LogForum

2017, 13 (3), 313-326

http://dx.doi.org/10.17270/J.LOG.2017.3.6

http://www.logforum.net p-ISSN 1895-2038 e-ISSN 1734-459X

ORIGINAL PAPER

THE IMPACT OF COI-BASED STORAGE ON ORDER-PICKING TIMES

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ABSTRACT. **Background:** The increasing competitiveness on the global markets enforces the need for a fast and reliable delivery. This task is possible to perform by improving the order-picking systems. The implementation of automated storage and retrieval systems (AS/RS) is not always profitable. In the warehouses where the order-picking is performed in accordance with the principle of picker-to-part rule, the picking efficiency optimization includes among others: the warehouse layout, the storage policy, the routing heuristic, the way of zoning, the order-batching method, and the sequencing of pick-lists. In the paper the impact of the storage policy on the order-picking times is checked.
Methods: The influence of storage based on Heskett's cube-per-order index (COI) on the average order-picking times is analyzed. The items based on increasing values of COI index are divided on classes. To determine the demand for items the analytical function proposed by Caron is used.
Results: In the paper the benefits of storage based on COI index are compared with random storage and storage based only on picking frequency. It is assumed that the bin, to which the picker collects items has limited capacity – some orders has to be divided on smaller pick-lists. The analysis was performed using simulation tools. Additionally, the algorithm (taking into account different sizes of picker's bin) for order-batching is presented.
Conclusions: The analysis shows that the COI-based storage is particularly effective when the size of items increases. The COI-based curve is less skewed than the curve based only on picking frequency. The choice of storage policy should be carried out together with routing heuristic. The use of batching algorithm significantly increases the effectiveness of the order-picking process, but the optimal size of picker's bin (and batch) should be optimized with consideration the sorting process.

Key words: order-picking, COI index, simulations.

INTRODUCTION

Order-picking – the process of retrieving items from storage locations to fill customer orders is the activity that influences the warehouse effectiveness to the greatest extent. It makes up to 55% of total operating costs of a typical warehouse [Tompkins et al. 1996]. There are few ways to improve the performance of order-picking in low-level picker-to-part systems: storage, routing, batching, zoning. All elements interact and may lead to the growth of the effectiveness of the order-picking process measured by the average time needed for picking items from one order. As for manual systems order-picking time is a monotone increasing function of traveled distance, the issue of order-picking optimization can be solved by minimizing the average distance traveled by the picker while completing items from orders [Kallina and Lynn 1976, Caron, Marchet and Perego 1998]. The different problems connected with the order-picking process are explored even by Polish scientists (see e.g. Krawczyk and Jakubiak [2011], Jakubiak and Tarczyński [2012], Jacyna and Kłodawski [2011, 2012], Kłodawski and Jacyna [2010, 2011], Jacyna et al. [2015], Kłodawski et al. [2017]).

Citation: *Grzegorz Tarczyński G., 2017. The impact of COI-based storage on order-picking times. LogForum 13 (3), 313-326, http://dx.doi.org/10.17270/J.LOG.2017.3.6*

Received: 20.03.2017, Accepted: 11.05.2017, on-line: 20.06.2017.

There are few popular storage location assignment methods. The most popular are: random, dedicated, and class-based. In this paper it will be analyzed the influence of the class-based storage policy on average traveled by the picker distance. The classes will be established using the cube-per-order index (COI). In such approach it is assumed that both: storage locations and items are divided into classes. Inside a class the items are assigned to the locations randomly. Muppani and Adil [2008b] notice that when the number of classes takes extreme values the class-based storage changes to: totally random (when there is only one class) or dedicated storage (when each location forms a new class). The cube-per-order index is the storage assignment method of items based on the ratio of the required space to the order frequency discovered by Heskett [1963].

The performance of the order-picking activity varies depending on the system applied in the warehouse. The automated storage/retrieval systems (AS/RS) are faster, but also much more expensive. For that reason the picker-to-part systems are still very common. In such warehouses the order-picking can be performed in two ways. In the first way (called unit-load) it is assumed that the picker always carries only one type of items (placed usually on a pallet), so during a picking tour he or she has to visit only one location while performing storage or retrieving operation (single-command) or two locations while performing: first storage operation and later retrieving operation (dual-command). In the latter way the picker retrieves many different items in one cycle. Here the key role plays the proper routing, too.

The aim of this paper is to determine the conditions when the storage based on COI performs better than the storage based only on picking frequency in picker-to-part warehouses considering order-picking with multiple stops. It is assumed that the item's cube influences not only the size of reserved for that item storage area, but also the ability of the picker to carry items together.

The structure of this paper is as follows. In the next section the review of literature associated with COI is presented. Section 3 discusses the function that maps the Pareto rule used in theoretical analysis for class division. The description of performed experiments and the received results are described in section 4. In section 5 the algorithm for order-batching is proposed. The paper is concluded in section 6.

LITERATURE REVIEW

The effectiveness of cube-per-order rule discovered by Heskett [1963] was analyzed by many researchers. Kallina and Lynn [1976] enlarge the COI rule by defining four criterion for proper storage of items: popularity, space, compatibility, and complementarity. The first two refer directly to the COI. Compatibility means that on adjacent locations cannot be stored items that are not compatible (e.g. food and gasoline). The last criterion is met when items frequently ordered together are stored close to each other. In this paper only COI rule will be considered. Kallina and Lynn [1976] propose the algorithm for a warehouse costs minimization (in fact it is rather less formal procedure). The authors consider three problems that influence the costs: the division of warehouse space into storage and reserve areas, the locations and amounts for items in storage areas, the frequency of restocking each item from reserve to storage area. The best way for solving this problem is by the use of simulations. Malmborg and Bhaskaran [1990] analyze the COI rule for dual-command unit-load warehouses and present the optimality proof for COI storage. The authors consider dedicated storage and assume that each item is stored on specified number of locations. The traveled distance is measured using both: rectilinear and Euclidean metric. Malmborg [1995] propose the procedure using simulated annealing for COI based storage location assignment taking into account zoning constraints.

Caron, Marchet and Perego [1998] simultaneously optimize the storage and routing in low-level picker-to-part systems. The authors analyze two very popular routing heuristics: return with a cross-aisle storage policy and S-shape with within-aisle storage. The classes for ABC storage are formed based on the cube-per-order index. In fact only for S-shape routing a class based storage (with class borders) is considered. For return heuristic in each picking aisle the items are stored based on the ascending values of COI. The authors consider the two-blocks warehouse layout with PD located at the beginning of the cross-aisle and derive the analytical formulations for average distance traveled by the picker. Muppani and Adil [2008a, 2008b] investigate the single-command unit-load warehouses and present the model for both: allocation items to classes, and allocation storage locations to classes. The goal is to simultaneously minimize the storage space costs and the order-picking costs. Kłodawski [2014] considers single-command unit-load warehouses with COI-based storage and shows that increasing the number of classes will imply in shorter average order-picking time. The conclusions are consistent with Van Kampen et al. [2012] remarks, that dedicated storage (where each item creates a separate class) is superior to the division on less number of classes. However, the very actual research of Yu et al. [2015] indicate that mentioned benefits are possible to reach only when one assume an infinite amount of items. Otherwise, increasing the number of classes may lead to the deterioration of the order-picking efficiency. Additionally, Kłodawski [2014] compares variants with different number of classes using operating costs and costs connected with maintaining the stock level (the author presents a model for optimal storage that minimizes the warehousing costs). Here his conclusions are similar to Yu et al. [2015]: the optimal number of classes is rather small.

The analysis of the influence of COI-based storage on the picker-to-part system's performance can by conducted by the use of simulations or with analytical models. Simulations can take into account a bigger number of parameters and generate more accurate results, but they are more time-consuming than analytical approach. For this reason the researchers try to develop the formulations for average order-picking time. The problem of mapping the unit-load systems (single- or dual-command) is not complicated. More difficult to derive are the equations for average order-picking time when picking with multiple stops is considered. Manzini et al. [2007] present the simulation-based model for picking time taking into account among others different skewness of ABC curve and two routing heuristics (S-shape and return). Other formulas are based on statistical analysis. Tarczyński presents equations for random storage for return heuristic [Tarczyński 2015a] and S-shape [Tarczyński 2015b], which after modifications can be used for ABC storage. The analytical models for COI-based ABC storage are derived by Caron, Marchet and Perego [1998, 2000] and Hwang, Oh and Lee [2004]. Unfortunately all presented (in listed above papers) equations assume constant number of items picked in a tour. In this paper the orders are batched based on the capacity of picker's bin criterion and the pick-list's size is variant. For this reason the further analysis will be performed by the use of simulations.

THE ABC CURVE

As the picking frequency for items differs, one has to use a function (so called ABC curve) to map the cumulated demand for items from one class. Caron et al. [1998] use the function:

$$F(x) = \frac{(1+s)\cdot x}{s+x},$$

where:

x – a cumulative fraction of total storage space required for items (the items need to be sorted: ascending for COI or descending for picking frequency), $x \in \langle 0,1 \rangle$,

$F(x)$ – a (normalized) cumulated demand for items, $F(x) \in \langle 0,1 \rangle$,

s – a shape factor, $s > 0$. s takes the values: 0.07, 0.12, 0.20, 0.33 respectively for 80/20, 70/20, 60/20, 50/20 ABC curves. The notation 80/20 means that the curve maps the Pareto rule (figure 1), i.e. 20% of items (more precisely: items stored on 20% most easily accessible storage space) generate 80% of demand. Other curves are less skewed. For large values of s (e.g. $s = 1000$) the ABC curve forms a straight line and the demand for all items is equal.

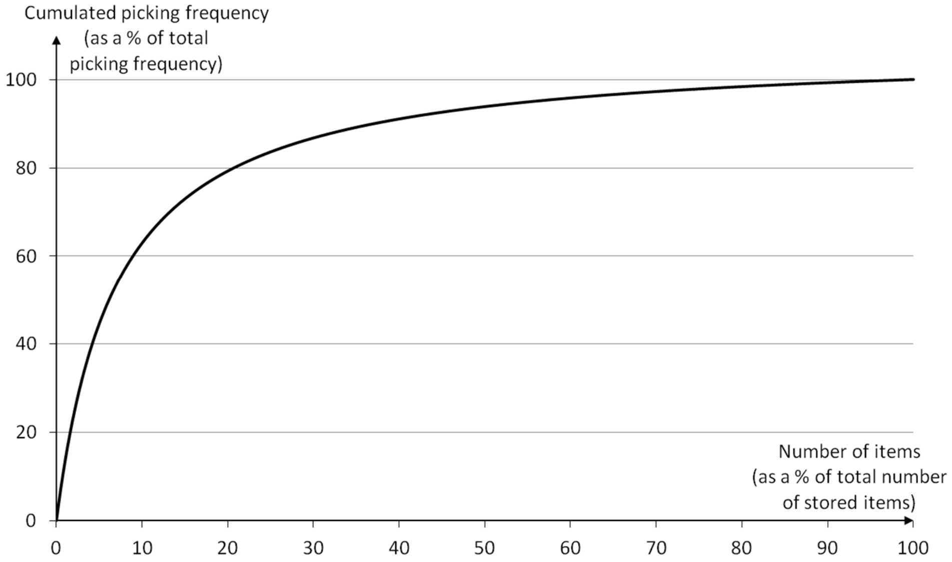

Fig. 1. The 80/20 ABC curve used for generation the demand for stored in the warehouse items
Rys. 1. Krzywa ABC odwzorowująca regułę Pareto 80/20 użyta do wygenerowania popytu na towary składowane w magazynie

In actual literature the ABC storage based on COI is usually compared only with totally random storage [Caron et al. 1998]. It seems to be reasonable to use for comparison the ABC storage based only on picking frequency, too. The ABC curve for COI will be less skewed than for picking frequency. This suggests that classes formed based on picking frequency are superior to classes with COI rule. However, for COI the items with largest size are stored far from PD and items with smallest size are easily accessible for the picker, so he or she can visit more locations covering less distance before returning to the PD. The small items can be stored more densely, too. This allows to reserve less area for class A, which should imply in shorter average traveled distance.

THE DESCRIPTION OF EXPERIMENTS

The aim of this section is to check out how the ABC storage based on COI interact the distance covered by the picker when the capacity of bin, to which the items are collected is limited. Two variants will be checked: (1) the storage area reserved for each item is constant - it is one location (figure 2a), (2) the storage area depends on the size of items – on each location up to five different items can be stored (figure 2b). The number of items stored in the warehouse is 1.000. The warehouse (presented on figure 3) is one-block rectangular with the pick-up/drop-off (PD) point located in the corner (at the beginning of the front cross-aisle).

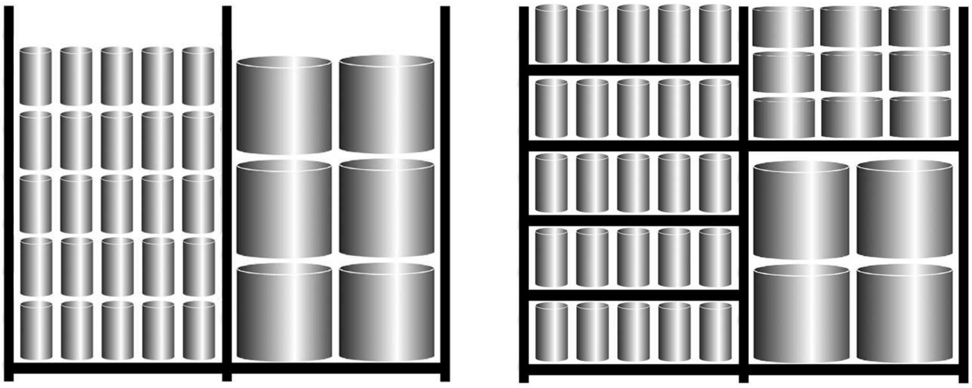

Fig. 2. Warehouse racks - it is assumed that on each localization: (a) only one item is stored, (b) from one to five different items can be stored (on the picture: five items on the left side and two items on the right side).

Rys. 2. Regały magazynowe – zakłada się, że w każdej lokalizacji: (a) przechowywany jest tylko 1 towar, (b) składuje się od 1 do 5 różnych towarów (na rysunku: 5 składowanych towarów po lewej i 2 po prawej)

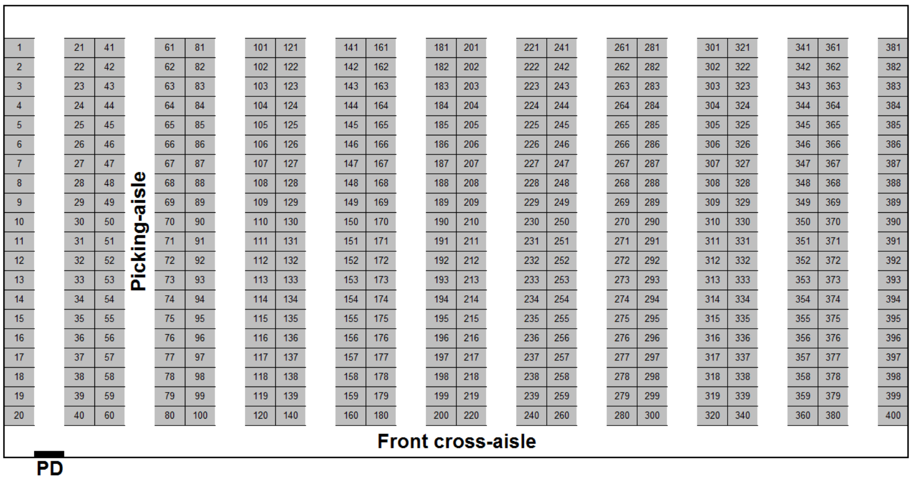

Fig. 3. The one-block rectangular warehouse with 10 picking-aisles

Rys. 3. Magazyn jednoblokowy z 10 alejkami, w których składowane są towary

The COI factors are calculated based on the cube of single item (not the storage area reserved for this item) – such approach was used by Kallina and Lynn (1976). For designating the size of items five different functions are used (figure 6). For function F1 ($c_k = \frac{k}{n}$) it is assumed that the number of items of each size is similar. Using functions F2 ($c_k = \left(\frac{k}{n}\right)^2$) and F3 ($c_k = \left(\frac{k}{n}\right)^4$) will imply in greater number of small items. For F4 ($c_k = 1 - \left(1 - \frac{k}{n}\right)^2$) and F5 ($c_k = 1 - \left(1 - \frac{k}{n}\right)^4$) the size of most items is greater than half the capacity of bin (n – number of stored in the warehouse items, k – item's number (based on ascending sorted cubes), c_k – cube of k-th item). It is assumed that the maximum cube is 20, 50 or 100 times larger than the minimum cube. The values are rounded, so all possible sizes are the multiple of the smallest size (figure 7). The obtained values are normalized and expressed as a percentage indicate both: how much of storage location will be occupied by this item, and how much space of a bin carried by the picker will be filled by the item. The picking frequency for items are designated by the use of 80/20 ABC curve (figure 1). For further calculations the following assumptions are adopted:

- the items are replenished from reserve area each day after the picking is finished.

For this reason there is no need to store items in huge amount in the storage area,

- the capacity of the bin where the picker collects items is limited. The size of items corresponds to the storage area reserved for them,
- while generating orders the amount of each item on the order is only 1,
- two routing heuristics are considered: return with a cross-aisle storage policy (figure 4) and S-shape with within-aisle storage policy (figure 5). The storage based on COI will be compared with storage based on picking frequency and random storage.

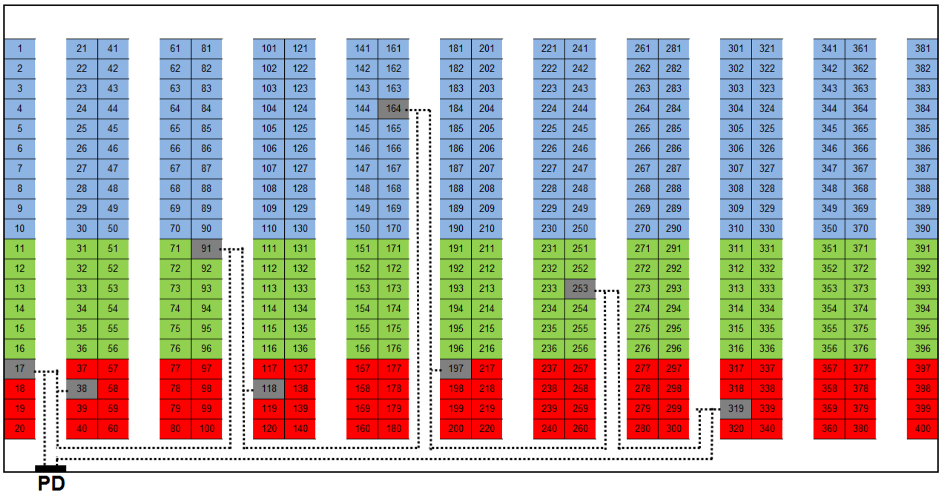

Fig. 4. The example of return route with across-aisle storage policy (red color – locations for A class, green color – locations for B class, blue color – locations for C class, grey color – locations to be visited in a tour)

Rys. 4. Przykład trasy wyznaczonej zgodnie z heurystyką return i składowania across-aisle (kolor czerwony – klasa A, kolor zielony – klasa B, kolor niebieski – klasa C, kolor szary – lokalizacje, które należy odwiedzić)

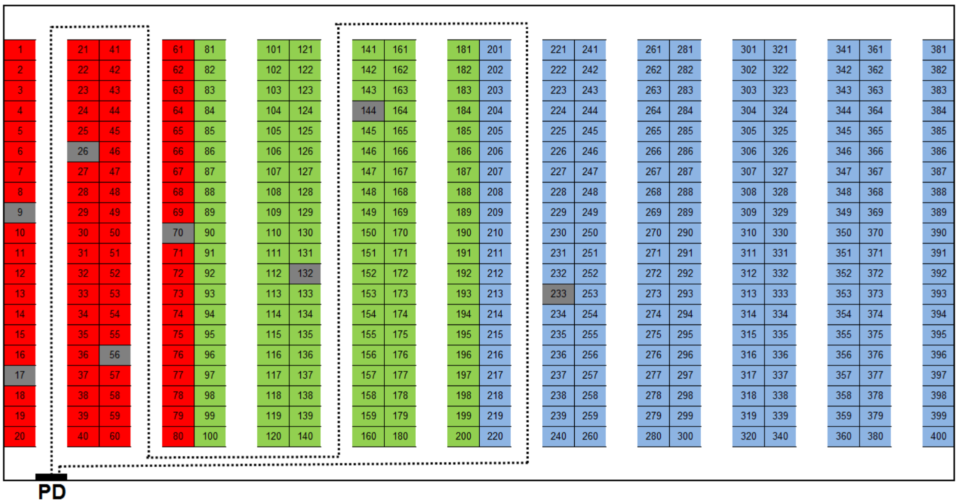

Fig. 5. The example of S-shape route with within-aisle storage policy (red color – locations for A class, green color – locations for B class, blue color – locations for C class, grey color – locations to be visited in a tour)

Rys. 5. Przykład trasy wyznaczonej zgodnie z heurystyką S-shape i składowania within-aisle (kolor czerwony – klasa A, kolor zielony – klasa B, kolor niebieski – klasa C, kolor szary – lokalizacje, które należy odwiedzić)

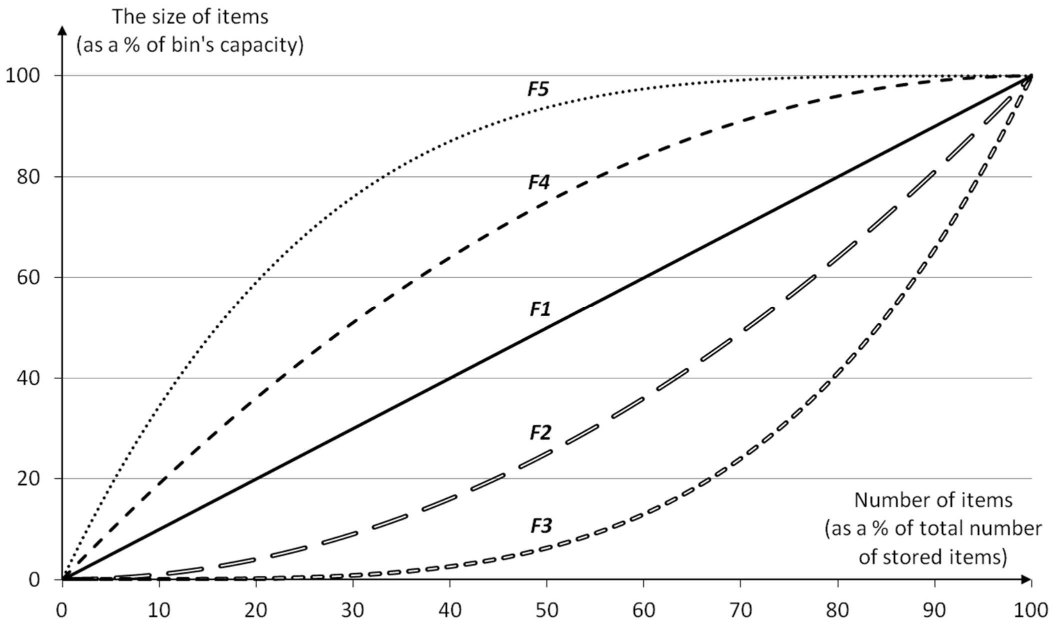

Fig. 6. Different functions used for generation the size of items
Rys. 6. Różne funkcje wykorzystane do wygenerowania wielkości przechowywanych w magazynie towarów

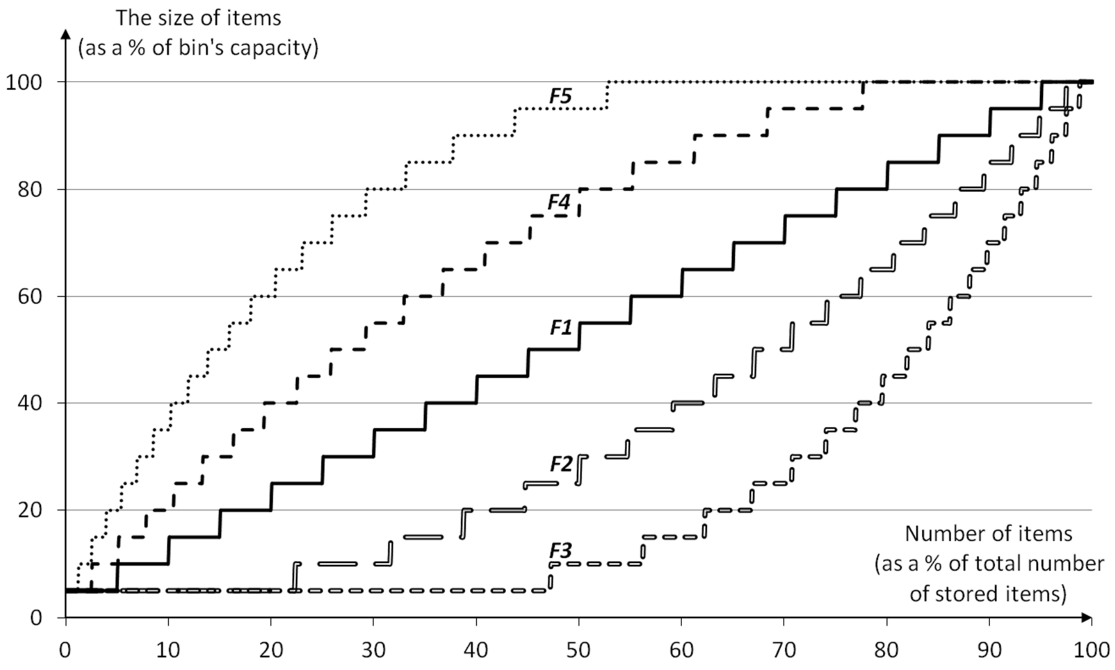

Fig. 7. Rounding of functions used for generation the size of items for maximum quotient of sizes equal 20
Rys. 7. Zaokrąglenia funkcji użytych do wygenerowania wielkości przedmiotów dla maksymalnego ilorazu równego 20

Table 1. Average distances for maximum quotient of sizes of items equal 20 (in the brackets the percentage excess over the best variant)

Tabela 1. Średnie odległości dla maksymalnego ilorazu wielkości przedmiotów równego 20 (w nawiasach procentowe pogorszenie wyniku w porównaniu do najlepszego wariantu)

Size function	Routing method	Average number of items picked in one cycle	Average distance for one route		
			ABC COI based storage	ABC turnover based storage	Random storage
F1	S-shape	1,90	97,71 (41,33)	95,95 (38,78)	126,61 (83,13)
	Return	1,90	72,51 (4,89)	69,14 (0,00)	127,32 (84,16)
F2	S-shape	2,88	131,42 (45,41)	122,39 (35,41)	171,17 (89,38)
	Return	2,88	99,93 (10,56)	90,38 (0,00)	174,39 (92,94)
F3	S-shape	4,37	163,61 (42,52)	161,89 (41,03)	220,99 (92,51)
	Return	4,37	131,13 (14,23)	114,79 (0,00)	231,40 (101,58)
F4	S-shape	1,37	75,26 (35,23)	74,30 (33,51)	98,38 (76,77)
	Return	1,37	57,83 (3,91)	55,65 (0,00)	98,13 (76,32)
F5	S-shape	1,17	66,55 (32,35)	66,01 (31,28)	87,11 (73,25)
	Return	1,17	51,34 (2,10)	50,28 (0,00)	86,89 (72,81)

Table 2. Average distances for maximum quotient of sizes of items equal 50 (in the brackets the percentage excess over the best variant)

Tabela 2. Średnie odległości dla maksymalnego ilorazu wielkości przedmiotów równego 50 (w nawiasach procentowe pogorszenie wyniku w porównaniu do najlepszego wariantu)

Size function	Routing method	Average number of items picked in one cycle	Average distance for one route		
			ABC COI based storage	ABC turnover based storage	Random storage
F1	S-shape	1,93	100,46 (42,30)	97,23 (37,73)	128,56 (82,10)
	Return	1,93	73,56 (4,20)	70,60 (0,00)	128,90 (82,59)
F2	S-shape	3,03	136,93 (45,95)	126,69 (35,04)	178,22 (89,96)
	Return	3,03	103,92 (10,76)	93,82 (0,00)	181,87 (93,86)
F3	S-shape	5,08	177,38 (38,98)	158,36 (24,07)	244,69 (91,71)
	Return	5,08	143,63 (12,53)	127,63 (0,00)	258,55 (102,57)
F4	S-shape	1,37	76,85 (37,69)	74,76 (33,95)	98,30 (76,12)
	Return	1,37	58,17 (4,22)	55,82 (0,00)	98,39 (76,27)
F5	S-shape	1,16	66,24 (32,11)	66,06 (31,76)	86,30 (72,13)
	Return	1,16	50,64 (0,99)	50,14 (0,00)	86,49 (72,50)

The results of calculations for equal storage area for all items are presented in the tables 1-3. The distances are expressed in the average number of storage locations passed by the picker in one picking tour. For all experiments the COI storage performs worse than storage based only on picking frequency (tables 1-3). The possibility of carrying more items located near the PD point does not lead to the distance reduction. In all presented 15 experiments (for different: size functions and quotient in sizes) the return routing heuristic in combination with across-aisle turnover-based storage policy performs best.

Table 3. Average distances for maximum quotient of sizes of items equal 100 (in the brackets the percentage excess over the best variant)
Tabela 3. Średnie odległości dla maksymalnego ilorazu wielkości przedmiotów równego 100 (w nawiasach procentowe pogorszenie wyniku w porównaniu do najlepszego wariantu)

Size function	Routing method	Average number of items picked in one cycle	Average distance for one route ABC COI based storage	ABC turnover based storage	Random storage
F1	S-shape	1,17	66,69 (32,35)	66,47 (31,90)	87,41 (73,45)
	Return	1,17	51,46 (2,13)	50,39 (0,00)	87,26 (73,16)
F2	S-shape	1,39	76,18 (35,42)	75,39 (34,01)	99,30 (76,52)
	Return	1,39	57,98 (3,07)	56,26 (0,00)	99,15 (76,24)
F3	S-shape	4,85	175,69 (40,87)	157,08 (25,94)	241,20 (93,40)
	Return	4,85	140,46 (12,62)	124,72 (0,00)	253,01 (102,87)
F4	S-shape	2,90	132,33 (44,37)	123,23 (34,44)	172,47 (88,16)
	Return	2,90	100,55 (9,70)	91,67 (0,00)	175,80 (91,78)
F5	S-shape	1,87	97,69 (41,24)	94,18 (36,15)	124,92 (80,60)
	Return	1,87	72,01 (4,11)	69,17 (0,00)	125,42 (81,32)

Table 4. Average distances for maximum quotient of sizes of items equal 20 and different storage space (in the brackets the percentage excess over the best variant)
Tabela 4. Średnie odległości dla maksymalnego ilorazu wielkości przedmiotów równego 20 i niestałej wielkości przestrzeni magazynowej (w nawiasach procentowe pogorszenie wyniku w porównaniu do najlepszego wariantu)

Size function	Routing method	Average number of items picked in one cycle	Average distance for one route ABC COI based storage	ABC turnover based storage	Random storage
F1	S-shape	1,90	68,13 (18,55)	69,46 (20,86)	100,14 (74,25)
	Return	1,90	57,47 (0,00)	58,16 (1,21)	100,17 (74,31)
F2	S-shape	2,88	65,70 (3,28)	68,36 (7,45)	107,50 (68,98)
	Return	2,88	63,62 (0,00)	65,19 (2,48)	109,83 (72,64)
F3	S-shape	4,37	69,72 (0,00)	71,37 (2,36)	116,63 (67,28)
	Return	4,37	72,36 (3,78)	75,26 (7,94)	121,23 (73,87)
F4	S-shape	1,37	65,43 (27,43)	66,84 (30,17)	91,76 (78,70)
	Return	1,37	51,35 (0,00)	51,60 (0,50)	91,25 (77,72)
F5	S-shape	1,17	64,72 (30,90)	65,42 (32,32)	86,62 (75,20)
	Return	1,17	49,44 (0,00)	49,50 (0,11)	86,72 (75,40)

When the storage is totally random, then the return heuristic gives very poor results – it is always worse than S-shape. For the ABC storage – when the number of picked items in a tour is small – the return method with across-aisle storage gives smaller distance values than S-shape with within-aisle policy. For COI-based storage the best routing is according to the return heuristic, too. However, the distance for COI storage is longer than for storage based on turnover from 0.99% to 14.23%.

Table 4 shows the results for the case where the storage area reserved for item depends on the cube-per-order index. Only here all the benefits from ABC storage based on COI are visible. The COI storage is superior to the storage based only on turnover, but the difference in traveled distance is not significant – it varies from 0.11% to 2.48%. Also here the return heuristic performs better than S-shape. However, there is one exception – for the size function F3 the S-shape gives better results.

ORDER BATCHING

One of the ways of order-picking optimization is order-batching. The problem of transforming orders into pick lists was analyzed by many scientists (see e.g. Gibson and Sharp [1992]). In this paper the influence of the size of the bin carried by the picker on the average traveled distance will be analyzed. It is assumed that the batching procedure should generate the pick lists without losing the integrity of particular orders so as to facilitate the further sorting process. Gademann and Van de Velde [2005] show that the batching problem is NP-hard. For this reason the researchers discover algorithms for approximate value of optimized objective function (usually the traveled distance). The proposed in this paper procedure minimizes the number visited aisles in one picking tour and consists of 5 steps: (1) choose the base order with the largest number of visited aisles and remove this order from the set of not connected orders; (2) choose the order (and add it to the base order), that will minimize the total number of visited aisles and after adding the entire size of items will not exceed the capacity of the picker's bin (remove this order from the set of not connected orders); (3) if the step (2) does not change the size of the base order (connecting orders was not possible) go to step (4); otherwise repeat step (2); (4) move the base order to the set of pick-lists; (5) if the set of not connected orders is not empty go to the step (1); otherwise finish the procedure.

The percentage reduction of the distance traveled by the picker after random batching and batching with the use of presented procedure for ABC COI based storage is presented in table 5. The improvement of results is especially visible when the size of the bin increases. The results could be even better when the orders will be split into separate orders before batching. However, in this case the sorting process (after the items are picked) will play a more prominent role.

Table 5. Reduction of the average travelled distance after batching orders - expressed as a percentage improvement in comparison to the original distance

Tabela 5. Redukcja średnich odległości pokonywanych przez magazynierów po połączeniu zamówień – wyrażona jako procentowa wartość poprawy względem wariantu bez łączenia

Dataset	Batching method	Routing method							
		Return				S-shape			
		Bin's size							
		2	3	4	5	2	3	4	5
F1	random	11,28	22,18	31,77	38,97	15,50	28,18	38,27	45,42
F1	heur.	14,32	27,19	38,65	46,98	19,74	35,31	47,03	55,01
F2	random	24,91	37,24	45,57	51,47	31,03	43,82	51,89	57,31
F2	heur.	30,16	45,10	54,26	60,28	38,11	53,20	61,49	66,65
F3	random	43,04	53,37	60,18	64,79	49,18	59,19	65,51	69,93
F3	heur.	50,82	61,89	69,66	74,53	58,35	68,14	75,22	79,57
F4	random	5,46	12,38	20,72	28,45	7,94	17,37	27,11	35,18
F4	heur.	7,54	15,33	25,58	34,63	10,72	21,67	33,79	43,50
F5	random	2,95	7,62	14,10	21,50	4,47	11,19	19,38	27,89
F5	heur.	5,09	9,77	17,31	26,72	6,74	14,44	24,32	35,15

DISCUSSION

The class-based storage is very convenient and for that reason it is often applied in practice. The application of class-based storage (with random storage inside each class) leads to significant improvement of the order-picking activity (the traveled distances can be even more than twice shorter in comparison to fully random storage). The items can be assigned into classes based on picking frequency or cube-per-order index. The second approach may result in reduction of distances traveled by the picker only when the COI is calculated based on occupied storage area (not the size of single item). The possibility of picking many smaller items located close to the PD in one tour does not affect to a large degree the expected distance traveled by the picker. For unit-load warehouses we know from literature that the COI-based storage is optimal. The presented in this paper research shows that in the warehouses where the pickers collect many items in one tour the storage based on picking frequency is superior to the storage based on COI. However, note that presented results do not take into account the costs of replenishment of items from the reserve area to the storage area. This problem should be analyzed.

The increase of the size of picker's bin will allow to create the larger batches of orders. This implies a reduction of the distance covered by the picker, but could generate additional sorting costs. It was showed that the presented batching algorithm is superior to the random batching. The issue of searching the optimal bin's size should be further investigated.

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WPŁYW SKŁADOWANIA TOWARÓW ZGODNEGO ZE WSPÓŁCZYNNIKAMI COI NA CZASY KOMPLETACJI TOWARÓW

STRESZCZENIE. Wstęp: Ciągły wzrost konkurencyjności na światowych rynkach wymusza konieczność szybkiej i niezawodnej dostawy zamówionych towarów. Zadanie to możliwe jest do wykonania dzięki doskonaleniu systemów kompletacji. Nie zawsze wdrożenie systemów automatycznych jest opłacalne. W przypadku magazynów, w których kompletacja odbywa się zgodnie z zasadą „człowiek do towaru", optymalizacja wydajności odbywa się poprzez prawidłowy wybór: układu magazynu, metody składowania towarów, sposobu wyznaczania trasy magazynierów, odpowiedniej metody kompletacji strefowej, zasady tworzenia zleceń łączonych czy ustalenia kolejności realizacji zleceń. Artykuł poświęcony jest analizie wpływu metody składowania towarów na czasy kompletacji.

Metody: W artykule zbadano jaki wpływ na średnie czasy kompletacji w magazynach niskiego składowania ma składowanie towarów zgodne z zaproponowanym przez Hesketta współczynnikiem COI (cube-per-order index), będącym ilorazem zajmowanej powierzchni magazynowej i częstości pobrań. Towary w oparciu o rosnące wartości COI podzielone zostały na klasy. Do określenia popytu na towary wykorzystano postać analityczną funkcji zaproponowanej przez Carona.

Wyniki: W artykule sprawdzono jakie korzyści przynosi składowanie oparte o COI w porównaniu do składowania losowego i składowania bazującego wyłącznie na współczynniku rotacji. W tym celu w badaniach uwzględniono możliwość przepełnienia koszyka podczas procesu kompletacji zamówienia – wówczas zamówienie dzielone jest na kilka zleceń realizowanych osobno. Analizę przeprowadzono z wykorzystaniem symulacji. Dodatkowo zaproponowano algorytm umożliwiający tworzenie zleceń łączonych.

Wnioski: Z przeprowadzonej analizy wynika, że składowanie zgodne ze współczynnikiem COI jest szczególnie korzystne, gdy gabaryty towarów są zróżnicowane oraz tak duże, że często zamówień nie da się skompletować podczas jednego cyklu. Krzywa określająca popyt na towary ulega spłaszczeniu, w porównaniu ze składowaniem opartym wyłącznie na współczynniku rotacji. Ustalenie, jaką metodę składowania należy zastosować, powinno odbywać się razem z wyborem sposobu wyznaczenia trasy magazyniera. Wykorzystanie algorytmu łączenia zamówień prowadzi do znacznej redukcji odległości pokonywanych przez magazyniera. Wielkość zleceń łączonych powinna być jednak optymalizowana z uwzględnieniem ewentualnych kosztów związanych z późniejszym sortowaniem towarów.

Słowa kluczowe: kompletacja zamówień, współczynnik COI, symulacje

EINFLUSS DER LAGERUNG AUF DIE ZEIT DER MIT DEN COI-KOEFFIZIENTEN ÜBEREINSTIMMENDEN WARENKOMMISSIONIERUNG

ZUSAMMENFASSUNG. Einleitung: Der laufend steigende Wettbewerb auf den Weltmärkten erzwingt die Notwendigkeit einer schnellen und leistungsfähigen Anlieferung von bestellten Waren. Die Aufgabe ist machbar dank der gezielten Vervollkommnung von Kommissionierungssystemen. Die Einführung von automatisierten Systemen bleibt nicht immer rentabel für eine leistungsfähige Kommissionierung. Bei Lagern, in denen die Kommissionierung gemäß dem Prinzip „Mann zur Ware" zustande kommt, erfolgt die Optimierung der Leistungsfähigkeit durch die richtige Auswahl von: Lageranordnung, Lagerungsmethode, Art und Weise der Festlegung von Routen der Lagerarbeiter, Kommissionierungsmethode, Prinzip der Bildung von Sammelaufträgen und Reihenfolge der Ausführung von Kommissionierungsaufträgen. Der Artikel vermag die Analyse des Einflusses der Lagerungsmethode auf die Zeitintervalle der Warenkommissionierung zu projizieren.

Methoden: In dem vorliegenden Artikel erforschte man, inwieweit die Warenlagerung anhand des von Heskett vorgeschlagenen COI-Koeffizienten (cube-per-order index), der ein Quotient der in Anspruch genommenen Lagerfläche und der Entnahmefrequenz ist, die durchschnittliche Kommissionierungszeit in Niedrigregallagern beeinflusst. Die Waren wurden anhand der wachsenden COI-Werte in Klassen eingestuft. Für die Bestimmung der Nachfrage für Waren wurde die analytische Form der von Caron vorgeschlagenen Funktion in Anspruch genommen.

Ergebnisse: Im Artikel prüfte man welche Nutzen die auf den COI-Koeffizienten gestützte Lagerung im Vergleich zur zufälligen Lagerung und der ausschließlich auf den Rotationskoeffizienten gestützte Lagerung mit sich bringt. Zu diesem Zweck berücksichtigte man in den Forschungen die Möglichkeit einer Überfüllung des Korbes während der Kommissionierung des Auftrages – gegebenenfalls wird die Bestellung in einige Einzelaufträge aufgeteilt. Die betreffende Analyse wurde unter Anwendung der Simulation durchgeführt. Zusätzlich schlug man einen die Bildung von Sammelaufträgen ermöglichenden Algorithmus vor.

Fazit: Aus der durchgeführten Analyse ergibt sich, dass die mit dem COI-Koeffizienten übereinstimmende Lagerung dann besonders günstig ist, wenn die Warenabmessungen unterschiedlich und so groß sind, dass sich oft während eines Zyklus die Bestellungen nicht kommissionieren lassen. Die die Nachfrage bestimmende Kurve erliegt einer Abflachung im Vergleich zur Lagerung, die ausschließlich auf den Rotationskoeffizienten gestützt ist. Die Bestimmung der anzuwendenden Lagerungsmethode sollte parallel zur Auswahl der Art und Weise der Bestimmung der Lagerroute des Lagerarbeiters erfolgen. Die Inanspruchnahme des Algorithmus der Sammelaufträge führt zu einer weitgehenden Reduzierung der vom Lagerarbeiter überwundenen Entfernungen. Die Größe der Sammelaufträge sollte jedoch unter Berücksichtigung der eventuellen, mit der späteren Warensortierung verbundenen Kosten optimiert werden.

Codewörter: Kommissionierung von Aufträgen, COI-Koeffizient, Simulationen

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