UDC 004.89:005.53:005.511:664.6 https://doi.org/10.35546/kntu2078-4481.2022.2.8

N. V. LIMANSKA
National University of Food Technologies
ORCID: 0000-0002-7000-9452
S. V. HRYBKOV
National University of Food Technologies
ORCID: 0000-0002-2552-2839
M. P. KOSTIKOV
Taras Shevchenko National University of Kyiv,
National University of Food Technologies
ORCID: 0000-0002-1569-8179

AN INTELLIGENT PRODUCTION PLANNING SUPPORT SYSTEM BETWEEN BAKERY ENTERPRISES

The paper proposes an intelligent system for production planning support between bakery enterprises. Considering the specifics of bakery enterprises, a mathematical model of profit is proposed. This model takes into account logistical features when distributing orders among several enterprises in this industry. The paper considers the complex task of taking into account the necessary raw materials supply to corresponding factories, as well as the supply of finished products to customers.

The proposed mathematical model allows the creation of an order fulfillment plan that takes into account all operations of the technological process in the manufacturing of products. It also allows adjustment and evaluation of the order fulfillment efficiency depending on the objective and subjective advantages provided by the decision maker and allows both consideration and exclusion of certain partial criteria depending on a specific situation. The model makes it possible to estimate and build an operational-calendar order fulfillment plan.

The paper analyzes several methods and approaches that are included in the intelligent support system for planning the manufacturing of products between bakery enterprises that belong to the same company or have a cooperation agreement concluded between them, which will make it possible to derive the entire management process to a new level.

The proposed information system structure makes it possible to combine the use of modified algorithms and methods based on combining algorithms, which were also analyzed in the work, as well as some classical approaches. The system provides a possibility to select a set of algorithms and methods, which increases the range of applications.

The proposed system quickly forms an operational calendar plan for order fulfillment with cost minimization aimed at maximizing profit; enables reduction of logistics costs, which ensures obtaining higher quality products with minimal waiting time; allows quick adjustment of the existing calendar plan of orders, which makes it possible to respond to orders in real-time and ensure optimal use of technological equipment; significantly increases the efficiency of using raw materials, and also ensures the minimization of costs for their storage; ensures a quick response in case of negative and extraordinary situations by making appropriate changes to the current order fulfillment plan.

Key words: *artificial intelligence, decision support system, intelligent system, mathematical model, production planning, bakery enterprise.*

Н. В. ЛІМАНСЬКА
Національний університет харчових технологій
ORCID: 0000-0002-7000-9452
С. В. ГРИБКОВ
Національний університет харчових технологій
ORCID: 0000-0002-2552-2839
М. П. КОСТІКОВ
Київський національний університет імені Тараса Шевченка,
Національний університет харчових технологій
ORCID: 0000-0002-1569-8179

ІНТЕЛЕКТУАЛЬНА СИСТЕМА ПІДТРИМКИ ПЛАНУВАННЯ ВИГОТОВЛЕННЯ ПРОДУКЦІЇ МІЖ ХЛІБОПЕКАРСЬКИМИ ПІДПРИЄМСТВАМИ

У роботі запропоновано інтелектуальну система підтримки планування виготовлення продукції між хлібопекарними підприємствами. Враховуючі специфіку хлібопекарських підприємств, запропоновано математична модель отримання прибутку. Модель враховує логістичні особливості при розподіленні замовлень між декількома підприємствами цієї галузі. В роботі розглянуто комплексну задачу врахування постачання потрібної сировини на відповідні заводи, а також постачання готової продукції до замовників.

Запропонована математична модель дозволяє сформувати план виконання замовлень із урахуванням усіх операцій технологічного процесу при виготовленні продукції. Вона також дозволяє коригувати та оцінювати ефективність виконання замовлень залежно від об'єктивних та суб'єктивних переваг, наданих особою, що приймає рішення, а також забезпечує як урахування, так і виключення певних часткових критеріїв залежно від певної ситуації. Модель дає змогу оцінити та побудувати оперативно-календарний план виконання замовлень.

Запропонована структура інформаційної системи дає можливість поєднати використання модифікованих алгоритмів та методів, заснованих на комбінуванні алгоритмів, які також були проаналізовані в роботі, а також цілої низки класичних підходів. У системі передбачено можливість підібрати сукупність алгоритмів і методів, що збільшує сферу застосування.

Запропонована інтелектуальна система швидко формує оперативно-календарний план виконання замовлень із мінімізацією витрат, спрямований на максимізацію прибутку; дає змогу зменшити логістичні витрати, дозволяючи отримувати більш якісну продукцію з мінімальним часом очікування; дає змогу оперативно коригувати існуючий календарний план замовлень, реагувати на замовлення в реальному часі та забезпечувати оптимальне використання технологічного обладнання; значно збільшує ефективність використання сировини та матеріалів, а також забезпечує мінімізацію витрат на їх зберігання; забезпечує швидке реагування при виникненні негативних та позаштатних ситуацій шляхом внесення відповідних змін до поточного плану виконання замовлень.

Ключові слова: *штучний інтелект, система підтримки прийняття рішень, інтелектуальна система, математична модель, планування виробництва, хлібопекарське підприємство.*

Introduction

The food industry is one of the strategic industries in any country as it ensures its food independence. The food industry market is characterized by very high competition. The main fields of the food industry include the bakery industry, which is characterized by a wide assortment, and a specific technological process. Its main task is to satisfy the population's demand for food products in accordance with needs and physiological norms. It should be noted that, in addition to the manufacturing process, the quality of finished products is affected by the delivery of finished products to the customer, namely the product range, the specification of production equipment, the influence of production factors, and logistics.

Therefore, an urgent task is to create and use an intelligent support system for production planning between bakery enterprises.

Analysis of recent research and publications

I. Novoytenko [1] examines the main trends in bread development in Ukraine, analyzes equipment for bread factories, and offers a solution to the problem of extending the shelf life of products. However, the main attention is paid only to the direction of product packaging, and delivery to shops of packaged bread cut into pieces.

In the work of M. Corrado [2], the issue of storage of finished products is considered from the point of view of changes in their chemical properties. A conclusion is drawn about which types of bakery products have better storage properties and do not go stale so quickly.

The work of T. Vorkut et al. [3] substantiates theoretical and methodological approaches to improving the efficiency of perishable product supply management. They are based on methods and models of rational management of transport service systems in the corresponding supply chains. The analysis carried out in the study showed that the supply system, which involves additional deliveries, is more economically feasible from the point of view of the operating conditions of the supply chains of perishable products. However, it does not take into account the seasonality of the demand for bakery products.

The research [4] describes the formulas that allow applying the obtained results to optimize and forecast decision-making in the enterprise's procurement logistics system against the background of changes in external and internal business environments. S. Markova proposed the formulas of the optimal value of the delivery frequency of several goods based on the asymptotic approach in conditions of minor changes in the input parameters. These formulas should be used to determine the cost of maintaining stocks and the optimal order interval when placing an order. But the proposed models and methods of inventory management in the enterprise's logistics system and corresponding software products that improve inventory management mainly perform accounting functions, which significantly limit their effectiveness for enterprise management.

In the work of D. Bikulov [5], discrete increase in order fulfillment costs and inventory storage costs are assumed the parameters that take into account periodic fluctuations in the demand. The built model can be used to optimize the enterprise's logistics management system due to its closeness to reality and ease of use. It can help determine the optimal order quantity and total costs, but it does not take into account the seasonality of demand and the rapid period of product spoilage.

Based on the model of the order's economic volume, which has developed significantly over the past decades due to the inclusion of realistic factors, a model of reverse logistics is proposed in [6]. S. Sanni argues that in practice enterprises can implement a return policy, that is, they can reuse products to increase customer loyalty and, at the same time, not suffer a loss of profit. The inventory problem of when to order and how much to order when there is a reverse flow of goods into the system is considered in profit maximization form but does not consider the maximization of customer demand satisfaction.

Innovative enterprises are leaders in the product sales market and differ from other enterprises in their high competitiveness and economic growth [7]. L. Rodchenko considers an example of solving the problems of time and resource limitations during the work tasks. This approach is based on the developed complex methodologies of implementation management. It is worth considering this issue from the point of view of using the information system for the optimization of innovative projects according to the criterion of time and with limited resources.

To identify the main trends, prospects, and threats to the sale of finished products, V. Nemchenko considered and researched the consumption of food products by the population [8]. The author claims that a person becomes the goal and the main factor of production, and production itself is directly social and non-market, which requires the use of such levers of enterprise management as planning, forecasting, etc. But increasing the competitiveness of the bakery is considered from the point of view of improving the quality of the manufactured products, and does not take into account the improvement of the functions of delivery of raw materials or products.

In [9], I. Irtysheva shows an active interest in the problem of changes in logistics systems, and the lack of their tools, which could become a technical and methodological basis for well-founded decisions. The growing role of material and technical support, the number and intensity of product flows, the expansion of the company's activities, and high market demand are described. However, with the author's high attention to ensuring the enterprise survival and improving the company's adaptation to the market, the question of increasing the profitability of the enterprise due to the reduction of transportation costs is not covered.

Order fulfillment time, as one of the main constraints that affect planning at each stage of the supply system, is considered by scientist M. Vijayashree [10]. The paper investigated how the order cost reduction depends on the order execution time and the problem of two echelons of the supply chain for one supplier and one buyer was considered. The analysis was carried out by determining the optimal decisions regarding the quantity, cost of the order, lead time, and the number of deliveries from one supplier to the customer in one production cycle, but the costs of fuel and lubricating materials were not taken into account.

In [11], information technology is proposed for solving the problem of planning the order execution for the manufacturing of products at food enterprises. It is based on information technology with a combination of the method of data mining, modified multi-agent, and genetic algorithms. The paper proposes a mathematical model of the problem of planning contract execution but does not take into account the criterion of storage and supply of finished products. A combined algorithm for solving the planning problem was developed, aimed at taking into account the peculiarities of the subject area.

The authors of [12] use methods of linear programming to optimize profit in bakery production by allocating resources and finding maximum and minimum limits for product types.

In [13], a total quality management system for a small bakery is considered, but the paper does not cover the issues of production planning. The paper [14] tells about using Enterprise Resource Planning (ERP) to support decision-making and resource management, but the authors do not go into detail on the mathematical foundations for such planning.

A number of works [15, 16, 17] consider certain important aspects of production planning, but the described models are either general or intended for use in other industries. Therefore it is hard to apply those approaches to bakery enterprises due to their specifics.

Some papers [18, 19, 20, 21, 22] propose models for perishable products and therefore may be useful for our research.

The authors of [23] have made a systematic review of modeling approaches for supply chains in the food industry that describe the methods used by researchers in recent years.

Aim of the Study

The analysis of the above mentioned literary sources gives reasons to assert the feasibility of creating and using an intelligent support system for manufacturing of products planning between bakery enterprises.

Methods for Solving the Problem

The above aspects characterize different approaches in production methods, accounting, and formation of the cost of finished products, in the construction of analytical accounting of enterprises of the bakery branch of the food industry and are characterized by a specific production process, organizational and technological features. Since a significant number of bakery enterprises of various capacities and forms of ownership operate in this industry, a competitive environment is characteristic of bread factories.

One of the peculiarities of the bakery branch is the conditionally constant demand for the products produced. This is related to the historically formed specifics of the nutrition of the Ukrainian population. For us, bread is a mandatory component of nutrition, not a supplement to food, but the main product. The historically formed specifics of the Ukrainian consumer's diet are constant demand for the main products produced by bread factories. The volume of bread and bakery products can be sold within the physiological norms of human consumption (0.3–0.33 kg per day), and their assortment depends on the traditions, tastes, and preferences of consumers.

The production of bread and bakery products is clearly regulated by the recipes of the technological process and has a short production cycle (for wheat flour, the maximum duration of the production process is up to 9 hours, for wheat and rye – up to 12 hours, for rye varieties of bread – up to 36 hours) [24].

Bread must be sold at food courts from the very morning, fresh and in full volume. Therefore, the time for its delivery from the bakery is very short, and the costs for this delivery are among the highest among food products.

The way out of this situation can be a significant increase in the delivery radius, going beyond the "home" regions, or changing logistics flows.

A preliminary analysis of logistics flows that are formed and implemented at the enterprise, which is diverse in their economic nature (material, financial, information, and labor) was conducted. This analysis allowed us to divide them according to the importance of their influence on the content and form of organization of industrial logistics of the enterprise. The majority of foreign and domestic scientists in the field of logistics single out the material flow as the key, and other types of flows – informational, financial, service, human, and transport – are considered secondary. The management of the enterprise's logistics system covers the entire set of tasks for managing material flows in the "supplier-consumer" area.

Bakery products spoil quickly, so delivery to the consumer must be high-quality and fast, and optimization of the routes of transportation of bakery products is an important logistical task. The routes are planned in such a way that the car, leaving the factory, goes around the shops in a circle and returns to the enterprise.

The sale volume of these bakery products primarily depends on freshness, and only after that on other quality characteristics [25]. Immediately after leaving the oven, the crust of the bakery product is strong and fragile. When the product is stored, moisture from the middle of the product migrates to the crust and softens it, which leads to staleness. Characteristic signs of bread staleness are a decrease in its elasticity, and an increase in fragility, which is a consequence of a change in the microstructure of the finished product. The technological process of baking must be carried out by the calculations of the productivity of the equipment for each technological line, as well as all technological parameters and hardware for the execution of the recipe.

The production capacity of the enterprise is characterized by the leading equipment, which is bakery ovens. The main elements are assortment and quality of manufactured products; the composition of the equipment and its quantity by type; equipment operation time and use of space during the year; progressive technical and economic norms of productivity and use of equipment, manufacturing of products per unit of area, norms of the duration of the production cycle and the labor intensity of the manufactured products.

When bread, which stayed some time in the trade network, becomes not fresh, its further sale at a constant price is extremely small. Unsold discounted products are returned to the enterprise as raw materials for processing (depending on the recipe for the production of breadcrumbs or bakery products).

With a sufficiently wide range of products, the composition of production stocks is not very diverse, since the products do not require a large variety of raw materials. We have a short term of product storage and the need to sell it within a day, transportation restrictions, and the impossibility of long-term storage of products in warehouses. All this determines the need to take into account the features of product delivery to the consumer.

In the conditions of the economic crisis and the constant increase in prices for fuel and lubricating materials, the question arises of optimizing the process of supplying raw materials to bakery enterprises and routes for the sale of finished products.

To reduce the load on the logistics system and ensure prompt adjustment of the order fulfillment plan, it is worth considering the complex task of taking into account the supply of the necessary raw materials to the relevant factories, as well as the supply of finished products to customers. Fulfillment of an order can be unsatisfactory if it is fulfilled before or after the specified time, because it can cause spoilage of finished products, failure of the sequence of replenishment of stocks, etc.

As the basis, we have taken the mathematical model of the task of planning the execution of contracts, which is presented in works [11, 25]. The authors also propose using a modified ant colony algorithm, but the mathematical model and solution are aimed at enterprises of the non-food industry.

Let's introduce the following notations:

F – set of factories owned by the enterprise;

f – factory number, $f \in F$;

P – set of types of products (assortment) manufactured at all factories;

p – product type, $p \in P$;

J_f – set of technological equipment for manufacturing of products at factory f;

j_f – number of technological equipment for manufacturing of products at factory f;

I – the set of all orders received by the enterprise;

i – number of the order that is in the execution queue;

t_i – the specified deadline by which the i-th order must be completed;

w_{ip} – the volume of products of the p-th type that must be produced for the i-th order.

The main indicator is obtaining the maximum profit in money from the fulfillment of orders for manufacturing of products for a given period, which is described by formula (1) for the planned period *dt*.

$$Z_1(dt) = \sum_{i=1}^{I}\sum_{f=1}^{F}\sum_{j_f=1}^{J_f}((r_{pi} - x_{ipjf} * c_{pij_f}) * w_{ip} * q_i) \to \max \tag{1}$$

where *dt* is the planned period for which the order must be fulfilled;
rp_i – the cost of products of type *p* for the *i*-th order for the period *dt;*
x_{ipjf} – a parameter that takes the value {0,1} (1 if products of type *p* according to the *i*-th order will be manufactured on j_f technological equipment at factory *f*;
c_{pij_f} – the production cost of products of type *p* for the *i*-th order, if it will be manufactured on j_f-th technological equipment at factory *f;*
q_i – the coefficient of the fine, which depends on the prescribed conditions of the order, corresponding to the *i*-th order, which is calculated according to formula (2):

$$q_i = 1 + d_i * \begin{cases} -df_i, & (tf_i - t_i) < 0, \\ 0, & 0 \le (tf_i - t_i) \end{cases} \tag{2}$$

where d_i is a coefficient of 1 if a fine is provided for the untimely execution of the *i*-th order;
tf_i – the time for which the *i*-th order was executed;
df_i – penalty coefficient $0 \le df_i \le 1$ if the service is not performed on time, which is described by the condition $(tf_i - t_i) < 0$.

In case of storage of finished products in the warehouse, additional costs arise, because depending on the type of products, it is necessary to ensure the necessary storage conditions, which incur additional costs, which is determined by formula (3):

$$Z_2(dt) = \sum_{i=1}^{n}(vz_{ip} * wzp_{pi}) \to \min \tag{3}$$

where vzp_i is the storage cost of a unit of product type p for the *i*-th order for the period *dt*;
wzp_{pi} – the volume of products of type p for the *i*-th order, which will be stored for the period *dt*.

The production time of each *i*-th order per period ($t+\Delta t$) is a partial criterion and affects the overall effectiveness of the plan option (4), and constraint (5) regulates products manufacturing for the period ($t+\Delta t$), constraint (6) conditions the completion of the products manufacturing no later than the specified period.

$$F_{2i}(t + \Delta t) = \sum_{j=1}^{\omega_i}\sum_{l=1}^{\sigma_i}(o_{ijl} * (pt_{ijl} + t_{ijl} + \eta t_{ijl} + to_{ij-1})) \to \min \tag{4}$$

$$t \le t_i + F_{2i}(t + \Delta t) \le t + \Delta t \tag{5}$$

$$t \le t_i + F_{2i}(t + \Delta t) \le dt_i \tag{6}$$

where ($t+\Delta t$) is the planning period for which the production plan is calculated;
t is the start time of the plan, which is indicated by the date and time to the minute;
Δt – the time required to complete all orders in minutes;
i – the order, which is in the execution queue, regulates one type of product, which must be released during the ($t+\Delta t$) period;
j – stage number from the set of stages ($j \in \omega_i$) for the *i*-th order;
ω_i – the number of necessary stages of production of the *i*-th order;
l – equipment number from the set of equipment ($j \in \sigma_i$)for the *i*-th order;
σ_i – the amount of equipment used to perform all stages in the production of the *i*-th order;
t_i – the time of the start of production according to the *i*-th order;
dt_i – the time for which it is necessary to produce products according to the *i*-th order;
Δt_{ijl} – execution time of the *j*-th stage on the *l*-th equipment for manufacturing of products according to the *i*-th order;
pt_{ijl} – the time required to prepare the *l*-th equipment for the implementation of the *j*-th stage in the manufacturing of products according to the *i*-th order can be zero if no preparation is required;
to_{ij-1} – time of transition/waiting between the execution of the *j*-th stage to the (*j*–1) stage;
ηt_{ijl} – time for cleaning the equipment after the *j*-th stage of manufacturing of products according to the *i*-th order on the *l*-th equipment;
o_{ijl} – a parameter that takes the value {0,1} (1 if the *j*-th stage can be performed on the *l*-th equipment for manufacturing of products according to the *i*-th order; 0 – otherwise).

The developed mathematical model makes it possible to estimate and build an operational-calendar order fulfillment plan, and this problem belongs to the class of multi-criteria NP-complex combinatorial problems [11, 25].

The complexity of solving such a problem increases with the number of orders, as well as with the increase in the stages of various execution options at different plants and technological production units. It should be noted that part of the equipment used in domestic food enterprises requires additional adjustment efforts when introducing new types of products. In this case, costs for setting up and adjusting technological equipment are added under each production process.

Taking into account the specifics of the task, the authors proposed the structure of the information system to support production planning between bakery enterprises that belong to the same company or have a cooperation agreement between them, which is presented in Figure 1. The main components of the system include (Figure 1): a “data lake”, data download tools, data storage, knowledge bases, a server part, and a web user interface. The system architecture supports the implementation of client-server architecture in the form of a “thin” client, where all logic is focused on the server part, and the user part is only responsible for displaying data, that is, the result of execution is displayed in the user's browser.

The choice of such an architecture for building a system is due to the following advantages: simplified integration with third-party software products; ease of implementation, which consists in the absence of the need to configure the hardware or software of users; increased fault tolerance, since all software necessary for operation is installed only on the server. The proposed structure allows integration with existing information systems at the enterprise. It is important to note that the user interface is made in the form of web pages for display in the user's browser [25].

The simulation-based units include the following:

1. Models of the work of the repair team made it possible to analyze the quantitative and qualitative composition of the personnel of the repair department and the workload of the employee during the production shift. An option to change the number of workers during the execution of the model is provided, which allows viewing the result of the model in real-time.

2. A simulation model of the repair of technical equipment of the line, which took into account the type of equipment, as well as the possibility of carrying out the repair process in time.

The use of simulation models allows us to reduce the time of making management decisions, analyze the possible consequences of these decisions, predict the state of the repair system, and optimize the system before its implementation. Studying the repair system with the help of a simulation model makes it possible to change the operating time of the system without interfering with the actual operation of the bread factory, to understand the interrelationship of elements within the system, to assess the degree of influence of various factors and to identify weak points. With the help of the developed process model of technological equipment repair, the classification of types of repair interconnections and maintenance of mechanisms installed and operated at the bakery enterprise was carried out.

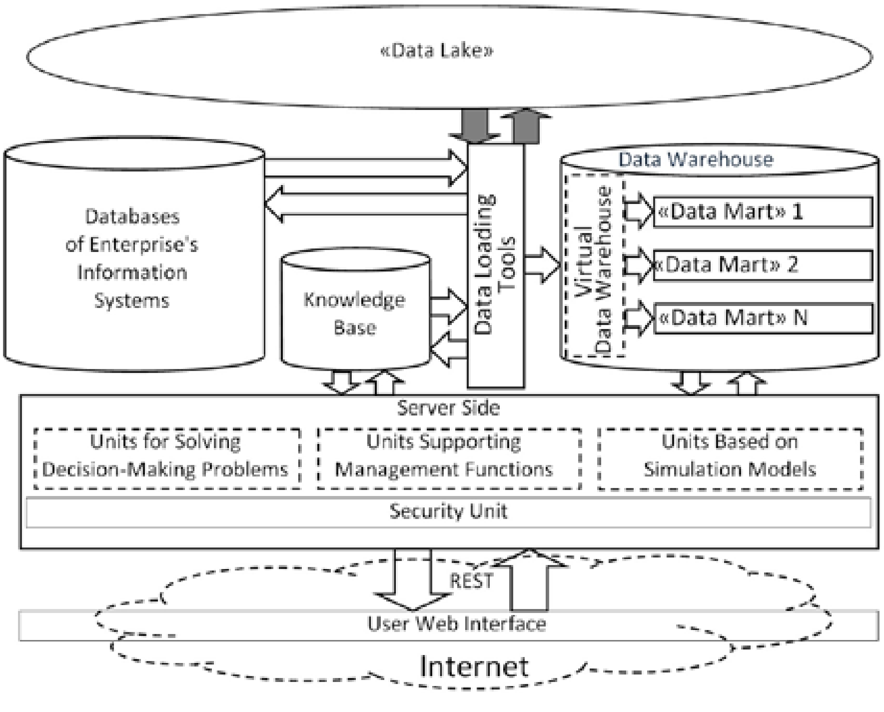

Fig. 1. Information system architecture

Determining the technical condition of the bakery equipment is associated with significant difficulties due to the complexity of its structure and configuration, as well as a large number of its operational and regulatory indicators and characteristics. Since the production capacity of the enterprise is specified by regulatory documents, the technical support of technological equipment can be considered a tool for managing the repair work process

The operation of simulation models and support for decision-making is provided by the information in the data warehouse: about the state of technological equipment and its operational characteristics, available raw materials, the current plan for the receipt of raw materials at the enterprise, the terms of current contracts, all the necessary details of contracts (the amount of fines for late execution, general conditions) and orders (terms, types of products, volumes, terms) that have arrived at the moment, features of the stages of the technological sequence of manufacturing on existing equipment, technical and economic indicators, complete information on the status of the current plan, detailed information on orders included in the current plan, etc.

Results

The developed architecture of the intelligent decision support system, which implements the proposed information technology based on modified methods and algorithms, is based on flexible integration in the “data lake” of information from various information sources. The proposed architecture combines several information technologies, which are aimed at increasing the technical and economic indicators of the enterprise by supporting management decision-making in the formation of the order fulfillment plan. The proposed architecture will also ensure: operational formation and flexibility when changing plans for order fulfillment; will significantly reduce time spent on data collection and information preparation; the ability to quickly adapt to the current situation and make appropriate changes to order fulfillment plans.

The sources of data for the data warehouse are the databases of information systems and the “data lake”, which ensure the adequacy and reliability of information support to support management decision-making. Accumulation of information in the “data lake” and the storage takes place in automatic mode due to the use of data loading tools. It is proposed to choose a multi-level architecture of the data warehouse, which ensures the integration and coordination of data from the “data lake” and other sources first into the “virtual data warehouse”, and from there it is loaded into the “data store”.

“Virtual data warehouse” is built according to the rules of relational databases. This ensures the avoidance of redundancy when working with large volumes of information. Also, the “virtual data warehouse” provides intermediate granular storage of the data set obtained from the “data lake” and other sources for loading “data marts”. Each “data mart” is designed to hold a set of data to support a specific task or provide information over a specific time period.

Data stored in data stores are updated according to business logic and have certain aggregation and granularity. “Data mart” is designed to solve a specific local problem, has a target purpose, and contains a set of data that ensures the following tasks: conducting complex analytical queries; solving a specific optimization problem; formation of reporting; answers to a certain number of requests, etc. For example, one of the “data showcases” contains information on recipe ingredients, their physicochemical and functional-technological properties, auxiliary materials, and quality indicators, and stores user-specific data on recipe composition, physicochemical characteristics of ingredients, and recipe status.

The knowledge base is accumulated during the formation of rules and knowledge according to the situation. It contains rules regarding the technological features of manufacturing [26].

“Data lake” ensures the accumulation of untransformed information from various sources, which allows for reducing the time for its consolidation and processing. “Data lake” includes structured data from relational databases (rows and columns), semi-structured data (CSV, log files, XML, JSON), unstructured data (mail messages, documents), and even binary data (video, audio, graphic files). In effect, the proposal is to use the “data lake” as a “standard data archive”, the data gets there using data load packages with minimal modification. In the “data lake”, the elements of the structures fully correspond to the structures of the corresponding sources. Thus, centralized data storage is ensured. The advantages of “data lakes” include [27]: obtaining complete information without conversion; provision of detailed statistics; the ability to experiment with different types of data from different sources; providing access to information that managers need in one place; ensuring a high level of centralization and detailing of data; the possibility of scaling, which is suitable for small enterprises, and also easily integrates with other systems; simplifying the work of users; cheaper than storage because they do not require pre-processing.

The use of a data lake ensures the accumulation of all data represented by heterogeneous structures and then makes it possible to obtain any data sets for solving various problems.

“Data loading tools” provide automatic acquisition of data sets from enterprise databases and knowledge bases, transfer them to the “data lake”, and then obtain the necessary information from it and transfer it to the data warehouse. “Data loading tools” provide data acquisition, transformation, aggregation, and loading. To avoid redundant information, all elements of BZ, SD, “data lakes” and “data marts” are checked for available up-to-date information. If necessary, “data loading tools” perform the destruction of redundant and redundant information. The Data Transformation Services toolkit acts as a toolkit of “data loading tools” in modern client-server DBMSs.

The functional capabilities of the server part meet the needs of users of the information system and are generally divided into units that are designed to solve specific problems. Each unit, when processing some request, turns to the SD or BZ to receive data. After data processing and necessary calculations, the result is displayed in the client part in the given form.

The main units of the system include units for solving decision-making problems, units for solving problems using simulation models, and units for supporting management functions that combine statistical accounting and report generation.

Support units for management functions provide complete and up-to-date information on order fulfillment, adherence to calendar deadlines, movement of resources and materials, etc. These units realize the formation of reporting documentation and the performance of the functions of creating various types of reporting documentation in the forms and presentations selected by the user.

The units of decision-making tasks include the unit of creating a calendar plan for the execution of orders. Among the units, it is proposed to use the BSP (Business Systems Planning) methodology. The unit for forming a calendar plan for order fulfillment is designed for forming variants of a calendar plan using combined algorithms [11]. It is also possible to evaluate each of the options and compare them, make corrections, and determine additional parameters. The constructed and selected plan is submitted in electronic form for review by the responsible persons, and after approval, it is recorded in the databases of the information systems operating at the enterprise. First, the order is received and the conditions for its execution are analyzed. If at the moment no plans are being implemented, then an analysis of the condition of the technological equipment is carried out to find out the planned repair and preventive works of the equipment and the possibility of their postponement or transfer. The planned start and end dates of the order execution plan are clearly formed. All this acts as a limitation when forming an order fulfillment plan. If necessary and by common agreement, it is possible to adjust the terms of repair and preventive works of technological equipment, if this does not violate the passport requirements for its operation.

The proposed architecture makes it possible to combine several information technologies, namely: the use at food industry enterprises of an expert modeling system for simulating complex product recipes, which makes it possible to choose replacement components in the recipe under production conditions; the use of order fulfillment planning technology through the use of combined methods and algorithms; the use of information technology to improve the process of analysis and planning of order fulfillment at food enterprises, which, unlike the known ones, is based on determining the assortment and adjusting recipes to reduce the cost and quickly fulfill orders.

Conclusions

The intelligent support system for production planning between bakery enterprises proposed in the paper ensures the fulfillment of orders with the following advantages: it quickly forms an operational-calendar plan for the fulfillment of orders with cost minimization aimed at maximizing profit; allows for reducing logistics costs, which ensures obtaining higher quality products with minimal waiting time; allows you to quickly adjust the existing calendar plan of orders, which makes it possible to respond to orders in real-time and ensure optimal use of technological equipment; significantly increases the efficiency of the use of raw materials and materials, and also ensures the minimization of costs for their storage; ensures a quick response in the event of negative and out-of-hours situations by making appropriate changes to the current order fulfillment plan. The proposed structure of the information system makes it possible to combine the use of modified algorithms and methods based on combining algorithms, which were also analyzed in the work, as well as several classical approaches. The system provides an opportunity to select a set of algorithms and methods, which increases the range of applications.

The proposed mathematical model is included in the system and the following criteria are distinguished: obtaining the maximum profit from the execution of orders for the manufacturing of products for a given period of time, taking into account fines for late execution of the order; the criteria take into account the need to store finished products in the warehouse, which leads to the occurrence of additional costs, because depending on the type of products, it is necessary to ensure the necessary storage conditions, which incur additional costs; the time for the manufacturing of products of each individual order for a given period is a partial criterion and affects the overall effectiveness of the selected variant of the execution plan, and the described restrictions regulate the manufacturing of products for the required period, as well as restrictions that determine the end of the manufacturing of products no later than the specified period. The proposed mathematical model and the corresponding unit in the system allow you to create an order fulfillment plan taking into account all operations of the technological process during the manufacturing of products from distribution to factories. The created unit allows you to adjust and evaluate the efficiency of order execution depending on the objective and subjective advantages provided by the ODA and also provides both consideration and exclusion of certain partial criteria depending on a specific situation.

Bibliography

1. Новойтенко І. В. Стан та основні тренди розвитку хлібопекарської промисловості України / І. В. Новойтенко, В. В. Малиновський // Ефективна економіка. – 2020. – № 11. – 7 с. DOI: 10.32702/2307-2105-2020.11.52.

2. Corrado M. Impact of storage on starch digestibility and texture of a high-amylose wheat bread / M. Corrado, P. Zafeiriou, J. H. Ahn-Jarvis // Food Hydrocolloids. – 2023. – Vol. 135. – 108139. – 9 p. DOI: 10.1016/j.foodhyd.2022.108139.

3. Vorkut T. The model to optimize deliveries of perishable food products in supply chains / T. Vorkut, L. Volynets, O. Bilonog, O. Sopotsko, I. Levchenko // East.-Eur. J. Enterp. Technol. – 2019. – Vol. 5. – Pp. 43–50.

4. Markova S. Asymptotic methods in optimization of multi-item inventory management model / S. Markova, L. Horoshkova, I. Khlobystov, V. Volkov, O. Holovan, A. Golub, O. Oliynyk // CEUR Workshop Proceedings. – 2020. – Vol. 2713. – Pp. 393–414.

5. Bikulov D. Optimization of inventory management models with variable input parameters by perturbation methods / D. Bikulov, O. Holovan, O. Oliynyk, K. Shupchynska, S. Markova, A. Chka, E. Makazan, K. Sukhareva, O. Kryvenko // East.-Eur. J. Enterp. Technol. – 2020. – Vol. 3/3(105). – Pp. 6–15.

6. Sanni S. An economic order quantity model with reverse logistics program / S. Sanni, Z. Jovanoski, H. S. Sidhu // Operations Research Perspectives. – 2020. – Vol. 7. – 100133. – 8 p. DOI: 10.1016/j.orp.2019.100133.

7. Rodchenko L. Optimization of Innovation Projects According To Criteria of Time and Resource Constraints / L. Rodchenko, O. Goncharenko, O. Koval, I. Tarasov, H. Nemchenko, T. Tkachuk // International Journal of Recent Technology and Engineering. – 2019. – vol. 8. – pp. 1431–1434.

8. Немченко В. Управління харчовими підприємствами у контексті забезпечення якості харчування / Немченко В. В., Немченко Г. В. // European journal of economics and management. – 2019. – Vol. 5. – Iss. 3. – Pp. 54–60.

9. Irtysheva I. Types, purposes and formation process of the program of changes in logistics system / I. Irtysheva, S. Minakova // Actual Problems of Economics. – 2015. – Vol. 3(165). – Pp. 155–160.

10. Vijayashree M. A single-vendor and a single-buyer integrated inventory model with ordering cost reduction dependent on lead time / M. Vijayashree, R. Uthayakumar // Journal of Industrial Engineering International. – 2017. – Vol. 13. – Pp. 393–416.

11. Hrybkov S. Development of information technology for planning order fulfillment at a food enterprise / S. Hrybkov, O. Kharkianen, V. Ovcharuk, I. Ovcharuk // East.-Eur. J. Enterp. Technol. – 2020. – Vol. 3(103). – Pp. 62–73.

12. Nasir D. S. M. Comparison of Linear and Integer Linear Programming for the Profit Optimization in Bakery Production: A Case Study at Temptlicious Enterprise / D. S. M. Nasir, N. N. Hamdan, N. H. Shafii, N. A. M. Nor // Journal of Computing Research and Innovation. – 2022. – Vol. 7. – No. 2. – Pp. 142–152. DOI: https://doi.org/10.24191/jcrinn.v7i2.297.

13. Zorpas A. A. Total quality management system (TQMS) in small winery and bakery in Cyprus. A case study / A. A. Zorpas, D. M. Pociovălişteanu, V. J. Inglezakis, I. Voukalli // Analele Universităţii Constantin Brâncuşi din Târgu Jiu : Seria Economie. – 2012. – Vol. 2. – No. 2. – Pp. 17–26.

14. Reyes R. J. R. Impacto de un sistema ERP en la productividad de las PYME / R. J. R. Reyes, S. D. R. Lugo, J. B. Velándia // Tecnura. – Dec 2012. – vol. 16. – no. 34. – pp. 94–103.

15. Dey B. Forecasting ethanol demand in India to meet future blending targets: A comparison of ARIMA and various regression model / B. Dey, B. Roy, S. Datta, T. S. Ustun // Energy Reports. – Mar 2023. – Vol. 9. – Pp. 411–418.

16. Kumar T. J. An ordered precedence constrained flow shop scheduling problem with machine specific preventive maintenance / T. J. Kumar, M. Thangaraj // Journal of Project Management. – Jan 2023. – Vol. 8. – No. 1. – Pp. 45–56. DOI: 10.5267/j.jpm.2022.8.002.

17. Marta D. Simulations in planning logistics processes as a tool of decision-making in manufacturing companies // Production Engineering Archives. – Dec 2022. – Vol. 28. – No. 4. – Pp. 300–308. DOI: 10.30657/pea.2022.28.38.

18. Liu Z. Multiperiod competitive supply chain networks with inventorying and a transportation network equilibrium reformulation / Z. Liu, A. Nagurney // Optimization and Engineering. – 2012. – Vol. 13(3) . – Pp. 471–503. DOI: 10.1007/s11081-011-9170-2.

19. Musavi M. A multi-objective sustainable hub location-scheduling problem for perishable food supply chain / M. Musavi, A. Bozorgi-Amiri // Computers & Industrial Engineering, 2017. – Vol. 113. – Pp. 766–778. DOI: 10.1016/j.cie.2017.07.039.

20. Patak M. Demand planning specifics in food industry enterprises / M. Patak, V. Vlckova // Business and Management, 2011. – Vol. 7. – Pp. 1168–1175. DOI: 0.3846/bm.2012.150.

21. Amorim P. Multi-objective integrated production and distribution planning of perishable products / P. Amorim, H. O. Günther, B. Almada-Lobo // International Journal of Production Economics. – 2012. – Vol. 138(1) . – Pp. 89–101. DOI: 10.1016/j.ijpe.2012.03.005.

22. Ahumada O. A tactical model for planning the production and distribution of fresh produce / O. Ahumada, J. R. Villalobos // Annals of Operations Research. – 2011. – Vol. 190(1). – Pp. 339–358. DOI: 10.1007/s10479-009-0614-4.

23. Stüve D. A systematic literature review of modelling approaches and implementation of enabling software for supply chain planning in the food industry / D. Stüve, R. Meer, M. S. A. Agha, M. L. Entrup // Production and Manufacturing Research: An Open Access Journal. – Dec 2022. – Vol. 10. – No. 1. – Pp. 470–493. DOI: 10.1080/21693277.2022.2091057.

24. Харченко Т. М. Особливості функціонування підприємства хлібопекарської галузі / Т. М. Харченко, А. В. Вакуленко // Фінансово-економічний розвиток України в умовах трансформаційних перетворень: матер. міжнар. наук.- практ. конф. – Т.: Крок, 2019. – С. 58–59.

25. Hrybkov S. Weboriented decision support system for planning agreements execution / S. Hrybkov, V. Litvinov, H. Oliinyk // East.-Eur. J. Enterp. Technol. – 2018. – Vol. 2(93) . – Pp. 13–24.

26. Hrybkov S. Hybrid expert system to model the ice cream recipes / S. Hrybkov, N. Breus, G. Polischuk // Ukrainian Journal of Food Science. – 2017. – Vol. 5(2). – Pp. 294–304.

27. Amazon. What is a data lake? [online]. – 2020. – URL: https://aws.amazon.com/big-data/datalakes-and-analytics/what-is-a-data-lake.

References

1. I. Novoytenko, V. Malinovskiy, "State and main trends of the development of the bread bakery industry in Ukraine", *Efektyvna ekonomika*, vol. 11, 7 p., 2020. DOI: 10.32702/2307-2105-2020.11.52.
2. M. Corrado, P. Zafeiriou, J. H. Ahn-Jarvis, "Impact of storage on starch digestibility and texture of a high-amylose wheat bread", *Food Hydrocolloids,* vol. 135, 108139, 9 p., 2023. DOI: 10.1016/j.foodhyd.2022.108139.
3. T. Vorkut, L. Volynets, O. Bilonog, O. Sopotsko, I. Levchenko, "The model to optimize deliveries of perishable food products in supply chains", *East.-Eur. J. Enterp. Technol.,* vol. 5, pp. 43‒50, 2019.
4. S. Markova, L. Horoshkova, I. Khlobystov, V. Volkov, O. Holovan, A. Golub, O. Oliynyk, "Asymptotic methods in optimization of multi-item inventory management model", *CEUR Workshop Proceedings*, vol. 2713, pp. 393–414, 2020.
5. D. Bikulov, O. Holovan, O. Oliynyk, K. Shupchynska, S. Markova, A. Chka, E. Makazan, K. Sukhareva, O. Kryvenko, "Optimization of inventory management models with variable input parameters by perturbation methods", *East.-Eur. J. Enterp. Technol.,* 3/3(105), pp. 6–15, 2020.
6. S. Sanni, Z. Jovanoski, H. S. Sidhu, "An economic order quantity model with reverse logistics program", *Operations Research Perspectives*, vol. 7, 100133, 8 p., 2020. DOI: 10.1016/j.orp.2019.100133.
7. L. Rodchenko, O. Goncharenko, O. Koval, I. Tarasov, H. Nemchenko, T. Tkachuk, "Optimization of Innovation Projects According To Criteria of Time and Resource Constraints", *International Journal of Recent Technology and Engineering*, vol. 8, pp. 1431–1434, 2019.
8. V. Nemchenko, H. Nemchenko, "Management of Food Enterprises in Terms of Ensuring Food Quality", *European journal of economics and management*, vol. 5, iss. 3, pp. 54–60, 2019.
9. I. Irtysheva, S. Minakova, "Types, purposes and formation process of the program of changes in logistics system", *Actual Problems of Economics*, 3(165), pp. 155–160, 2015.
10. M. Vijayashree, R. Uthayakumar, "A single-vendor and a single-buyer integrated inventory model with ordering cost reduction dependent on lead time", *Journal of Industrial Engineering International*, vol. 13, pp. 393–416, 2017.
11. S. Hrybkov, O. Kharkianen, V. Ovcharuk, I. Ovcharuk, "Development of information technology for planning order fulfillment at a food enterprise", *East.-Eur. J. Enterp. Technol.,* vol. 3(103), pp. 62–73, 2020.
12. D. S. M. Nasir, N. N. Hamdan, N. H. Shafii, N. A. M. Nor, "Comparison of Linear and Integer Linear Programming for the Profit Optimization in Bakery Production: A Case Study at Temptlicious Enterprise", *Journal of Computing Research and Innovation*, vol. 7, no. 2, pp. 142–152, 2022. DOI: https://doi.org/10.24191/jcrinn.v7i2.297.
13. A. A. Zorpas, D. M. Pociovălişteanu, V. J. Inglezakis, I. Voukalli, "Total quality management system (TQMS) in small winery and bakery in Cyprus. A case study", *Analele Universității Constantin Brâncuşi din Târgu Jiu: Seria Economie*, vol. 2, no. 2, pp. 17–26, 2012.
14. R. J. R. Reyes, S. D. R. Lugo, J. B. Velándia, "Impacto de un sistema ERP en la productividad de las PYME", *Tecnura*, vol. 16, no. 34, pp. 94–103, Dec 2012.
15. B. Dey, B. Roy, S. Datta, T. S. Ustun, "Forecasting ethanol demand in India to meet future blending targets: A comparison of ARIMA and various regression model", *Energy Reports*, vol. 9, pp. 411–418, Mar 2023.
16. T. J. Kumar, M. Thangaraj, "An ordered precedence constrained flow shop scheduling problem with machine specific preventive maintenance", *Journal of Project Management*, vol. 8, no. 1, pp. 45–56, Jan 2023. DOI: 10.5267/j.jpm.2022.8.002.
17. D. Marta, "Simulations in planning logistics processes as a tool of decision-making in manufacturing companies", *Production Engineering Archives*, vol. 28, no. 4, pp. 300–308, Dec 2022. DOI: 10.30657/pea.2022.28.38.
18. Z. Liu, A. Nagurney, "Multiperiod competitive supply chain networks with inventorying and a transportation network equilibrium reformulation", *Optimization and Engineering*, vol. 13(3), pp. 471–503, 2012. DOI: 10.1007/s11081-011-9170-2.
19. M. Musavi, A. Bozorgi-Amiri, "A multi-objective sustainable hub location-scheduling problem for perishable food supply chain", *Computers & Industrial Engineering,* vol. 113, pp. 766–778, 2017. DOI: 10.1016/j.cie.2017.07.039.
20. M. Patak, V. Vlckova, "Demand planning specifics in food industry enterprises", *Business and Management*, vol. 7, pp. 1168–1175, 2011. DOI: 0.3846/bm.2012.150.
21. P. Amorim, H. O. Günther, B. Almada-Lobo, "Multi-objective integrated production and distribution planning of perishable products", *International Journal of Production Economics*, vol. 138(1), pp. 89–101, 2012. DOI: 10.1016/j.ijpe.2012.03.005
22. O. Ahumada, J. R. Villalobos, "A tactical model for planning the production and distribution of fresh produce", *Annals of Operations Research*, vol. 190(1), pp. 339–358, 2011. DOI: 10.1007/s10479-009-0614-4.
23. D. Stüve, R. Meer, M. S. A. Agha, M. L. Entrup, "A systematic literature review of modelling approaches and implementation of enabling software for supply chain planning in the food industry", *Production and Manufacturing Research: An Open Access Journal,* vol. 10, no. 1, pp. 470–493, Dec 2022. DOI: 10.1080/21693277.2022.2091057.
24. T. Kharchenko, A. Vakulenko, "Features of functioning of the bakery enterprises", *Financial and economic development of ukraine in terms of transformations: III International scientific and practical conference*, Krok, Ternopil, Ukraine, pp. 58–59, 2019.
25. S. Hrybkov, V. Litvinov, H. Oliinyk, "Weboriented decision support system for planning agreements execution", *East.-Eur. J. Enterp. Technol.,* vol. 2(93), pp. 13–24, 2018.
26. S. Hrybkov, N. Breus, G. Polischuk, "Hybrid expert system to model the ice cream recipes", *Ukrainian Journal of Food Science,* vol. 5(2), pp. 294–304, 2017.
27. Amazon, "What is a data lake?", *Amazon.com,* 2020. Available: https://aws.amazon.com/big-data/datalakes-and-analytics/what-is-a-data-lake.