Order Picking Area Layout and Its Impact on the Efficiency of Order Picking Process

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Abstract—**Paper deals with the efficiency of the order picking process according to the order picking area layout. The conducted research addresses the problem of congestion in the order picking area, which affects the locking time of workers during order picking. A copyright computer application was used to implement the research, allowing the construction of variants in the order picking system and simulating the implemented processes in the variants of order picking, as well as estimating specific characteristics.**

Index Terms—**order picking efficiency, order picking area layout, congestion in order picking area**

I. Introduction

To boost competitive advantage in the global market and maximize productivity, effective distribution systems are needed. One of the ways to reach this aim is to form the right structures of the previously mentioned system and optimize the implemented processes in the areas of outer transport [1], [2]. It is also important to take into consideration logistic facilities, which play an important role in every distribution system. They are used for storage, buffering, and transformation streams (raw materials, semi-finished or finished products) and accompanying them information streams, moving between points of origin (production) and reception (consumption). They perform the function of bonding distribution system cells, thus determining its effectiveness and efficiency (in accordance with the principle - "a chain is only as strong as its weakest link"). It is not surprising that designing or reorganizing the distribution system a great deal of attention is given to the point elements, i.e. logistics facilities.

Due to the diversity of customer needs and a well-developed retail market, operating mixed unit load plays a larger role in the distribution systems. This in turn, causes more time to be devoted to the issue of increasing the efficiency of the order picking processes implemented in logistics facilities

In the reference books, the analysis of the problem has been subjected to a number of factors that affect the efficiency of the order picking process, among other things, e.g.:

- Order picking area layout [3] - [13],
- Storage assignment [14] - [16],
- Order batching [17] - [20],
- Routing [21], [19], [9], [10],
- Congestion in order picking area [22] - [26].

In this paper, emphasis will be placed on the order picking area layout and its impact on the efficiency of the order picking process. The research includes the problem of congestion in the area resulting from the picking by many employees at the same time. Therefore, also for the implementation of research has been developed authoring application that enables computer simulation of the process of picking and estimate its efficiency.

II. Order Picking Area Layout

Resources indicate that the problem of the storage/ order picking area layout is divided into two separate sub-problems.

The first issue concerns where and how to place the specific elements of the order picking area, i.e. the reception area, picking area, storage, sorting, forming, etc. An example of this problem was addressed by Le-Duc T. [8] and primarily discusses dependences and the distance between the previously mentioned elements. The objective is to minimize the costs associated with the implementation order picking activities.

The second sub-problem, known as the internal problem of designing order picking area [14], deals with naming the number of blocks as well as amount and length, of the pick aisles in each of the blocks. An essential aspect of these analyses is deciding on the localization of the depot point, in other words the place from which the picking list is collected and where the completed unit load is placed. In the event of analyzing the picking area of more than one storage block, it is necessary to specify both the number of cross aisles as to identify their location.

The analysis of the picking area for picking systems of lower areas was carried out in publications as early as the 1980s. Bassan, Roll and Rosenblat [3] elaborated on the relationship between two different order picking area layouts of parallel pick aisles. Authors analyzed exploitation and expenditure costs which generated both spatial and organizational solutions.

A few years later, in 1988, Roll and Rosenblat [13] focused on the impact of randomness of demand for offered by the order picking system goods and founded

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customer service level on the size of the necessary storage inventory and order picking area layout system.

Another approach to order picking area layout presents Roodbergen in [9], [10], [11]. In these publications was proposed non-linear function mapping the pick path length of execution of the picking list with a certain number of items to be taken and when known total length of the pick aisles. Values of function determined the number of pick aisles in order picking area as well as the location of the depot. In this study the author of the publications [9], [10], [11] focused on random storage assignment method in picking area.

Minimizing the distance travelled during the implementation picking processes at different order picking area layouts was also dealt by other authors.

Caron in [4] considered two-blocks order picking area layouts in which items were allocated according to the COI storage assignment method (Cube-Order-Index). However, Le-Duc and De Koster in [7] focused on the order picking areas with the class-based storage assignment methods.

In the case of single-block layouts Roodbergen and Vis presented in [12] mathematical formulas describing the relationship between order picking area layouts and average length of pick road. In these studies used different heuristic routing methods and determined the best location of the depot according to pick path length and random storage assignment methods.

An innovative approach to the order picking area layout was presented in [13]. Gue and Meller proposed to use of diagonal cross aisles arranged in the shape of the letter "X" and pick aisles of various lengths. The purpose of this was to improve warehouse processes including order picking processes.

Another innovative approach to the layout of storage/picking areas were presented by Gue and Meller'a in [5]. Authors have evaluated layouts called Flying-V, Fishbone and Chevron.

III. PICKERS LOCKING PHENOMENON

The congestion problem can occur in almost any kind of transportation system, starting from large national or regional transportation systems, through city transportation systems, and finishing on internal transportation systems in logistic facilities. Regarding above the congestion problem refers also to man-to-goods picking systems where workers moving between pick locations can disrupt and lock each other. This can cause the decrease of the picking area throughput and order picking efficiency.

The phenomenon of pickers locking occurs when actions performed by the worker fulfilling an order are disrupted by another worker. This causes the time loss arising from waiting for ability to continue picking process. Time spent for this waiting is then called picker's locking time [24].

In case of manual picking systems (man-to-goods) picker locking situations can occur in:

- Around depot (Fig. 1c),
- In cross aisle (Fig. 1a and Fig. 1c),
- In wide pick aisles allowing workers to pass each other,
- In narrow pick aisles not allowing workers to pass each other (Fig. 1d - Fig. 1f),

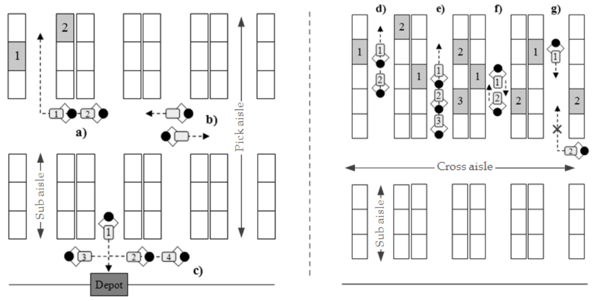

Figure 1. Examples of pickers locking in order picking area

IV. OF THE ORDER PICKING EVALUATION

Analyzed in the article order picking process involves fulfilling a series of picking lists generated on the basis of customer orders. These operations are performed by one or more order picking system workers.

Picking of a single order (or group of orders) begins at the moment of carry it (them) out to fulfilling, but ends at the moment of putting off by an employee heterogeneous unit at the depot. In order to determine the duration of the whole order picking process (time of picking all picking lists) it is necessary to determine the starting moments ($t^{start}(pr,zk)$) and end of the process ($t^{end}(pr,zk)$) by all pickers, and then placing them on the timeline. Next, determine the earliest moment of beginning and the latest moment of ending picking for each employee. Length of time between these two moments defines the time of fulfilling all picking list (see Fig. 2).

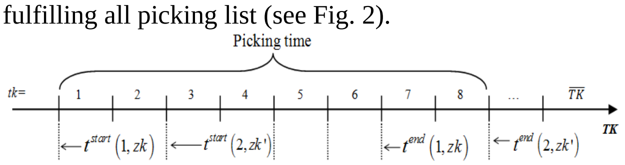

Figure 2. Moments of the beginning and ending of fulfilling individual picking lists

To presenting criteria of the order picking evaluation was mapped set of pickers ***PR***, set of all picking lists ***ZK***, set of picking lists assigned to *pr*-th pickers $\boldsymbol{ZK^{pr}}$, set of types of picked articles (SKUs) ***RA*** and set of rows in *zk*-th picking lists $\boldsymbol{WZ^{zk}}$.

Therefore, time of fulfilling all picking lists could be presented as:

$$T_{pick} = \max_{pr\in \boldsymbol{PR}, zk\in \boldsymbol{ZK}} t^{end}(pr,zk) - \min_{pr\in \boldsymbol{PR}, zk\in \boldsymbol{ZK}} t^{start}(pr,zk) \quad (1)$$

Moments of beginning order picking process by individual employees may be different, depending on the variant of order picking system and method of distributing picking lists between employees. For example, when all orders are executed at the same time and all employees at the same time begin the process, there is a relationship:

$$t^{start}(1,1) = \ldots = t^{start}(pr,zk) = \ldots = t^{start}(PR,ZK) \quad (2)$$

where *PR* is the number of pickers, and *ZK* the number of picking lists.

Moments of ending individual picking lists by each employee can be determined based on the sum of the beginning moment and the time of fulfilling picking lists:

$$\forall\ pr \in \boldsymbol{PR},\ zk \in \boldsymbol{ZK}^{\boldsymbol{pr}}\quad t^{end}\ \ pr, zk\ \ = t^{start}\ \ pr, zk\ \ + \Delta t\ \ pr, zk \tag{3}$$

Time of fulfilling individual picking list by one picker can be presented as:

$$\forall\ pr \in \boldsymbol{PR},\ zk \in \boldsymbol{ZK}^{\boldsymbol{pr}}$$
$$\Delta t\ \ pr, zk\ \ = \Delta t^{ride}\ \ pr, zk\ \ + \Delta t^{pick}\ \ pr, zk\ \ + \Delta t^{wait}\ \ pr, zk \tag{4}$$

Order picking efficiency is usually measured by the number of orders, lines or SKU items fulfilled or picked per time unit.

In the first case, this parameter can be determined as:

$$W_{pick} = \frac{\sum_{zk \in \boldsymbol{ZK}^{pr}} \sum_{pr \in \boldsymbol{PR}} zpp(zk, pr)}{\max_{pr \in \boldsymbol{PR}, zk \in \boldsymbol{ZK}^{pr}} t^{end}\ \ pr, zk\ \ - \min_{pr \in \boldsymbol{PR}, zk \in \boldsymbol{ZK}^{pr}} t^{start}\ \ pr, zk} \tag{5}$$

where *zpp*(*zk*,*pr*)=1 if and only if *pr*-th employee has been assigned to implement *zk*-th picking list. Otherwise, *zpp*(*zk*,*pr*)=0.

If the efficiency of the order picking will be measured by the number of lines picked in a unit of time (defined as the rows of picking list), then:

$$W_{pick} = \frac{\sum_{zk \in \boldsymbol{ZK}^{pr}} \sum_{pr \in \boldsymbol{PR}} zpp(zk, pr) \cdot \overline{WZ}(zk)}{\max_{pr \in \boldsymbol{PR}, zk \in \boldsymbol{ZK}^{pr}} t^{end}\ \ pr, zk\ \ - \min_{pr \in \boldsymbol{PR}, zk \in \boldsymbol{ZK}^{pr}} t^{start}\ \ pr, zk} \tag{6}$$

where $\overline{WZ}(zk)$ is the total number of rows (lines) contained in the *zk*-th order picking list.

If, for the research, one line will be defined as a one picked item, then order picking efficiency would be presented in the form of the number of items picked per unit time, ie:

$$W_{pick} = \frac{\sum_{zk \in \boldsymbol{ZK}^{pr}} \sum_{pr \in \boldsymbol{PR}} \sum_{wz\ \ zk\ \ \in \boldsymbol{WZ}^{zk}} \sum_{ra \in \boldsymbol{RA}} zpp(zk, pr) \cdot \overline{WZ}(zk) \cdot la(wz\ \ zk\ \ , ra)}{\max_{pr \in \boldsymbol{PR}, zk \in \boldsymbol{ZK}^{pr}} t^{end}\ \ pr, zk\ \ - \min_{pr \in \boldsymbol{PR}, zk \in \boldsymbol{ZK}^{pr}} t^{start}\ \ pr, zk} \tag{7}$$

where *la*(*wz*(*zk*), *ra*) is number of items of *ra*-th type of articles picked in *wz*(*zk*)-th row of *zk*-th picking list.

For the study of the order picking process and evaluating its organization can be used parameters such as efficiency of individual pickers or pickers work time utilization.

Efficiency of the *pr*-th worker, in this paper is measured in items picked by him in a unit time. It can be presented in the form of the following relationship:

$$\forall pr \in \boldsymbol{PR}\ W_{pick}\ \ pr\ \ = \frac{\sum_{zk \in \boldsymbol{ZK}^{pr}} \sum_{wz\ \ zk\ \ \in \boldsymbol{WZ}^{zk}} \sum_{ra \in \boldsymbol{RA}} \overline{WZ}(zk) \cdot la(wz\ \ zk\ \ , ra)}{\max_{pr \in \boldsymbol{PR}, zk \in \boldsymbol{ZK}^{pr}} t^{end}\ \ pr, zk\ \ - \min_{pr \in \boldsymbol{PR}, zk \in \boldsymbol{ZK}^{pr}} t^{start}\ \ pr, zk} \tag{8}$$

Work time utilization of the *pr*-th picker, which is the ratio of the time of his free work (not taking into account time of waiting / locking employee) and the total time of picking this employee, can be presented as:

$$\forall pr \in \boldsymbol{PR}\ PTU\ \ pr\ \ = \frac{\sum_{zk \in \boldsymbol{ZK}^{pr}} \Delta t\ \ pr, zk\ \ - \Delta t^{wait}\ \ pr, zk}{\sum_{zk \in \boldsymbol{ZK}^{pr}} \Delta t\ \ pr, zk} 100\% \tag{9}$$

V. Problem Formulation

In order to present dependency between the efficiency of order picking and the order picking area layout 25 of its variants were formulated. They are characterized by a varying number of pick aisles, rack bays, blocks and storage levels (see Table I).

TABLE I. ORDER PICKING AREA VARIANTS

Variant	Aisles	Bays in Rack	Blocks	Levels
1	16	10	1	5
2	14	12	1	5
3	12	14	1	5
4	10	16	1	5
5	10	20	1	4
6	8	25	1	4
7	6	35	1	4
8	4	50	1	4
9	10	10	2	4
10	8	13	2	4
11	6	17	2	4
12	4	25	2	4
13	2	50	2	4
14	10	7	3	4
15	7	10	3	4
16	5	14	3	4
17	3	23	3	4
18	2	34	3	4
19	10	10	4	2
20	6	17	4	2
21	4	25	4	2
22	7	10	6	2
23	10	7	6	2
24	20	1	20	2
25	40	1	10	2

In addition, simulated and analyzed variants of order picking process are characterized as follows:

- Man-to-goods order picking method,
- Single picking strategy,
- Class based ABC storage assignment,
- S-shape routing method,
- 3 pickers picking simultaneously,
- Pickers are workload evenly (pick a similar number of articles),
- Order picking efficiency measured by the number of articles picked per unit time.

Study of the efficiency of order picking, depending on order picking area layout was performed using copyright computer application *SymPick*. It allows to constructing model of order picking system, simulating processes occurring in it, as well as estimating of certain characteristics of the order picking process, including its efficiency. So it allows to choose the order picking area layout, allocate items of SKU to pick locations according to specified storage assignment methods, generate and distribute picking lists between a certain number of employees, generate pick routes, simulate the order picking process and identify series of characteristics of the process.

VI. Results and Conclusions

After the formulation of project variants of order picking system was carried out simulation studies of processes implemented in these systems. The characteristic of order picking system like: total picking time, process efficiency, road lengths, picking time of each picker, free ride time of each picker, locking time of each picker, efficiency of each picker, and picking time utilization of each picker were determined. Selected characteristics of the process are summarized in Table II and in Fig.3-Fig.7.

TABLE II. Order Picking Simulation Results

Variant	T_{pick}	W_{pick}	T_{lock}	*Road*	*PTU*
1	41,46	12,71	0,78	1311,47	97,53
2	39,17	13,45	1,60	1182,77	95,27
3	37,34	14,11	2,87	1136,00	91,66
4	42,18	12,49	1,59	1070,23	95,21
5	41,55	12,69	3,66	1205,70	90,24
6	37,27	14,14	4,25	1202,43	88,40
7	42,88	12,29	5,55	1163,20	84,78
8	52,25	9,90	18,75	1148,23	62,64
9	31,73	16,61	0,62	1053,83	97,96
10	42,85	12,30	1,93	1050,33	94,42
11	36,66	14,38	1,90	1040,07	94,67
12	44,17	11,93	4,51	1128,90	87,72
13	76,26	6,91	24,29	1618,57	62,20
14	33,46	15,75	1,15	1030,40	96,47
15	32,25	16,34	0,76	1011,03	97,34
16	39,90	13,21	3,80	1093,97	89,16
17	51,26	10,28	8,82	1283,67	80,19
18	59,22	8,90	14,19	1693,40	74,07
19	39,36	13,39	0,12	1401,53	99,65
20	44,95	11,73	1,96	1677,37	95,39
21	62,10	8,49	8,14	1927,57	84,73
22	43,84	12,02	1,30	1514,43	96,73
23	41,12	12,82	1,71	1460,63	95,75
24	55,05	9,57	0,30	2358,60	99,46
25	69,28	7,61	0,23	3040,37	99,61

The highest order picking efficiency and lowest time of its implementation is characterized by a variant No. 9 (10 aisles, 10 bays, 2 blocks, 4 levels). In this variant the length of the picking road and the average time of locking pickers is one of the shortest, and average employee work time utilization one of the highest among the analyzed.

The worst in terms of efficiency turned out to be a variant No. 13 (2 aisles, 50 bays, 2 blocks, 4 levels). In this case, increased length of the pick road (see Fig. 5), and also the longest of the all analyzed was the average locking time of pickers (see Fig. 6), time of fulfilling all pick lists (see Fig. 3), and the same percentage pickers work time utilization (see Fig. 7). This is due to the fact that the order picking area layout is characterized by only two long pick aisles located in one storage block. In assumed method of routing (S-shape) very often in order to fulfill pick lists pickers have to go all their length. In addition, this lengthens the time of occupancy of pick aisles and thus increases the time of locking pickers.

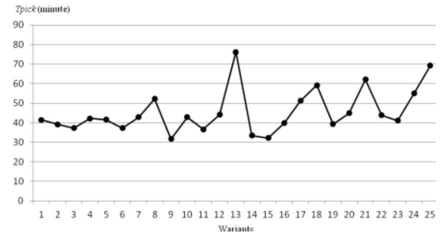

Figure 3. Order picking time in different area layouts

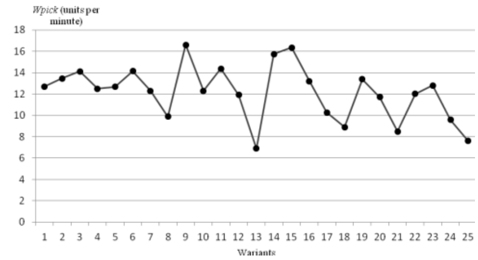

Figure 4. Order picking efficiency in different area layouts

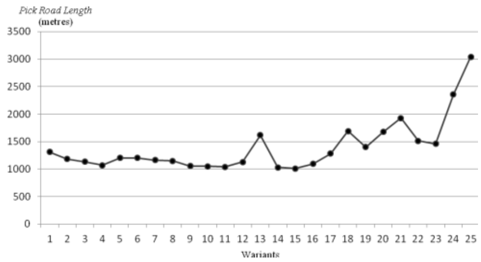

Figure 5. Pick road length in different area layouts

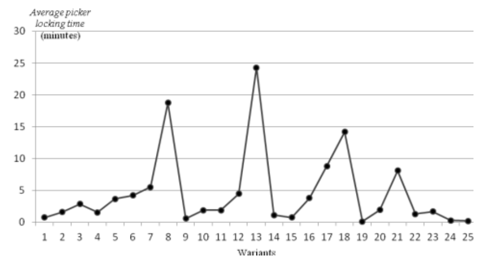

Figure 6. Average picker locking time in different variants

It also should be paid attention to the variant No. 15. It is characterized by the shortest picking route, and yet it is not the highest performance variant of the order picking process. Significant in this case turns out to be a problem of congestion in order picking area and the consequent time of locking employees.

Similar conclusions can be drawn from the analysis of Fig. 8. It represents the dependence of the efficiency of order picking process and the surface and cubage of the order picking area. In this case not always layouts with the smallest surface area (and thus the shortest path) provide for the highest efficiency of the process. A similar situation is in the case of cubage and efficiency of order picking area. This indicates how important it is to include in the analysis of the impact of the order picking area layout on the efficiency of order picking process the problem of congestion and employees locking phenomena.

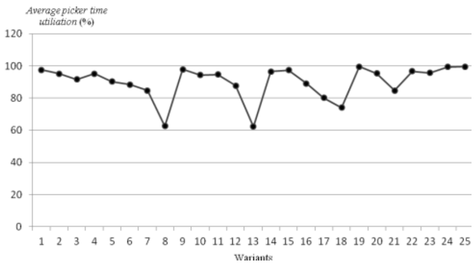

Figure 7. Average picker time utilization in different variants

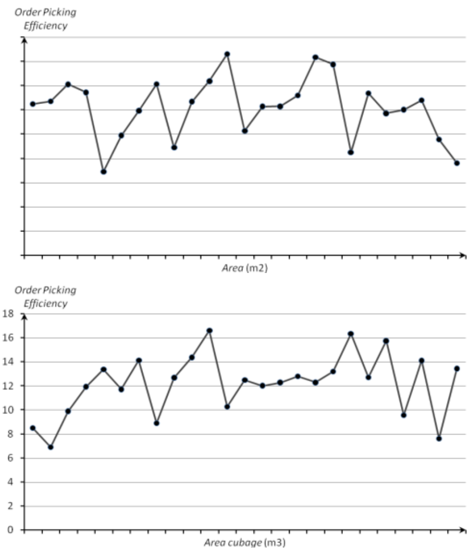

Figure 8. Order picking efficiency according to surface and cubage of order picking area

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