An integrated approach to order picking systems in warehouses

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Abstract: Locating technologies represent one of the main resources and time saving opportunities of the order picking system. The aim of this study is to examine the two types of order picking strategy used in the warehouse of the enterprise from the perspective of time saving. In order to shorten the picking travel time, a change was initiated in the order of products on the order picking list. The order picking list based on the numerical increase of the original ascending code article international identifier was switched to an order picking list based on the alphabetical order of storage locations. Consequently, preparation based on the desired new order picking list is more effective with higher storage location involvement. Employees performing the order picking system can obtain an ideal route with the order picking list based on the ascending alphabetical order of storage location names.

Keywords: warehouse management; order picking list; order picking system; time saving; storage location.

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1 Introduction

The ever increasing trend towards more product variety and short response times (Christopher and Lee, 2004) has placed a tremendous emphasis on the ability to establish smooth and efficient logistic operations. These operations even play a vital role in determining a company's competitiveness, since logistic costs constitute an important part of the overall production costs. The efficiency and effectiveness in any distribution network are in turn largely determined by the operation of the nodes in such a network, i.e., the warehouses. Indeed, the innovations in warehouse technology during the last decade have been numerous (Rouwenhorst et al., 2000; Muppani and Adil, 2008; Yang, 2014; Trab et al., 2015).

Warehouses have been facing various challenges; for example, supply chains are becoming more integrated (Rao and Young, 1994), there is a shorter, globalised operation, customers are more demanding and technology changes are occurring rapidly.

A supply chain is a system that consists of facilities or entities whose activities involve the transformation of raw materials into finished products that are later delivered from the supplier to the end customer (Ahmed et al., 2017). Companies need to have control over their supply chain stages by measuring the supply chain's performance, as well as monitoring its financial indicators to establish successful operations (Sabri et al., 2017).

Carter and Rogers (2008) introduced the concept of sustainability – the integration of environmental, social, and economic criteria that allow an organisation to achieve long-term economic viability – to the logistics literature, and position sustainability within the broader rubric of sustainable supply chain management. According to Näslund

(2002), modern logistics is based on holistic and systemic thinking and uses multi-disciplinary and cross-functional approaches.

In order to cope with these challenges, organisations are adopting innovative approaches such as warehouse management systems (Ramaa et al., 2012). Van Der Vorst and Beulens (2002) suggest that to identify effective supply chain redesign strategies one should focus on the identification and management of the sources of uncertainties in supply chain decision-making processes.

Warehouse management is a critical issue in strengthening company logistics. Furthermore, new developments and trends (Power et al., 2001) in the global economy have had a substantial impact on the order picking process for many warehouses; the demand pattern (customer order characteristics) has changed from a few but large orders, to many but small orders, which have to be processed within very tight time windows. Therefore, simultaneously reducing the cost and increasing the speed of order picking becomes more and more critical (Le-Duc and De Koster, 2005; Tompkins et al., 2010 Richards, 2014).

In order to minimise the throughput time of picking an order while maximising the use of space, equipment and labour, as well as the accessibility to all items, careful design and control of the order picking system (OPS) is necessary. The most common objective of any OPS is to maximise the service level (i.e., factors such as the average and variations of order delivery time, order integrity and accuracy) subject to resource constraints such as labour, machines and capital (Gu et al., 2010). The picking travel time in a warehouse can be shortened in many ways, such as redesigning the layout of racks, assigning better storage places, selecting shorter ordering picking routes and accumulating orders into batches to decrease picking frequency. For an existing pick-by-order warehouse, layout alteration and order batching may not be realistic options.

In this paper, we study the manual picker-to-part order picking process with paper-based pick lists, which is a commonly used method in practice. The manual order picking process typically consists of several tasks, such as setup, travel, search and pick that are carried out by order pickers. The fundamental problem for the investigated tyre manufacturer enterprise is to identify the route that the order picker should follow to access all locations in the shortest possible time and picking travel distance. In order to shorten the picking travel time, we changed the order of products on the order picking list. The order picking list based on the numerical increase of the original ascending code article international (CAI) identifier was switched to an order picking list based on the alphabetical order of storage locations. Thus our research objective is to examine the two types of order picking strategy used in the warehouse of the enterprise from the perspective of time saving. It was also an objective to examine whether picking travel time can be reduced by developing order picking routes. Data are obtained from a real case. The remainder of this paper is organised as follows: Section 2 reviews relevant literature. Section 3 presents the methodology. Results and key findings are presented in Section 4. Section 5 presents this paper's conclusions and discussions.

2 Theoretical solutions

In this section, the necessary background on the warehouse OPS is provided. The order picking problem in warehouse operations is introduced, and focus is then directed to routing methods, and sequencing, as methods that reduce picking travel time and distance.

2.1 The warehouse OPS

An OPS, determining how the ordered stock keeping unit (SKUs) are retrieved from their storage locations according to the customer orders, has come under increased analysis as it has long been identified as the most labour-intensive and costly activity for almost every warehouse (Roodbergen and Koster, 2001; De Koster et al., 2007). For reviews of OPSs, readers may refer to Van Den Berg et al. (1998), Rouwenhorst et al. (2000), De Koster et al. (2007), Gu et al. (2007), Chackelson et al. (2013) and Gu et al. (2010).

There are four typical tactical and operational decision problems faced by warehouse managers. They are:

1 layout design

2 picking policies

3 storage assignment policies

4 routing policies.

Layout design concerns both the layout of the facility containing the OPS and the layout within the OPS. Picking policies determine how orders are to be grouped into picking tours. Storage assignment policies identify where items are to be stored in the warehouse. Routing policies indicate the sequence of items to be picked during any tour (Chan and Chan, 2011).

Storage assignment is the most important factor affecting the performance of picking. Many factors influence the location of products in the warehouse. These include the OPS, size and layout of the storage system, material handling system, product characteristics, demand trends, turnover rates and space requirements. Selecting an appropriate storage assignment policy helps to improve the performance of picking (Chan and Chan, 2011).

The main idea of class-based storage is to divide products into classes. Each class is then assigned to a dedicated area of the warehouse. Storage within an area is random. The advantage of this policy is that fast moving products can be stored close to the depot while the flexibility and high storage space utilisation of random storage are applicable. Generally, there are two kinds of class-based storage,

1 dedicated purposes (Brynzér and Johansson, 1996; Liu, 1999)

2 ABC classification (Montulet et al., 1998; Li et al., 2015; Balaji and Kumar, 2014; Millstein et al., 2014).

In fact, most research on class-based storage has been performed in the context of an automated storage/retrieval system (AS/RSA). Items are divided into classes according to three aspects:

1 system cycle time

2 inventory turnover

3 bill of materials (BOM).

Mansuri (1997) compared the effectiveness of random, dedicated and class-based storage assignment policies. For all types of OPS, an appropriate inventory classification method is of vital importance to divide products into classes that increase the efficiency of picking. In this regard, Guvenir and Erel (1998) and Partovi and Anandarajan (2002) proposed to classify inventory into classes based on multiple attributes.

Undoubtedly, the efficiency of OPS is closely related to the configuration of classes and aisles. For example, the size of the classes would affect the workload balance. In a real situation, the size of the warehouse is fixed. To decrease the number of aisles would increase the size of each class or storage space. However, the implications for the efficiency of picking should be evaluated. For example, it may cause congestion within the aisles. To conclude, in the warehousing literature, there is no firm rule to define a class partition (number of classes, percentage of items per class and percentage of the total pick volume per class) for picker-to-part systems. Also, the optimal assignment depends on the routing policies, size of the warehouse and number of SKUs per pick route (Chan and Chan, 2011).

The way to classify an OPS is to establish whether the order picker is travelling to the picking locations (picker-to-part) or whether the materials are brought to the picker (part-to-picker). The OPS can either be manually or (partly) automated, and it is generally recognised as the most expensive warehouse operation. The OPS is one of the most labour-intensive and time-consuming internal warehousing activities, accounting for more than 55–75% of the operational costs of a warehouse (Hwang and Lee, 1988; Rana, 1990; Roodbergen and Koster, 2001; Frazelle and Frazelle, 2002; Tompkins et al., 2010; Chiang et al., 2011; Grosse et al., 2013). Therefore, an OPS has the highest priority for productivity improvement (De Koster et al., 2007). Order-picking operations are particularly important in manual picker-to-parts picking systems, which account for over 80% of all OPS systems in Western Europe (De Koster et al., 2007; Gong and De Koster, 2008). However, it is clear that the cognitive and motor capabilities of the order picker may influence the order picking process as well (Grosse and Glock, 2013).

2.2 Routing strategies and sequencing

Routing strategies define the sequence in which an order picker retrieves ordered items and determine the order picker's travel distance through the warehouse (Grosse et al., 2013). A variety of different routing strategies has been proposed in the literature (Ratliff and Rosenthal, 1983; Petersen and Schmenner, 1999; Roodbergen and Koster, 2001; Hwang et al., 2004; Petersen and Aase, 2004; Theys et al., 2010). This well-researched problem consists of the determination of the optimal sequence and route to pickup a set of requested items, subject to the layout of the warehouse and working methods (Van Nieuwenhuyse and De Koster, 2009). Optimisation is often achieved by minimising the total travel distance or time of the picker(s), or minimising the total material handling costs. Gunasekaran and Ngai (2003) emphasise that the location analysis will influence the management of inventories.

Gelders and Heeremans (1994) analyse routing in a conventional warehouse. De Koster and Van der Poort (1998) and Goetschalckx and Ratliff (1988) determine analytical expressions to evaluate the routing in a conventional warehouse. Guenov and Raeside (1989) analyse three heuristics for two-dimensional item picking in a conventional warehouse. Bozer et al. (1990) suggest an algorithm for routing in a two-dimensional rack with more than two locations to be visited, and test its performance with the aid of a simulation study. Kanet and Ramirez (1986) evaluate sequencing policies in an AS/RSA. In addition to the usual costs associated with retrieval, this study also considers the cost of a location breakdown. Cormier (1987) presents an algorithm for sequencing retrievals with due-dates in AS/RSAs, using dynamic programming. Linn and Xie (1993) suggest a sequencing rule for the same problem. To pursue the optimal or near-optimal order-picking route in a typical rectangular, multi-parallel-aisle warehouse, the order-picking routing problem is classified as the Steiner travelling salesman problem (STSP) (Le-Duc and De Koster, 2007; Theys et al., 2010). There are two general methods to solve the STSP (Theys et al., 2010): the first one is to reformulate a STSP into the classic TSP by computing the shortest paths between every pair of required nodes, allowing many well-studied TSP heuristics to be applied to STSP (Makris and Giakoumakis, 2003; Renaud and Ruiz, 2008). The second method for the solution of a STSP is by using exact (dedicated) algorithms.

2.2.1 Picking travel time or distance

Russell (2001) and Shulte (2003a, 2003b, 2003c) focus on the role and development opportunities of order picking activities in warehousing systems. Bozer and White (1984) and Hwang and Lim (1993) deal with determining the time needs of order picking activities.

Picking travel distance in a warehouse is influenced by complex interactions between warehouse design and operating parameters, such as warehouse layout, demand patterns, storage policies, order batching methods, routing and sorting methods, and order pick size (Petersen and Schmenner, 1999; Le-Duc and De Koster, 2005). Warehouse layout decisions involve warehouse floor dimensions and aisle lengths along with their number and orientation. Storage policy refers to how the items are assigned to the storage locations (Rao and Adil, 2013). Traditionally, much attention has been paid to minimising the pick travel distances within the picking tours, in order to reduce the resources needed. This is as important in kitting environments as in ordinary order-picking systems (Brynzér and Johansson, 1996). Frazele and Sharp (1989) claimed that pick travel distance corresponds to 60% of the order picker's time in a typical picker-to-part system.

There are four methods to reduce the picking travel distance of an order-picker (De Koster et al., 2007; Petersen and Schmenner, 1999): storage location assignment, warehouse zoning, order batching and pick-routing methods. Generally, there are four approaches to reducing order picking travel time or distance in warehouses (Roodbergen and Koster, 2001). The first approach plans the order picking routes to minimise the picking travel distance. The second approach zones the warehouse so that certain order pickers pick only product items located in their assigned zone. The third approach is stock location assignment, in which storage locations are chosen to make the best use of storage shelves. The last approach is order batching, in which some orders are grouped and picked in a single trip to reduce pick travel distance. Consequently, the time available for order-picking is increasingly shorter. Hence, a fast response is critical for warehouses to operate in such a complex environment (Otto and Chung, 2000).

Picking travel time is the time workers need to fulfil these tasks. Its individual components can be defined as follows (Tompkins et al., 2010): setup time is the time a worker spends on preparing his/her pick tour, e.g., time to print pick lists, sort them, check items on the lists, determine their pick priority, label etc. (Yu and De Koster, 2008). Travel time is the time an order picker spends in the warehouse travelling to, from and between the storage locations. Search time is the time required by the order picker to identify articles on shelves in a warehouse. Pick time is the time needed by an order picker to physically extract ordered items from their storage locations, document the pick, count items and sort them by priority. This time also includes idle time from interrupted work and the time to restock items (Henn, 2012). Picking travel time estimations using order batching considerations were analysed by Gibson and Sharp (1992), Chew and Tang (1999) and De Koster et al. (2007). The effect of routing as well as storage and warehouse layout on pick travel distances has received considerable attention in the warehouse literature (Petersen et al., 2004; Le-Duc and De Koster, 2007). Estimation of pick travel distances using traversal, return and largest gap routing policies applicable to randomised storage in manual low-level picking environments was provided by Goetschalckx and Ratliff (1988), Hall (1993) and Roodbergen and Vis (2006). Several travel-time models that consider a specific equipment, storage policy, and picking area layout combination have been proposed in the OPS literature (see Rouwenhorst et al., 2000; Gu et al., 2007). Le-Duc and De Koster (2007) emphasise that minimising the order retrieval time is a need for any OPS, highlighting the fact that the shorter the order retrieval time, the higher the flexibility in handling late changes in orders. Among them, travelling accounts for more than 50% of the total retrieval time (Tompkins et al., 2010). Furthermore, picking travel time is considered a waste since it costs labour hours and adds no value (Bartholdi and Hackman, 2011). Therefore, in order to improve the performance of OPS, reducing travel time is critical. Order picking is a time-intensive and costly logistics process as it involves a high amount of manual work. Since order picking operations are repetitive by nature, it can be observed that workers gain familiarity with the job over time, which implies that learning takes place (Grosse et al., 2015; Grosse and Glock, 2015).

3 Methodology

This research used case study and in-depth interview research methods. A case study relies on multiple sources of evidence, and benefits from the prior development of theoretical propositions. It is also a research strategy, an empirical inquiry investigating a phenomenon within its real-life context. In a case study, it is necessary to explore present and past changes that affect the whole organisation or compare the groups of individual organisational units in a certain situation. Occasionally, conclusions from the results of the exploration should be drawn and suggestions made for future progress

(Majoros, 2004). On the other hand, a single-subject design or single-case research design is often used in applied fields of human behaviour in which the subject serves as a particular group or event observed at a given time, usually after a phenomenon that has caused some change (Ghauri and Gronhaug, 2011). The in-depth interview with the logistics manager of the tyre manufacturing company was completed in 2015. The length of the interview was 40 minutes at the headquarters of the company. The questions of the interview mainly focused on the problem we examined. The study used important secondary research as well, by using primary research sources – books, scientific journals and the internet – as a source of data for analysis. The excel tables and inventory data constituted an integral part of our work and contributed to achieving the research goal and addressing research questions. In order to understand the processes of the company, we investigated the company's documents (process descriptions, warehouse instructions) and an internal web site for the period of 2010–2015. We analysed the change in the number of tyres in stock between 2010 and 2015 and the monthly distribution of time saving in each complexity category in 2014.

The deliveries of an average workday (9 August 2015) were taken as a basis for the comparison of the two types of order picking processes and the results obtained were used to demonstrate the monthly and yearly results for 2014. Based on the order picking lists prepared the previous day, two order picking processes were carried out in accordance with the real order picking lists put together on Saturday. The time differences between various order picking methods were compared to each other. The order picking lists were rather different from each other, both in terms of the number of products and the affected storage locations.

4 Study findings

4.1 Description of the examined warehouse

Warehousing is an important activity of the examined enterprise which operates various warehouse types. In this study, the order picking process of a warehouse supporting Magasin Usine (MU) manufacturing is examined. Tyres are not directly delivered from the examined factory into the MU warehouse, but they are left in the factory for 24 hours before delivery, so that it is possible to filter out any quality problems in time. Tyres manufactured in Romania are also stored here. The central warehouse base consists of four warehouses of 10,000 m^2 each, while 2–3 hired warehouses are also operated seasonally. The total area of these hired warehouses is up to 30,000–40,000 m^2 and they are used to store tyres which are planned to be stored for longer periods (preparation for the summer and winter seasons). There are around 240 storage locations in each warehouse. Up to 20–32 racks fit in a storage location, depending on the rack type, the given storage location, and its length. In general, the number of tyres ranges from 380,000 to 750,000, including the products in hired warehouses, depending both on seasonality (summer and winter periods) and various campaigns.

4.2 Change in the number of tyres in stock between 2010 and 2015

The examined enterprise constantly keeps pace with the development required by the market; therefore, the number of manufactured items grows year by year. As a result of today's development level, a given car can be equipped with up to 5–6 different sizes of tyres. Formerly, cars were fitted with only two sizes (summer and winter tyres). The reason for this high number of items and for its increase is that car manufacturers put new types of car into service every half year. There was a significant increase in the number of stored tyres items between 2010 and 2015 (Table 1). The number of tyres items imported from Romania was 8 in 2010, 72 in 2013 and 197 in 2015. A similar development can be seen for tyres manufactured by the examined enterprise. The number of tyre items manufactured in 2010 was 56. As a result of the development of manufacturing, the number of tyre items manufactured in 2013 was 147 and in 2015 it was 412. The total number of tyre items increased from 64 to 609 between 2010 and 2015. However, the complexity of the stock resulted in a significant reduction of the average stock. Based on these data, it was considered to be important to perform a repeated inspection and re-evaluation of the order picking processes used so far. The complexity of the warehouse perfectly shows that the currently used order picking strategy is expected to result in great time loss if the number of tyres further increases.

Table 1 Change in the number of tyres in stock between 2010 and 2015

Year	*Tyres imported from Floresti*		*Tyres from Nyíregyháza*		*Total number of items*
	Number of items	*Average stock per item*	*Number of items*	*Average stock per item*	
2010	8	11,400	56	2,125	64
2011	37	4,800	90	1,647	127
2012	66	3,000	110	882	176
2013	72	2,000	147	1,285	219
2014	152	1,474	297	988	449
2015	197	1,099	412	750	609

Source: Central Database (2015) and authors' own composition (2015)

The basic management structure of the currently used order picking list is built on the numerical increase of the CAI which serves the identification of items on the list (Table 2). Storage location addresses are sorted in ascending alphabetical order in each building. It can be seen from the structure of the order picking list that the addresses of the storage locations on the list are not in consecutive order. The order picker retrieves item number 037136_101 from storage location XC01, then proceeds to storage locations XC02 and TA11, before returning to storage location XC01 again. Therefore, the order picker enters the room of storage location XC01 at least twice in a non-consecutive order. This example only refers to one page, while the daily used order picking lists even reach up to 9–10 pages and the number of listed products could be as many as 80–100. It was established that order pickers are unable to plan the shortest order picking route based on the lists given to them and they often enter a given part of the warehouse more than once.

It was proposed to change the product order on the order picking list to reduce picking travel time.

Table 2 The old order picking list based on CAI item number

YZOP							*Reference HU150658*	*09.08.2015*	
	Building	*Storage location*	*Item number description*	*DOT*	*Origin*	*Package type*	*Package composition*	*Number*	*Delivery type*
1	*A*	*XC01*	*037636101*	3315	NYH 6I	1 P11	8 A0	*8*	RCMS
			235/65R17 104VTL LATTOURHP						
2	*A*	*XC02*	*049336101*	3315	NYH 6I	1 P11	8 A0	*8*	RCMS
			175/65R14 82T TL GFORCEWIN GO.						
3	*A*	*TA11*	*246305101*	3015	NYH 6I	2 P11	42 A0	*42*	RCMS
			235/55R19 101H TL LAT ALP2 AOGRNX MI						
4	*A*	*TA12*	*315609101*	2815	NYH 6I	1 P11	14 A0	*14*	RCMS
			235/60R18 103V TL CROSCLISUV AOMI						
5	*A*	*UA13*	*409363101*	2215	NYH 6I	1 P11	2 A0	*2*	RCMS
			245/45R20 99T TL LA XICEN2+ GRNX MI						
6	*A*	*XC03*	*487930101*	1615	NYH 6I	1 P11	11 A0	*11*	RCMS
			255/45R20 101V TL LA2 AOGRNX MI						
7	*A*	*XC01*	*755091101*	5214	NYH 6I	2 P11	36 A0	*36*	RCMS
			265/45R19 105V XLTL PILALP4 N0GRX MI						

Source: Central Database (2015) and authors' own composition (2016)

Table 3 The new order picking list based on the ascending alphabetical order of storage locations

YZOP							*Reference HU150658*	*09.08.2015*	
	Building	*Storage location*	*Item number description*	*DOT*	*Origin*	*Package type*	*Package composition*	*Number*	*Delivery type*
1	*A*	*TA11*	*246305101*	3315	NYH 6I	2 P11	42 A0	*42*	RCMS
			235/55R19 101H TL LAT ALP2 AOGRNX MI						
2	*A*	*TA12*	*315609101*	2815	NYH 6I	1 P11	14 A0	*14*	RCMS
			235/60R18 103V TL CROSCLISUV AOMI						
3	*A*	*UA13*	*409363101*	2215	NYH 6I	1 P11	2 A0	*2*	RCMS
			245/45R20 99T TL LA XICEN2+ GRNX MI						
4	*A*	*XC01*	*037636101*	3315	NYH 6I	1 P11	8 A0	*8*	RCMS
			235/65R17 104VTL LATTOURHP						
5	*A*	*XC01*	*755091101*	5214	NYH 6I	2 P11	36 A0	*36*	RCMS
			265/45R19 105V XLTL PILALP4 N0GRX MI						
6	*A*	*XC02*	*049336101*	3315	NYH 6I	1 P11	8 A0	*8*	RCMS
			175/65R14 82T TL GFORCEWIN GO.						
7	*A*	*XC03*	*487930101*	1615	NYH 6I	1 P11	11 A0	*11*	RCMS
			255/45R20 101V TL LA2 AOGRNX MI						

Source: Central Database (2015) and authors' own composition (2015)

Most existing publications consider minimising the order picker travel time by batching the orders. However, with increases in batch size, the travel time of the order picker decreases, whereas the waiting time increases. There is a trade-off between them (Xu et al., 2014).

The physical stock management system was unable to deal with this task; therefore, a development of the system was made. The original order picking list which was based on the numerical increase of the ascending order of CAI item numbers was replaced with an order picking list based on the ascending alphabetical order of storage locations (Table 3). Several preliminary studies were used together with manually prepared lists to confirm our sequence of ideas. After the development of the program, the idea was implemented in practice. The order of looking up the names of the storage locations (TA11, TA12, UA13, XC01, ...) on the order picking list can be observed in Table 3. It is assumed that the list based on the ascending alphabetical order of storage locations makes it possible to find the ideal route and save time, as is shown by our research. Lu et al. (2016) introduced an intervention routing algorithm for optimising the dynamic order-picking routes. The algorithm is tested using a set of simulations based on an industrial case example.

The issue of dynamically updating a pick-list was previously examined by Gong and De Koster (2008). In their work, the authors use stochastic polling theory to analyse the benefit of a picking system in which the picking information can dynamically change during a pick-cycle. In order to calculate the updated route of a picker in this system, a heuristic procedure, which can lead to non-optimised results, is used.

4.3 Picking travel time of different order picking processes

Table 4 shows the diversity of the number of items and the inclusion of storage locations in accordance with the given order picking list. Accordingly, four categories (A, B, C, D) were set up, based on the following principle:

1. Category 'A' includes order picking lists containing 60–90 items.
2. Category 'B' includes order picking lists containing 20–60 items.
3. Category 'C' includes order picking lists containing 10–20 items.
4. Category 'D' includes order picking lists containing 1–10 items.

The following assumptions are made in this study.

Six order pickers were dealing with order picking during the examination. The following rules were set out in order to perform the comparison.

- A given reference delivery always has to be performed by one order picker using both types of order picking strategies and no help can be requested from anyone.
- A given reference order picking always has to be performed with the same type of forklift truck.
- The storage locations on the order picking list of a reference delivery must be the same for both procedures.

Course of the examination

- The process control employee prepared an order picking list of the freight launched by the freight forwarder. The order picker carried out the order picking based on the order picking list.
- The beginning and end of order picking were registered.

  Registering all other important information which may be significant from the perspective of evaluating picking travel times (e.g., time spent replacing the battery of the forklift truck, meal breaks).

15 reference identifiers were used during the examined day to perform both order picking procedures (order picking list prepared based on the numerical increase of the originally ascending CAI identifiers and order picking list prepared on the basis of the ascending alphabetical order of the different storage location names), the results of which are shown in Table 5.

Table 4 Complexity categories of order picking

Categories based on complexity	*Reference no.*	*Number of items*	*Number of storage locations*
Category ‘A’	UT150483	84	91
	UT150491	71	82
	UT642706	61	65
Category ‘B’	UT150458	38	42
	UT642703	39	32
	UT150509	32	15
	UT150568	31	29
	UT150501	27	23
Category ‘C’	UT150480	16	16
	UT150505	12	13
	UT150482	7	13
Category ‘D’	UT150481	4	9
	UT150529	3	7
	UT150566	3	7
	UT150567	2	5

Source: Authors’ own composition (2015)

Only a slight (2%) time saving was obtained during the examination of category ‘D’ in terms of picking travel time during the comparison of the two different order picking methods (Table 4). The reason for this is that even though the number of items to retrieve was high, there were only a few item types. The time saving was 6% in category ‘C’ and 9% in category ‘B’, while the highest time saving (11%) was observed in category ‘A’. Thus it was concluded that significant time saving can be achieved with an order picking list based on the ascending alphabetical order of storage locations if several storage locations are involved and a high number of items has to be retrieved.

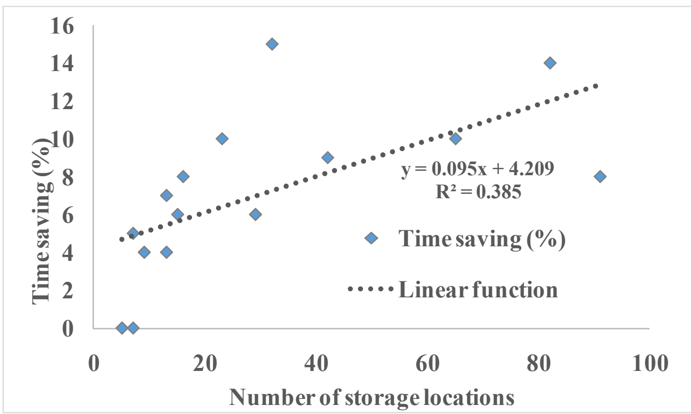
Table 5 Connection between the time savings of both order picking procedures in the different complexity categories

Complexity categories	*Reference number*	*Number of items*	*Number of storage locations*	*Number of rounds*	*Planned order picking travel time (minutes)*	*Picking travel time – order picking list based on ascending CAI (minutes)*	*Picking travel time – order picking list based on ascending alphabetical order of storage locations (minutes)*	*Time saving (minutes)*	*Time saving (%)*	
Category ‘A’	UT150483	84	91	56		360	330	30	8%	*11%*
	UT150491	71	82	60	*270*	180	155	25	14%	
	UT642706	61	65	71	*385*	200	180	20	10%	
Category ‘B’	UT150458	38	42	55	*220*	165	150	15	9%	*9%*
	UT642703	39	32	48	*265*	170	145	25	15%	
	UT150509	32	15	42	*205*	160	150	10	6%	
	UT150568	31	29	33	*190*	155	145	10	6%	
	UT150501	27	23	58	*265*	155	140	15	10%	
Category ‘C’	UT150480	16	16	33	*125*	130	120	10	8%	*6%*
	UT150505	12	13	42	*135*	140	130	10	7%	
	UT150482	7	13	36	*125*	125	120	5	4%	
Category ‘D’	UT150481	4	9	33	*100*	115	110	5	4%	*2%*
	UT150529	3	7	13	*75*	75	75	0	0%	
	UT150566	3	7	25	*90*	95	90	5	5%	
	UT150567	2	5	17	*75*	90	90	0	0%	

Source: Authors’ own composition (2015)

Figure 1 shows the tendency of time saving (%) depending on the number of storage locations involved. If the involvement of storage locations (the number of storage locations that the order picker has to visit based on the order picking list) is below 10–15, then only a slight (0–4%) time saving can be achieved. Supposing a linear relationship, the meaning of the parameter of the linear function is that if the number of storage locations increases by ten items, the percentage time saving will increase by one item on average. Consequently, this new type of order picking list is more efficient from the perspective of time saving in the case of higher storage location involvement.

Figure 1 Time saving (%) depending on the number of storage locations (see online version for colours)



Source: Authors' own composition (2015)

The results of the examined day lead to conclusions projected to a month and a year with reference to expected results. Different amounts of time saving can be concluded for each month, since warehouse activity is not the same in every month. The percentage distribution of the delivery categories calculated for January 2014 was used for the remaining months of the year, also considering the delivery data resulting from the differences in activity between different months. The number of deliveries is the highest in August (601) and September (590), due to the delivery of a large number of winter tyres. The lowest warehouse activity was observed in December (392) due to the end of the winter tyre season. The deliveries of January 2014 were grouped into four categories (A, B, C, D) based on the same principle as the categories used in a previous examination. Highly complex (items in category 'A') deliveries represented 28% of all deliveries in 2014, while less complex (items in category 'B') deliveries made up 41% of the total. Furthermore, items in categories 'C' and 'D' represented 19% and 12% of all deliveries, respectively. Based on the number of deliveries in 2014 and the four different complexity categories, it is shown how much time saving could have been achieved in 2014 with the order picking procedure performed on the basis of the ascending alphabetical order of new storage locations.

Table 6 Monthly distribution of time saving in each complexity category in 2014

		Category A		*Category B*		*Category C*		*Category D*			
		% of affected deliveries	*28%*	*% of affected deliveries*	*41%*	*% of affected deliveries*	*19%*	*% of affected deliveries*	*12%*		
		Saved time – minutes	*25*	*Saved time – minutes*	*15*	*Saved time – minutes*	*8*	*Saved time – minutes*	*3*		
Month	*Number of deliveries*	*Number of affected deliveries*	*Monthly saved time*	*Number of affected deliveries*	*Monthly saved time*	*Number of affected deliveries*	*Monthly saved time*	*Number of affected deliveries*	*Monthly saved time*	*Total saved time*	*Average*
January	429	120	3,003	176	2,638	82	652	51	154	6,448	7,236
February	420	118	2,940	172	2,583	80	638	50	151	6,313	7,236
March	431	121	3,017	177	2,651	82	655	52	155	6,478	7,236
April	481	135	3,367	197	2,958	91	731	58	173	7,229	7,236
May	490	137	3,430	201	3,014	93	745	59	176	7,365	7,236
June	487	136	3,409	200	2,995	93	740	58	175	7,320	7,236
July	504	141	3,528	207	3,100	96	766	60	181	7,575	7,236
August	601	168	4,207	246	3,696	114	914	72	216	9,033	7,236
September	590	165	4,130	242	3,629	112	897	71	212	8,868	7,236
October	480	134	3,360	197	2,952	91	730	58	173	7,214	7,236
November	472	132	3,304	194	2,903	90	717	57	170	7,094	7,236
December	392	110	2,744	161	2,411	74	596	47	141	5,892	7,236
							Average			*7,236*	
							Amount of time saved in 2014 – minutes			*86,828*	
							Amount of time saved in 2014 – hours			*1,447*	

Source: Authors' own composition (2015)

Table 6 shows most time can be saved on a monthly basis with deliveries in category 'A' (the most complex deliveries), while the least time saving is realised in the case of category 'D' deliveries (the least complex deliveries). Consequently, the more complex a delivery is (involving various item types and storage locations), the more time can be saved with the order picking list proposed in this study. The months representing above average time saving are the ones during which the highest numbers of deliveries were performed (August, September). Most time could be saved in August (9,033 minutes), followed by September (8,868 minutes). In the case of less complex order picking, the reason why no significant time saving could be achieved in February (6,313 minutes) and December (5,892 minutes) is that order pickers have to visit only a few storage locations and only a few items are involved, making it easier for order pickers to plan the optimal order picking route properly. More complex categories (category 'A') represent the majority of time saving. It was possible to save time even during the months which showed the least time saving (February – 2,940 minutes; December – 2,744 minutes).

However, if the two strongest months are taken into consideration (August – 4,107 minutes; September – 4,230 minutes), the amount of time saved with the proposed order picking list exceeds even 4,000 minutes. The analysis of the four different complexity categories (A, B, C, D) led to the conclusion that 7,236 minutes could be saved in an average month in 2014. The total amount of time which could be potentially saved in 2014 was 86,828 minutes which equals to 1,447 working hours and 180 working days. This amount of time is not enough to save one year's worth of working hours of an employee, but the competitiveness of the warehouse can still be improved if these 180 days can be spent on making up for the days-off of other employees.

5 Conclusions and discussions

In order to shorten the picking travel time, a change was initiated in the order of products on the order picking list. The order picking list based on the numerical increase of the original ascending CAI identifier was switched to an order picking list based on the alphabetical order of storage locations. Four categories (A, B, C, D) were established based on the number of goods on each list and the involvement of storage locations. Only a small amount (2%) of picking travel time can be saved in the case of category 'D', since the list consisted of a large amount of items belonging to only a few item types. The amount of saved time was 6% in category 'C' and even more (9%) in category 'B', while the highest amount of time (11%) could be saved in category 'A'.

The two different order picking procedures led us to conclude that using an order picking list based on the ascending alphabetical order of storage locations results in significant time saving. The extent of this saving is affected by the products and storage locations involved in the preparation of orders. The more storage locations which need to be visited and the more items which need to be retrieved during order picking, the more time can be saved with using the order picking list based on the ascending alphabetical order of storage locations.

Designing an OPS is a complex task. A designer is required to make several decisions related to different order picking strategies and storage considerations. Introducing a simple, cost-based optimisation model in this area would include expanding its scope. Perhaps the most important challenged for research is to provide a comprehensive comparative analysis of the various alternatives of the order picking methods. The OPS is one of the most important warehouse activities. When an order is picked faster, it will be ready for shipment sooner, enabling the warehouse to provide a higher service level. In this study, a theory was developed and tested in empirical research. Therefore, for further research it is recommended to test the hypotheses in a different sample, preferably in another international tyre manufacturing enterprises in Europe.

Our recommendations for practice are: the development of an application which is based on the accurate distance of all storage locations from each other within the warehouse. This application would plan the shortest order picking route which would result in even more significant time saving. In addition, this application could help in pointing out the loading ramp with a preparation location in front where the order picker can prepare the order (the application analyses which part of the building most tyres need to be retrieved from). The most significant and most time-consuming part of introducing this application would be the measurement of distances and the integration of hindering factors into the system. However, these tasks need to be performed only once and they potentially lead to more significant time saving. One of the ways to increase traceability is to use RFID, which is the technology of the future.

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