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MODELS OF INVENTORY MANAGEMENT FOR INDUSTRIAL ENTERPRISES UNDER ENERGY RESOURCES PRICE INCREASE

The paper provides an inventory management model for industrial enterprises under conditions of expected increase of energy prices. Different approaches to the formation of reserves will allow industrial enterprises to be aware of the risks of energy prices increase and, depending on the choice of a particular strategy of stockpiling of raw materials or components, to calculate the size and timing of deliveries while minimizing costs for shipping and storing.

Keywords: industrial enterprises, inventory management, energy prices, price increase, risk of increased cost of raw materials.

Problem statement. The specificity of most sectors of Ukraine's economy today is characterized by the term "high energy consumption". The problem of excessive energy consumption, which is twice or even three times higher than the energy consumption for similar production in the EU and the US, hinders economic development, contributes to pollution of environment, leads to uncompetitive prices for products. It is impossible to solve this problem without a simultaneously attracting of foreign investment. In the near future, due to the complicated external political and economic situation of the country, there are also no prospects of its solution.

Under these circumstances companies that receive raw materials or components with a high degree of inherent energy cost should create reserves in the period of low energy prices and use them during the price inrcrease. For example, manufacturers of concrete and concrete products have to look for ways to reduce production costs by increasing materials inventory during the period of low energy prices. The main component of concrete is cement and its production is energy-consuming; in the cement prime cost the cost of energy can reach 30%. After the rise in energy prices come higher prices for cement, so in this case companies that produce concrete should increase supplies of cement in warehouses at the time when energy prices have not risen yet.

Analysis of recent researches and publications. Formation of stocks of raw materials for production is the task of logistics. The mathematical model of inventory management, according to which the cost of shipping and storage of raw materials or materials in stock are minimized, was first proposed by F. Harris [1], and it became known owing to the work of R. H. Wilson [2] in 1934. But Wilson's model has a list of restrictions that impede its usage in practice, such as full use of pre-order before the next delivery or regular delivery time for the order. The complexity of its use is still discussed even in the sphere of physics and mathematics [3].

R. Petersen and E.A. Siver [4] combined determination of parameters of inventory

management models with decision making concerning the type of demand, which is divided into deterministic and stochastic one. Models of costs minimizing in rational relation between production and commodity stocks are grounded in works of M.R. Linder and H.E. Fearon [5]. Cost optimization in logistics supply chains is analyzed in the works of D. J. Bowersox, D.J. Closs, and M. B. Cooper [6; 7].

Ukrainian scientists N.I. Chukhrai, V.I. Perebyinis and Y.V. Krykavskyi [8-10] grounded and developed the question concerning the formation of supply chain and logistics inventory management in an enterprise.

Unsolved questions, which are part of the general problem. In today's scientific researches the questions concerning formation of inventories at enterprises in conditions of sharp fluctuations in energy prices still remain unresolved. This question is relevant for productions, where the price of raw materials contains a large proportion of energy costs.

The object of the article is to develop the models of inventory management for industrial enterprises under expected energy resources price increase.

Basic material. The scope of industrial enterprises that buy raw materials or components with high energy costs is characterized by a wide range of risks. One of the global economic risks is a rise in energy prices ("energy shock price"). Let's consider approaches to inventory management of such enterprises on the example of concrete manufacturers and concrete products.The increase in cement stocks, purchased in the period preceding the increase in energy prices, will allow the concrete manufacturer to solve two important tasks on optimization of commercial activity:

1) to reduce production costs for future periods so far as cement was purchased for less prices than current ones;

2) to increase the income of the company by increasing the market share as the price of concrete in the enterprise may be lower than the competitor's one due to cheaper components.

Until quite recently, the main supplier of gas to Ukraine was the Russian Federation. The gas of own production was used in Ukraine for needs of the population. The cost of gas, which the Russian Federation exports, is tied to oil quotations. The change in the price of gas on a certain formula happens in 4-8 months after the change in oil prices. The European Union demands from Russia to move from gas pricing in relation to oil prices to spot contracts in European gas hubs. This method of price formation will result in price depending on the share price in the spot contract.

For the time, Ukraine passed through the winter 2015-2016 without Russian gas, but the gas that was bought in Europe is partly Russian. That is, after the increase or decrease in oil prices the increase or decrease in gas prices can be expected in the long term of 4-6 months in a row.

The task, which is associated with the use of economic and mathematical modeling for assessment and risk management for manufacturers of concrete is the inventory management based energy prices.

The manufacturer of concrete in the subsystem of marketing information system monitoring collects information on current prices for gas and oil and the prospects of their changes. There are three cases:

- an increase in world oil prices is noted, so a rise in price of gas is forecasted;
- a decrease in world oil prices is noted, so a reduce of cost of gas is forecasted;
- no change in world oil prices is noted, so no change in the price of gas is forecasted.

In the first case it is recommended to make strategic reserves of cement and inert materials for the manufacture of concrete, as this will reduce the risks of market share loss due to rapid

rise in energy. In other cases it is recommended neither increase nor reduce strategic stocks of concrete components. Under the predicted decline in energy prices it would be possible to reduce the stock of components expecting the price reduction, but this can lead to another risk that is the failure to fulfill orders due to lack of necessary inert materials in stock.

To create a stock of components for concrete production and concrete products the company can follow three strategies of accumulation in order to save the cost of acquisition and storage of raw materials:

– simultaneous delivery of the total volume of raw materials, such as cement, to save the cost of acquisition;

– even delivery of raw materials with same batches and incomplete use;

– delivery of raw materials in smaller and then larger quantities to save resources for its storage.

According to each of these strategies we get graphic and mathematical models of inventory management which can be applied to industrial enterprises of any field of activity. In the first strategy the amount of raw materials that will satisfy forecasted demand for the period prior to the increase of the price of gas is simultaneously supplied to the enterprise – T_1 and will satisfy the demand during the gas price increase – T_2. We will assume that the demand for raw materials during the period T_1 is lower than T_2 because during the second period the company will have competitive cost advantages (Fig. 1).

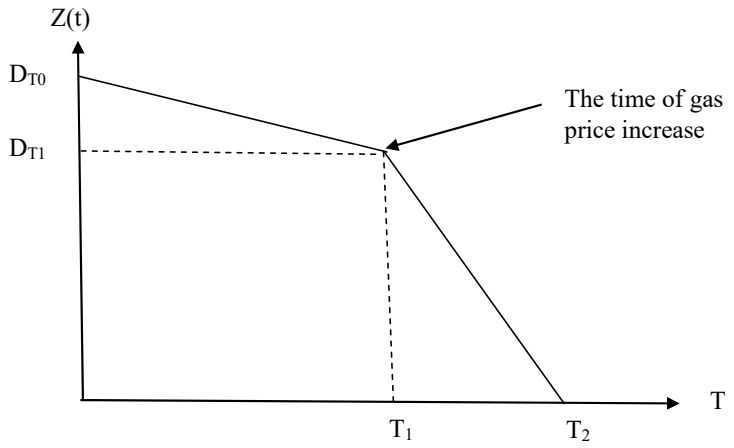

Figure 1 – **Simultaneous delivery of total volume of raw materials**

On the Fig. 1: *Z(t)* is the volume of raw materials available in the company; *T* is time; $D(T_0)$ is the amount of raw materials that will meet the demand before gas the price increase and after; $D(T_1)$ is the demand for raw materials after the gas price increase.

Suppose that the number of raw materials in the amount of $D(T_0)$ can be delivered by *k* supplies. The cost for each *k* supply is *Q* currency units. Costs for storage of each unit of raw material are *g* currency units.

In this case the costs for transporting and storing of raw materials will be:

$$Qk + g\,(D\,(T_0) + D\,(T_1))\,/\,2 + g\,D\,(T_1)\,/\,2 = Qk + g\,(D\,(T_0) + 2D\,(T_1))\,/\,2. \quad (1)$$

Let's analyze the inventory management model in the case of an even supply of raw materials with underutilization.

In the second case, the raw materials are delivered in even identical batches (Fig. 2). Here the period T_1 is divided into n equal intervals the length of which is $\tau = T_1 / n$. The size of the supply in times $t_1, t_2, ..., t_{n-1}$ is the same and equals d. Demand for raw materials during the period before price increase will be considered as the same for each period and will be d_1.

Let the cost of one batch of raw materials in volume d be Q currency units. The total demand for raw materials before the time of rise in price is DT_1, so $DT_1 = nd_1$. The total demand for raw materials before the time of rise in price (T_1) and after (T_2) is D ($D = DT_1 + DT_2$), so $D = nd$. The total demand for raw materials after the rise in price is DT_2.

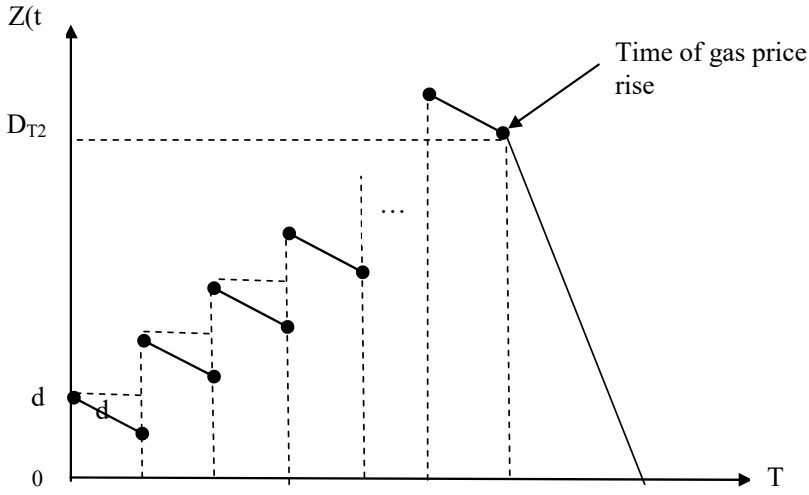

Figure 2 – **Even delivery of raw materials by identical batches**

Total costs for delivery of raw materials to the company and its storage in this case are:

$$Qn + g(\frac{d + (d - d_1)}{2} + \frac{2d - d_1 + 2d - 2d_1}{2} + \frac{3d - 2d_1 + 3d - 3d_1}{2} + \frac{nd - (n-1)d_1 + nd - nd_1}{2})\tau +$$

$$. + gD_{T_2} / 2 = Qn + g(d(1 + 2 + 3... + n) - \frac{d_1}{2}(1 + 3 + 5 + ... + (2n-1))\tau + gD_{T_2} / 2 = Qn +$$

$$+ g(d\frac{n(n+1)}{2} - \frac{d_1}{2}n^2)\tau + gD_{T_2} / 2 =$$

(given that $\tau = T_1 / n$, $D = nd$, and $DT_1 = nd_1$ we will get)

$$= Qn + g(D\frac{n+1}{2} - D_{T_1}\frac{n}{2})\frac{T_1}{n} + gD_{T_2} / 2. \qquad (2)$$

Formula (2) is a function of the cost depending on the number of intervals *F* (n). Then the minimum cost of purchasing and storage of raw materials can be defined as *min F* (n).

$$minF(n) = min(Qn + \frac{g}{2}(D(n+1) - D_{T_1} n)\frac{T_1}{n} + gD_{T_2} / 2). \quad (3)$$

Minimum of the function *F* (n) can be found using the derivative. Let us equate the derivative to zero

$$F'(n) = 0 \to \frac{2Qn^2 - gT_1 D}{2n^2} = 0 \to n = \sqrt{\frac{gT_1 D}{2Q}}. \quad (4)$$

Thus, with the number of periods

$$n = \sqrt{\frac{gT_1(D_{T_1} + D_{T_2})}{2Q}}, \quad (5)$$

function *F* (n), that is the cost of delivery and storage of raw materials, becomes minimum. From the formula (5) it can be seen that the optimal number of periods of raw materials supply is independent of the length of the period of raw materials consumption after the price increase that is T_2.

The optimal number of periods of raw materials supply to the warehouse of the company (5) can be considered as an improvement to Wilson's formula [2]. A similar problem is solved by Robert Wilson with the full use of raw materials imported for one period, without formation of stock reserves for subsequent periods.

Finding the length of the period τ, where the cost of delivery and storage of raw materials will be minimal and considering that $\tau = T_1 / n$, we get

$$\tau = \sqrt{\frac{2T_1 Q}{g(D_{T_1} + D_{T_2})}}. \quad (6)$$

Finding the volume of a delivery *d*, where the cost of purchasing and storage of raw materials will be minimal and considering that d = D / n, we get

$$d = \sqrt{\frac{2Q(D_{T_1} + D_{T_2})}{gT_1}}. \quad (7)$$

Thus, importing raw materials to the company in the amount of *n* even supplies,with the amount of each supply in *d* units, with the cost of each delivery of *Q* units, with the projected total demand for raw materials before its rise in D_{T1} and after in D_{T2} units, the use of raw materials in each of the periods in d_1 units:

– the volume of one supply that will provide a minimal cost of delivery and its preservation in the warehouse is given in the formula (7);

– the period of time among deliveries for which a minimum delivery and storage of raw materials cost is provided is given in the formula (6);

– the number of periods for which it is necessary to put the raw materials to the warehouse for providing the minimum cost of delivery and storage of raw materials is in the formula (5).

The minimum cost of transportation and storage of raw materials will be

$$F(n=\sqrt{\frac{gT_1(D_{T_1}+D_{T_2})}{2Q}})=Q\sqrt{\frac{gT_1(D_{T_1}+D_{T_2})}{2Q}}+\frac{g}{2}(D(\sqrt{\frac{gT_1(D_{T_1}+D_{T_2})}{2Q}}+1)-$$

$$-D_{T_1}\sqrt{\frac{gT_1(D_{T_1}+D_{T_2})}{2Q}})\frac{T_1}{\sqrt{\frac{gT_1(D_{T_1}+D_{T_2})}{2Q}}}+gD_{T_2}/2=Q\sqrt{\frac{gT_1(D_{T_1}+D_{T_2})}{2Q}}+$$

$$+\frac{g}{2}(D\ T_1+\frac{DT_1\sqrt{2Q}}{\sqrt{gT_1D}}-D_{T_1}T_1)+gD_{T_2}/2==\sqrt{\frac{gQT_1(D_{T_1}+D_{T_2})}{2}}+\frac{g}{2}(D\ T_1+$$

$$+\frac{\sqrt{2DT_1Q}}{\sqrt{g}}-D_{T_1}T_1)+gD_{T_2}/2=\sqrt{\frac{gQT_1(D_{T_1}+D_{T_2})}{2}}+\frac{g}{2}DT_1+\frac{\sqrt{2g(D_{T_1}+D_{T_2})T_1Q}}{2}-$$

$$-\frac{g}{2}D_{T_1}T_1+gD_{T_2}/2=\sqrt{2gQT_1(D_{T_1}+D_{T_2})}+\frac{g}{2}D_{T_2}(T_1+1).$$

Thus, the minimum costs for delivery and storage of raw materials will be

$$\text{Minimum costs}=\sqrt{2gQT_1(D_{T_1}+D_{T_2})}+\frac{g}{2}D_{T_2}(T_1+1). \tag{8}$$

In the third case, raw materials are firstly imported in smaller quantities, and further in bigger ones, leading to saving resources for their storage (Fig. 3).

Let us suppose that with irregular supply of raw materials for the first *k* periods during the time T_1 the same batches of raw materials in volume of *d* units are supplied, that are completely consumed during this period. Demand for raw materials during the period T_1 is D_{T1}. The optimum size of delivery (*d*), the number of periods of supplies (*k*) and the length of each period (τ) in this interval are determined by Wilson's formulas [2]:

$$k=\sqrt{\frac{gT_1D_{T_1}}{2Q}}, \tag{9}$$

$$\tau=\sqrt{\frac{2T_1Q}{gD_{T_1}}}, \tag{10}$$

$$d = \sqrt{\frac{2QD_{T_1}}{gT_1}} \cdot \tag{11}$$

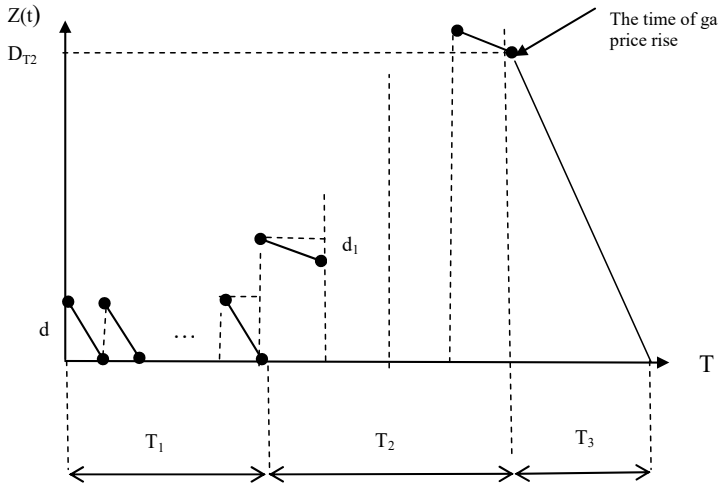

Figure 3 – **Uneven delivery of raw materials (firstly by smaller batches, then – bigger)**

The minimum cost of supply and storage of raw materials on the interval T_1 will be

$$\text{The minimum costs}_{T_1} = \sqrt{2\,gQT_1 D_{T_1}} \cdot \tag{12}$$

The reserves are forming during the period T_2 and they meet the projected demand of period T_2 before the rise in energy prices and demand of period T_3 after the rise in energy prices. *Let the required amount of projected demand for raw materials during periods* $T_2 + T_3$ *be* $D_{T2} + D_{T3}$. Let us suppose that it is possible to save it for l periods. During T_2 before the rise of raw materials price the consumption for each of l periods is equal to d_1. Then the number of periods l, the volume of supply for each period d, and the length of each period of supplies τ are found by formulas 13-15:

$$l = \sqrt{\frac{gT_2(D_{T_2} + D_{T_3})}{2Q}}, \tag{13}$$

$$\tau = \sqrt{\frac{2T_2Q}{g(D_{T_2} + D_{T3})}}, \tag{14}$$

$$d = \sqrt{\frac{2Q(D_{T_2} + D_{T3})}{gT_2}}, \tag{15}$$

The minimum costs for supply and storage of raw materials in the interval $T_2 + T_3$ will be:

$$\text{Minimum costs}_{T_2+T_3} = \sqrt{2gQT_2(D_{T_2} + D_{T_3})} + \frac{g}{2} D_{T_3}(T_2 + 1). \quad (16)$$

During the simultaneous delivery of the total volume of raw materials that will meet the demand for the period before and after the price increase, delivery and storage of raw materials according to the formula (1) are the largest. If the company-manufacturer of concrete selects this strategy, there is also a risk of a possible damage of material because of a prolonged period of storage. In our view, the first strategy, that is a simultaneous delivery of total volume of raw materials, should be used when competitors also begin to purchase raw materials in stock, and that increases its cost before the rise of energy cost.

Choosing the strategy of even delivery of raw materials in same batches with underusage, storage costs and delivery are much smaller than in the first strategy. The risk of material damage is also smaller than in the first case, it increases only during the increasing raw material accumulation period T_1.

Choosing the strategy of delivery raw materials first in smaller, then in larger quantities to save resources for their storage, the risk of raw materials damage because of a prolonged period of storage is reduced. The costs for delivery and storage of raw materials in this case are the lowest. The risk of prices raise for raw materials by suppliers in case of increased demand from competitors in this case is the highest.

Let's make a comparative table with the choice of a certain strategy for inventory management for concrete manufacturers under raw material price raise for companies producing concrete and concrete products (Table 1).

Table 1 – **Comparison of inventory management strategies for industrial enterprises under energy resources price increase**

Strategy	Costs for delivery and storage of raw material	The risk of raw materials damage because of a prolonged period of storage	The risk of prices raise for raw materials by suppliers in case of increased demand from competitors
The strategy of a simultaneous delivery of the total volume of raw materials	the highest	the highest	the lowest
The strategy of even delivery of raw materials by the same batches with their incomplete use	medium	medium	medium
The strategy of delivery of raw materials firstly by smaller and then larger batches	the lowest	the lowest	the highest

The manufacturer of concrete in case of predictable increase of energy prices chooses one of three strategies assessing the risks.

Conclusions. In terms of expected increase of energy prices industrial enterprises can make reserve stocks of raw materials for further production for lower prices than competitors. In this case, the company can supply raw materials according to three strategies: simultaneous

delivery, even delivery, and firstly by smaller and then larger batches. For each of these strategies it was got: an optimal size of delivery, number of delivery periods, and the length of each period. Different approaches to formation of reserves will allow industrial enterprises to take into account risks of increased cost of energy and with the choice of a certain strategy of raw stockpiling to calculate the size of supply and delivery terms to minimize the cost of delivery and storage.

Perspectives for further research. The practical approbation of theoretical results obtained on actual data is important in further studies. The main objective of approbation is to determine the situations according to which one of the three proposed in the study strategies is chosen: a simultaneous delivery, even delivery and delivery firstly by smaller then by larger batches.

In further studies it is also important to determine the other risks that arise with increasing energy prices. Among them can be defined such as reduced demand for products of the enterprise, inability to fulfill contractual obligations, increased competition in the market.

1. Harris F. Operations and Costs / F. Harris // Factory Management Series. – Chicago : A.W. Shaw Co, 1915. – P. 48-52.
2. Wilson R.H. A Scientific Routine for Stock Control / R.H. Wilson // Harvard Business Review. – 1934. – № 13. – P. 116-128.
3. Орлов А.И. Оптимальный размер управления запасами нельзя найти на основе квадратного корня / А.И. Орлов // Научный журнал КубГАУ. – 2015. – № 106 (02). – С. 1-31.
4. Petersen R. Decision systems for inventory management and production planninfg / R. Petersen, E.A. Siver. – N. Y. : Wiley, 1979.
5. Michael R. Linder. Supply management and inventory management. Logistics / R. Linder Michael, E. Fearon Harold. –Victoria Plus, 2002.
6. Donald J. Bowersox. Logistical management : the integrated supply chain process / Donald J. Bowersox, David J. Closs. – New York : McGraw-Hill Companies, 1996.
7. Donald J. Bowersox. Supply chain logistics management / Donald J. Bowersox, David J. Closs, M. Bixby Cooper. – New York, N.Y McGraw-Hill/Irwin, 2002.
8. Чухрай Н.І. Формування ланцюга поставок: питання теорії та практики : монографія / Н.І. Чухрай, О.Б. Гірна. – Львів : Інтелект-Захід, 2007. – 232 с.
9. Перебийніс В.І. Логістичне управління запасами на підприємствах : монографія / В.І. Перебийніс, Я.А. Дроботя. – Полтава : ПУЕТ, 2012. – 279 с.
10. Крикавський Є. Від планування логістики до логістичного планування / Є. Крикавський, І. Петецький, І. Рикованова // Вісник Хмельницького національного університету. – 2009. – № 5, Т. 3. – С. 160-165.

1. Harris, F. (1915). Operations and Costs. Factory Management Series. Chicago: A.W. Shaw Co, 48-52 [in English].
2. Wilson, R.H. (1934). A Scientific Routine for Stock Control. Harvard Business Review, *13*, 116-128. [in English].
3. Orlov, A.I. (2015). Optimalnyi razmer upravleniia zapasami nelzia naiti na osnove kvadratnoho kornia [The optimal size of inventory management can not be found based on square root]. *Nauchnyi zhurnal KubGAU – Scientific Journal of Kuban State Agrarian University*, *106 (02)*, 1-31 [in Russian].
4. Petersen, R., & Siver, E.A. (1979). *Decision systems for inventory management and production planninfg.* N.Y. : Wiley [in English].
5. Linder, M.R. & Fearon, H.E. (2002). *Supply management and inventory management. Logistics.* Victoria Plus [in English].
6. Bowersox, D.J. & Closs, D.J. (1996). *Logistical management: the integrated supply chain process*. New York: McGraw-Hill Companies [in English].

7. Bowersox, D.J., Closs, D.J., & Cooper, M.B. (2002). *Supply chain logistics management.* New York, N.Y McGraw-Hill / Irwin [in English].

8. Chukhrai, N.I., & Hirna, O.B. (2007). *Formuvannia lantsiuha postavok: pytannia teorii ta praktyky [Formation of supply chain: theory and practice questions*. Lviv: Intellect-Zakhid [in Ukrainian].

9. Perebyinis, V.I., & Drobotia, J.A. (2012). *Lohistychne upravlinnia zapasamy na pidpryiemstvak [Logistics inventory management in enterprises]*. Poltava: PUET [in Ukrainian].

10. Krykavskyi, Ie., Petetskyi, I. & Rykovanova, I. (2009). Vid planuvannia lohistyky do lohistychnoho planuvannia [From planning the logistics to logistics planning]. *Visnyk Khmelnytskoho natsionalnoho universytetu – Bulletin of Khmelnytskyi National University*, *5(3)*, 160-165 [in Ukrainian].

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Моделі управління запасами промислових підприємств в умовах підвищення цін на енергоносії

У статті запропоновано моделі управління запасами промислових підприємств в умовах очікуваного підвищення цін на енергоносії. Різні підходи до формування запасів дозволять промисловим підприємствам враховувати ризики щодо здорожчання енергоносіїв та за вибором певної стратегії накопичення запасів сировини або складових розраховувати розміри та терміни поставок за умовою мінімізації витрат на доставку та зберігання.

Ключові слова: промислові підприємства, управління запасами, ціни на енергоносії, підвищення ціни, ризик здорожчання сировини.

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Модели управления запасами промышленных предприятий в условиях повышения цен на энергоносители

В статье предложены модели управления запасами для промышленных предприятий в условиях ожидаемого повышения цен на энергоносители. Различные подходы к формированию запасов позволят промышленным предприятиям учитывать риски подорожания энергоносителей и в зависимости от выбора определенной стратегии накопления запасов сырья или комплектующих рассчитывать размеры и сроки поставок при условии минимизации затрат на доставку и хранение.

Ключевые слова: промышленные предприятия, управление запасами, цены на энергоносители, повышение цены, риск удорожания сырья.

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