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DEVELOPING SOFTWARE TO SOLVE CERTAIN PROBLEMS OF INVENTORY MANAGEMENT

Summary. In modern conditions of intensifying competition in consumer markets, stable operation of enterprises is ensured by the implementation of strategies for maximum satisfaction of consumer demand for goods and related services. Planning such strategies requires improvements in various enterprise systems, in particular, the inventory management system based on the rationalization and optimization of product flows, use of appropriate models and methods for these tasks. Every company strives to satisfy the customer at the highest possible level. This task requires a significant investment in inventory. At the same time, an equally important task is to find new opportunities to reduce all types of costs and increase profits, therefore, from the point of view of finance, the ideal state is when there is no stock while the production needs of the company are met in full. But such a situation is absolutely impossible in real conditions. In order to work as efficiently as possible and reach acceptable financial indicators, it is necessary to effectively manage inventory stock at the enterprise. An essential feature of inventory modeling process is uncertainty in real conditions, which is associated with the inaccuracy or incompleteness of information about demand, supply, time delays of ordered goods, product spoilage and other parameters of the logistics system. This necessitates an effective inventory management mechanism in conditions of uncertainty. Solving this problem requires calculation of exact date and quantity of each subsequent order. Most modern software packages for inventory management are quite difficult to understand or require large financial expenses. In addition, most practical applications are designed for deterministic parameters of demand and production schedule. In fact, demand has a high level of uncertainty, which requires improved algorithms using stochastic theory of inventory management. Thus, a number of issues related to this field still remain unresolved or incompletely resolved. Most publications consider the classic toolkit with some well-known modifications. However, classic models are quite difficult to apply in in real life because the ideal conditions are difficult to achieve in practice. The models do not take into account the limitations imposed by internal and external factors. Based on this, we have created software that would perform the required task. The final product of the research is a software product that enables warehouse operators and managers to optimize drafting a schedule of production inventory deliveries in conditions of demand uncertainty, as well as controlling deliveries based on an economic-mathematical model of inventory management in conditions of demand uncertainty. The software is able to determine the optimal period of delivery of several types of resources, total costs for storage and ordering, the effect of the obtained savings, speeding up and simplifying the dispatcher's work.

Keywords: inventory management, uncertainty of demand, order period, mathematical expectation, variance.

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РОЗРОБКА ПРОГРАМНОГО ЗАБЕЗПЕЧЕННЯ ДЛЯ ВИРІШЕННЯ ДЕЯКИХ ЗАДАЧ УПРАВЛІННЯ ВИРОБНИЧИМИ ЗАПАСАМИ

Анотація. В сучасних умовах, коли загострюється конкуренція на споживчих ринках, стабільна робота підприємств забезпечується реалізацією стратегій на максимальне задоволення споживчого попиту на товари і пов'язані з цим процесом послуги. Формування таких стратегій вимагає удосконалення різних систем підприємства, зокрема і системи управління товарними запасами на основі раціоналізації та оптимізації товарних потоків, використання адекватних постановок цих завдань моделей та методів. Суттєвою особливістю в процесі моделюванні запасів є існування в реальних умовах невизначеності, яка пов'язана з неточністю або неповнотою інформації про попит, постачання, часові затримки замовлених товарів, псування продукції та інші параметри логістичної системи, що вимагає пошуку ефективного механізму управління запасами в умовах невизначеності. Більшість сучасних програм, направлених на це, досить складні в розумінні або ж вимагають великих фінансових затрат. До того ж вони розроблені для детермінованих параметрів попиту та виробничого розкладу. Насправді попит характеризується високим рівнем невизначеності, тому виникає потреба вдосконалення алгоритмів з урахуванням використання апарату стохастичної теорії управління запасами. Таким чином, низка питань, що належать до даної галузі, досі залишається невирішеною, або вирішеною не повною мірою. У більшості публікацій розглядається класичний інструментарій з деякими широко відомими модифікаціями, проте застосування класичних моделей у реальній дійсності дуже утруднене через важко досяжні на практиці умов. У моделях не враховуються обмеження, пов'язані з внутрішніми та зовнішніми факторами. На базі цього було вирішено створити програмне забезпечення, що виконає цю задачу. Кінцевим продуктом дослідження є створення програмного продукту, за допомогою якого оператори та менеджери складу матимуть змогу оптимізувати процес складання графіку поставок виробничих запасів в умовах невизначеності попиту та контролювати поставки на основі економіко-математичної моделі управління запасами в умовах невизначеності попиту. Розроблений програмний продукт дозволяє визначати оптимальний період поставки кількох видів ресурсів, сукупні затрати за зберігання і замовлення, ефект отриманої економії, що прискорює та спрощує роботу диспетчера.

Ключові слова: управління запасами, невизначеність попиту, період замовлення, математичне сподівання, дисперсія.

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Problem statement. Intensifying competition in consumer markets, stability of both trading and manufacturing enterprises is achieved by implementing strategies that maximize satisfaction of consumer demand for both goods and services related to this process, as well reducing the trading costs. Such strategies necessitate improvement of various enterprise systems, including inventory management systems improvements based on optimization of product flows using appropriate models and methods for these tasks.

The desire of companies to satisfy desires of consumers at the highest possible level requires significant investments, in particular investments in inventory. On the other hand, an equally important task is to ensure the profitability of investments and to find new opportunities for reduction all types of costs and increase profits, therefore, from the point of view of finance, the most favorable state is when the inventory stock is minimal while the production needs of the company are met in full.

However, such a situation is difficult to achieve in real conditions due to a number of objective reasons. Thus, in order to achieve the most efficient operation of the enterprise and achieve excellent financial indicators, the inventory must be effectively managed. Many companies do not pay appropriate attention to the process of inventory management, the result of which is a significant increase in the amount of money invested in the inventory management system than expected.

Modeling the company's inventory management system answers the two main questions: selection of optimal volumes of stock replenishment along with optimal timing of resupply.

An essential feature of inventory modeling is uncertainty associated with inaccuracy or incompleteness of information about demand, supply, temporary delays of ordered goods, product spoilage, and other parameters of the logistics system. This requires the inventory management mechanism to be effective in such uncertainty. There is a need for a more detailed study of methods and models that take into account the uncertainty of the parameters of the inventory management process. A particular practical interest lies in the study of models which would take into account the temporary structure of interest rates on the market, along with the usual stochastic nature of demand and delivery terms. The ability to take into account the principle of the time value of money provides a significant reserve for increasing the efficiency and economic profitability of inventory management systems.

Optimization methods as well as the mathematical apparatus underlying inventory management models can be used in liquidity management models designed to solve such tasks as forming the optimal cash balance in the required amounts, accelerating payment turnover, etc.

State of the art in research. It is practically impossible to perform optimal inventory management tasks manually, as it requires accurately calculating the exact date and quantity of each subsequent order. Therefore, in order to get out of this predicament, companies attempt to automate this process. But most modern software for inventory management is quite difficult to understand or requires large financial investment.

In the end of the 1960s, industrial inventory management technologies like MRP, ERP, APS, MRPII started to appear. With the development of the international software market, manufacturers (e.g., Jda, Toolsgroup) strive to enable full integration of their software with various systems for managing product flows at enterprises (MRP/ERP in SAP, 1C, Oracle, etc.) Most practical applications are designed for deterministic parameters of demand and production schedule. In fact, demand is characterized by a high level of uncertainty, so there is a need to improve algorithms taking into account the stochastic theory of inventory management. Thus, a number of issues related to this field still remain unresolved or incompletely resolved. In most publications, the classical toolkit with some well-known modifications is considered. However, application of classical models in real life is very difficult due to conditions that are difficult to achieve in practice (for example, a constant rate of consumption of stock, etc.) Models often do not take into account limitations related to internal and external factors.

Therefore, we decided to create software that would perform this task.

Goals of this paper. The result of the research is a completed software product that allows warehouse operators and managers to optimize scheduling of production inventory deliveries in conditions of demand uncertainty, then control deliveries based on an economic-mathematical model of inventory management in conditions of demand uncertainty.

Scientific novelty of the obtained results lies in the application of a discrete multi-product model for determining the optimal moment of delivery, taking into account the uncertainty of demand. Developed software significantly reduces the effort required for drafting a schedule of production stock deliveries.

Practical significance. Results of the study allow to reduce the time spent on drafting the supply schedule in conditions of uncertainty of demand, to increase its quality, which in turn reduces the load on warehouses and increases the efficiency of the use of production resources.

The body of the paper. The success of any enterprise in the market depends on the degree of consumer orientation. That is, on how rationally the enterprise satisfies demand of solvent customers. The difficulty lies not in solving problems, but in seeing them [7].

Every enterprise strives to increase the turnover of stock in order to obtain the largest volume of sales and therefore profit, using a smaller area of warehouses and lower costs for maintaining stocks. Of course, the ideal system would be to sell without storage, immediately after delivery by the supplier. However, this type of trade with many assortments of goods is impossible, therefore inventory turnover is an important criterion that is carefully analyzed by enterprises.

The general formulation of the concept of stock can be defined as follows: “Material stock is items at various stages of production and circulation, products of industrial and technical purpose, consumer goods and other goods that are waiting to enter the process of personal or industrial consumption” [6].

We will consider a discrete model for determining the optimal moment of delivery, taking into account the uncertainty of demand. This economic-mathematical model makes it possible to optimize the timing of delivery in risk conditions, based on statistical data on the demand for stock for the previous period. Availability of demand statistics allows constructing a probability distribution for a random demand value. In this case, risk is understood as the deviation of demand values for production stocks from the forecasted average expected indicators.

In addition, our model makes an assumption that there are no deviations in terms of delivery. The criterion of optimization in the model is aggregated average costs. The total costs include, 1) the costs associated with product storage, and 2) the losses incurred by the company as a result of incomplete demand satisfaction due to untimely delivery of products. On the one hand, possible costs due to early delivery of production stocks lead both to additional costs for storage and maintenance, and to losses due to incomplete use, in particular to losses during the liquidation of the remaining stock. On the other hand, a possible deficit leads to underachieved profit, the risk of losing customers (real and potential). There are "opportunity losses", as a result of the freezing of capital reserves, which could potentially be allocated to other areas of business activity and bring profit. In order to consider the behavior of costs, it is necessary to introduce and describe the parameters of the problem being solved [3].

Thus, we need to determine the time at which to assign the supply t*, based on the uncertainty of demand. Let's make an assumption that the volume of the batch of production stock has a fixed value Q. The moment of exhausting the stock in the warehouse, which corresponds to the magnitude of demand, is denoted by λ. In our problem, we will interpret the uncertainty of demand due to the time during which the stock in the volume Q is used up. Consider the value $I(\lambda - t^*)$ as a function of the costs associated with the storage of excess stock in the volume Q after delivery t* in the time interval until the actual zeroing of the stock $\lambda > t^*$, meaning the stock is resupplied before it runs out. Graphically, the behavior of the storage cost function in the linear case is presented in Figure 1 [4].

Consider the dependency $D(t^* - \lambda)$ as a function of costs in the case of incomplete demand satisfaction, associated with a shortage of stock in the interval from the moment of the real zeroing of the stock $\lambda < t^*$ to the moment of delivery t* in the volume Q. At this stage, we assume that deficit costs describe only foregone profit.

Graphically, the behavior of deficit costs due to incomplete demand satisfaction is presented in Figure 2 [4].

Thus, storage costs follow the equation (1):

$$I(\lambda - t^*) = \begin{cases} Q \cdot c \cdot (\lambda - t^*), & \lambda > t^* \\ 0, & \lambda \le t^* \end{cases} \quad (1)$$

where c = const is the daily cost of storing a stock unit.

And deficit costs are described by the equation (2):

$$D(\lambda - t^*) = \begin{cases} \frac{Q}{\lambda} \cdot z \cdot (\lambda - t^*), & t^* > \lambda \\ 0, & t^* \le \lambda \end{cases} \quad (2)$$

where z = const is the expected profit from the sale of a unit of the product, and value I describes the intensity of demand, that is, the time during which the product is sold in volume Q.

Thus, the value $\frac{Q}{\lambda}$ represents the daily volume of the product sold.

Let us then consider a discrete case with demand uncertainty and several types of products [5].

Assume the enterprise is engaged in production that requires *m* types of resources, then let

Q_j – delivered quantity of product *j*,

c_j – storage cost of product *j* per unit of time,

z_j – profit from the sale of a unit of product *j*,

λ_j – intensity of demand for product *j*, i.e. the time during which product j is sold in volume Q_j for $j=1,\dots,m$,

t^* – desired time of the next resupply.

In the case of demand uncertainty, consider λ_j a discrete random variable. Suppose that based on statistical observations, we know n_j values of the random variable λ_j for each of the *m* products – λ_{ij}, as well as the frequencies τ_{ij} of these values. Then it is possible to calculate the probabilities of the values of the random variable characterizing different amounts of demand for different types of products according to the equation (3):

$$p_{ij} = \frac{\tau_{ij}}{\sum_i \tau_{ij}}, \quad i = 1,\dots,n_j, \quad j = 1,\dots,m. \quad (3)$$

Storage costs and losses from shortage of products for different values of demand are described by equations (4)-(7), respectively [3]:

$$I_{ij} = I_j(\lambda_{ij} - t^*) = \begin{cases} Q_j \cdot c_j \cdot (\lambda_{ij} - t^*), & \lambda_{ij} > t^* \\ 0, & \lambda_{ij} \le t^* \end{cases} \quad (4)$$

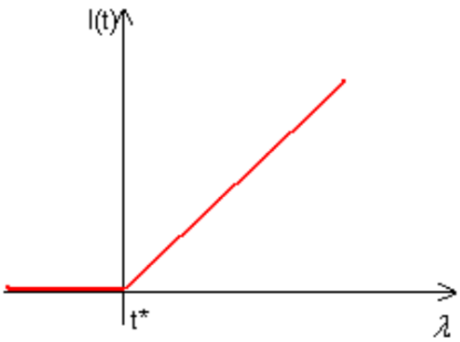

Figure 1. Storage cost function (linear)

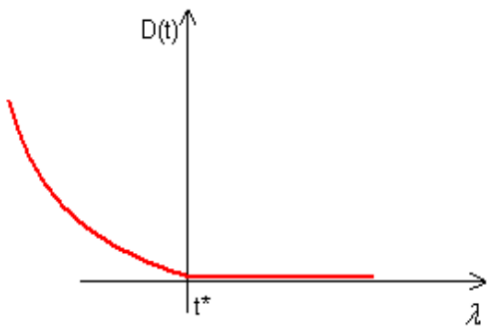

Figure 2. Deficit cost function

$$D_{ij} = D_j(t^* - \lambda_{ij}) = \begin{cases} \dfrac{Q_j}{\lambda_{ij}} \cdot z_j \cdot (t^* - \lambda_{ij}), & t^* > \lambda_{ij} \\ 0, & t^* \le \lambda_{ij} \end{cases} . \quad (5)$$

$$D_j(t^* - \lambda_{ij}) = \sum_{i=1}^{n_j} p_{ij} D_{ij} \quad (6)$$

$$I_j(\lambda_{ij} - t^*) = \sum_{i=1}^{n_j} p_{ij} I_{ij} \quad (7)$$

while mathematical expectation of total storage costs and losses for all types of stocks $M(I)$ and $M(D)$ are described by equations (8) and (9) [3]:

$$m(I) = \sum_{j=1}^{m} I_j(\lambda_{ij} - t^*) = \sum_{j-1}^{m} \sum_{i=1}^{n_j} p_{ij} I_{ij} \quad (8)$$

$$m(D) = \sum_{j=1}^{m} D_j(t^* - \lambda_{ij}) = \sum_{j-1}^{m} \sum_{i=1}^{n_j} p_{ij} D_{ij} \quad (9)$$

In this case, the mathematical model of the given problem can be described as follows [3]:

$$M(I) + M(D) \to \min_{t^*}, \quad t^* \in Z_+ \quad (10)$$

Thus, the moment of delivery appointment t^* is determined by solving the problem of minimizing the mathematical expectation of total costs.

Developing software to solve the problem of determining the optimal moment of delivery, taking into account the uncertainty of demand, will simplify and speed up the work of the dispatcher, as well as reduce the overall costs of ordering and storage of production resources, which is achieved by automating the calculation process [1].

The scheduling software is developed using Microsoft Visual Studio 2017 Professional (C# programming language). The software can be used at any production enterprises. There is a scope for further improvement.

The software has a convenient and intuitive user interface which simplifies and speeds up the dispatcher's work, enabling them to produce the most optimal schedule of orders in conditions of uncertainty of demand.

User interface of the software product is a window with a menu that has three tabs. On the «General information» tab, there are fields for entering the number of types of resources to be ordered, the calculation period, and data about resources (Figure 3).

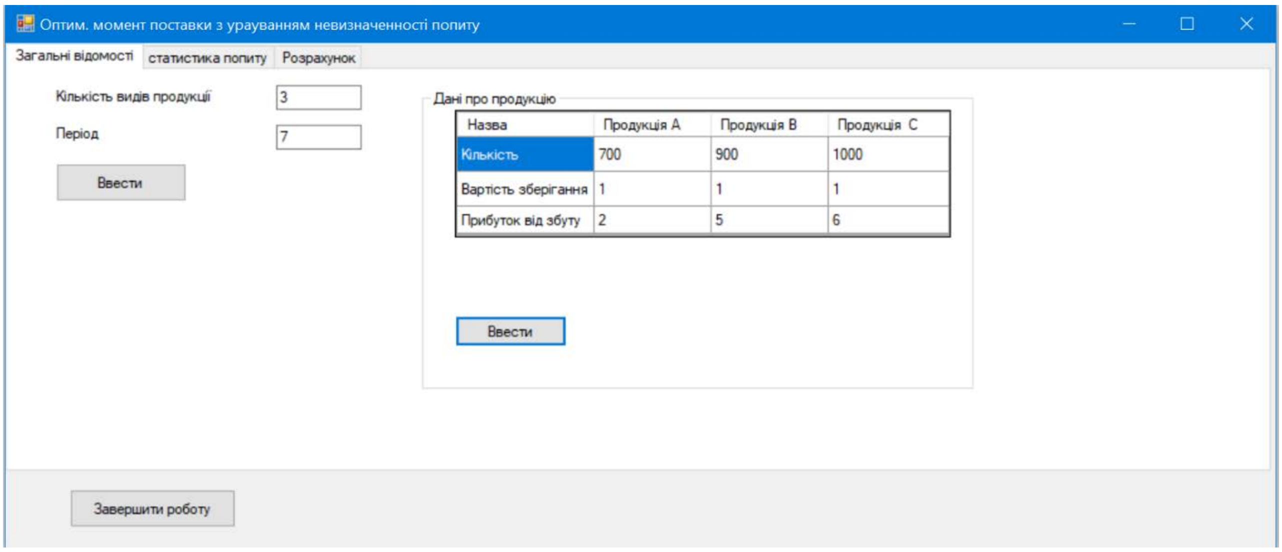

Figure 3. «General information» tab

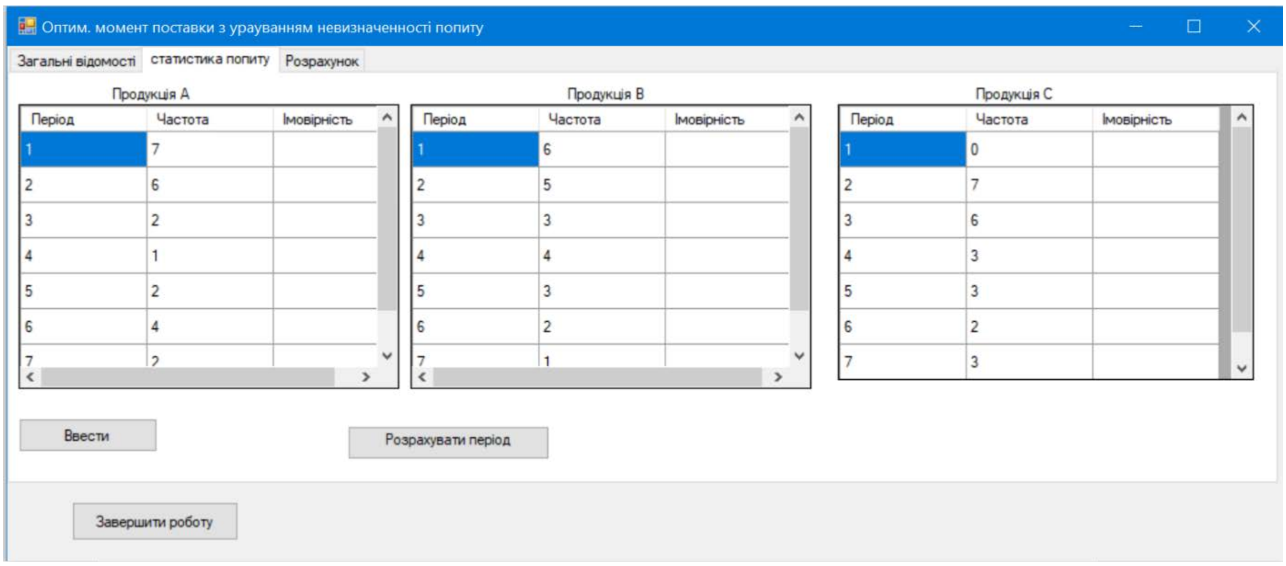

Figure 4. «Demand statistics» tab without data

The product table becomes visible only after entering the number of products and the calculation period.

Once general information is entered, the user proceeds to the «Demand statistics» tab to enter the appropriate data. The tab has two buttons and a table for each of the resources being ordered. The «Demand Statistics» tab is shown in Figure 4. Each table contains the number of rows corresponding to the entered calculation period and three columns (the «Frequency» column is filled by the user, and the «Probability» data is calculated after pressing the «Enter» button (Figure 4).

Now, after clicking the «Calculate period» button, the user is taken to the «Calculation results» tab (Figure 5), where there are two groups of calculations taking into account the uncertainty of demand (solving the given problem) and for comparison, data without taking into account the uncertainty of demand, as well as the calculated savings.

Developed software product determines optimal period of delivery of several types of resources, total costs of storage and ordering, acquired savings, all of which speeds up and simplifies the dispatcher's work [2].

Implementation does not require the existence of data files from which the necessary information is taken. All data is entered directly on the tabs of the software product.

As a result, the software produces optimal order periods, total costs for ordering and storing production resources with and without taking into account the uncertainty of demand and the accumulated savings.

Conclusions and further research prospects. The «Time» software product allows users to quickly and qualitatively determine the most optimal period of placing orders for production resources in conditions of uncertainty of demand. The need to quickly and qualitatively determine the supply terms in conditions of uncertainty of demand explains the relevance of this software development. The desire for uninterrupted production at enterprises often leads to accumulation of significant stock of certain types of material resources, which in turn creates a distorted picture of the true need for resource suppliers and often leads to an unreasonably high amount of stock in the production and

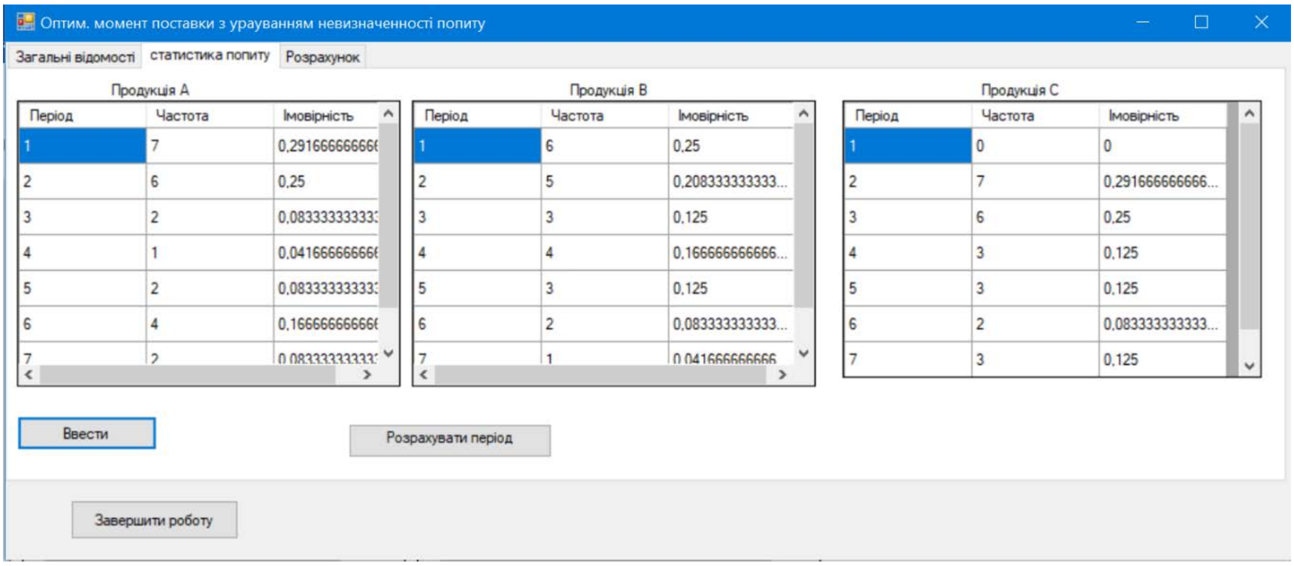

Figure 5. «Demand statistics» tab with probabilities calculated

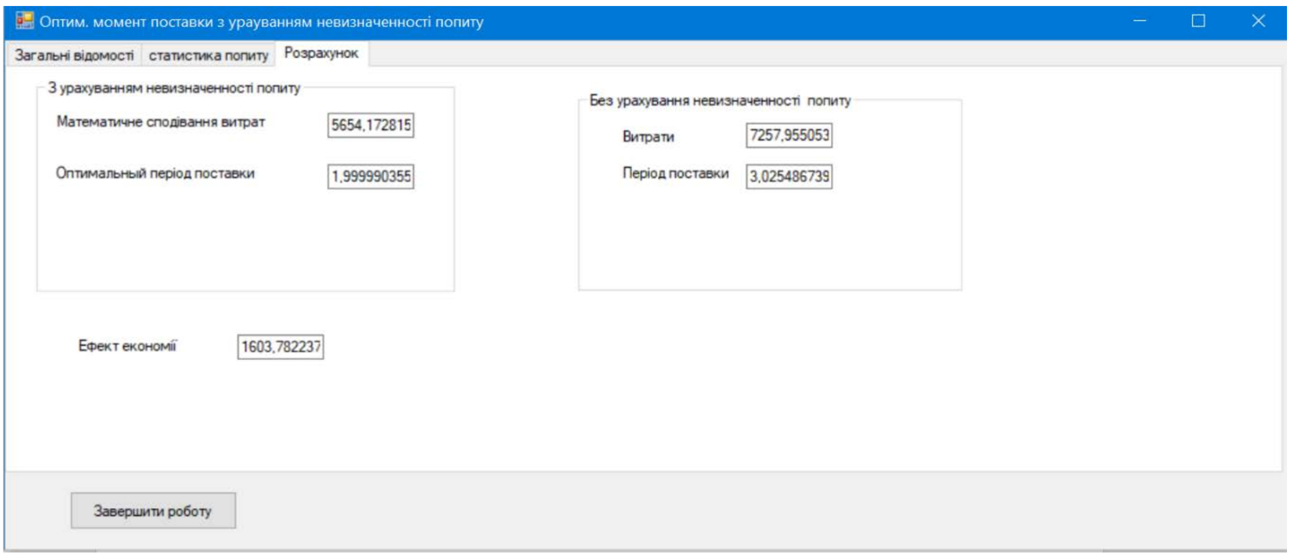

Figure 6. «Calculation results» tab

economic system and a shortage of consumers. Application of active systems theory to modeling the problem of resource management with unreliable demand and consumption data allows for the formation of management actions aimed at providing more reliable information about consumer demand and the production capabilities of competing companies. Use of the developed software will help to reduce the time for the formation of orders for production stock.

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