Optimization of a simulation model of the picking process using ABC analysis on the example of automated storage systems

A L Nosko, E V Safronov and P V Boslovyak*

Bauman Moscow State Technical University, Faculty of Robotics and Complex Automation, Department of Vertical Transport Systems, 105005, Moscow, 2nd Baumanskaya Str., 5, 1, Russia

*boslovyak89@mail.ru

Abstract. The optimization of the simulation model using ABC analysis has been considered. It has been determined that the rational arrangement of groups of goods in automated storage systems can increase the productivity of the picking process by 50%.

1. Introduction

The uninterrupted delivery of goods to a given destination is an urgent issue in the modern economic system. Therefore, in industrial logistics, the tasks appear, which are associated with optimizing the process of cargo movement [1, 2] and increasing the storage volume, as well as increasing the shipment productivity.

Automated systems, such as stacker cranes, conveyor and shuttle systems [3, 4, 5], as well as high-density storage systems, such as gravity racks [6, 7] are used to solve the problems of the storage volume and the shipment productivity increasing.

When storing breakbulk goods, the greatest impact on the shipment productivity is affected by the time of an order picking, which can take up to 50% of all time [8]. In this regard, the optimization of the order picking process depending on the product groups, for example, obtained by the ABC analysis method [9], plays the same role in reducing costs as the process of optimizing the metal consumption of conveyor structures while reducing equipment costs [10, 11].

2. The object of study

The work [8] shows the use of modelling for the process of picking orders using automated storage systems of the lift type. In this paper, it is proposed to consider the optimization of the simulation model using ABC analysis [9]. As an objective function, we take the order picking time. Its minimizing leads to an increase in productivity. It is possible to make by reducing the time of the extractor movement by arranging shelves with the most frequently encountered product numbers (groups A and B) closer to the picking window.

The standard distribution of product numbers by groups (ABC analysis) is presented at Fig. 1 [8]:

- group A - 20% of product numbers (724 product numbers, shelf numbers from 1st to 13th) provide 80% of orders;
• group B - 30% of product numbers (1086 product numbers, shelf numbers from 14th to 34th) provide 15% of orders;
• group C - 50% of product numbers (1811 product numbers, shelf numbers from the 35th to the 72nd) provide 5% of orders.

Figure 1. Standard distribution of product numbers by groups (ABC analysis).

The characteristics of the real system (initial data) are presented in Table 1 [8].

Table 1. The characteristics of the industrial warehouse facility.

| №  | Characteristics                                      | Value                        |
|----|-----------------------------------------------------|------------------------------|
| 1  | The total number of part numbers (items)            | 5000 items                   |
| 2  | Item dimensions                                    | 100×50×100 mm                |
| 3  | Quantity of automated storage systems              | 2 items                      |
| 4  | Effective shelf dimensions of automated storage     | 4300×825×100 mm              |
|    | systems (Length× Width × Height)                   |                              |
| 5  | The distance between the shelves, ΔL               | 175 mm                       |
| 6  | Quantity of shelves of automated storage systems   | 72 items                     |
| 7  | Quantity of stored product numbers on a shelf      | 51                            |
| 8  | Total shelf storage units                          | 255                           |
| 9  | Shelf loading/unloading time to/from the extractor  | 5 sec                        |
|    | Extractor                                          |                              |
| 10 | Shelf extractor lift speed V                        | 0.3 m/s                      |

3. Optimized logical-mathematical model of the picking orders process

Picking orders productivity $P$:

$$P = \frac{N}{T}, \text{orders per hour},$$

$N$ – total number of processed orders, ord; 
$T$ – time spent on N orders, hours.

As the initial state of the automated storage system, we take the location of the shelf with the product number of the first order in the delivery window.
Cycle time (picking of one order) is equal to [8]:

\[ t_c = \sum_{i=1}^{8} t_i, \text{sec}, \]

\( t_i \) – the time of each of the 8 intervals of the picking subprocess [8].

The numbering of shelves and the arrangement of automated storage system for a non-optimized and optimized simulation models are presented in Figure 2.

![Figure 2. Numbering and arrangement of automated storage system’s shelves.](image)

The algorithm of the optimized logical-mathematical model is shown at Fig. 3.

Then the number of shelf may be determined by the formula:

\[ \text{Shelf}_{NUMj} = \left[ \frac{SKU_{NUMj}}{51.1} \right] + 1, \]

\( SKU_{NUMj} \) – generated product number for j-th order;

\( j = 1 \ldots N \) – order number,

\( N \) – total number of processed orders.

It is most expedient to determine the distance between the shelf and the picking window and the its direction instead of a number of shelves in an optimized model.

The distance between the shelf and the picking window \( \Delta Shlf_j \):

\[
\Delta Shlf_j = \begin{cases} 
0, & \text{if } j = 0; \\
\left\lfloor \frac{SKU_{NUMj} - 1}{3.01} \right\rfloor + 1, & \text{if } 13 \geq SKU_{NUMj} > 1; \\
\left\lfloor \frac{SKU_{NUMj} - 13}{4.01} \right\rfloor + 5, & \text{if } 54 > SKU_{NUMj} > 13; \\
\left\lfloor \frac{SKU_{NUMj} - 53}{2.01} \right\rfloor + 15, & \text{if } 64 > SKU_{NUMj} > 53; \\
SKU_{NUMj} - 68, & \text{if } 69 > SKU_{NUMj} > 64; \\
\left\lfloor \frac{SKU_{NUMj} - 68}{2.01} \right\rfloor + 15, & \text{if } SKU_{NUMj} \geq 69. 
\end{cases}
\]
Figure 3. Algorithm of the optimized logical-mathematical model.

Let’s take the direction of the distance between the shelf and the picking window $\Delta Dir_j$ as the following values: “-1” - down, the value “+1” – up:
\[ \Delta D_i = \begin{cases} 0, & \text{if } j = 0; \\ 1, & \text{if } (13 \geq \text{SKU}_{\text{NUM}} > 1) \cap \left( \left( \text{SKU}_{\text{NUM}} - 1 - 3 \left( \frac{\text{SKU}_{\text{NUM}} - 1}{3} \right) = 0 \right) \cup \left( \left( \text{SKU}_{\text{NUM}} - 1 - 4 \left( \frac{\text{SKU}_{\text{NUM}} - 1}{4} \right) = 0 \right) \right) \right); \\ 1, & \text{if } (54 > \text{SKU}_{\text{NUM}} > 13) \cap \left( \left( \text{SKU}_{\text{NUM}} - 4 \left( \frac{\text{SKU}_{\text{NUM}} - 1}{4} \right) = 0 \right) \cup \left( \left( \text{SKU}_{\text{NUM}} - 1 - 4 \left( \frac{\text{SKU}_{\text{NUM}} - 1}{4} \right) = 0 \right) \right) \right); \\ -1, & \text{in other case.} \end{cases} \]

Then the transporting time \( t_3, t_5, t_7 \) can be defined as the time costs of vertical movement between the rows of shelves. The remaining time intervals remain unchanged as in the work [8].

**Determination of \( t_3 \):**
Taking into account that the picking window is at the level of the 27th row, the time \( t_3 \) may be determined as:

\[
\Delta t_{3j} = \begin{cases} 0, & \text{if } (j = 1) \cup (\Delta \text{Shelf}_j \cdot \Delta \text{Dir}_j = \Delta \text{Shelf}_{j-1} \cdot \Delta \text{Dir}_{j-1}) \end{cases}, \text{sec.}
\]

**Determination of \( t_5 \):**

\[
\Delta t_{5j} = \frac{\Delta \text{Shelf}_j \cdot \Delta \text{Dir}_j - \Delta \text{Shelf}_{j-1} \cdot \Delta \text{Dir}_{j-1} \cdot \Delta L}{V}, \text{sec.}
\]

**Determination of \( t_7 \):**

\[
\Delta t_{7j} = \frac{\Delta \text{Shelf}_j \cdot \Delta L}{V}, \text{sec.}
\]

\( \Delta L = 175 \text{ mm} \) – distance between shelves;
\( V = 0.3 \text{ m/s} \) – shelf lifting speed;
\( j = 1 \ldots N \) – shelf number;
\( N \) – total number of processed orders.

Thus, the optimized logical-mathematical model of the picking process has been fully described.

**4. Results**
Three simulation experiments were performed for \( N = 1000 \) pcs for the model described in [8] and the proposed optimized model. The results are shown in Fig. 4.

**Figure 4.** The simulation results.
According to the results, the average productivity of the automated storage system picking process (Figure 5) is:

- \( P = 79.39 \pm 0.91 \) orders per hour – without optimization;
- \( P = 119.01 \pm 1.19 \) orders per hour – with optimization.

![Figure 5: The average performance \( P \) for the automated storage system picking process.](image)

5. Conclusion

The following conclusions can be drawn on the results of the study:

1. The rational arrangement of groups of goods in automated storage systems can increase the picking process productivity by 50%.
2. The developed optimized logical-mathematical model may be used for calculation of the process the productivity of picking orders taking into account the ABC-analysis with a different distribution of product groups.

References

[1] I. Popova, A. Vlasov, N. Nikitina, Optimization of inventory distribution logistics in industrial enterprises, Espacios, Vol. 39, Issue 24, Art.no 16 (2018)

[2] T. Agasiev, A. Karpenko, The Program System for Automated Parameter Tuning of Optimization Algorithms, Procedia Computer Science, No. 103, 347-354 (2017)

[3] Kulwiec R. (1985), Material handling handbook, 2-nd edition, John Wiley & Sons, Inc, USA

[4] Heragu, SS., Cai, X., Krishnamurthy, A., Malmborg, CJ. (2011), Analytical models for analysis of automated warehouse material handling systems, Int J Of Prod Res, Vol. 49, No. 22, 6833-6861

[5] Lerher, T., Borovinsek, M., Ficko, M., Palcic, I. (2017), Parametric study of throughput performance in SBS/Rs based on simulation, Int J Of Simul Model, Vol. 16, No. 1, 96-107

[6] Eo, J., Sonico, J., Su, A., Wang, W., Zhou, C., Zhu, Y., Wu, S., Chokshi, T. (2015), Structured comparison of pallet racks and gravity flow racks, IIE Annual Conference and Expo 2015, 1971-1980

[7] Safronov, E., Nosko, A. A Method to Determine Allowable Speed for a Unit Load in a Pallet
Flow Rack, Acta Mechanica et Automatica, 13(2), P. 80-85 (2019)
[8] Nosko, A.L., Safronov, E.V., Boslov'yak, P.V. Throughput analysis for order picking system with automated storage system, IOP Conference Series: Materials Science and Engineering 709(2), 022102 (2020)

[9] Kučera, T., Dastych, D. Use of ABC analysis as management method in the rationalization of logistic warehousing processes: A case study (2018) Conference Proceedings of 12th International Days of Statistics and Economics, pp. 959-968

[10] P. Boslov'yak, G. Emelyanova, Optimization Mathematical Modeling of the Weight of Metal Structure of Suspended Belt Conveyor Linear Section. IFAC-PapersOnLine, No. 51, 616-619 (2018)

[11] P. Boslov'yak, A. Lagerev Optimization of the conveyor transport cost. IFAC-PapersOnLine, No. 52, 397-402 (2019)