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THE "LOAD BALANCING" AND "ADAPTIVE TASK COMPLETION" ALGORITHMS IMPLEMENTATION ON A PHARMACEUTICAL SORTING CONVEYOR LINE

The **subject matter** of the article is advantages and disadvantages of using the "load balancing" and "adaptive task execution" algorithms on the pharmaceutical sorting conveyor. The **goal** of the work is to analyze the Load Balancing (LB) and Adaptive Task Completion (ATC) sorting algorithms application on pharmaceutical sorting conveyor lines. And also, to consider their advantages and disadvantages in the context of optimizing sorting processes for pharmaceutical products. The following **tasks** were solved in the article: analysis of the latest research and publications on the research topic; study of the specifics of the application of algorithms for sorting pharmaceutical products on conveyor lines to balance the load on sorting robots; analysis of the Load Balancing (LB) algorithm from the point of view of its application for load balancing on conveyor lines with sorting robots in the field of pharmaceuticals; development of the Load Balancing algorithm for load balancing on conveyor lines with sorting robots in the pharmaceutical field; analysis of the Adaptive Task Completion (ATC) algorithm from the point of view of its application for load balancing on conveyor lines with sorting robots in the field of pharmaceuticals; development of a general Adaptive Task Completion (ATC) algorithm for load balancing on conveyor lines with sorting robots in the pharmaceutical field; highlighting the advantages and disadvantages of the specified algorithms. The following **methods** were used: simulation modeling methods. The following **results** were obtained – the advantages and disadvantages of Load Balancing and Adaptive Task Completion algorithms for load balancing on conveyor lines with sorting robots in the pharmaceutical field are formulated; recommendations are given, in which situations, under which conditions, which algorithm should be used. **Conclusions**. In the context of the pharmaceutical industry, where not only speed but also sorting accuracy is important, Adaptive Task Completion may be a better choice because it takes into account different criteria and dynamically responds to changing conditions. On the other hand, Load Balancing can be effective in environments where sorting speed is paramount, and tasks are homogeneous.

Keywords: Industry 4.0; Smart Manufacturing; Logistics 4.0; Warehousing 4.0; Load Balancing; Adaptive Task Completion.

Introduction

In the Industry 4.0 era, Smart Manufacturing and Logistics 4.0, where the concept of Warehousing 4.0 becomes fundamental, the implementation of advanced technologies and sorting algorithms on conveyor lines is of paramount importance to optimize production processes in the pharmaceutical industry. In this context, Load Balancing (LB) and Adaptive Task Completion (ATC) algorithms become key components of sorting strategies, enabling more efficient resource utilization and improved performance in Warehousing 4.0. LB is aimed at evenly distributing the load between sorting robots, it improves the conveyor line, which is an important step in the transition to integrated and intelligent production systems. In turn, ATC, with the added element of adaptability, is able to dynamically respond to changing conditions, making it an ideal choice for production environments where a high level of flexibility and adaptation is required. This article is intended to conduct an in-depth study of the application of LB and ATC sorting algorithms on conveyor lines in the pharmaceutical industry, evaluating their effectiveness within the framework of Industry 4.0 and Warehousing 4.0 concepts. Through analysis of research results, the authors highlight the advantages of each algorithm and provide recommendations for optimal selection in the context of smart manufacturing and modern logistics methods and their application on pharmaceutical sorting lines.

The **purpose** of this paper is to analyze the Load Balancing (LB) and Adaptive Task Completion (ATC) sorting algorithms application on pharmaceutical sorting conveyor lines. And also, to consider their advantages and disadvantages in the context of optimizing sorting processes for pharmaceutical products.

Related researches

The problems of creating warehouses and logistics in the pharmaceutical industry are a subject of keen interest to scientists [1–3].

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In an article by Xavier Delorme, the authors explored the issue of energy efficiency in manufacturing systems, given that energy efficiency has become a key issue for manufacturing systems, which are the largest consumer of limited energy sources [4]. The authors considered balancing such a production line to integrate energy peak minimization at the design stage. Thus, a new combinatorial problem was formulated – Parallel-Serial-with-Crossover Assembly Line Balancing Problem with Power Peak Minimization, which is NP-hard. Consequently, the authors did not develop an effective solution algorithm and did not propose an algorithm for solving all problems in a given NP class. The authors Rico Walter, Philipp Schulze and Armin Scholl in their work considered the possibility of an optimal solution for balancing the SALBP-SX assembly line, for this they proposed an individual branch and bound procedure. It contains a new station-oriented branching scheme, new lower bound arguments, logic tests and, in particular, a dynamic programming scheme for pre-calculating potential workloads, which significantly speeds up the procedure [5]. As you can see, the authors solved the problem of balancing a simple assembly line by leveling the load at stations taking into account the given cycle time and the number of stations, unfortunately this solution is not suitable for use within the framework of their use on pharmaceutical sorting conveyor lines, since it takes into account the square deviation workload of each station from the average (or ideal) load. This index is related to variance, a widely used measure of dispersion in statistics, which leads to large errors in simulations. Zixiang Li and Mukund Nilakantan Janardhanan consider the problem of balancing a robotic line while taking into account the development costs of such a system, which is a relevant issue in the context of Industry 4.0. The focus is on minimizing cycle time and total procurement cost when designing a robotic line. The authors develop a mixed integer linear program to formulate this problem. They also create the NSGA-II (Elite Non-Dominant Sorting Genetic Algorithm) and the Improved Multi-Objective Artificial Bee Colony Algorithm (IMABC) to obtain a set of Pareto-optimal solutions [6]. As you can see from the article, the proposed model is able to achieve a balanced compromise between the efficiency of the line and the overall purchasing costs, however, the proposed solution does not allow its use in the context of optimizing sorting processes for pharmaceutical products, but is an interesting solution from the point of view of applying the synthesis algorithm of a bee colony, which includes the phase busy bees and a scout phase, which improves exploration and use of solutions. In the work of Zeynel Abidin Çil, Hande Öztop and Zülal Diri Kenger, the authors try to solve the integrated problem of balancing a dismantling line and transport routing by developing new solution approaches such as integer linear programming, integer nonlinear programming and constraint programming models [7]. The multi-start algorithm proposed for use, from the point of view of its application, has a number of disadvantages such as: computational complexity, convergence, the need for multiple launches, as well as greater sensitivity to initial conditions, which is not suitable for use in the context of these studies. Ming-Liang Li used an algorithm in his research to balance assembly lines in the context of Industry 4.0. The main challenge was to balance the assembly lines by matching operators and workstations so that the workstations achieved the same output targets [8]. The author used a cluster algorithm based on the concept of group technology to form cells of operators according to skill levels and determine the families of operators. It is worth noting that cluster algorithms, including group technology algorithms, may have some disadvantages in the context of optimizing pharmaceutical product sorting processes, such as: failure to take into account the dynamics of processes, the requirement for interpretation of results, difficulty in processing large volumes of data and sensitivity to source data, and therefore are not suitable to solve the problem of balancing the sorting processes of pharmaceutical products. In [9] scientists propose a centralized task management approach that is adaptive to the system dynamics. They describe a novel task conversion algorithm that generates tasks from a batch of orders and provides a high pile-on value. Paper [10] discusses some of the existing shortcomings -referred to as "the productivity gap" – in current assembly automation processes. To cope with this gap, adaptive human-robot task sharing is proposed and implemented as a complementary task allocation model. Its potential to increase productivity and flexibility in new and existing assembly applications is evaluated. Authors in [11] put forward in task space an adaptive impedance controller for human-robot co-transportation. They note a great number of theoretical and practical challenges arising mainly from the unknown human-robot interaction model as well as from the difficulty of accurately model the robot dynamics. Article [12] aims to present a concise review on the variant state-of-the-art dynamic task allocation strategies. It presents a thorough discussion

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about the existing dynamic task allocation strategies mainly with respect to the problem application, constraints, objective functions and uncertainty handling methods. Chutima P. in his article [13] considers the assembly line balancing problem in which robots and automated equipment are employed to take on human workers' roles to form a flexible assembly line. And from the findings of the review, future research directions are pinpointed and discussed. Task allocation is an important problem in multi-robot system which can be defined with different setup for different application, i.e. coverage, surveillance and mining mission in static or dynamic scenarios [14]. To search for solutions in this problem, two methods are built on a tailor-made multi-objective scheme of Genetic Algorithm (GA) with a different setup and search operators, and a reinforcement learning approach. Researchers in [15] note several objectives are to be optimized in an assembly line balancing problem and optimizing line efficiency along with purchasing cost sometimes results in conflicting situation. They present the study to tackle the cost-oriented assembly line balancing problem with collaborative robots, where several different types of collaborative robots with different purchasing costs are available and selected.

1. Study of the specifics of using algorithms for sorting pharmaceutical products on conveyor lines to balance the load on sorting robots

Sorting pharmaceutical products on an assembly line using robotic sorters is a highly technical and highly demanding process that requires careful attention to detail and strict safety and quality standards. Let us list the basic aspects of this specificity:

– variety of shapes and packaging, since products in the pharmaceutical industry can have different sizes, shapes and types of packaging. Sorting robots must be flexible and able to adapt to a variety of product characteristics;

– accuracy and reliability, as a result of which pharmaceutical products often require high accuracy and reliability during sorting. Robots must be equipped with advanced machine vision systems and sensors to accurately recognize and identify each product;

– compliance with tracking and translation standards: due to the particular importance of traceability of each product in the pharmaceutical industry, sorting robots must ensure accurate tracking and translation of data about each package throughout the entire production process;

– personnel safety, within the framework of Industry 5.0 concepts, sorting robots must be integrated into the safety system, preventing possible collisions with operators or other equipment. This includes the use of modern safety systems such as sensors and emergency braking systems;

– Industry 4.0 compatibility in pharmaceutical manufacturing requires sorting robots to be compatible with digital technologies such as IoT networks, cloud computing and data analytics to improve production efficiency and control.

Load balancing when sorting pharmaceutical products on a conveyor line with robot sorters is an important aspect to ensure the efficiency and accuracy of the production process. Maintaining an even distribution of tasks between robots avoids overloads and underutilization, which optimizes sorting time and increases line productivity.

Load control also ensures that resources are used evenly, which reduces equipment wear and extends its life. This is especially important in the pharmaceutical industry, where the requirements for precision and hygiene are high. Uniform loading of robots helps prevent human errors and minimize material waste. In addition, load balancing management helps improve process safety by reducing the risk of accidents due to overload or lack of tasks. This is especially true in the pharmaceutical industry, where strict compliance with safety standards and product quality control is required. When balancing the load of sorting pharmaceutical products on conveyor lines with robotic sorters, various algorithms can be used. Some of the basic algorithms are shown in Table 1.

Of these algorithms, Load Balancing (LB) and Adaptive Task Completion (ATC) are particularly promising for the study of load balancing on robotic sorting conveyor lines in the pharmaceutical industry. The Load Balancing algorithm effectively distributes tasks between robots, trying to achieve optimal uniform load distribution throughout the line. Adaptive Task Completion, in turn, is an innovative approach that adapts task execution in real time, taking into account changes in production conditions and current system load. These algorithms are highly flexible and can effectively respond to dynamic changes, which is especially important in the pharmaceutical industry, where accuracy, productivity and safety requirements are paramount. Conducting research on the application of LB and ATC in this context will help identify optimal balancing strategies and

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improve the efficiency of sorting processes on pharmaceutical production lines.

Table 1. *Basic algorithms that can be used when balancing the load of sorting pharmaceutical products on conveyor lines with sorting robots*

Algorithm name	Description
Greedy Algorithms	These algorithms make local optimal decisions at each stage, which ensures fast response to the current load
Round Robin (RR)	Tasks are distributed among robots in rotation, which ensures even loading, but may not take into account differences in task complexity.
Machine Learning Algorithms	Using machine learning techniques such as supervised learning or unsupervised learning can allow the system to adapt to changes in workload and production conditions
Load Balancing (LB)	Aimed at distributing packages between robots in order to achieve optimal load balance. It operates based on the current robot load, assigning each task to the robot with the lowest current load, which promotes efficient use of resources and increased conveyor line productivity
Dynamic Programming (DP)	Application of dynamic programming to optimize task execution time and uniform load distribution.
Adaptive Task Completion (ATC)	It is an approach that adapts the distribution of tasks in real time depending on current conditions and system load. It seeks to optimize the process of completing tasks, taking into account dynamic changes in the workload and efficiency of robots.

2. The operating principle of the Load Balancing (LB) algorithm from the point of view of its application for load balancing on conveyor lines with sorting robots in the pharmaceutical industry

The Load Balancing (LB) algorithm in the pharmaceutical industry, used to balance the load on conveyor lines with sorting robots, can be represented by mathematical models that take into account key parameters and stages of work.

At the first step, we initialize the data, let us assume that within the framework of this research topic article we need to take into account the following input parameters: N – the number of types of packages, M_i – the total number of packages of each type i, R – the number of sorting robots, $T_{i,j}$ – the sorting time for the robot i packaging j type, $S_{i,j}$ – execution speed sorting tasks for the robot i packaging j type, W_i – the distance of the working zone for the robot i, D – the distance of the dead zone, C – the overall speed of the conveyor. Then the sorting machine time model can be described by the following model:

$$T_{i,j} = \frac{(W_i + D)}{S_{i,j}} \quad (1)$$

where: $T_{i,j}$ – the sorting time for the robot i packaging j type. This value represents the total time required to complete the sorting task for a particular robot and package type;

W_i – the distance of the working zone for the robot i. This distance represents the area within which the robot can efficiently perform sorting tasks;

D – the distance of the dead zone. This distance represents the area where the robot can be located but not perform sorting, for example due to safety restrictions or other factors;

$S_{i,j}$ – execution speed sorting tasks for the robot i packaging j type.

Thus, the model describes the ratio of the distance of the working zone and the dead zone to the speed of the sorting task, which allows us to calculate the total sorting time for a specific robot and type of packaging.

To solve the problem of minimizing sorting time under the condition of uniform loading of robots or other load balancing, it is proposed to use the following function:

$$\min \sum_{i=1}^{R} \sum_{j=1}^{N} T_{i,j} \quad (2)$$

where: $T_{i,j}$ – the sorting time for the robot i packaging j type. This function is the objective function that you want to minimize. It represents the sum of sorting times for all robots and packaging types;

R – robot sorters number;

N – package types number.

As a result of the sorting, the condition $\sum_{j=1}^{N} M_j = 0$ must be satisfied, indicating that the total number of unsorted packages remaining must be zero. M_j – this variable is one of the decision vector variables and denotes the number of packages of type, which remained unsorted.

This variable is one of the decision vector variables and denotes the number of type j packages that remain unsorted. Condition indicates that the total number of remaining unsorted packages should be zero. The problem of minimizing sorting time under the

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condition of uniform load is to distribute sorting tasks between robots so that the total sorting time is minimal, provided that all packages are sorted.

To calculate the time to sort and move each task after execution the following model is used:

$$T_{Ri,j} = T_{i,j} + \frac{W_i + D}{S_{i,j}} \quad (3)$$

where: $T_{Ri,j}$ – the sorting time for the robot i packaging j type. This variable represents the sorting time that has already been spent on a given robot for a given type of packaging;

W_i – the distance of the working zone for the robot i. This is the fixed time it takes the robot to process one package;

D – distance of the working area for the robot. This is the distance the robot can travel per unit time;

$S_{i,j}$ – execution speed sorting tasks for the robot i packaging j type.This is an indicator that determines how quickly a robot can process a package.

This equation represents a model of sorting time for a specific robot and package type. It takes into account the fixed execution time of the sorting task, the distance between tasks, and the speed of task execution. The increase in sorting time $T_{i,j}$ occurs in accordance with the task completion time, distance and speed of the robot.

After completing the sorting task, it is necessary to update the number of packages of each type, as represented in the following model:

$$M_j = M_{j-1} - 1 \quad (4)$$

where: M_j – the number of packages j type after the sorting task is completed. This represents the remainder of the type j tasks after sorting is completed;

M_{j-1} – number of packages j type the before performing the sorting task. This represents the initial number of tasks of the type j before sorting

That is, model (4) describes how the number of packages j type changes after the sorting task is completed. The number of tasks after sorting (M_j) becomes equal to the number of tasks before sorting (M_{j-1}).

Mathematical models (1–4) describe the principle and sequence of operation of the Load Balancing algorithm in the context of load balancing on conveyor lines with sorting robots in the pharmaceutical industry. They take into account the parameters of sorting time, task execution speed, working and dead zone distances, ensuring optimization of the sorting process.

In general, the Load Balancing algorithm has the following structure, which is presented in Figure 1.

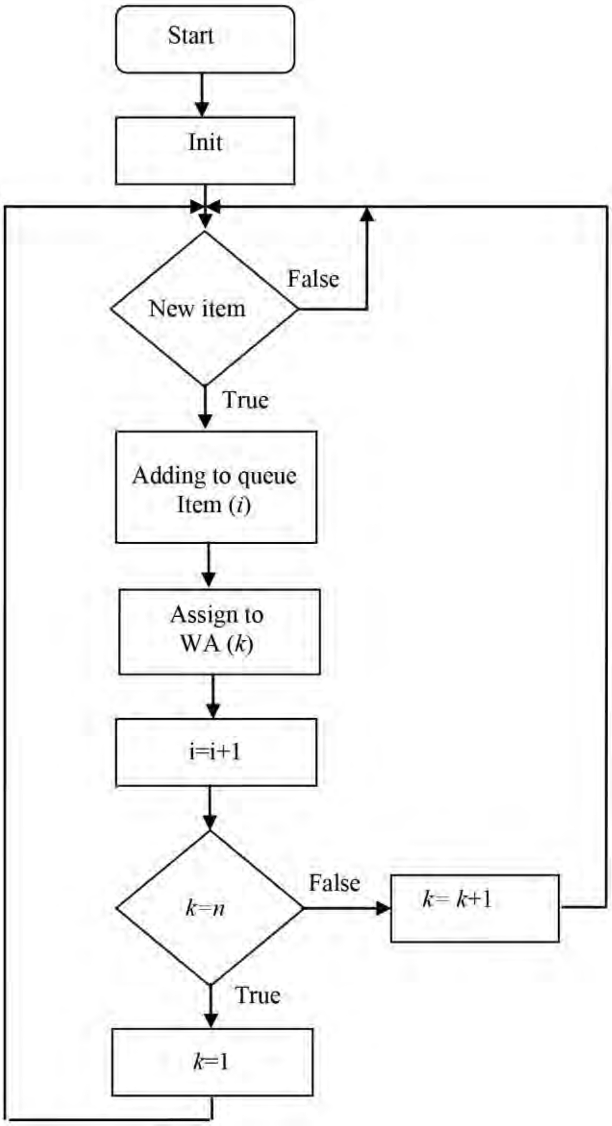

Fig. 1. General view of the Load Balancing algorithm for load balancing on conveyor lines with sorting robots in the pharmaceutical industry: i – position index; k – work area index; n – work area number; WA – selected work area

Further a fragment of the Load Balancing algorithm implementation for load balancing on conveyor lines with sorting robots in the pharmaceutical industry is presented based on the mass simulation language on GPSS. There are following input conditions: 3 types of packages, 50 pieces each, fall onto a conveyor belt that moves at a speed of 1 m/s. In the process of sorting

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from a common conveyor line, 3 sorting robots are involved, each of them performs sorting with the following time parameters: 20+-4s, 32+-8s, 29+-10s. The total system simulation time is 5000s.

```
GENERATE 50,50,50            ; Each type packages generation
CONVEY Type1,1               ; Sending type 1 packages to the conveyor
CONVEY Type2,1               ; Sending type 2 packages to the conveyor
CONVEY Type3,1               ; Sending type 3 packages to the conveyor
START 1                      ; Starting the conveyor

ROBOT1   STORAGE 1           ; Declaring a storage area for robot 1
ROBOT2   STORAGE 1           ; Declaring a storage area for robot 2
ROBOT3   STORAGE 1           ; Declaring a storage area for robot 3

ROBOT1   ASSIGN 20,4         ; Assigning time parameters for the robot 1
ROBOT2   ASSIGN 32,8         ; Assigning time parameters for the robot 2
ROBOT3   ASSIGN 29,10        ; Assigning time parameters for the robot 3

MAIN   ADVANCE 5000          ; Total simulation time
    TERMINATE                ; Completing the simulation

Type1   UNIFORM 20,24        ; Generating processing time for package type 1
Type2   UNIFORM 32,40        ; Generating processing time for package type2
Type3   UNIFORM 29,39        ; Generating processing time for package type3

    TRANSFER 1               ; Go to the beginning of the conveyor
```

3. The operation principle of the Adaptive Task Completion (ATC) algorithm in terms of its application for load balancing on conveyor lines with sorting robots in the pharmaceutical industry

The main difference between the Adaptive Task Completion (ATC) algorithm and the Load Balancing (LB) algorithm above is that LB strives for overall performance improvements, while ATC focuses on adapting to the dynamics of the task environment, making the LB algorithm suitable for stable scenarios work on conveyor lines, where changes in the process are rare and predictable, and the ATC algorithm is effective in conditions where frequent changes in task priorities and robot load are possible.

The mathematical representation in the form of models and principles, the sequence of operation of the Adaptive Task Completion (ATC) algorithm within the framework of these studies can be presented in next way. Let's describe the main parameters: $T_{i,j}$ – sorting time for a packaging type j robot i; W_i – task weight; D – distance between tasks and conveyor lines; S_i – speed of completing a sorting task for the robot i; M_{j} – maximum robot j load. Then the computer time model for sorting the Adaptive Task Completion (ATC) algorithm can be represented by model (1). Let us carry out a mathematical description of the parameters for model (1). The weight of each task can be determined according to priority, urgency or other parameters and can be represented as:

$$W_i\left(1 \le i \le N\right)$$

The distance to the task, which may depend on the location of the robot and the location of the task, can be described by the following expression:

$$D\left(1 \le i \le N\right)$$

The speed of the robot when performing a task i can be described by the following expression:

$$S_i\left(1 \le i \le N\right)$$

The next step of the ATC algorithm is to solve the ranking problem, that is, the process of determining the priority of tasks based on their weight W_i, urgency or other parameters, which may include comparing the weights of tasks and ordering them in descending order of priority. This can be represented mathematically by the following model:

$$P_{i,j} = f\left(W_i, D, \ldots\right) \tag{5}$$

$P_{i,j}$ – task i priority for the robot j;

i – task number;

j – robot number.

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As an example, we can use multi-criteria ranking in the context of ongoing research, then model 8 can be represented in next way:

$$F_{ij} = w_1 \cdot C_1(W_i, D, ...) + + w_2 \cdot C_2(W_i, D, ...) + ... + w_k \cdot C_k(W_i, D, ...) \quad (6)$$

where: C_k – separate criteria;

w_k – weight.

It is worth noting that an example of a criterion in this context can be: task weight (W_i), distance to task (D), urgency of task completion, availability of resources and other parameters.

Weights (w_k) may reflect the relative importance of each criterion. The sum of the weights can be written as follows:

$$\sum_{k=1}^{n} w_k = 1 \quad (7)$$

As an example, let's give a representation of the priority function, let's say C_1 represents the weight of the task, and C_2 is the inverse distance, then the priority function based on models 8 and 9 can be:

$$P_{ij} = w_i \cdot W_i + w_2 \cdot \frac{1}{D} \quad (8)$$

Thus, the mathematical description of multi-criteria ranking includes determining the priority function based on various criteria and their weights, which provides a more flexible and adaptive selection of tasks for robots within the ATC algorithm.

From here, for each task, an available robot is selected with $0 \leftarrow T_{i,j}$, if it is a robot with $M_j \rightarrow \max$, then the task is transferred to the next available robot.

Trailer sorting occurs: the selected robot performs the selected task according to the execution time $(T_{i,j})$, after which the maximum robot load (M_j) is updated. The process is repeated for all tasks until the work is completed.

This method balances the load on the robots, allowing tasks to be completed efficiently while taking into account the robots' weights and speeds. Maximum load settings ensure that robots are not overloaded and ensure that tasks are evenly distributed among them.

In general, the Adaptive Task Completion (ATC) algorithm has the following structure, which is presented in Figure 2.

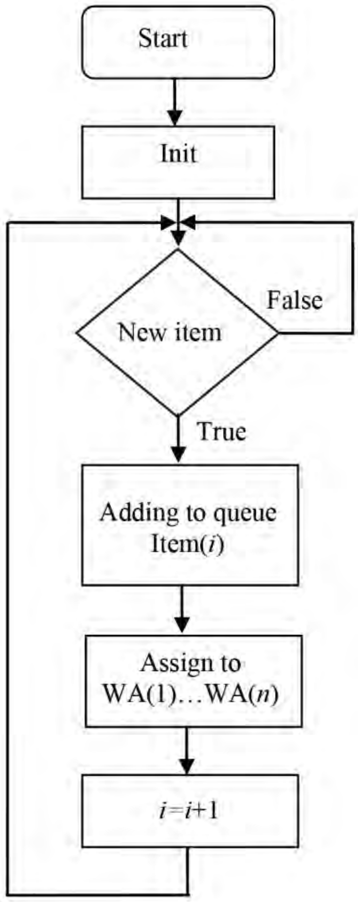

Fig. 2. General view of the Adaptive Task Completion (ATC) algorithm for load balancing on conveyor lines with sorting robots in the pharmaceutical industry: i – position index; k – work area index; n – work area number; WA – selected work area

Fragment of the Adaptive Task Completion algorithm implementation for load balancing on conveyor lines with sorting robots in the pharmaceutical industry based on the mass simulation language on GPSS:

```
GENERATE 150, 1              ; Package flow generation
QUEUE Line                   ; Queue of packages on a conveyor

CONVEYOR Line, 1             ; Conveyor belt with a speed of 1 m/s

ROBOT Sorter1, 20, 4         ; Robot-sorter 1
ROBOT Sorter2, 32, 8         ; Robot-sorter 2
```

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```
ROBOT Sorter3, 29, 10            ; Robot-sorter 3

START                            ; Start
  SEIZE Sorter1                  ; Robot 1 takes the packaging
  DEPART Line                    ; Packaging leaves the conveyor
  ADVANCE 0, UNIFORM(20, 4)      ; Robot 1 sorts
  RELEASE Sorter1                ; Robot 1 releases the package

  SEIZE Sorter2                  ; Robot 2 takes the packaging
  DEPART Line                    ; Packaging leaves the conveyor
  ADVANCE 0, UNIFORM(32, 8)      ; Robot 2 sorts
  RELEASE Sorter2                ; Robot 2 releases the package

  SEIZE Sorter3                  ; Robot 3 takes the packaging
  DEPART Line                    ; Packaging leaves the conveyor
  ADVANCE 0, UNIFORM(29, 10)     ; Robot 3 sorts
  RELEASE Sorter3                ; Robot 3 releases the package

TERMINATE 1                      ; End
```

Having conducted several experiments to simulate the operation of the Adaptive Task Completion (ATC) and Load Balancing (LB) algorithms from the point of view of their application to solving the problem of load balancing on conveyor lines with sorting robots in the pharmaceutical industry, the following conclusions were obtained, which are presented in the table 2.

Table 2. *Comparison of the advantages and disadvantages of the LB and ATC algorithms in terms of their application to solving the problem of load balancing on conveyor lines with sorting robots in the pharmaceutical Industry*

Criteria	Algorithm	
	Load Balancing (LB)	**Adaptive Task Completion (ATC)**
Advantages		
Even load	Even distribution of tasks among robots.	Adaptive balancing that takes into account changing conditions.
Ease of implementation	Relatively easy to implement and understand	Highly flexible and adaptable.
Stability	Suitable for stable conditions without sudden changes.	Effective under dynamic change and uncertainty.
Disadvantages		
Flexibility	May not adapt to changing conditions.	Complex parameter settings may be required.
Lack of adaptation	Does not respond to changes in conditions and performance.	Requires more computing resources
Possibility of downtime	In case of uneven performance, overload of some robots and downtime of others may occur.	It may be difficult to configure and adapt parameters for optimization.

Conclusion

The Adaptive Task Completion (ATC) algorithm and the Load Balancing (LB) algorithm are two different approaches for load balancing on robotic sorting conveyor lines in the pharmaceutical industry. ATC is based on multi-criteria ranking of tasks and dynamic adaptation to the current load. This method takes into account not only the task completion time, but also other criteria, which makes it possible to respond more flexibly to changing conditions and improves balancing efficiency. LB, on the other hand, takes a greedy balancing approach, aiming to minimize the total sorting time. This algorithm is focused on the current situation and, at each step, selects the optimal robot to perform the next task. In the context of the pharmaceutical field, where not only speed but also sorting accuracy is important, ATC may be the preferred choice as it takes into account various criteria and dynamically responds to changing conditions. On the other hand, LB can be effective in environments where sorting speed is of utmost importance and tasks are homogeneous. Thus, the choice between ATC and LB depends on the specific requirements and operation of the pharmaceutical sorting line, giving the choice between flexibility and time optimization.

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References

1. Yevsieiev, V., Maksymova, S., & Starodubcev, N. (2022), "A Robotic Prosthetic a Control System and a Structural Diagram Development". *Collection of scientific papers "ΛΌΓΟΣ"*. P. 113–114. DOI: https://doi.org/10.36074/logos-12.08.2022.33
2. Maksymova, S., Nevliudov, I., Yevsieiev, V., Klymenko, O., & Vzhesniewski, M. (2023), "Shuttle-based storage and retrieval system 3d model improvement and development". *Journal of Natural Sciences and Technologies*, 2(2), P. 232–237. DOI: https://doi.org/10.5281/zenodo.10354730
3. Yevsieiev, V., Nevliudov, I., Maksymova, S., O. Omarov, M., Klymenko, O. (2023), "Conveyor Belt Object Identification: Mathematical, Algorithmic, and Software Support". *Appl. Math. Inf. Sci.* №17(6). P. 1073–1088. DOI:10.18576/amis/170615
4. Xavier, Delorme, Paolo, Gianessi (2023), "Line balancing and task scheduling to minimise power peak of reconfigurable manufacturing systems". *International Journal of Production Research*. P. 1–26. DOI: https://doi.org/10.1080/00207543.2023.2283568
5. Rico, Walter, Philipp, Schulze, Armin, Scholl (2021), "ALSA: Combining branch-and-bound with dynamic programming to smoothen workloads in simple assembly line balancing". *European Journal of Operational Research*. №295(3). P. 857–873. DOI: https://doi.org/10.1016/j.ejor.2021.03.021
6. Li, Z., Janardhanan, M. & Ponnambalam, S. (2021), "Cost-oriented robotic assembly line balancing problem with setup times: multi-objective algorithms". *J Intell Manuf.* 32. P. 989–1007. DOI: https://doi.org/10.1007/s10845-020-01598-7
7. Zeynel, Abidin Çil, Hande, Öztop, Zülal, Diri Kenger, Damla, Kizilay (2023), "Integrating distributed disassembly line balancing and vehicle routing problem in supply chain: Integer programming, constraint programming, and heuristic algorithms". *International Journal of Production Economics*. Vol. 265. 109014 p. DOI: https://doi.org/10.1016/j.ijpe.2023.109014
8. Li, Ming-Liang (2021), "An Algorithm for Arranging Operators to Balance Assembly Lines and Reduce Operator Training Time". *Applied Sciences.* 11(18). 8544 p. DOI: https://doi.org/10.3390/app11188544
9. Bolu, Ali, Korçak, Ömer (2021), "Adaptive task planning for multi-robot smart warehouse". *IEEE Access*, Vol. 9. P. 27346–27358. DOI: 10.1109/ACCESS.2021.3058190
10. Schmidbauer, C., Schlund, S., Ionescu, T. B., Hader, B. (2020), "Adaptive task sharing in human-robot interaction in assembly". In: *2020 IEEE international conference on industrial engineering and engineering management (IEEM)*. IEEE. P. 546–550. DOI: 10.1109/IEEM45057.2020.9309971
11. YU, Xinbo, Li, B., He, W., Feng, Y., Cheng, L., Silvestre, C. (2021), "Adaptive-constrained impedance control for human-robot co-transportation". *IEEE transactions on cybernetics*. Vol. 52(12). P. 13237–13249. DOI: 10.1109/TCYB.2021.3107357
12. Seenu, N., RM, K. C., Ramya, M. M., Janardhanan, M. N. (2020), "Review on state-of-the-art dynamic task allocation strategies for multiple-robot systems". *Industrial Robot: the international journal of robotics research and Application.* Vol. 47(6). P. 929–942. DOI: https://doi.org/10.1108/IR-04-2020-0073
13. Chutima, Parames (2022), "A comprehensive review of robotic assembly line balancing problem". *Journal of Intelligent Manufacturing.* Vol. 33(1). P. 1–34. https://doi.org/10.1007/s10845-020-01641-7
14. Alitappeh, Reza Javanmard, Jeddisaravi, Kossar (2022), "Multi-robot exploration in task allocation problem". *Applied Intelligence*, Vol. 52(2). P. 2189–2211. DOI https://doi.org/10.1007/s10489-021-02483-3
15. Li, Zixiang, Janardhanan, Mukund Nilakantan, Tang, Qiuhua (2021), "Multi-objective migrating bird optimization algorithm for cost-oriented assembly line balancing problem with collaborative robots". *Neural Computing and Applications*. Vol. 33. P. 8575–8596. DOI https://doi.org/10.1007/s00521-020-05610-2

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РЕАЛІЗАЦІЯ АЛГОРИТМІВ "БАЛАНСУВАННЯ НАВАНТАЖЕННЯ" ТА "АДАПТИВНЕ ВИКОНАННЯ ЗАВДАНЬ" НА ФАРМАЦЕВТИЧНОМУ СОРТУВАЛЬНОМУ КОНВЕЄРІ

Предметом дослідження в статті є переваги та недоліки застосування алгоритмів "балансування навантаження" та "адаптивне виконання завдань" на фармацевтичному сортувальному конвеєрі. **Мета роботи** – проаналізувати переваги та недоліки алгоритмів сортування *Load Balancing* (LB) та *Adaptive Task Completion* (ATC) для оптимізації та підвищення ефективності процесів сортування фармацевтичних виробів. У статті вирішуються такі **завдання:** аналіз останніх досліджень і публікацій з окресленої теми; вивчення особливостей застосування алгоритмів для сортування фармацевтичних виробів на конвеєрних лініях для балансування навантаження на роботів-сортувальників; аналіз алгоритму *Load Balancing* (LB) з погляду його застосування для балансування навантаження на конвеєрних лініях з роботами-сортувальниками у сфері фармацевтики; розроблення алгоритму *Load Balancing* для балансування навантаження на конвеєрних лініях з роботами-сортирувальниками у фармацевтичній сфері; аналіз алгоритму *Adaptive Task Completion* (ATC) з погляду його застосування для балансування навантаження на конвеєрних лініях з роботами-сортирувальниками у сфері фармацевтики; розроблення загального алгоритму *Adaptive Task Completion* (ATC) для балансування навантаження на конвеєрних лініях з роботами-сортирувальниками у фармацевтичній сфері; виокремлення переваг та недоліків вказаних алгоритмів. Упроваджується метод імітаційного моделювання. Здобуто такі **результати**: сформульовано переваги та недоліки алгоритмів *Load Balancing* та *Adaptive Task Completion* для балансування навантаження на конвеєрних лініях з роботами-сортувальниками у фармацевтичній сфері; надано рекомендації, в яких ситуаціях, за яких передумов, який алгоритм необхідно використовувати. **Висновки.** У контексті фармацевтичної галузі, де важливі не лише швидкість, а й точність сортування, *Adaptive Task Completion* може бути кращим вибором, оскільки він бере до уваги різні критерії та динамічно реагує на мінливі умови. З іншого боку, *Load Balancing* може бути ефективним у ситуаціях, коли швидкість сортування має першорядне значення та завдання однорідні.

Ключові слова: Індустрія 4.0; Розумне виробництво; Логістика 4.0; Складське господарство 4.0; Балансування навантаження; Адаптивне виконання завдань.

Бібліографічні описи / Bibliographic descriptions

Невлюдов І. Ш., Євсєєв В. В., Максимова С. С., Клименко О. М. Реалізація алгоритмів "балансування навантаження" та "адаптивне виконання завдань" на фармацевтичному сортувальному конвеєрі. *Сучасний стан наукових досліджень та технологій в промисловості*. 2024. № 1 (27). С. 154–163. DOI: https://doi.org/10.30837/ITSSI.2024.27.154

Nevliudov, I., Yevsieiev, V., Maksymova, S., Klymenko, O. (2024), "The "load balancing" and "adaptive task completion" algorithms implementation on a pharmaceutical sorting conveyor line", *Innovative Technologies and Scientific Solutions for Industries*, No. 1 (27), P. 154–163. DOI: https://doi.org/10.30837/ITSSI.2024.27.154