designers in choosing the most suitable OPS in the initial design phase, where few detailed data and short time-to-design are available. Furthermore, we validated the proposed OPS design methodology by implementing step by step the four stages.

7 Conclusions and further research

The present study is focused on design of order picking system (OPS). The analysis involved over 68 warehouses representing best performing cases recently built in Italy. Results showed that the number of order lines picked per day, along with the number of items and the average order size, are the key parameters in the OPS selection. To support warehouse designers in the stage of OPS selection, a new taxonomy has been developed. This allowed to complete the original procedure by Yoon and Sharp [14], enriched by inserting forward reserve problem and setting operational policies in the final stage. Afterwards, the new OPS design methodology has been successfully applied to a case study.

The proposed OPS taxonomy resulted from the analysis on a specific sample. We believe that the key findings are reliable, although they must be integrated with a number of other considerations introduced in the input stage (e.g. pay back time, physical constraints and item features). On the contrary, the threshold values in the selection of OPSs partially suffer from the examined sample, thus their use with respect to different industries should be further investigated.

References

1. Ashayeri J, Goetschalckx M (1989) Classification and design of order picking. Logistics Inf Manage 2(2):99–106
2. Drury J (1988) Towards more efficient order picking. IMM Monograph No. 1, The Institute of Materials Management, Cranfield, UK
3. De Koster R, Le-Duc T, Roodbergen K (2007) Design and control of warehouse order picking: a literature review. Eur J Oper Res 182:481–501
4. Van der Berg JP (1999) A literature survey on planning and control of warehousing systems. IIE Trans 31:751–762
5. Goetschalckx M, McGinnis L, Sharp G, Bodner D, Govindaraj T, Huang K (2001) Development of a design methodology for warehousing systems: hierarchical framework. Proceedings of the Industrial Engineering Research, Orlando, FL, USA
6. Frazelle EH, Hackman ST, Passy U, Platzman LK (1994) The forward reserve problem. In: Ciriani TA, Leachman RC (eds) Optimization in industry 2. Wiley, New York, pp 43–61
7. Van der Berg JP, Sharp GP, Gademann AJRM (1998) Forward reserve allocation in a warehouse with unit-load replenishment. Eur J Oper Res 111:98–113
8. Chincholkar AK, Krishnaiah Chetty OV (1996) Simultaneous optimisation of control factors in automated storage and retrieval systems and FMS using stochastic Petri nets and the Taguchi method. Int J Adv Manuf Technol 12(2):137–144
9. Sankar SS, Ponnanbalam SG, Rajendran C (2003) A multi-objective genetic algorithm for scheduling a flexible manufacturing system. Int J Adv Manuf Technol 22(3–4):229–236
10. Caron F, Marchet G, Perego A (1998) Routing policies and COI-based storage policies in picker-to-part systems. Int J Prod Res 36:713–732
11. Caron F, Marchet G, Perego A (2000) Optimal layout in low-level picker-to-part systems. Int J Prod Res 38:101–117
12. Petersen CG (1997) An evaluation of order picking routing policies. Int J Oper Prod Manage 17(1):1096–1111
13. Yoon CS, Sharp GP (1995) Example application of the cognitive design procedure for an order pick system: case study. Eur J Oper Res 87:223–246
14. Yoon CS, Sharp GP (1996) A structured procedure for analysis and design of order pick systems. IIE Trans 28:379–389
15. Sharp GP (1992) Order picking: principles, practices and advanced analysis, perspectives on material handling practice. www.mhia.org
16. Hwang H, Oh YH (2004) An evaluation of routing policies for order-picking operations in low-level picker-to-part system. Int J Prod Res 34(18):3873–3889

17. Dallari F, Marchet G, Ruggeri R (2000) Optimisation of man-on-board automated storage/retrieval systems. Integrated Manuf Syst 11(2):87–93
18. De Koster R, Le-Duc T (2005) Determining number of zones in a pick-and-pack Order picking System. ERIM Report Series Research in Management
19. Russel ML, Meller RD (2003) Cost and throughput modeling of manual and automated order fulfillment systems. IIE Trans 35 (7):589–603
20. Frazelle EH (1996), World-class warehousing. Logistics Resources International
21. Manzini R, Gamberi M, Regattieri A (2005) Design and control of an AS/RS. Int J Adv Manuf Technol 28(7–8):766–774
22. Frazelle EH (2003) Warehouse benchmarking survey. TLI/WERC
23. De Koster R, Warffemius PMJ (2005) American, Asia and third-party international warehouse operations in Europe. Int J Oper Prod Manage 25(8):762–780
24. Montgomery DC, Ranger GC, Hubele NF (2004) Engineering Statistics. John Wiley & Sons
25. Greene WH (2003) Econometric analysis. Prentice Hall, Upper Saddle, NJ
26. Hackman ST, Rosenblatt MJ, Olin JM (1990) Allocating items to an automated storage retrieval system. IIE Trans 22(1):7–14
27. Manzini R, Gamberi M, Persona A, Regattieri A (2006) Design of a class based storage picker to product order picking system. Int J Adv Manuf Technol 32(7–8):811–821