ІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ

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SIMULATION MODELING OF MARKET EQUILIBRIUM

There are many factors in the market that influence its behavior: tastes and preferences of consumers, interests of consumers and sellers, competition, market monopolization, legislation in the country, seasonal changes. Some are random in nature. It is impossible to take everything into account. The market of one product is considered from the point of view of the seller who sells it. At the same time, three cases are possible: a shortage of goods, a surplus of goods and an equilibrium state. A model was built, the purpose of which is to determine the optimal volume of purchases, which provides the seller with the greatest profit. Delivery delays and market inertia are also taken into account. An approach such as simulation modeling is used for market research. Application of the simulation model is of great importance for the analysis of economic phenomena. This provides advantages compared to performing experiments on a real system and using other methods. Analyzed Walras-Marshall models and web-like model. In the Walras-Marshall model, market value depends on supply and demand, that is, on the needs and funds of buyers, on the one hand, and on the labor and costs of producers, on the other. The dynamic model determines the change of market factors over time. All variables are functions of time. In the spider-like model, the volume of supply reacts to price changes with some delay. Then the analysis of the model is complicated. The amount of demand is determined by the prices of the current period, and the amount of supply is determined by the prices of the previous period, that is, the required amount of goods arrives late. Solving the task of finding optimal purchase volumes, a market model without a supply line is considered. The demand function is assumed to be constant. Delayed deliveries are taken into account. The price is determined by the market, that is, for a fixed volume of goods, the market price is set, it is this price that provides the greatest profit. By changing purchasing strategies and order volumes, you can choose the optimal strategy in such a way as to determine the optimal supply line. Market inertia means that the price is constant over a short period of time. Certain limits limit the trader from significantly increasing or decreasing the price.

Key words: *dynamical system, demand function, offer function, optimization, simulation modeling.*

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ІМІТАЦІЙНЕ МОДЕЛЮВАННЯ РИНКОВОЇ РІВНОВАГИ

На ринку є безліч чинників , які впливають на його поведінку: смаки та вподобання споживачів, інтереси споживачів та продавців, конкуренція, монополізація ринку, законодавство у країні, сезонні зміни. Деякі мають випадковий характер. Все врахувати неможливо. Розглянено ринок одного товару із погляду продавця, який його реалізує. При цьому можливі три випадки: дефіцит товару, надлишок товару та рівноважний стан. Побудована модель, ціль якої: визначення оптимального обсягу закупівель, що забезпечує продавцю найбільший прибуток. Також враховано запізнення постачання та інерційність ринку. Для дослідження ринку застосовано такий підхід, як імітаційне моделювання. Застосування імітаційної моделі має велике значення для аналізу економічних явищ. Це дає переваги у порівнянні з виконанням експериментів над реальною системою та використанням інших методів. Проаналізовані моделі Вальраса-Маршалла та павутиноподібна модель. У моделі Вальраса-Маршалла ринкова вартість залежить від попиту та пропозиції, тобто, від потреб і коштів покупців, з одного боку, та від праці і витрат виробників, з іншого. Динамічна модель визначає зміну ринкових чинників у часі. Усі змінні є функціями часу. У павутиноподібній моделі обсяг пропозиції реагує на зміни цін із деяким запізненням. Тоді аналіз моделі ускладнюється. Розмір попиту визначається цінами поточного періоду, а величина пропозиції визначається цінами попереднього періоду, тобто необхідний обсяг товару надходить із запізненням. Вирішуючи завдання пошуку оптимальних обсягів закупівель, розглядається ринкова модель без лінії пропозиції. Функція попиту вважається незмінною. Враховується запізнення поставок. Ціну визначає ринок, тобто за фіксованого обсягу товарів встановлюється ринкова ціна, саме вона забезпечує найбільший прибуток. Змінюючи стратегії закупівель та обсяги замовлень, можна підібрати оптимальну стратегію таким чином, щоб визначити оптимальну лінію пропозиції. Інерційність ринку означає, що у невеликому проміжку часу ціна постійна. Певні рамки обмежують торговця від значного підвищення чи зниження ціни.

Ключові слова: *динамічна система, функція попиту, функція пропозиції, оптимізація, імітаційне моделювання.*

Analysis of recent research and publications

The problem of building a market model, modeling and forecasting its development is one of the most important problems of the economy in connection with Ukraine's transition to market relations. Most of the market models were built according to the principle of establishing a competitive equilibrium, the existence of which was declared in the work of Walras [1]. Mathematical substantiation of the Walras hypothesis was carried out in the 1950s in the works of Arrow-Debre [2], McKenzie, Gale, Nikaido. Further work was carried out on the improvement of models and their generalization. These studies are considered quite fully in the monographs of Morishima, Nikaido, Lancaster and other modern authors. Most of these works analyzed the balance of aggregate supply and demand (Market equilibrium) [3, 4]. These market models established a balance between supply and demand, but could not be a market model, since, firstly, there was no competition between both producers and consumers in them, and secondly, the purposefulness of the actions of market participants was not reflected (producers and consumers), which is the basis of competition. The market model should reflect not only the balance between supply and demand, but also the purposefulness of each market participant, taking into account their overall relationship. A vector (multi-criteria) problem of mathematical programming [5] is such a mathematical model that, along with the balance sheet, can reflect the purposefulness of each market participant. To solve this problem, the methods of solving the vector problem, based on the normalization of criteria and the principle of guaranteed result, have been developed [6, 7].

Formulation of the goals of the article

Study of the effect on the dynamics of the product price of random fluctuations in demand, the position of the demand line, the purchase price of the product, the strategy of ordering the product. Statistical assessment of the seller's profit at a fixed price of the product and the strategy of ordering the product. Determination of the optimal price and order strategy taking into account the delay. Practical implementation of a mathematical model that simulates the market of one product, taking into account random fluctuations and delays, which allows you to estimate the profit of the seller, as well as to find the price of the product and the volume of purchases that provide the seller with the greatest profit.

Presenting main material

1. *Description of the modeling algorithm.* A program was used that simulated processes in the market and displaying the results in the form of graphs. The parameters of the model can be changed: the presence or absence of delay and random fluctuations. Using such a model, you can test various purchasing strategies and get visual results, explore the influence of deterministic and random factors on the process of selling goods. Modeled quantities: the number of goods in stock, the volume of purchases, demand, supply, profit, the amount of resources. Variables used in the program: penalty function coefficient, delay, quantity of goods in stock, volume of purchases, supply value, demand value, sale price, purchase price, profit, order payment, storage payment, time (discrete),time interval, average maximum profit, average profit, optimal purchase search boundaries, constant purchase value, optimal purchase. Sale of goods at the current moment at the market price, in accordance with the demand equation:

$$Qd(t) = Qd_0(t) + \xi(t) \tag{1}$$

and formulas:

$$Qs(t) = \begin{cases} Q(t) + Qz(t-\tau), & Qd(t) \geq Q(t) + Qz(t-\tau) \\ Qd(t), & Qd(t) < Q(t) + Qz(t-\tau) \end{cases} \tag{2}$$

$$Q(t+1) = \begin{cases} 0, & Qd(t) \geq Q(t) + Qz(t-\tau) \\ Q(t) + Qz(t-\tau) - Qd(t), & Qd(t) < Q(t) + Qz(t-\tau) \end{cases} \tag{3}$$

$$Q(t) \geq Qd(t), \quad Qz(t) = 0 \tag{4}$$

When finding the value of demand, a random variable is added – $\xi(t)$. This value is generated by matlab. The program calculates the values of variables $Qs(t)$, $Qd(t)$, $J(t)$ – simulated values of demand, supply, profit and other simulated values.

$$J(t) = Qs(t) \cdot P(t) - Qz(t-\tau) \cdot P_1 - Q(t) \cdot P_2 + F(t) \tag{5}$$

Profit as a function of price, with a fixed supply volume, taking into account the penalty function with the coefficient alf. The result of the function is taken with a "minus" sign, and when searching for an extremum, the function is examined for a minimum. This is done so that when investigating a function, it is possible to use MATLAB computational functions that allow you to search only for minimum points. $Qz(t)$ – profit as a function of purchase volume. Determining the market price at each step, we sell goods, estimate the profit, thus determining what profit we will receive in the future, depending on the volume of purchases at the moment. We establish this dependence in order to search for the optimal purchase volume. Due to the action of random factors, the actual profit value will differ from the value estimated by this function. Due to fluctuations in demand, unsold goods may remain, or vice versa, there may not be enough of them, which means lost profits. The result of the function for the reason described above is taken with a negative sign. Modeling the processes of purchasing and selling goods with a delay is implemented as follows. We set the initial quantity of goods $Q_{sk}(1)$, time interval *t*. During the entire time interval, we first receive supplies of goods, then we sell goods, then we set the volume of the next purchase of goods. Delivery of goods: to the number of goods in the warehouse, we add the volume of goods ordered on τ earlier. While $t < \tau$ the seller does not receive any deliveries, he only sells the initial quantity of goods. The greater the delay in deliveries, the more goods must be installed at the initial moment in order to make a profit. However, it is assumed that the initial amount has little effect on further profit or average profit over a long time interval. When $t > \tau$, the seller receives shipments and the quantity of goods offered is the sum of the balance in the warehouse and the volume of shipments received. The sale of goods is carried out in accordance with the demand model with random fluctuations, the values are calculated by formulas (2), (3) . If the volume of demand is greater than the volume of supply, then all goods are sold out, the number of goods sold is equal to the volume of supply. If the volume of demand is less than the volume of supply, then the quantity of goods sold is equal to the difference between the supply and demand. Profit is calculated according to the formula (4). Then we set the volume of purchase of goods. The purchase price is considered constant. The volume of purchases can be set based on various considerations, thus realizing various strategies.

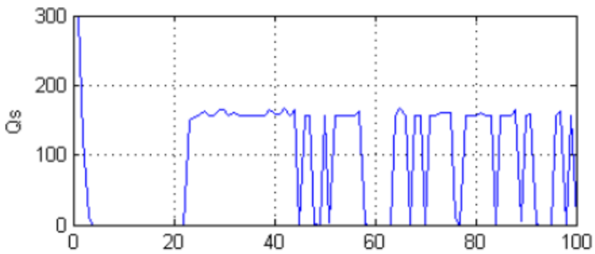
2 Simulation results. Search for the optimal supply strategy. The created model was applied to the problem of finding the optimal supply strategy. For the study and analysis of the market model, the line of demand for oranges was taken.

$Q_d(t) = 360 - 3 \cdot P(t) + \xi(t)$. Various strategies for delivering goods to the market are considered. First, the supply strategy was considered, which determines the optimal value at each point in time. Finding this value is done as a search for the extremum of the function $Qz(t)$, which estimates the future profit. Modeling this strategy showed the following results: Model parameters: $Q_d(t) = 360 - 3 \cdot P(t)$, $Q_{sk}(1) = 300$ – initial quantity of goods; $\tau = 20$ – lag; $alf = 2$ – penalty function coefficient; T=100 – time interval.

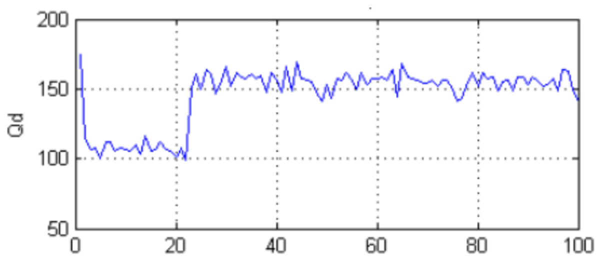
A large delay $\tau = 20$ led to a shortage of goods in the initial period. Then the ordered goods arrived, but there was no overstocking. On the purchase schedule, you can see that the amount of purchases has remained the same, but purchases have become more rare, more than zero purchases. The shortage of goods in the initial period caused the price to rise rapidly and remain at that value until supplies were delivered. At a high price, demand decreased, and increased only after its decrease. Then the price began to fluctuate around a constant value. Purchases either increased or decreased. The number of unsold goods was insignificant and arose only due to random fluctuations in demand. After the deficit was eliminated, supply and demand were about the same, except for zero intervals. Due to condition (4), some deliveries were zero, but lagged behind the appearance of unsold balances. This led to the fact that the number of goods offered and the profit were equal to 0.

Thus, the initial quantity of goods was insufficient. But then the strategy of determining purchases led to finding optimal purchases that provide more profit.

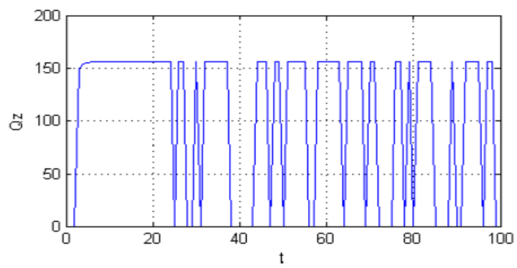
Another purchasing strategy implemented with the model is constant supply. Let us determine the optimal constant supply empirically. Before determining it, you need to evaluate the upper and lower bounds of the search. Consider the following situations: 1) Market overstocking: $Qz(t) = 300$, but subject to condition (4).



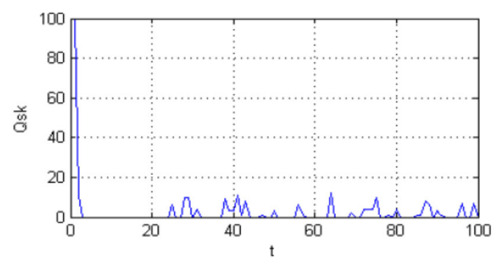
Rice 1. Schedule for changing the offer



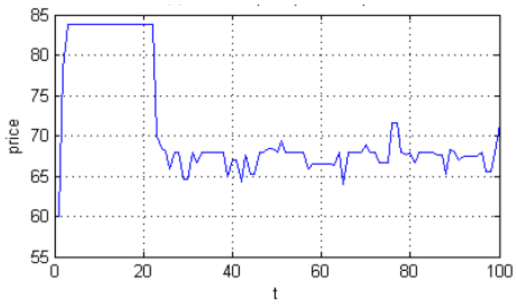
Rice 2. Graph of change in demand



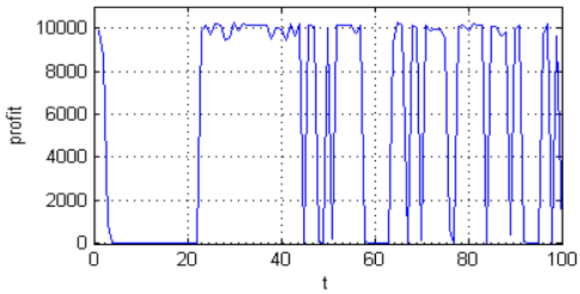
Rice 3. Schedule of purchases



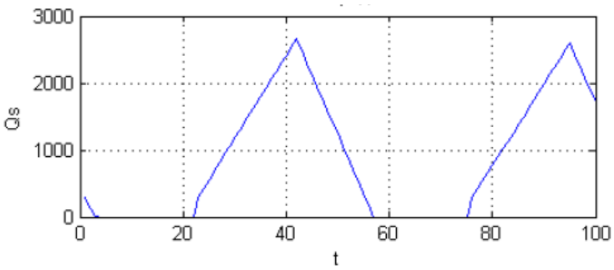
Rice 4. Schedule of unsold balances of goods



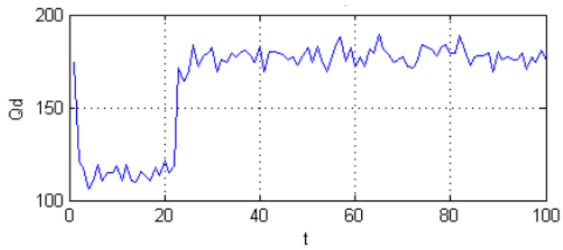
Rice. 5. Graph of price changes



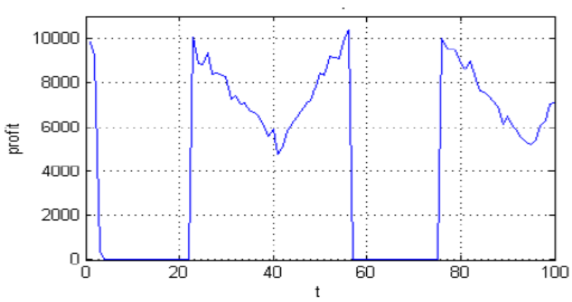
Rice 6. Graph of profit change



Rice 7. Schedule of changes in supply when overstocked



Rice 8. Graph of change in demand during overstocking

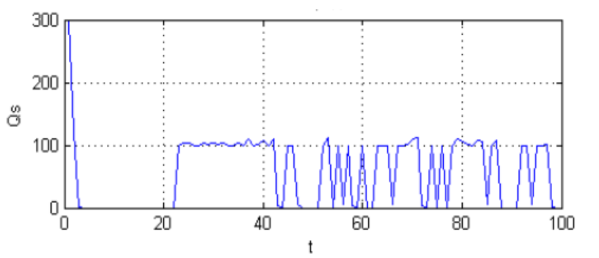


Rice 9. Graph of profit when overstocked

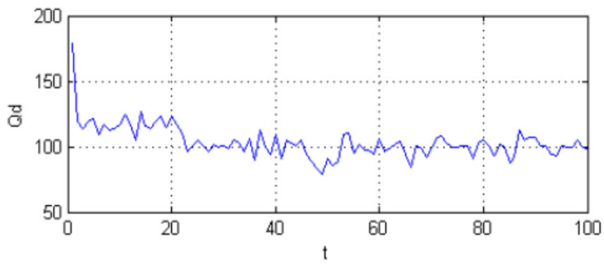
The price changes similarly to the previous situation, so the chart is not shown. Purchases: either $Q_{sk}(t) = 300$ or $Q_{sk}(t) = 0$. In this case, the supply of goods significantly exceeds the demand, which leads to the accumulation of unnecessary volumes of goods. Obviously, this leads to unnecessary storage costs. With a surplus of goods, profit is reduced by 2 times.

2) Shortage of goods on the market: $Q_{sk}(t) = 100$.

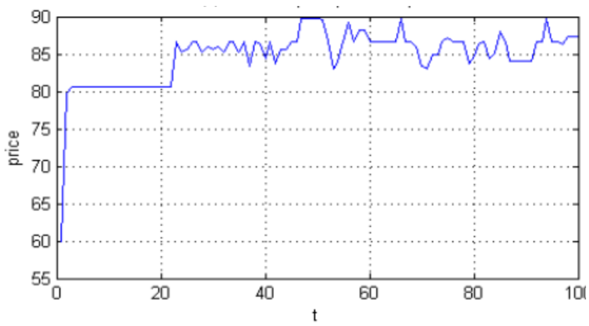
In conditions of scarcity, the price rises, because of this, demand falls. Profit falls from the initial point in time and then keeps at a lower level. Thus, with a constant value of supply equal to 300, there was an excess of goods, with a constant value of supply equal to 100, there was a shortage of goods. Next, we determine the empirically optimal amount of supplies. It turned out to be 175. By setting the supply equal to this value, taking into account condition (4), we obtain the following results.



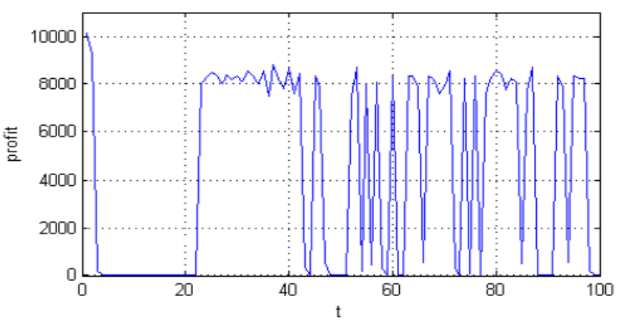
Rice 10. Supply schedule with a shortage of goods



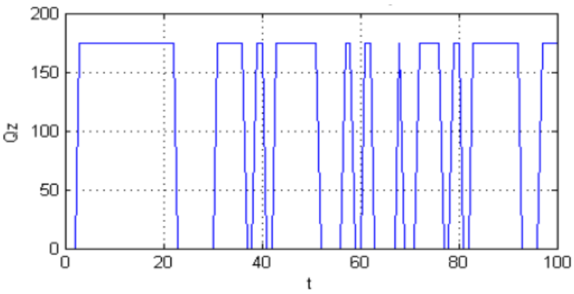
Rice 11. Demand schedule with a shortage of goods



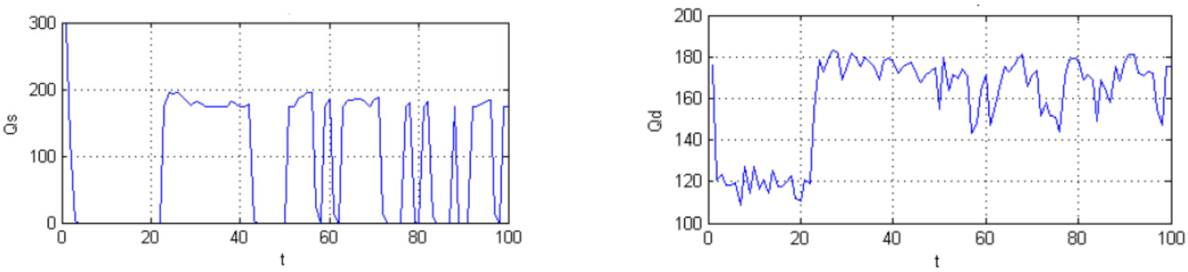
Rice 12. Price chart with a shortage of goods



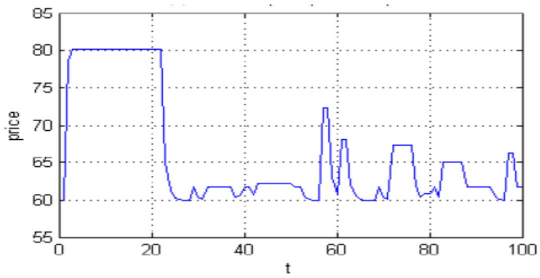
Rice 13. Graph of profit with a shortage of goods



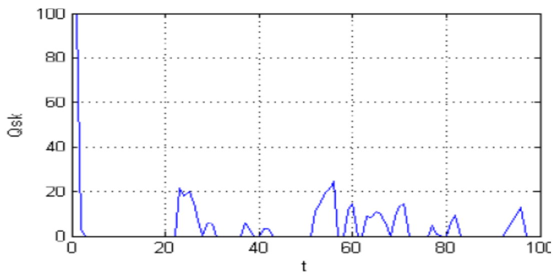
Rice 14. Graph of purchases at a constant value of purchases



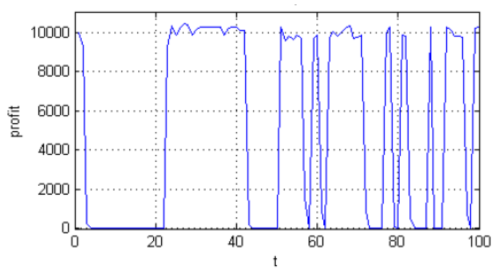
Rice. 15. Graphs of supply and demand for a constant supply of 175



Rice 16. Price chart at a constant supply value of 175



Rice 17. Graph of product balances at a constant value of purchases equal to 175



Rice 18. Graph of profit at a constant value of purchases equal to 175

Conclusions

The optimal strategy involves not only finding the supply that leads to the greatest profit, but also the fulfillment of other important conditions. The quantity of offered goods, which is the sum of the balance of goods and the supply of goods, depends on the prices of the previous period and should correspond as much as possible to the demand in currently. The price dynamics is not profitable for the trader, because this reduces his profit, so the price of the goods must be stable.

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