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DEVELOPMENT OF INFORMATION TECHNOLOGY FOR PLANNING ORDER FULFILLMENT AT A FOOD ENTERPRISE

Запропоновано інформаційну технологію для розв'язання задачі планування виконання замовлень по виготовленню продукції на харчових підприємствах в умовах невизначеності та ризику. Інформаційна технологія ґрунтується на комбінуванні алгоритмів мурашиної колонії, сірих вовків та генетичного, а також розробленій математичної моделі оперативного виконання замовлень. Перевагами комбінування алгоритмів є формування альтернативних варіантів планів та уникнення локальних оптимумів. Запропонована математична модель містить часткові критерії, обмеження та оціночну функцію для визначення ефективності сформованого варіанту плану виконання замовлень. Для наочності оцінки ефективності варіанту виконання замовлень запропоновано застосування пелюсткової діаграми та адитивної згортки часткових критеріїв. Математична модель дозволяє ОПР визначити будь-який набір часткових критеріїв для врахування особливостей параметрів виконання замовлень.

Інформаційна технологія забезпечує швидку реконфигурацію поточного плану виконання замовлень у разі виникнення позаштатних ситуацій або необхідності терміновогo виконання певного замовлення

Ключові слова: математична модель, планування виконання замовлень, комбінований алгоритм

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1. Introduction

The food industry is one of the strategic sectors in many countries. Its enterprises' products are vitally important for people in terms of providing food safety. Food industry companies should strictly adhere to the sanitary and hygienic requirements for the resulting product and to the manufacturing process based on regulatory and legal state and international standards. Seasonal demand and constant fluctuations in prices for raw materials and energy resources affect the functioning of food making enterprises. Tough competition among internal and external manufacturers requires that managers should respond quickly to the demands of consumers.

In this case, the demand for the finished products varies depending on the socio-economic circumstances in a country. Consumers are constantly put forward requirements for new assortment, quality, price, and physical-organoleptic indicators of products. To satisfy these needs, a food industry enterprise must permanently improve and expand its product range, devise alternative formulations, including new or improved components, as well as improve its own technological processes.

Most food enterprises produce a wide range of products, which leads to additional requirements and restrictions during production. A change in the production plan can lead to changes in the volume of the use of raw materials, in the required human resources, to changes or reconfiguration of production equipment, to changes in the schedules of shipment of finished products. Under these conditions, the enterprise management structure should enable flexible and fast responsive production.

Control over complex organizational and technological complexes, such as food industry enterprises, requires constant improvement of management procedures. Under modern competitive conditions, achieving high economic and social indicators is possible only with the use of information technologies that would provide for the monitoring and analysis of external and internal indicators of the enterprise. Their development and implementation could enable flexible dynamic management with maximum consideration of external and internal influences and constraints in making operational and strategic decisions.

At present, solving the task of drawing operational and calendar plans and resolving production issues involves the so-called goal decomposition method. According to it, the tasks are solved locally without considering all the factors that can further influence the activity of an enterprise. Most modern information systems are aimed at supporting control over production, resources, automated planning, accounting, monitoring and analysis of all business operations of an enterprise. And the links among departments are ensured by the use of corporate databases and data warehouses.

Existing information systems tend to have a high price and require the adaptation/integration to a particular production. Implementing a new information system often requires the reengineering of management business processes while tasks are sometimes tackled without taking into consideration all impacts. The process of integration and implementation of an information system requires additional expenditures and its use implies the high qualification of managers at different levels in the field of IT. Therefore, the application of such systems may not always ensure the accuracy and objectivity of decisions being made, especially under conditions of uncertainty and risk.

The scheduling of order execution based on the use of classical, heuristic, and evolutionary methods was considered by different scientists, but the task has remained relevant up to now. It is associated with the emergence of Industry 4.0, which is the fourth industrial revolution. The main objective of the 4.0 Industry is complete production automation; all industrial processes are to be managed in real time, taking into consideration changing external conditions. The main feature of the 4.0 Industry implies that enterprises must manufacture products according to an individual customer's requirements while optimizing production costs. All the company's links must be managed in concert, which is not possible when using standard management methods. Their application leads to the waste of time resources, which does not meet the need for real-time management. All this necessitates the development and construction of the new-generation intelligent information systems that employ heuristic, evolutionary, and multi-agent methods and approaches of intelligent optimization based on modeling the collective intellect of social animals, insects, and other living beings. By using modern information systems, such methods produce good results in solving various optimization problems, indicating the prospects of this direction. The field of information technology development based on the modified algorithms and methods is especially important.

2. Literature review and problem statement

The authors of work [1] proposed a mathematical model for the problem on planning the fulfillment of contracts and determined partial criteria for assessing the effectiveness of the derived solution, as well as suggested an additive convolution of the specified criteria whereby establishing the priority of meeting each of them. The modified ACO (Ant Colony Optimization) algorithm was proposed for finding the alternatives to scheduling order execution. To apply it, the input data are formed in the form of a multilayer graph, each layer of which corresponds to the working time of a single performer, and the nodes define the time of synchronization between the layers. The use of the proposed algorithms is impossible without application of information systems, therefore, work [1] proposed a structure of the web-oriented DSS for planning the fulfillment of contracts, as well as the technology for its practical implementation. However, the disadvantage of the proposed approaches is their focus on enterprises that render services, which does not make it possible to take into consideration the restrictions on the volume of the raw materials, required for the production of food, as well as packaging materials and the shelf life of finished products.

In work [2], the information technology was proposed for adjusting the structure of product range by means of intelligent data mining. The devised technology aims to provide information support for a food enterprise in making managerial decisions on finding reserves to reduce the aggregate cost of products and to receive additional income. The proposed technology could be used both at a multi-nomenclature food enterprise and in other industrial sectors. However, it does not imply the scheduling of orders fulfillment and is aimed only at the production of proposals for adjusting the structure of the product mix.

Management optimization tasks and planning of industrial processes are examined by the authors of work [3] based on genetic algorithms; however, the peculiarities of certain industrial sectors were not considered.

The authors of work [4] reported the approbation of their proposed hybrid algorithm of planning based on the particle swarm algorithm and the ACO algorithm. The work also compares the constructed algorithm with various modifications of the genetic algorithm. The proposed algorithm does not take into consideration the economic and social impacts when searching for an optimal plan.

Study [5] considers the process of task planning on parallel equipment. The proposed mathematical model accounts for only certain performance criteria in the planning of execution of operations at different technological machines. The possibility of changing the number of periods, the number of performers, parallel performance of operations on different machines are all taken into consideration. However, the considered method of branches and boundaries has difficulties when solving problems for the equipment, which is used in parallel.

Publication [6] focuses on the description of the planning algorithm based on a basic algorithm of the increased use of the artificial bee colony algorithm with a local search method. The additional neighborhood operator, used in the publication, is based on a greedy constructive and destructive procedure. This algorithm does not make it possible to take into consideration the priorities of partial criteria and constraints.

Work [7] proposed to improve the genetic algorithm by using the selective initialization mechanism. It is possible to use the modified method under consideration only as part of another method or technology.

A mathematical model of production planning at a small enterprise was considered in [8], which makes it possible to automate the construction of optimum production schedules, as well as to investigate the dynamics of production movement at all stages of production. The built model is intended for use at small enterprises and ignores the possibility of such factors as the imposition of penalties, the need to establish order in orders, the need to replace raw materials.

The authors of work [9] proposed and substantiated the structure of a fuzzy situational network for a decision support system. The proposed approach should be used in cases of the weakly-structured or unstructured problems and the absence of exact models to describe problematic situations. The approach, considered in [9], could improve the efficiency of control over the organizational-technical (technological) systems that operate over significant time intervals.

The information technology, suggested in work [10], is aimed at solving the problem of support to decision making regarding the conversion of production at virtual instrument-making enterprises in accordance with market conditions. The production program is formed based on the current demand for different categories of products included in the nomenclature of goods of the enterprise or corresponds to the direction of operation of production at virtual instrument-making enterprises. The authors constructed a model of the processes on an information-analytical portal, which allows the client to compile the orders, which are subsequently sent for production, as well as a mathematical model that substantiates the allocation of resources to manufacture products at an enterprise. The calculation results make it possible to solve the task of production reconfiguration. The study disregarded the issue of decision-making on determining the expediency of fabricating a specific type of product and defining the limits of production volumes, as well as the allocation of production resources.

The theoretical concepts for planning different production processes are given in paper [11]. The authors performed a critical analysis of the common factors that hinder the application of planning based on optimization methods and proposed approaches to eliminate them. Paper [11] is more general in character and does not apply to the food industry.

An analysis of the above literary sources [1–11] allows us to assert the expediency of creating information technology with the use of the modified multi-agent and genetic algorithms in order to solve the task on scheduling order execution for manufacturing products at food enterprises.

The information technology would ensure the formation of order fulfillment variants, their assessment, the search for optimal options, the possibility of refining and correcting the initial and intermediate data in order to obtain different variants of the plan with their subsequent assessment.

3. The aim and objectives of the study

The aim of this study is to develop information technology to maintain the planning process of order execution at food enterprises, to perform them accurately at a preset time to minimize costs.

To accomplish the aim, the following tasks have been set:

– to construct a mathematical model for scheduling order execution, taking into consideration peculiarities of the technological process of food production;

– to devise the concept of information technology for scheduling order execution.

4. Construction of a mathematical model for scheduling order execution

Each level of enterprise management requires the consideration of a complex hierarchical influence along the vertical levels of management. The main management task that requires the consideration of the task and constraints at all levels is the operative correction of the production plan to fulfill orders. Typically, solving such a problem was reduced to its decomposition to the desired level. However, in this case, only the necessary criteria and functions with constraints were taken into consideration, but the interrelations among all impact criteria were ignored.

The task of scheduling order execution implies compiling such a schedule in which various tasks are assigned to the technological lines/departments that correspond to the order of execution of production stages. The drawn-up plan should ensure minimizing the total production costs, order execution time optimization, minimizing the costs of storing raw materials and finished products.

The operative reconfiguration of a production plan emerges in the following cases:

– the need to include, in the current production plan, the order that has only been received and has a high priority of execution;

– the occurrence of emergencies related to the violation of the delivery schedule of raw materials, the operation and condition of technological equipment, the violation of the terms of contracts with suppliers;

– the socio-economic needs related to seasonal and political preferences of consumers;

– changes in the strategic direction of the enterprise.

A production plan is optimal if its implementation provides maximum profit over the predefined period. The optimal production plan does not violate the general strategic plan of the enterprise, it minimizes variable costs, it makes it possible to maximally utilize production and technological equipment.

A given problem belongs to the class of hierarchical multi-criteria optimization problems, it includes a variety of partial criteria that collectively influence the choice of an optimal solution and the use of which is determined by specific conditions.

For enterprises in the food industry, we distinguish the following partial criteria:

– the maximization of profits from fulfilling all orders;

– the minimization of time for production;

– the maximization of time reserves when fulfilling orders;

– the minimization of total fines for untimely fulfillment of the order;

– the minimization of the total downtime of all units of technological equipment and departments;

– the minimization of total expenses in production;

– the minimization of the total downtime costs when equipment is not used, when some technological contours, despite their non-use, require electricity and heat consumption;

– the minimization of the total expenses for recycling and disposal of the received substandard products when fulfilling all orders;

– the minimization of total expenses for the storage of finished products;

– the minimization of the total costs of storing raw materials and material.

Obtaining the maximum profit from fulfilling orders for products manufactured within the specified time is the first partial criterion for assessing the efficiency of the plan (1) variant over the planned period $(t+\Delta t)$.

$$F_1(t+\Delta t)= \\ =\sum_{i=1}^{n}\left(\theta_i\cdot\left(\begin{matrix} sd_i(t+\Delta t)- \\ -\left(\begin{matrix} vc_i(t+\Delta t)+ \\ +vz_i(t+\Delta t)\end{matrix}\right)\end{matrix}\right)\cdot op_i(t+\Delta t)\right)\to \max, \quad (1)$$

where $(t+\Delta t)$ is the planned period over which the production plan is calculated;

t is the start time of the plan execution, specified by the date and time to the minute;

Δt is the time over which it is required to execute all orders to minutes;

i is the order in a queue, which regulates one type of a product, which must be produced in time $(t+\Delta t)$, and which also regulates the type of packaging and packing;

n is the total number of orders to be performed over period $(t+\Delta t)$;

θ_i is the parameter that accepts the values {0, 1} (θ_i=1, if the i-th order is executed over time $(t+\Delta t)$; θ_i=0 otherwise);

$sd_i(t+\Delta t)$ is the cost of a product unit for the i-th order over time $(t+\Delta t)$;

$vc_i(t+\Delta t)$ are the constant costs for the manufacture of a product unit for the i-th order over time $(t+\Delta t)$;

$vz_i(t+\Delta t)$ are the changes in the cost of a product unit for the i-th order over time $(t+\Delta t)$;

$op_i(t+\Delta t)$ is the volume of finished products that must be manufactured for the i-th order over time $(t+\Delta t)$.

The minimization of time for the manufacture of products for every i-th order over time $(t+\Delta t)$ is the partial criterion that influences the overall efficiency of the plan (2) variant, and constraint (3) regulate the manufacture of products over time $(t+\Delta t)$, constraint (4) predetermines the end of the production not later than the defined period.

$$F_{2i}(t+\Delta t)= =\sum_{j=1}^{\omega_i}\sum_{l=1}^{\sigma_i}\left(o_{ijl}\cdot\begin{pmatrix} pt_{ijl}+t_{ijl}+\\ +\eta t_{ijl}+to_{ij-1}\end{pmatrix}\right)\to \min, \quad (2)$$

$$t\le t_i+F_{2i}(t+\Delta t)\le t+\Delta t, \quad (3)$$

$$t\le t_i+F_{2i}(t+\Delta t)\le dt_i, \quad (4)$$

where $(t+\Delta t)$ is the planned period over which the production plan is calculated;

t is the start time of the plan, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders to minutes;

i is the order in a queue, which regulates one type of product that must be produced over time $(t+\Delta t)$;

j is the number of a stage from the set of stages $(j\in\omega_i)$ for the i-th order;

ω_i is the number of necessary stages for fulfilling the i-th order;

l is the equipment number from the set of equipment $(l\in\sigma_i)$ for the i-th order;

σ_i is the number of equipment involved in the execution of all stages in the manufacture of the i-th order;

t_i is the start time of production for the i-th order;

dt_i is the time by which it is necessary to manufacture products for the i-th order;

Δt_{ijl} is the execution time of the j-th stage on the l-th equipment for the manufacture of products for the i-th order;

pt_{ijl} is the time required to prepare the l-th equipment to execute the j-th stage in the manufacture of products for the i-th order, which can accept zero if the preparation is not required;

to_{ij-1} is the transition/waiting time between the execution of the j-th stage to the (j–1) stage;

ηt_{ijl} is the time to clean the equipment after the j-th stage of production for the m-th order at the l-th equipment;

o_{ijl} is the parameter that accepts the value {0, 1} ($o_{ijl}=1$, if the j-th stage can be performed at the l-th equipment for the manufacture of products for the m-th order; $o_{ijl}=0$ – otherwise).

The maximization of the time reserve at execution of each i-th order over time $(t+\Delta t)$ is a partial criterion for a particular order and influences the overall efficiency of the plan (5) variant.

$$F_{3i}(t+\Delta t)= =\begin{cases} dt_i-t_i+ & \\ +F_{2i}(t+\Delta t), & \text{if } \begin{pmatrix} t_i+F_{2i}\times\\ \times(t+\Delta t)\end{pmatrix}<dt_i\to \max,\\ 0, & \text{otherwise}\end{cases} \quad (5)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

t is the start time of plan fulfillment, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders in minutes;

i is the order in a queue, which regulates one type of a product, which must be manufactured over period $(t+\Delta t)$;

j is the number of a stage from the set of stages $(j\in\omega_i)$ for the i-th order;

ω_i is the number of necessary stages to fulfill the i-th order;

t_i is the time to start the manufacture of products for the i-th order;

dt_i is the time over which it is necessary to manufacture products for the i-th order.

The fourth criterion is the total sum of fines for the untimely execution of an order in a scheduled period, which is determined from formula (6).

$$F_4(t+\Delta t)=\sum_{i=1}^{n}(g_i*\Psi_i*hk_i)\to \min, \quad (6)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

t is the start time of plan fulfillment, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders in minutes;

i is the order in a queue, which regulates one type of a product, which must be manufactured over period $(t+\Delta t)$;

g_i is the amount of the fine registered in the contract, which must be reimbursed to the customer in case dt_i is violated, the time of order execution;

Ψ_i is the coefficient calculated from formula (7), which determines the need to reimburse to the customer if the period of execution dt_i is violated;

$$\Psi_i=\begin{cases}1, & \text{if } (t_i+F_{2i}(t+\Delta t))<dt_i,\\ 0, & \text{otherwise,}\end{cases} \quad (7)$$

where t_i is the time to start the manufacture of products for the m-th order; hk_i is the coefficient that takes into consideration the need to pay a fine for delay, for each day, and which is calculated from formula (8).

$$hk_i = \begin{cases} 1, & \text{if the amount of the fine is fixed and does not depend on the number of days,} \\ \left\lceil \frac{F_{2i}(t+\Delta t)}{24} \right\rceil, & \text{otherwise the number of days is determined.} \end{cases} \quad (8)$$

The fifth criterion is the minimization of the total time of not using (downtime) all units of technological equipment and departments in general, which is determined from formula (9).

$$F_5(t+\Delta t) = \\ = \sum_{i=1}^{n} \sum_{j=1}^{\omega_i} \sum_{l=1}^{\sigma_i} \left(o_{ijl} \cdot \begin{pmatrix} tzl_{i(j-1)_l l} - \\ -tpl_{ij_l l} \end{pmatrix} \right) \rightarrow \min, \quad (9)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

t is the start time of plan fulfillment, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders in minutes;

i is the order in a queue, which regulates one type of a product, which must be manufactured over period $(t+\Delta t)$;

j is the number of a stage from the set of stages $(j \in \omega_i)$ for the i-th order;

ω_i is the number of necessary stages to fulfill the i-th order;

L is the equipment number from the set of equipment $(l \in \sigma_i)$ for the i-th order;

σ_i is the number of equipment involved in the execution of all stages when manufacturing the i-th order;

n is the total number of orders to be performed over period $(t+\Delta t)$;

$tzl_{i(j-1)_l l}$ is the completion time of the $(j–1)_l$ stage on the l-th equipment when manufacturing products for the i-th order;

$tpl_{i(j-1)_l l}$ is the start of the execution of the j_l-th stage at the l-th equipment when manufacturing products for the i-th order;

o_{ijl} is the parameter that accepts the value {0, 1} ($o_{ijl} = 1$, if the j-th stage is performed at the l-th equipment when manufacturing products for the i-th order; $o_{ijl} = 0$ – otherwise).

The sixth criterion is the value of total expenses, which are inevitable when executing the j-th stage at the l-th equipment when manufacturing products for the i-order per unit time; since a technological unit acts as a separate workshop, then one takes into consideration all the time of operation, calculated from formula (10).

$$F_6(t+\Delta t) = \\ = \sum_{i=1}^{n} \left(\sum_{j=1}^{\omega_i} \sum_{l=1}^{\sigma_i} \left(o_{ijl} \cdot \begin{pmatrix} pt_{ijl} + \\ +\Delta t_{ijl} + \eta t_{ijl} \end{pmatrix} \right) \cdot c_{ijl} \right) \rightarrow \min, \quad (10)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

t is the start time of plan fulfillment, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders in minutes;

i is the order in a queue, which regulates one type of a product, which must be manufactured over period $(t+\Delta t)$;

j is the number of a stage from the set of stages $(j \in \omega_i)$ for the i-th order;

ω_i is the number of necessary stages to fulfill the i-th order;

l is the number of equipment from the set of equipment $(l \in \sigma_i)$ for the i-th order;

σ_i is the number of equipment involved in the execution of all stages when manufacturing the i-th order;

Δt_{ijl} is the execution time of the j-th stage implementation at the l-th equipment for the manufacture of products for the i-th order;

pt_{ijl} is the time required to prepare the l-th equipment to implement the j-th stage in the manufacture of products for the i-th order; it can accept zero if the preparation is not required;

c_{ijl} are the expenses over one hour when implementing the j-th stage at the l-th equipment for the manufacture of products for the i-th order;

ηt_{ijl} is the time to clean the equipment after the j-th stage of manufacturing products for the i-th order at the l-th equipment, if it is not necessary or it is necessary before the repair and maintenance work;

o_{ijl} is the parameter that accepts the value {0, 1} ($o_{ijl} = 1$, if the j-th stage can be implemented at the l-th equipment for the production for the i-th order; $o_{ijl} = 0$ – otherwise).

The seventh criterion is the minimization of the costs for idling equipment, but when the equipment has contours that must be constantly enabled, determined from formula (11).

$$F_7(t+\Delta t) = \\ = \sum_{i=1}^{n} \sum_{j=1}^{\omega_i} \sum_{l=1}^{\sigma_i} \begin{pmatrix} NOT(o_{ijl}) \times \\ \times \begin{pmatrix} tzl_{i(j-1)_l l} - \\ -tpl_{ij_l l} \end{pmatrix} \cdot cp_l \cdot vk_l \end{pmatrix} \rightarrow \min, \quad (11)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

t is the start time of plan fulfillment, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders in minutes;

i is the order in a queue, which regulates one type of a product, which must be manufactured over period $(t+\Delta t)$;

j is the number of a stage from the set of stages $(j \in \omega_i)$ for the i-th order;

ω_i is the number of necessary stages to fulfill the i-th order;

l is the number of equipment from the set of equipment $(l \in \sigma_i)$ for the i-th order;

σ_i is the number of equipment to execute all stages when fulfilling the i-th order;

n is the total number of orders to be performed over period $(t+\Delta t)$;

$tzl_{i(j-1)_l l}$ is the completion time of the $(j–1)_l$ stage at the l-th equipment when manufacturing products for the i-th order;

$tpl_{i(j-1)_l l}$ is the start of the execution of the j_l-th stage at the l-th equipment when manufacturing products for the i-th order;

vk_l is the parameter that accepts the value {0, 1} ($vk_l = 1$, if the l-th equipment at idling has the constantly enabled elements; $vk_l = 0$ – otherwise);

cp_l are the expenses when the l-th equipment is idle);

o_{ijl} is the parameter that accepts the value {0, 1} ($o_{ijl} = 1$, if the j-th stage can be implemented at the l-th equipment to manufacture products for the i-th order; $o_{ijl} = 0$ – otherwise).

The eighth criterion is the minimization of the costs for recycling and disposal of the obtained substandard products in the execution of all orders, determined from formula (12).

$$F_8(t+\Delta t) = \\ = \sum_{i=1}^{n}\sum_{j=1}^{\omega_i}\sum_{l=1}^{\sigma_i}\begin{pmatrix} o_{ijl}\cdot cn_{ijl}\cdot vnk_{ijl}\times \\ \times op_i(t+\Delta t)\end{pmatrix} \to \min, \qquad (12)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

t is the start time of plan fulfillment, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders in minutes;

i is the order in a queue, which regulates one type of a product, which must be manufactured over period $(t+\Delta t)$;

j is the number of a stage from the set of stages $(j \in \omega_i)$ for the i-th order;

ω_i is the number of necessary stages to fulfill the i-th order;

l is the number of equipment from the set of equipment $(l \in \sigma_i)$ for the i-th order;

σ_i is the number of equipment involved to execute all stages when fulfilling the i-th order;

n is the total number of orders that need to be fulfilled over period $(t+\Delta t)$;

cn_{ijl} is the cost of recycling or disposal of a single unit of the obtained substandard products when performing the i-th order on the l-th technological equipment;

$op_i(t+\Delta t)$ is the volume of the finished products, which must be produced for the i-th order over period $(t+\Delta t)$;

vnk_{ijl} is the total number of substandard products, received per each unit of products during the execution of the j-th stage of the i-th order at the l-th technological equipment;

o_{ijl} is the parameter that accepts the value {0, 1} ($o_{ijl} = 1$, if the j-th stage can be performed at the l-th equipment to manufacture products for the i-th order; $o_{ijl} = 0$ – otherwise).

The ninth criterion is the minimization of costs for storing the finished products, determined from formula (13).

$$F_9(t+\Delta t) = \\ = \sum_{i=1}^{n}\begin{pmatrix} vz_i\cdot op_i(t+\Delta t)\times \\ \times\max\left(0, dt_i - \begin{pmatrix} t_i + F_{2i}\times \\ \times(t+\Delta t)\end{pmatrix}\right)\end{pmatrix} \to \min, \qquad (13)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

t is the start time of plan fulfillment, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders in minutes;

i is the order in a queue, which regulates one type of a product, which must be manufactured over period $(t+\Delta t)$;

$op_i(t+\Delta t)$ is the volume of the finished products, which must be produced for the i-th order over period $(t+\Delta t)$;

vz_i is the cost of storing products for the i-th order;

dt_i is the time by which it is necessary to manufacture products for the i-th order.

The tenth criterion is the minimization of costs for storing raw materials and articles necessary for the manufacture of products, determined from formula (14).

$$F_{10}(t+\Delta t) = \\ = \sum_{i=1}^{n}\sum_{k=1}^{r_i}\begin{pmatrix} vsr_{ik}\cdot rk_{ik}\cdot op_i(t+\Delta t)\times \\ \times\max(0, t_i - rt_{ik}\end{pmatrix} \to \min, \qquad (14)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

t is the start time of plan fulfillment, specified by the date and time to the minute;

Δt is the time over which it is required to fulfill all orders in minutes;

i is the order in a queue, which regulates one type of a product, which must be manufactured over period $(t+\Delta t)$;

k is the type of a resource required for the execution of the i-th order, and the total number of types of resources needed to perform the i-th order r_i;

r_i is the list of resources required to manufacture products for the i-th order;

vsr_{ik} is the cost of storing the k-th component to perform the i-th order;

rk_{ik} is the volume of the raw materials required for manufacturing a unit of the product for the i-th order;

$op_i(t+\Delta t)$ is the volume of the finished products, which must be produced for the i-th order over time $(t+\Delta t)$;

t_i is the start time of producing the products for the i-th order;

rt_{ik} is the time of arrival of the k-th component for executing the i-th order.

The following additional conditions and constraints are proposed for the mathematical model described, taking into account all the peculiarities of the problem:

1. Each l-th technological equipment or production unit can perform no more than one j-th stage of the i-th order, which is described by the condition in formula (15).

$$\sum_{j=1}^{\sigma_i} o_{ijl} = 1. \qquad (15)$$

2. In order to receive the finished products in full assortment according to the planned orders, all stages must be performed using the necessary technological equipment according to expression (16).

$$\sum_{j=1_i}\sum_{l=1} o_{ijl} = \omega_i. \qquad (16)$$

3. For each i-th order, it is necessary to consider that every stage of the technological process can begin only after completion of all the preceding stages. If $o_{i(j-1)(l-1)} = 1$ and $o_{ijl} = 1$, then the starting time of the execution of the l-th stage is determined from expression (17).

$$\tau_{i(j-1)(l-1)} + \Delta\tau_{i(j-1)(l-1)} \le \tau_{ijl}, \quad (17)$$

where $\tau_{i(j-1)(l-1)}$ is the start time to perform the (j–1) previous stage for the i-th order at the (l–1) preceding technological equipment;

$\Delta\tau_{i(j-1)(l-1)}$ is the total operating time of the (l–1) preceding technological equipment for the execution of the (j–1) preceding stage of the i-th order;

τ_{ijl} is the start time to execute the j-th current stage of the i-th order at the l-th technological equipment.

4. Constraint (3) regulates the manufacture of products over period $(t+\Delta t)$ and cannot go beyond these limits.

5. Constraint (4) predetermines the completion of making the products not later than the specified term, set by the customer.

6. The time of execution of the i-th order at the l-th technological equipment can be specified by a constant or a time, which is determined by the indicators of performance for a particular team at packing/packaging or at the beginning of manufacturing a specific type of products, it is described by expression (18).

$$\text{o}_{ijl} = \text{const} \ \text{ or } \ \text{o}_{ijl} \in [a, b], \ a, b - \text{const}. \quad (18)$$

For example, fulfilling the i-th order should be executed only by a second shift, that is $\text{o}_{ijl} \in [16:15..23:55]$.

7. If the planned period $(t+\Delta t)$ coincides with the execution of repair and maintenance work involving certain equipment, then the planned period is divided into two periods before and after the execution of such operations.

8. All kinds of resources to execute the i-th order must be fully available (18), and their arrival should be no later than the beginning of the stage for the implementation of the i-th order, determined from expression (19).

$$\sum_{k=1}^{r_i} rk_{ik} \cdot op_i(t+\Delta t) \ge rkz_k, \quad (19)$$

$$trp_{ik} \le \tau_{ijl},$$

where τ_{ijl} is the start time to execute the j-th stage of the i-th order at the l-th technological equipment;

k is the type of a resource necessary to execute the i-th order;

r_i is the list of resources necessary for manufacturing products for the i-th order;

$op_i(t+\Delta t)$ is the volume of the finished products, which must be produced for the i-th order over period $(t+\Delta t)$;

rk_{ik} is the volume of the raw materials necessary to produce a unit of a product unit for the i-th order;

rkz_k is the volume of the raw materials of the k-th type of a resource that arrived at time trp_{ik};

trp_{ik} is the time of arrival of the k-th type of a resource before the start of the execution of the j-th current stage of the i-th order at the l-th technological equipment.

9. There are cases when one needs to maintain full or partial order priority, so the partial or full order ranking can be introduced, as well as a clear sequence in the form of inequalities such as $u < p$, where u and p are the orders' numbers.

10. The volume of production cannot exceed the maximum possible capacity of an enterprise in general, and it is given by formula (20).

$$\min Op_i \le op_i(t+\Delta t) \le \max Op_i, \quad (20)$$

where $(t+\Delta t)$ –is the planned period for which the production plan is calculated;

$op_i(t+\Delta t)$ is the volume of the finished products, which must be produced for the i-th order over period $(t+\Delta t)$;

$\min Op_i$ is the minimum possible volume of production, for the i-th order over period $(t+\Delta t)$, which would be profitable;

$\max Op_i$ is the maximum possible volume of production, for the i-th order over period $(t+\Delta t)$.

11. The storage time of the finished products may not exceed the shelf life and is given by formula (21).

$$tvug_i(t+\Delta t) \le tvug_i(t+\Delta t) +$$
$$+ tper_i(t+\Delta t) \le tvug_i(t+\Delta t) + tvidg_i(t+\Delta t),$$

$$tvug_i(t+\Delta t) + tprid_i(t+\Delta t), \quad (21)$$

where $(t+\Delta t)$ is the planned period for which the production plan is calculated;

$tvug_i(t+\Delta t)$ is the time of manufacturing the products, manufactured for the i-th order over period $(t+\Delta t)$;

$per_i(t+\Delta t)$ is the time over which it is possible to process products, which were manufactured for the i-th order over period $(t+\Delta t)$;

$tvidg_i(t+\Delta t)$ is the time after which it is possible to ship the finished products, which were manufactured for the i-th order over period $(t+\Delta t)$;

$tprid_i(t+\Delta t)$ is the shelf life of the finished products, which were produced for the i-th order over period $(t+\Delta t)$.

12. The storing time of raw materials may not exceed the term of possible use and is assigned by formula (22).

$$tr_k \le tr_k + tvug_k, \quad (22)$$

where tr_k is the time when raw materials were received; $tvug_k$ is the time over which raw materials can be stored, which were received at time tr_k.

13. The storage of manufactured products is limited by the possible volume of storage (23).

$$pg_i(t) \le \max pg_i(t), \quad (23)$$

where $pg_i(t)$ is the volume of the i-th type of products, manufactured but not shipped by time t; $\max pg_i(t)$ is the maximum volume of the i-th type of products, which can be stored at time t.

14. The storage of raw materials is limited by the possible volume of storage (24).

$$pr_k(t) \le \max r_k(t), \quad (24)$$

where $pr_k(t)$ is the volume of the k-th type of the raw materials, which is available at time t;

$\max r_k(t)$ is the maximum volume of the k-th type of the raw materials that can be stored at time t.

The timely provision of resources for each stage of the production process would facilitate its continuity and reduce the time of equipment downtime.

Depending on the social and economic situation, as well as peculiarities of the manager responsible for drafting the operational schedule of order execution, the task can be solved in different ways, namely:

– when assessing the effectiveness of the operational-calendar plan of order execution, all criteria are accepted and they are ranked;

– the task is reduced to the choice of certain partial criteria.

For those criteria that are evaluated in monetary units, we apply an additive convolution by assigning priorities for each of them according to a specific case. The additive convolution is represented by formula (25); it aims to minimize the costs [1].

$$F' = \sum_{\gamma=1}^{\Omega} \xi_\gamma \cdot \lambda_\gamma \to \min, \tag{25}$$

where ξ_γ is the priority factor of a partial criterion, provided only partial criteria are used for cost optimization,

$$0 \le \xi_\gamma \le 1, \quad \sum_{\gamma=1}^{\Omega} \xi_\gamma = 1;$$

γ is the number of a criterion $(1 \le \gamma \le \Omega)$;

Ω is the total number of partial criteria that would be taken into consideration by a manager;

λ_γ is the normalized γ-th partial criterion; normalization is performed in order to bring different criteria to the unified dimensionality and is calculated from formula (26):

$$\lambda_\gamma = \frac{F_\gamma - F_\gamma^{\min}}{F_\gamma^{\max} - F_\gamma^{\min}}. \tag{26}$$

Often there is a situation when one needs to take into consideration all the criteria, and then it is necessary to correctly assess the variants of the plans. To visually represent information, we propose using a petal diagram (Fig. 1).

The diagram shows five variants of operational plans. Each axis corresponds to a specific partial criterion; the plans are marked in different colors. To assess the difference, each variant of the plan has the area occupied by the diagram.

The choice of this type of diagram is due to the fact that when evaluating a set of criteria that have different forms and gradations of scales, the diagram makes it possible to conveniently represent and evaluate each variant.

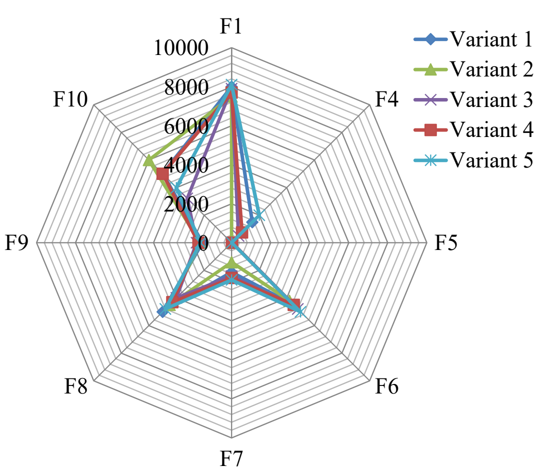

Fig. 1. Example of comparing five variants of plans

The constructed mathematical model makes it possible to estimate and build an operational-calendar plan of order execution; this problem belongs to the class of multi-criteria NP-complex combinatorial problems. The difficulty to solve such a problem increases with the number of orders, as well as with an increase in the stages of different variants for the implementation at different technological links of an enterprise. The task can be simplified only at enterprises where the technological process of production is carried out at a single automated technological complex, which has a conveyor-type continuous cycle of production. An example is macaroni production, where a certain type of a product is produced at a single automated technological line.

5. Devising a concept of the information technology for order fulfillment plan

Over many years of development and implementation of information systems in various fields and areas of activities, most food enterprises accumulated large amounts of data reflecting the consequences of decision-making in different standard and non-standard situations. Information about the activities of an enterprise, collected over a single year, can provide strategic insights for solving most tasks related to managing industrial processes.

Our information technology has been proposed to solve the task of operational planning of order fulfillment at a food enterprise. It combines the acquisition and processing of information, the elements in a virtual data storage, the elements of intelligent data mining, the use of metaheuristic algorithms and their modifications. The flow chart of information technology implementation is shown in Fig. 2.

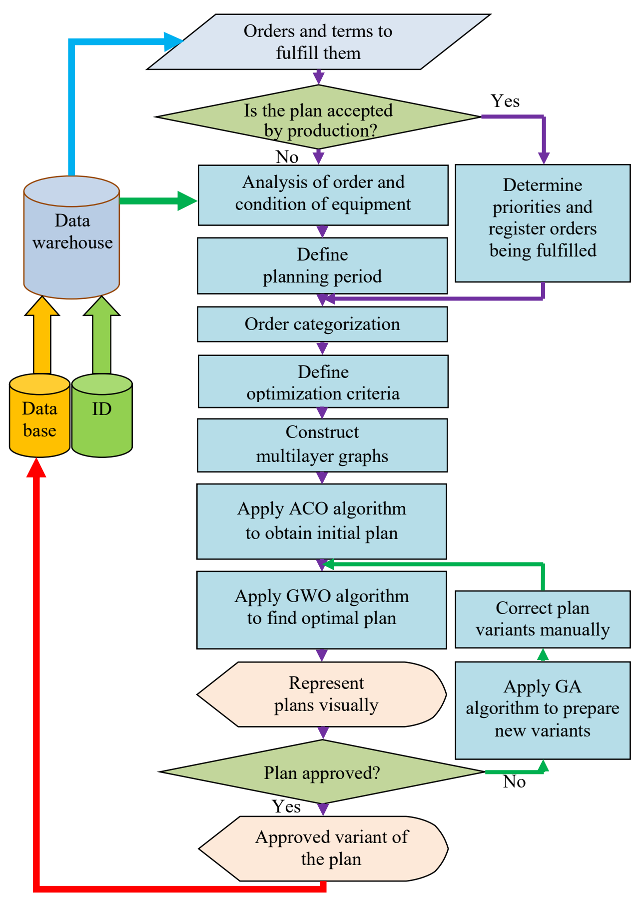

Fig. 2. The flow chart of information technology to plan order fulfillment

The use of information technology is based on the data accumulated in the databases (DB) of an enterprise and other information sources (ID). Information from DB and ID is uploaded to the virtual data warehouse (DW), which contains only that information that is relevant for the period defined by a DM (decision maker). Our choice of the virtual DW model is due to the fact that data would be downloaded for the required period, and there would be no need to store excessive information. Essentially, such a DW would be more like a showcase of data. It is cleared after use and when information is not required. We have developed the structure of a virtual DW using the CASE-tool CA AllFusion ERwin Data Modeler and implemented it employing the MS SQL Server. The DW structure is hybrid because it combines the relational and non-normalized structure. Data sampling and accumulation is carried out using the MS SQL Server Integration Services. This makes it possible to create and configure ways to retrieve data from any electronic sources, carry out their transformation (partitioning, merging, enrichment, conversion of types) and booting to the DW. When the data are uploaded, their redundancy and repetition are immediately eliminated. After applying and if necessary, the DW is cleared and would be re-loaded with the updated data if it is needed. Such an approach ensures the operation of information technology involving the information that is relevant. A DW stores the following information: the state of technological equipment and its operational characteristics, available raw materials, the actual plan of supply of raw materials to the enterprise, terms of acting contracts, all the necessary details of contracts (penalties for late execution, general conditions) and orders (terms, types of products, volumes) received by the specified time, the features of stages in the technological sequence of manufacturing using existing equipment, techno-economic indicators, complete information about the current status of the plan, detailed information about orders included in the current plan, etc.

First, an order is received and the conditions of its execution are analyzed. If no plans are carried out, the condition of technological equipment is analyzed in order to specify the types of equipment planned for repair and maintenance and to determine whether these operations can be postponed. The planned start and end date of the order execution plan are clearly formed.

If an urgent order is received for the production, or there is a non-standard situation (delays in the raw materials, equipment failure, revocation of a certain order, etc.), which requires a reconfiguration of the orders fulfillment plan, then the DM should specify in the existing plan those groups of orders that must be executed by all means or vice versa. In fact, it is possible to specify a full or partial reconfiguration of the plan being performed at present.

Next, the orders are categorized into groups using a solution tree algorithm. The choice of a given algorithm is due to its capability, based on the classification parameters, to represent objects in the form of a hierarchy, in which each element corresponds to a single node of decision making [1, 12, 13].

The advantages of the algorithm are a fast learning process, the generation of intuitive rules, a possibility to describe non-parametric models, the high accuracy of a forecast compared to other methods (statistics, neural networks). A given algorithm is ideal for describing the non-parametric models.

A solution tree algorithm makes it possible to represent resulting data in a compact form with an accurate description of objects based on the classification by certain attributes.

Our example of using a solution tree algorithm is the production of pasta that implies the following sequence of steps:

– all orders are divided into the short-cut and long-cut pasta. Each type of pasta would involve different technological lines; orders would be executed independently;

– each subgroup is divided into subgroups, categorized for a certain type of packaging;

– all orders are ranked according to the terms specified in the orders;

– if possible, orders are combined or executed in parallel;

– fines are defined for breaking the timing of orders.

Depending on the type of a product and the need to involve certain departments or equipment, we determine the number of plans to be executed in parallel.

At the next stage, the DM selects a series of criteria to be taken into consideration when assessing the optimality of the order fulfillment plan. The criteria are selected according to the socio-economic situation, as well as depending on the strategic directions of development of the enterprise in general.

Next, a multilayer graph is built for each plan. The graph nodes are the state of the choice and transition between one stage and the next. Edges that connect two nodes represent the process of executing a specific stage. The total duration of a certain stage denotes the weight of each edge. To eliminate a possible delay in the execution of a certain step, another additional edge is added between the adjacent nodes, which would provide a transition if no other stage is possible. Graph formation is carried out for clarity and implies the application of metaheuristic algorithms. One layer of the graph corresponds to the technological equipment. Each node corresponds to a certain time, and stopping at it does not necessarily require the need to move to the next node along another edge. This ensures the alignment between the stages when using different technological equipment [1].

In the next stage, the modified ACO algorithm, proposed by authors of [1, 14], is used to produce the earliest approximate schedule variants; the algorithm simulates the principle of an ant colony's activities. The condition for obtaining a variant of the plan of order fulfillment is to visit all different edges, except for the edges, which correspond to the delay, each layer of the graph to form a single complete path. At each iteration, the generated artificial ants search for a path along the graph according to the partial criteria, defined by a DM, or the general convolution of the criteria. To find the extreme values for an objective function at each iteration, the predefined number of artificial ants is used, which build the corresponding number of order execution schedules. By using the objective function and the partial criteria of the mathematical model for compiling an order execution plan, the best ones are selected. The chosen variants are stored and used independently at the following iterations. Each agent acts according to the rules of a probabilistic algorithm and, when choosing the direction, focuses not only on the increment in the objective function but also on the statistical information reflecting the previous history of collective search [1, 4]. However, if the process of manufacturing the finished products consists of less than three technological operations on different technological equipment, which can be located at different production sites, it is possible to immediately proceed to the evaluation of the variants obtained.

To avoid getting a pseudo-plan that can only be locally-optimal, a Grey Wolf Optimizer algorithm (GWO) is used, which simulated the process of their hunting in nature. In accordance with the task of compiling an order fulfillment plan, the wolf pack hunts for the victim, which corresponds to the optimum operational plan of order fulfillment. Each wolf in the pack corresponds to an alternative operational plan at every iteration. Following each iteration, we calculate for each wolf the value of its alternative operational plan by using the partial criteria or an evaluation function. According to the value of each wolf in the pack, they are divided into four types: "alpha" – a wolf leader, whose assessment has the optimal solution by the partial criteria or an evaluation function, which correspond to the constructed mathematical model, compared with other agents; "beta" and "delta" are the wolves that drive the victim, ranked second and third among the best; "omega" – all others [15–18]. The first three types of wolves are fixed for the next iterations, until new alternatives are found that are better than the current ones, or the specified number of iterations is exhausted. The "alpha", "beta", "delta" wolves affect the formation of "omega" wolves.

In the first iteration, each wolf is assigned a single order, without repetition, and then a population is generated for each wolf using a random number generator that eliminates the repetition of order numbers if one has already been generated for that agent. The "alpha", "beta" and "delta" used in the first iteration are the best options obtained when applying the ACO algorithm.

The modification is to correct the number of alpha, beta and delta populations that accelerates the search but increases the operation time of the algorithm. At the first iterations, we use the obtained variants from the preceding stage to reduce the search time and increase the number of populations. By using the GWO algorithm, we obtain variants of order fulfillment plans.

Applying the Gantt Chart, we deduce the variants for the fulfillment of orders, which makes it possible to visually assess the sequence of stage execution; to compare the score of each variant, we use a petal diagram.

If the manager serving as a DM accepts and approves one of the variants of the fulfillment of orders, it is accepted and transferred to the production units. The adopted plan is recorded in the database of the enterprise.

If the obtained variants of the fulfillment of orders do not satisfy the manager, the following steps are taken partially or completely:

– registration of certain parts of the order execution plan or, vice versa, the artificial substitution of order execution sequence;

– to form new variants, a genetic algorithm (GA) is applied.

The use of GA is due to the fact that it uses an iterative approach to improving outcomes in the vicinity of selected best variants [19, 20]. If such a solution is found, it becomes current and the new iteration begins. At each iteration, the application of the mutation, crossover, and cross-breeding operations makes it possible to quickly obtain the new modified variants for order execution plans. This continues until the specified number of iterations is completed. In this way, we receive new variants that are transferred to the stage of using the ACO algorithm.

It is important to note that the result depends not only on the number of contracts, but also on the number of stages to be performed to make a product, as well as the number of variants of technological equipment.

The combination of three algorithms into a single information technology enables finding complex variants for the execution of schedules on multi-nomenclature enterprises in the food industry.

We compared the proposed technology with different individual combined algorithms for forming the optimal order execution plan. The proposed information technology was tested based on the statistical data from the Ukrainian food industry enterprises, namely pasta production, a dairy enterprise, and an enterprise for manufacturing sausage and meat products.

We propose that the effectiveness of the information technology should be assessed based on the combination of an ACO (ant colony) algorithm, in order to obtain the initial plan, the GWO (gray wolves) algorithm, in order to find the optimum plan, and the GA (genetic algorithm), in order to obtain new variants. To assess the effectiveness of the combination of algorithms, the following indicators are applied: the time to search for an optimal schedule; the number of iterations executed in the search; the efficiency of the chosen plan (defined as a deviation from the actual plan's estimation based on an objective function); a decrease in the order execution time (calculated as the difference between the actual and proposed plan).

The verification was performed based on the statistical data on the execution of orders over previous periods, so the chosen actual plan was the executed plan. We have randomly selected 25, 50, 75, and 100 orders for different periods. Table 1 gives the comparison of algorithms' performance and the proposed information technology for data acquired at TOV "Slobozhansky Bacon" (Ukraine).

Table 1

Comparison between the use of information technology and algorithms

No. of entry	Algorithm title	Number of orders	Time to search for optimal plan, min.	Number of iterations performed for searching	Efficiency of the selected plan, c. u.	Decrease in the time of order fulfillment
1	Combination of ACO, GWO and GA algorithms	25	4	356	412	2
		50	9	836	1,234	15
		75	14	1,245	1,637	10
		100	21	1,689	4,678	36
2	Grey Wolf Optimizer	25	8	759	1,836	1
		50	12	973	367	7
		75	19	1,578	1,637	10
		100	37	1,971	4,325	30
3	Ant Colony algorithm	25	7	532	412	2
		50	15	798	591	10
		75	21	1,311	1,724	13
		100	39	1,699	4,325	30
4	Genetic algorithm	25	7	793	329	0
		50	12	798	757	8
		75	35	1,821	1,356	12
		100	43	2,169	2,125	24

Comparison of the proposed combination of the ant colony algorithm, gray wolves' algorithm, and the genetic algorithm, constituting a part of the developed information technology, to their other classical forms is possible only at each enterprise as each one has its own parameters and performance indicators. Based on the results of our comparison, the proposed combination of algorithms in the information technology is considerably better in terms of time because all algorithms are limited by the number of iterations, and the resulting execution plan of orders is more optimal with the increasing number of input data.

If one uses each algorithm and its modifications individually, increasing the dimensionality of the task prolongs the search time. For example, when compared to the ACO algorithm, a given technology, at the incoming number of orders over 50 in pasta production and at a sausage and meat products enterprise, finds a more optimal solution faster by 20–30 %. And when compared to the classical methods, the time cost is reduced by up to 70–80 %.

For the case of reconfiguring the current order execution plan, the proposed technology makes it possible to apply the current plan as a first approximation, which reduces the search time.

6. Discussion of results of the development and application of information technology

This paper reports the developed information technology to form and reconfigure operative calendar plans of order fulfillment, the scheme of which is shown in Fig. 2. Underlying the technology is the proposed combination of the ant colony algorithm, the gray wolves' algorithm, and the genetic algorithm, whose operation is based on a mathematical model of planning execution of orders for a food enterprise. The combination of algorithms ensures avoiding the algorithm stop while finding a local minimum.

The proposed technology makes it possible to solve the main task of decision making at any enterprise, namely compiling an optimum order fulfillment plan with the minimization of time and costs.

The proposed information technology ensures the implementation of contracts and gives the following advantages:

– it promptly generates an operative-calendar order fulfillment plan with the minimization of expenses, aimed at maximizing profits;

– it promptly and flexibly re-configures the acting schedule of orders, which makes it possible to process orders in real time and to ensure the optimum utilization of technological equipment;

– it significantly improves the efficiency of the use of raw materials, as well as ensures the minimization of their storage costs;

– it provides rapid response to the occurrence of unfavorable events and emergencies by making appropriate changes to the current order execution plan;

– it clearly allocates all tasks for the execution of each order among production units, which takes into consideration the sequence of execution and the necessary resources with reference in time;

– it makes it possible to optimize the utilization of production capacities.

The proposed information technology reduces the probability of making incorrect managerial decisions and, accordingly, protects a food enterprise from unnecessary costs when compiling an order fulfillment plan.

The proposed information technology for planning order fulfillment at the operational management of production has a theoretical and practical value for specialists in the field of management and information technologies.

Because the technology has various applications, its use is possible at any enterprise, except for very specific ones. It can be used not only for the entire production cycle but also to individual departments.

Since the constructed mathematical model takes into consideration all aspects of food production, it can be applied at any enterprise in the related industry. The proposed information technology is based on combining the algorithms of an ant colony, gray wolves and the genetic algorithm and the developed mathematical model, which makes it possible to find an optimal plan that accounts for the criteria chosen at the moment of decision-making.

The efficiency of the proposed technology is that the combination of algorithms ensures the use of approximate variants of the plans found by a preceding algorithm. That is, the search is not from scratch but involves close variants, which avoids the local optimal value. All this is due to the combination of three algorithms: ant algorithm, gray wolves' algorithm, and genetic algorithm.

The relevance of the proposed technology is in the prompt search for an alternative variant of order fulfillment because emergencies and errors threaten an enterprise with significant losses. For example, in pasta production, stopping a technological line made by Pavan would lead to a decrease in production volumes by larger than 10 tons.

The main disadvantages include the fact that the proposed information technology cannot take into consideration certain features of non-food enterprises, and is also not useful for non-industrial commercial organizations that sell goods by other manufacturers. It should also be noted that the proper use of information technology implies providing access to databases at an enterprise and, ultimately, to the consolidated corporate data.

The further advancement of this research is aimed at creating a separate online service that would make it possible to implement the proposed information technology and deploy it in the cloud. The devised on-line service should be made flexible for further integration with existing information systems at enterprises through a separate integration module.

7. Conclusions

1. We have constructed a mathematical model to plan the fulfillment of orders taking into consideration the main features of the food industry enterprises. The mathematical model accounts for all the nuances of a food enterprise and its order fulfillment planning process: the terms of storage of raw materials and finished products, the possibility of occurrence and the necessity to process substandard products, the patterns in the fulfillment of each individual order; the peculiarities of technological equipment utilization, etc. The additive convolution of criteria is used to form a generalized objective function. The constructed mathematical model makes it possible to compile an order fulfillment plan taking into consideration all technological operations in the production process. We have also proposed to use a petal

diagram to assess the alternatives to plans based on the general economic and social influences. The built mathematical model makes it possible to adjust and evaluate the fulfillment of orders depending on the objective and subjective advantages to a DM, as well as provides both the accounting for and exclusion of certain partial criteria depending on a particular situation.

2. The devised information technology of order fulfillment planning ensures the creation and adjustment of operative calendar plans in a short period of time. The speed of reaction to the occurrence of emergencies would reduce the losses of a food enterprise and make it possible to satisfy the requirements of customers. Owing to the combination of the ant colony, gray wolves and genetic algorithms, our information technology enables the formation of alternative plans of product manufacturing. The developed information technology is based not on the improvement of a certain algorithm but on the combination of algorithms, which distinguishes it from the traditional approach, namely the improvement of a specific algorithm. The constructed mathematical model is used to assess the effectiveness of alternative decisions and their formation. The proposed technology implies the possibility of influence from a DM, as well as his/her complete elimination, if necessary.

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