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Supportive Role of Dynamic Order Picking Area in Distribution Warehouse

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***Abstract*—Paper contains discussion about selected aspects of order picking systems in distribution warehouse and supportive role of dynamic order picking. The definitions and characteristics of static and dynamic order picking processes are given to compare these processes and determine rules for setting them in distributional warehouse. Warehouse activity profiling is presented in terms of assigning skus into dynamic and static order picking areas. The process of dynamic order picking is described and formally denoted. The simulation approach allowing investigation of dynamic order picking area is presented and used to obtain experimental data. Results are discussed.**

***Index Terms*—designing order picking area, dynamic order picking, order picking efficiency, warehouse design**

I. INTRODUCTION

Completion of customer orders is a fundamental process in distributional warehouse affecting the quality of services and deciding about its competitiveness. All other activities are subordinated to order picking and shipping phase. The quality of final product submitted to the client precisely results from the picking organization. One of the quality criteria is order execution time, and ability to keep the exact time of order realization agreed with a customer [1]. Mistakes made on this step are reflected in customer satisfaction [2]. The costs of order picking process and warehouse exploitation costs are factors influencing the prices offered to the client so must be considered together with order realization time [3].

The picking areas dispose most valuable locations in warehouse. They allow offering small amounts of all types of units (sku), so are expensive to maintain, and key for warehousing process [4]. Then the rational usage of picking area capacity, together with routing, slotting and batching problems, are fundamental elements of picking area organization.

Order picking systems are functional areas which, in most cases, need two types of operations for functioning: picking and replenishing. Picking empties the area whereas replenishment feeds it. Both operations are performed by people or equipment and are cost drivers for picking process [5]. The capacious order picking area consumes the space and makes the transportation cycles longer but ensures less replenishment cycles. Smaller area requires more replenishment cycles what influences duration of order completion. This tradeoff is also complicated by variable orders structure, batching policy, zoning, packing structure of units, congestion, slotting and routing problems and technology of order picking.

Literature offers plenty of methods and case studies for those problems (e.g.: [2], [4] and [6]-[9]) even comprehensive literature reviews like [10], but still selected aspects must be researched.

In most distributional warehouses it is impossible to represent all skus in order picking area (e.g. 50 000 of skus in pharmacy). Some of them-according to the flow velocity and order characteristics-must by constantly present in picking area, but some not. This is a rule for establishing static and dynamic order picking areas.

For the purpose of this article *static order picking area* is defined as the area where all offered skus have permanently assigned locations and this assignment changes rather rarely. Number of locations in static area is equal or higher then number of offered skus. *Dynamic order picking area* is defined as the area to which materials are putted only when they appear in clients orders. After completion material can stay there waiting for next order, or can be retrieved to reserve area to make room for other skus. The number of locations in dynamic area is less or much less then number of offered skus. Thanks to that it is possible to do order picking on limited storage capacity of order picking area. The trade-off is the necessity of additional handling. Dynamic picking area is a version of *forward reserve problem*, but proposed approach includes new elements.

Static picking areas are involved in about 75% – 85% [11] of material flow in typical warehouse and are *supported* by dynamic areas dealing with the rest. Static area is a key element, but when order includes sku offered only in dynamic area, then realization time is strongly dependent on dynamic area productivity [11].

The necessity of quick reassignment of skus in dynamic area forces using carriers like pallets or plastic containers for material handling, whereas in static area materials can be putted directly to the racking systems (i.e. bin shelving, gravity flow racks). Type of carrier arises from storage technology applied in reserve area.

Therefore, the dynamic areas can be used also for different operations, especially as buffers for combined transport cycles or temporary storage places when no orders are realized. Moreover dynamic area in most cases makes possible offering materials with outlying weight or

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dimensions restricting locating them in static area. Other opportunity to use dynamic area is when ordered amounts of material exceed stock in static area or would greatly reduce that stock causing additional replenishment cycle.

Organization of dynamic order picking area must take into account additional conditions [11]:

- Area should be located close to reserve areas in order to shorten replenishment and retrieving cycles.
- Warehouse should have a broken case/pallet handling capability to manage those units in reserve area.
- There must be formulated policy of gathering and working out the clients orders (to plan replenishment).
- Sharing replenishing (retrieving) devices as well as picking devices with other functional areas.
- Area emptying level γ should be found. It is the level of dynamic area fulfillment that when exceeded will start automatic procedure of retrieving (cleaning).

II. SETTING ORDER PICKING SYSTEM

A. *Activity Profiling*

Assortment of material must be analyzed according to flow density of particular skus to find significant items influencing the statistical structure of orders. This is done through *Warehouse Activity Profiling* (WAP) with known methods. WAP embraces analysis of historical data, characteristics of products and locations, packing patterns, and warehouse layout. For design purpose, the most important is *customer order profile* consisting of: order mix distributions, lines per order distribution, and lines and cube per order distribution ([7], p.18). WAP reveals the labor distribution on groups of items or individual items as well functional areas or particular stages of warehousing process.

This analysis allows, among others, creating ABC and XYZ classifications of materials for configuring order picking areas. The details of classifications are dependent on process held in warehouse. In most cases assigning skus to A, B or C group is based on the flow measures like number of pieces handled, but it can be also the total mass moved, number of pallets moved, or the number of order lines in which item appears. XYZ classification in most cases considers probability of appearing the sku in client order and regularity of ordered amounts. These two classifications are useful in deciding about assigning materials into static or dynamic order picking area as it is exemplary presented on Fig. 1.

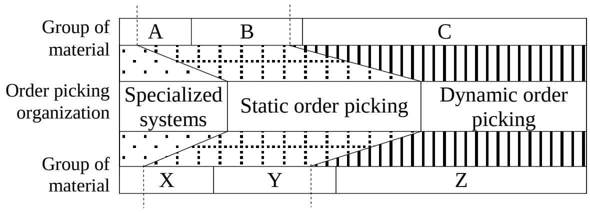

Figure 1. Assigning materials to order picking systems – example.

B. *Static or Dynamic Order Picking*

Classified skus must be assigned to one of the systems.

Rules of slotting assortment combine methods shortening picking cycles and lowering labor consumption [10]. The tradeoff is in allocation of space or labor resources to skus. When sku is in static area it consumes space of "golden zone" but statistically reduces transportation cycles. When it is in dynamic area it requires more handling, but uses less space.

Incoming orders consist of *lines* being a representation of particular skus and ordered amounts. Usually raw orders are consolidated and transformed into *picking lists*. These lists are in most cases constructed as a check lists indicating subsequent places to be visited while picking. When skus are permanently assigned to locations using picking lists is rational, but when skus are located dynamically it is impractical or requires strong planning algorithms to link static and dynamic picking. This is a reason why in dynamic area it is likely to pick single-line orders and then consolidate materials in another area.

When the order line is to be fulfilled, it must be checked which system will realize it. Each a-th sku is characterized by probability $P\left(a_{ordered}=a\right)$ of appearing in clients order. If all skus are sorted in descending order of probability of being ordered then the A_s of all A skus can be assigned to static picking and A_d for a dynamic picking area as it is presented on Fig. 2.

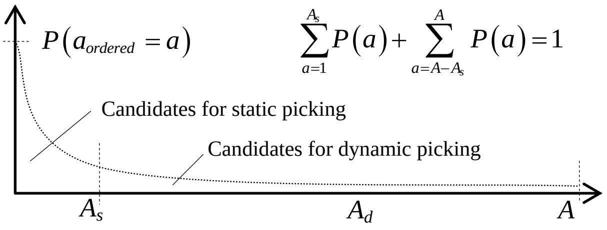

Figure 2. Dividing assortment for picking areas – example.

The static picking area storage capacity C_s should be then equal or greater then A_s and dynamic picking area C_d should be lower than A_d. According to that all necessary stock of A skus will be offered in area of capacity $C = C_s + C_d$ locations. Of course setting the border line requires analysis and is dependent on the individual warehouse activity profile embracing efficiency and productivity of order picking processes. This article is focused on researching the dynamic area as a less recognized.

III. DYNAMIC ORDER PICKING PROCESS

A. *Formal Description*

Let there be dynamic order picking area with a storage capacity of C_d equally-privileged locations ([11]). Let $\boldsymbol{A_d}$ denotes the set of numbers of skus to be picked from the area. Each a-th sku is characterized by probability of being ordered P (a). The area is serviced by auxiliary devices replenishing locations and retrieving unnecessary units denoted as set $\boldsymbol{U}$, and set of picking devices $\boldsymbol{K}$.

The duration of operations performed in the area are described by random variables: T_p for time of picking, T_{rp}

for time of replenishing, and T_{rt} for time of retrieving operation. The appropriate empirical probability distributions are known. All time measures are expressed by indivisible time periods $t \in \boldsymbol{T};\ t = \overline{1,T}$.

Let $\mathbf{Lz} = \left[\left(a_{lz}, \varepsilon_{lz}\right);\ a \in \boldsymbol{A}_d;\ lz = \overline{1,Lz}\right]$ be the vector of pairs representing order lines to be picked, where ε_{lz} ε_{lz} is ordered number of pieces of *a*-th sku.

At any moment *t*, *area fulfilment Z* is known. It depends on various factors like emptying level $\gamma \in (0,1)$, number of engaged picking (*K*) and, auxiliary (*U*) devices, strategy *s* (prioritising picking, replenishing, retrieving or emptying), and other indirect factors, so area fulfilment is expressed as $Z\left(t,\gamma,s,K,U\right)$.

Also the stock $\eta\left(a,t\right)$ of each sku stored in the dynamic order picking area at any moment *t* is known. If $\eta\left(a,t\right) = 0$ then there is no *a*-th sku in the area.

Order picking process starts in the moment $t = 0$ when first order is assigned to realization and finishes in $t = T^{cm}$ when last order is completed. Order lines appearing time is a random variable with known probability distribution.

The productivity of dynamic picking is evaluated by total realization time T^{cm}, average time of line completion T^{av}, and summary time of all lines completion T^{sm}.

B. Process Description

Line of order can be realized in three variants. 1st: it is picked straight from the stock gathered in the area. When there is no material or it is not enough of it, it must be replenished from reserve area by auxiliary equipment. This is done in two ways: when there is a free location in the area (2nd var.) or when there is not (3rd var.). If the second situation happens, then unnecessary unit must be retrieved firstly so the new unit can be put in.

Lines are assigned to picking devices subsequently as they came to the system so next order is unknown until it is given. The situation when lines are firstly reorganized to fit best the stock in picking area is not considered. If demanded sku is not available in the area, the picking device must pause and wait until it is supplied. This is time waste that to be avoided through rational planning.

At any moment *t*, the condition $Z\left(t,\gamma,s,k,U\right)/C_d \le \gamma$ is evaluated. If it is false, then auxiliary equipment retrieves selected unit and transports it to reserve area. This is s. c. *cleaning* operation. Selection of unit is random at this level of research. If the material is ordered in the future and must be sent back to the area, the priority is given to incomplete unit retrieved before, if the amount of material is enough to complete current order.

The priority of activities is another problem. Naturally picking has the highest priority, but decision of prioritising replenishment then cleaning influences area fulfilment and productivity – especially number of engaged devices. It is easy to imagine when insufficient number of auxiliary devices is doing only replenishing and retrieving and have no time to do lower priority *cleaning*, so area fulfilment $Z = C_d$ though $\gamma < 1$. The algorithm of process realization is presented on the Fig. 3.

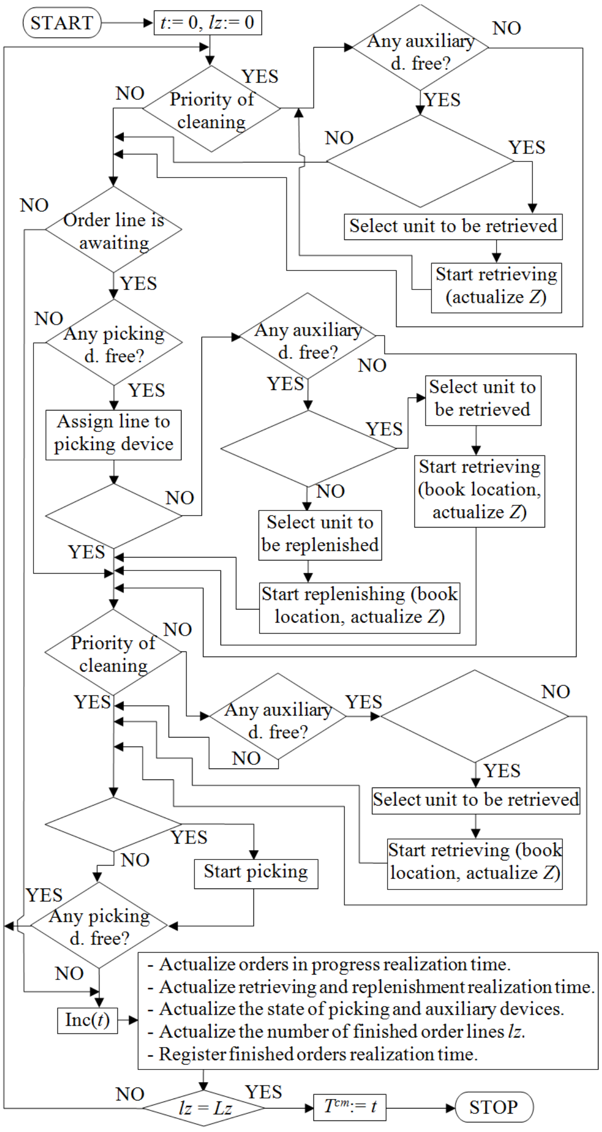

Figure 3. Basic algorithm of dynamic order picking realization.

The number of occurrences of each variants of order realization has a strong influence on whole area productivity. The realization variants are independent random events: X_1, X_2, and X_3 for which:

$$P\left(X_1\left(a_{lz},\varepsilon_{lz},t\right)\right) + P\left(X_2\left(a_{lz},\varepsilon_{lz},t\right)\right) + P\left(X_3\left(a_{lz},\varepsilon_{lz},t\right)\right) = 1 \ . \quad \forall\left(a_{lz},\varepsilon_{lz}\right) \in \mathbf{Lz} \tag{1}$$

where: $P\left(X_1\left(a_{lz},\varepsilon_{lz},t\right)\right)$, $P\left(X_2\left(a_{lz},\varepsilon_{lz},t\right)\right)$, $P\left(X_3\left(a_{lz},\varepsilon_{lz},t\right)\right)$ are probabilities of starting realization of *lz*-th line in *t*-th moment according to 1st, 2nd and 3rd variant.

When probability of ordering *a*-th sku is *P*(*a*), then:

$$P\left(X_1\left(a_{lz},\varepsilon_{lz},t\right)\right) = Z\left(t,\gamma,s,K,U\right) \cdot P\left(a_{lz} = a\right) \cdot \cdot\left(1 - P\left(a_{lz} = a\right)\right)^{Z(t,\gamma,s,K,U)-1} \cdot P\left(\eta\left(a_{lz},t\right) \ge \varepsilon_{lz}\right) \tag{2}$$

$$P\left(X_2\left(a_{lz},\varepsilon_{lz},t\right)\right) = = \left(1 - P\left(X_1\left(a_{lz},\varepsilon_{lz},t\right)\right)\right) \cdot P\left(Z\left(t,\gamma,s,K,U\right) < C_d\right) \tag{3}$$

$$P\left(X_3\left(a_{lz},\varepsilon_{lz},t\right)\right)= \\ =\left(1-P\left(X_1\left(a_{lz},\varepsilon_{lz},t\right)\right)\right)\cdot P\left(Z\left(t,\gamma,s,K,U\right)=C_d\right) \tag{4}$$

where:

$Z\left(t,\gamma,s,K,U\right)\cdot P\left(a_{lz}=a\right)\cdot\left(1-P\left(a_{lz}=a\right)\right)^{Z(t,\gamma,s,K,U)-1}$ is the probability of founding ordered a_{lz}-th sku in one of Z occupied locations in t-th moment.

Three vectors representing variants of lines realization are given. Vector $\mathbf{\Psi}_1=\left[\psi1\left(lz\right)\right]$ is composed of values:

$$\psi1\left(lz\right)=\begin{cases}P\left(X_1\left(a_{lz},\varepsilon_{lz},t\right)\right) & \text{if } lz\text{-th line is picked in var. 1,}\\ 1 & \text{otherwise.}\end{cases}$$

Vectors $\mathbf{\Psi}_2=\left[\psi2\left(lz\right)\right]$ and $\mathbf{\Psi}_3=\left[\psi3\left(lz\right)\right]$ are composed in the same manner, only number of variant changes.
Then, the number of occurrences *m*, *n* and *o* of variants can be found:

2nd variant: $$n=Lz-\sum_{lz=1}^{Lz}\left\lfloor\psi2\left(lz\right)\right\rfloor \tag{5}$$

3rd variant: $$o=Lz-\sum_{lz=1}^{Lz}\left\lfloor\psi3\left(lz\right)\right\rfloor \tag{6}$$

1st variant: $$m=Lz-n-o \tag{7}$$

Transforming a formula for probability mass function of multinomial distribution [12] allows calculating max. probability of occurring variants of line realizations:

$$P_{(n,o)}^{Lz}=Lz!\cdot\max_{n,o}\left\{\frac{\prod_{lz=1}^{Lz}\psi1\left(a_{lz}\right)\cdot\psi2\left(a_{lz}\right)\cdot\psi3\left(a_{lz}\right)}{n!\cdot o!\cdot\left(Lz-n-o\right)!}\right\} \tag{8}$$

The values n^* and o^* for which probability is maximal allows finding the summary time of all lines completion:

$$T^{sm}=Lz\cdot E\left(T_p\right)+E\left(T_{rp}\right)\cdot\left(n^*+o^*\right)+E\left(T_{rt}\right)\cdot o^*. \tag{9}$$

If $K=1$, then $T^{sm}=T^{cm}$.

High level of mutual correlation between dynamic parameters complicates the problem and hinders finding straight functions describing area productivity.

Also analytical counting of other time measures like total realization time T^{cm} and average time of line completion T^{av}, is difficult. The simulation approach then seems to be a good solution allowing taking into account all necessary data and get results in acceptable time.

IV. SIMULATION

Simulation takes into account all presented features of dynamic order picking area and necessary empirical and theoretical distributions of operations duration. For the purpose of research the following distributions were found: *Picking* (empirical): T_p: {U_1(90, 110), $P(U_1)$ = 0,6; U_2(111, 160), $P(U_2)$ = 0, 3; U_3(90, 110), $P(U_3)$ = 0, 1}. *Retrieving* (theoretical): T_{rt}: {*N*(150,60) cut off 50≤X≤400}. *Replenishment* (theoretic.): T_{rp}: {*N*(190,70), cut off 40≤X≤500}.

These are representative values for two-row dynamic order picking area organized in ground level of pallet racking system with high reaching forklift trucks servicing the area and low-lift electrical pedestrian forklifts for picking.

Realization of the batch of 500 order lines for 800 different skus was simulated for different area storage capacities C_d, and variable number of auxiliary and picking devices. Also, different values of area emptying level were considered. Simulated model assumes priority of replenishment than cleaning. Order lines are not sequenced and are completed as they appear. The time of appearance has a normal distribution.

Realized simulation presents the influence of disorders like reduction of number of devices or storage locations in area. It gave a precise estimation of average order completion time, total time of realizing the batch of orders and utilization of particular devices.

The extract from simulation results for different data sets is presented in Table I and Table II.

TABLE I. EXTRACT FROM RESULTS – TOTAL REALIZATION TIME T^{CM}

C_d	γ	*K* = 2	2	3	3	4	4
		U = 2	4	2	4	2	4
29	0,3	27h35'25"	26h26'47"	26h8'53"	18h14'53"	25h12'36"	13h41'32"
29	0,6	27h4'1"	25h52'15"	25h40'11"	17h59'34"	24h57'28"	14h1'18"
29	0,9	27h20'10"	26h26'31"	25h35'44"	18h0'3"	25h19'20"	13h51'58"
32	0,3	27h43'52"	27h2'48"	25h32'36"	17h46'25"	25h9'39"	14h6'7"
32	0,6	27h28'30"	25h57'26"	25h46'46"	17h58'7"	24h42'51"	13h56'40"
32	0,9	27h45'49"	26h15'36"	24h57'28"	18h1'5"	24h57'58"	14h8'36"
41	0,3	28h11'18"	25h49'1"	24h38'22"	17h49'27"	24h25'22"	13h41'6"
41	0,6	27h31'36"	25h47'35"	25h0'40"	17h56'30"	24h3'22"	13h48'3"
41	0,9	27h58'46"	26h7'13"	25h10'3"	17h51'13"	24h29'56"	13h51'52"
50	0,3	27h30'24"	26h36'29"	25h3'55"	18h1'44"	24h31'1"	14h3'13"
50	0,6	27h32'4"	26h5'40"	25h3'43"	17h35'10"	24h4'45"	13h59'40"
50	0,9	27h45'10"	25h31'23"	25h0'20"	17h19'21"	24h1'54"	13h46'34"

TABLE II. EXTRACT FROM SIMULATION RESULTS – AVERAGE ORDER LINE REALIZATION TIME T^{AV}

C_d	γ	*K* = 2	2	3	3	4	4
		U = 2	4	2	4	2	4
29	0,3	6'37"	6'20"	9'23"	6'33"	12'3"	6'32"
29	0,6	6'29"	6'12"	9'13"	6'27"	11'56"	6'43"
29	0,9	6'33"	6'20"	9'11"	6'27"	12'7"	6'37"
32	0,3	6'39"	6'29"	9'10"	6'39"	12'2"	6'44"
32	0,6	6'35"	6'13"	9'14"	6'40"	11'49"	6'40"
32	0,9	6'39"	6'18"	8'58"	6'37"	11'55"	6'46"
41	0,3	6'45"	6'11"	8'51"	6'32"	11'40"	6'32"
41	0,6	6'35"	6'11"	8'58"	6'40"	11'31"	6'36"
41	0,9	6'42"	6'15"	9'2"	6'35"	11'43"	6'37"
50	0,3	6'35"	6'22"	9'0"	6'37"	11'44"	6'44"
50	0,6	6'36"	6'15"	9'0"	6'32"	11'31"	6'42"
50	0,9	6'39"	6'6"	8'58"	6'32"	11'30"	6'35"

Differences in total realization time are significant according to area configuration. Two extreme values were obtained for $C_d=41$ locations and $\gamma=0,3$. This was caused by engagement of auxiliary devices *U* into cleaning operations.

From the other side average time of order line realization is strongly dependent on number of picking and auxiliary devices. The best results are achieved when proper support from auxiliary devices *U* is given for the picking devices *K*. Increasing number of pickers from 2 to 4 is even on the contrary to average order realization time which is strongly correlated to the number of auxiliary devices.

Changes in the area storage capacity influence total realization time when maximum number of auxiliary devices work. In simulated conditions it doesn't change significantly the average time of line realization.

Simulation also can show the average area fulfillment, utilization of particular devices (including time wasted for waiting), number of units replenished, and structure of broken-units in reserve area (number and content). It allows changing the strategy of picking and checking the impact of that changes on picking area productivity.

V. CONCLUSION

Concluding points I and II, the supportive role of dynamic order picking area manifests mostly in:

1. Handling low rotation or unpredictable demand skus impeding exact planning which is necessary to use the effect of scale when organizing static order picking areas. All orders mismatching the pattern of static picking areas can be realized in dynamic area.
2. Handling atypical skus (heavy, oversized), that can't be represented in static area or that with enormous flow volume. Dynamic order picking area allows avoiding additional replenishment cycles in static area.
3. Handling uniform units retrieved straight from reserve area (orders exceeding typical wholesale unit).
4. Taking over the tasks of static area (in rush hours) or taking over tasks of reserve area (drought time).
5. Buffering and supporting combined transport cycles in internal transport (universalism of that area).

Researching dynamic order picking area productivity is necessary to organize and design properly warehousing process. This area cooperates with all other functional areas, like: inbound and outbound buffers, reserve (storage) areas, other picking areas, packing and shipping areas. In some conditions it can be treated as a connector for different parts of warehousing processes and damper in situations requiring non-standard operations or handling non-standard units.

The frequent and varied usage of dynamic order picking areas requires frequent reorganization and efficiency estimation. The approach proposed in the article can be used for this purpose. Especially configuring and every-day adjusting of WMS is a potential field for application. Low time-consuming calculations can be performed in what-if analysis and applied in warehouse organizational patterns.

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