Throughput analysis for order picking system with automated storage system

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Abstract. An example of using vertical lift systems for order picking tasks is given. Logical-mathematical is described and a simulation model of the picking process is built. Using simulation modeling allows you to calculate the performance of the picking process, the amount of necessary equipment and workplaces.

1. Introduction
The modern economy is constantly undergoing various changes. Various techniques are being developed that increase the efficiency of enterprises [1, 2]. However, irrespective of the growth or decline of economic development, for the uninterrupted delivery of goods to the destination, it is necessary to take into account and optimize industrial logistics issues [3-5].

One of the main nodes in the industrial logistics chain is a warehouse, inside which various transport systems can be used, such as special belt-type conveyors [6–8]; gravity racks [9, 10], robotic systems [11], automated storage systems [19] and others.

Currently, the greatest difficulties when working in a warehouse causes the process of picking orders. The cost of manpower on the picking site can be up to 50% of the cost of all manpower used in the warehouse [12], and the throughput should not exceed 40-50 orders / hour. In this case, the working time of the operator-picker as a percentage is distributed in the following ratio:
- selection of goods by request of customers - 10%;
- forced idle time during replenishment in the picking area or while working in this area of another picker operator - 20%;
- work with selective sheets - 30%;
- movement between picking points - 40%.

Therefore, in warehouses, it is advisable to use an automated storage system (ASS) for goods [13-15], the use of which can significantly reduce the time and increase the throughput of the picking process.

2. Object of study
The object of the research is a production and warehouse complex, which is a two-story building. On the first floor there is a warehouse of goods, on the second floor - production areas.

The tasks of the production and warehouse complex are as follows:
1. Shipment of non-production orders from the warehouse.
2. Picking of production orders with the following parameters:
   - throughput - 3000 units of orders per day;
   - three-shift work - 20 working hours per day.

   The production order (node) consists of three parts: two - types A (left) and B (right), and one - type C (base).

   The production process consists of the following steps:
   1. A complete set of production plastic containers - a plastic box (selection of parts A, B and C from ASS, manual placement of parts A, B and C into a plastic box).
   2. Sending production packaging to the place of processing parts A and B by an industrial robot.
   3. Verification by the technical quality control department of parts A and B.
   4. Assembly by the operator of parts A, B, C in the knot.

   As a base option for the processes of storage and order picking (stage number 1), the use ASS lift type, passing through two floors of the production and warehouse complex is proposed.

   For the rational use of warehouse space and, based on the performance of the picking, it was proposed to use five standard ASS with a height of 7800 mm with overall (useful) dimensions of the shelves 4300 × 825 mm.

   The estimated distribution of parts in five ASS is as follows:
   - the first and second ASS – 36 000 units of type C parts;
   - the third and fourth – 96 000 units of storage of details of type A and B;
   - the fifth ASS - related products in the amount of 22 000 storage units.

   The accepted ASS allocation will allow:
   1. To unload the second floor (production area) from warehouse flows.
   2. Link the warehouse (1st floor) and production (2nd floor).
   3. Separate the operations of replenishing articles in the picking area and the picking itself.
   4. To achieve the required performance equipment: 3000 orders in 20 hours.

   In more detail we will stop on the calculation of the throughput of the process of picking production orders. As an example, choose the details of type C.

3. Simulation modeling of production and warehouse complex

   The performance calculation was based on the simulation method. The formation of a computer simulation model of the throughput of the process of picking production orders was carried out using an automated storage system [16-18].

   The basis of the simulation procedure is based on the following main elements [18]:
   - real system;
   - logical-mathematical model of the object being modeled;
   - imitation (machine) model;
   - the computer on which the imitation is carried out – a directional computational experiment.

   There are two main approaches to the promotion of modeling time simulation model [18]:
   1. Advance of time from event to event.
   2. Advance of time with a constant step.

   For a simulation model of the throughput of the process of picking production orders, the approach “advance of time from event to event” is used - the event method (the method of “special” states).

   The “arrival of an order” event was used as a model time change, which was simulated using a Microsoft Excel random number generator. The standard random number generator in Microsoft Excel has approximately the same random variable distribution. Since it is most often necessary to model the distribution of orders in groups A, B and C, the random number generator is modified by a special script written in the Visual Basic for Application (VBA) programming language. The distribution of goods in groups A, B, C was taken as the average [18]:
   - group A - 80%;
   - group B - 15%;
   - group C - 5%.
Characteristics of the production and warehouse complex are presented in Table 1.

**Table 1.** Characteristics of the production and warehouse complex.

| № | Characteristic                                           | Value                        |
|---|---------------------------------------------------------|------------------------------|
| 1 | Total number of articles (items) of details of type B, units | 5000                         |
| 2 | The details of the type B size, mm                     | 100×50×100                   |
| 3 | Amount of ASS, pcs.                                    | 2                            |
| 4 | Useful sizes of shelves ASS (Length × Width × Height), mm | 4300×825×1                   |
| 5 | The distance between shelves, mm                       | 175                          |
| 6 | Number of shelves ASS, pcs.                            | 72                           |
| 7 | The number of stored items on the shelf                 | 51                           |
| 8 | The total number of units of storage details on the shelf | 255                          |
| 9 | Time of loading / unloading the shelf to / from the extractor, sec | 5                            |
| 10| Shelf extractor lifting speed, m/s                       | 0.3                          |

4. **Logical and mathematical model of the process of completing parts of type C**

The performance of ASS has the following dependency:

\[ P = \frac{N}{T} \]  \tag{1}  

- \(N\) – the total number of processed orders, order;
- \(T\) – time spent on \(N\) orders, hour.

To build a logical-mathematical model, it is required to determine the time cost of the ASS in the picking process.

Finding the shelf with the article of the first order in the dispensing window is taken as the initial state ASS. Then the process of picking one (each) order will consist of the following time intervals:

1. The selection of the required article \(t_1 = 5\) s;
2. The loading time of the shelf from the pickup window to the extractor (if the article is on another shelf) \(t_2 = 5\) s;
3. Time of moving the extractor with the shelf to the place of its storage \(t_3\);
4. The loading time of the shelf to the place of its storage (in case of finding the article on the other shelf) \(t_4 = 5\) s;
5. Time for moving the empty extractor to the new \(t_5\) shelf;
6. The loading time of a new shelf from the place of main storage to the extractor (if the article is on another shelf) \(t_6 = 5\) s;
7. The time for moving the new shelf with the extractor to the \(t_7\) pickup window;
8. The loading time of the shelf to the dispensing window \(t_8 = 5\) s.

The process is repeated the required number of times.

Thus, the cycle time (picking a single order) is:

\[ t_{ci} = \sum_{i=1}^{8} t_i \]  \tag{2}
Shelves movements during one cycle are shown in Fig. 1. The algorithm of the logical-mathematical model is presented in Fig. 2. The numbering of shelves and rows in the automated storage system is shown in Fig. 3.

![Diagram of shelf movements](image)

**Fig. 1.** Scheme of movements of the extractor

The articles, in accordance with the dimensions of type C parts, are distributed as follows - each shelf contains 51 articles (average stock for the article number 5), respectively:

1st Shelf - articles from 01 to 51;
2nd Shelf - Articles 52 to 102;
3rd Shelf - articles from 103 to 153;
…………………………
72nd Shelf - articles from 3622 to 3672.

Then the shelf number is determined by the following dependency:

$$\text{ShelfNUM}_{j} = \left\lfloor \frac{\text{SKU}_{NUM_j}}{51} \right\rfloor + 1,$$

(3)

\(\text{SKU}_{NUM_j}\) – generated article number for the j-th order;
\(j=1...N\) – is the order number.

The shelf range \(\text{Shelf\_ROW}_{j}\) is determined by the dependency:

$$\text{Shelf\_ROW}_{j} = \begin{cases} 
\text{ShelfNUM}_i, & \text{if } \text{ShelfNUM}_i \leq 2 \\
\text{ShelfNUM}_i + 5, & \text{if } 22 > \text{ShelfNUM}_i \geq 2 \\
\text{ShelfNUM}_i + 10, & \text{if } 31 \geq \text{ShelfNUM}_i \geq 22 \\
\text{ShelfNUM}_i + 31 + \left\lfloor \frac{\text{ShelfNUM}_i}{71} \right\rfloor, & \text{if } \text{ShelfNUM}_i > 31 
\end{cases}$$

(4)
Fig. 2. Algorithm of logical-mathematical model
Then the travel time $t_3$, $t_5$, $t_7$ can be defined as the cost of vertical movement between the rows of shelves.

The configuration window is at the level of the 27th row, then

$$t_{3j} = \begin{cases} 
0, & \text{if } j=1 \\
0, & \text{if } \text{Shelf}_{\text{ROW}}(j)=\text{Shelf}_{\text{ROW}}(j-1) \\
\text{Shelf}_{\text{ROW}}(j-1)-27 \cdot \Delta L / V & \text{otherwise}
\end{cases} \quad (5)$$

$$t_{5j} = \begin{cases} 
0, & \text{if } j=1 \\
\text{Shelf}_{\text{ROW}}(j)-\text{Shelf}_{\text{ROW}}(j-1) \cdot \Delta L / V & \text{otherwise}
\end{cases} \quad (6)$$

$$t_{7j} = \begin{cases} 
0, & \text{if } j=1 \\
\text{Shelf}_{\text{ROW}}(j)-27 \cdot \Delta L / V & \text{otherwise}
\end{cases} \quad (7)$$

$\Delta L=175\text{mm}$ – the distance between the shelves;

$V=0.3\text{m/s}$ – the speed of the shelf lifting.

Thus, the logical-mathematical model of the picking process is fully described.

5. Results

To obtain the results, 3 simulation experiments were carried out for $N = 1000$ pcs., $N = 1500$ pcs. and $N = 2000$ pcs. The results are shown in Fig. 4.
Fig. 4. Simulation results

From the result of simulation modeling, it follows that the values of the average throughput $P_m$, depending on the total number of processed orders $N$, are as follows:
- $P_m = 81.35$ order / hour for $N = 1000$ orders (average linear deviation 1.42%);
- $P_m = 81.08$ order / hour for $N = 1500$ orders (average linear deviation 0.83%);
- $P_m = 80.95$ order / hour for $N = 2000$ orders (average linear deviation 0.59%).

Thus, the conducted simulation experiments showed that the required productivity - 3000 orders in 20 hours, i.e. 150 order / hour can be fully implemented using two ASS.

6. Conclusions

A specific example shows the use of simulation modeling for the process of picking production orders using ASS, which allows to calculate the process performance, the amount of necessary equipment and working places.

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