INVENTORY PLANNING AND CONTROL OF ELECTRODES FOR ELECTRIC ARC FURNACE

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Abstract
This paper presents the possibilities of using the systems for inventory management in metallurgy. It contains the characteristics, definition, classification and functions of these systems. The article is divided into four main parts - introduction, methodological background, case study and conclusion. The case study chapter describes the designed and applied algorithm used to simulate the process and evaluation of the economic efficiency of the best-known ordering systems and their use for ordering and replenishment of electrodes in electric arc furnace. The examined systems include the fixed order-quantity method and the fixed order-period method, whose main advantages and disadvantages of use are summarized in the conclusion.

Keywords: systems for inventory management, Fixed order-quantity method, Fixed order-period method

1. INTRODUCTION
The task of inventory management in an industrial company is to keep the inventory at such a level that enables high-quality performance of its functions, which include especially levelling of the geographical, time and quantitative discrepancies between the processes of suppliers and customers and also absorbing or completely eliminating random fluctuations during the follow-up processes, so as to maintain the continuity of the material flows in the supply chain. The basic approach is based on the optimization using mathematical and statistical methods, where the main criterion is the minimization of the total cost of purchasing and maintaining inventories, while respecting the demand of full coverage of the anticipated needs, which may show some degree of uncertainty. The systems of inventory management are defined by Horáková [1] as mechanisms trying to find optimal relationship between how the inventory meets its functions, and how high the costs a company spends on its acquisition and storage are. The selection of the right system of inventory management is a strategic decision that will fundamentally affect the operation of the whole industrial company. The characteristics that affect the choice of the inventory management system, according to Štůsek [2], include: the purpose of the inventory in a concrete plant, the character of needs / demand, the economic conditions of company, the quality of information sources and the system of material flows within the supply chain. The objective of this article is to present the potential of a practical application of inventory management systems in a metallurgical enterprise. Two systems (mathematical methods) that are most commonly applied in practice have been selected to serve this purpose: the fixed order-quantity method and the fixed order-period method. The methods are described, applied and compared in this article using a case study of inventory of carbon electrodes for electric arc furnace.

2. METHODOLOGICAL BASIS
There are many classifications that can be used to categorize the systems of inventory management. For the purpose of this article, it is most suitable to use the classification according to the parameters in the ordering system, which include: stability / fluctuation of order quantity and stability / fluctuation of the time interval between the individual orders. According to this classification, which is defined for example in [3], the systems can be divided into four basic categories, as shown in Figure 1. The first category does not consider
the stochastic nature of real processes and can be applied only when you adopt a number of simplifying assumptions. The main representative of this category is the EOQ model, which is based on Harrison-Wilson formula [4] symbolized by the equation (1).

$$Q_{opt} = \sqrt{\frac{2 \cdot P \cdot n_o}{n_u \cdot n}} = \sqrt{\frac{2 \cdot P \cdot n_o}{\pi \cdot h}}$$

(1)

Where:

- $Q_{opt}$ – economic order quantity
- $P$ – annual demand quantity of the product
- $n_o$ – fixed costs per order
- $\pi$ – share of annual holding costs per unit in the inventory unit value
- $h$ – inventory unit value
- $n_u = \pi \cdot h$ – annual holding costs per unit

The simplifying assumptions for the utilization of this model include [5]: continuous, constant and known demand; constant and known lead time (the time from the moment the producer places an order to the moment the delivery is received); complete satisfaction of demand – thanks to the previously mentioned prerequisites, it is possible to determine, without any problems, the reorder point and that way, the possible depletion of stock will be eliminated; stable purchase prices, regardless of order quantity or lead time; stable transportation costs regardless of order quantity or lead time; nonexistent inventory on the way, i.e. inventory not available until it reaches the point of destination; inventory consisting of a single product only or there are no links among the products; unlimited planning horizon; unlimited availability of capital.

While EOQ model relies on continuous, constant and known volume of demand and constant and known lead time, the other inventory control systems already take into consideration the random character of the mentioned parameters.

### 2.1 Fixed order-quantity system

The fixed order-quantity system is based on ordering fixed quantity of products. As soon as the quantity is specified it will be ordered in each order cycle. Different development of demand for a given item usually causes the individual orders to be issued in different time (the order cycle is different). That is why it is necessary to determine certain minimum amount of inventory which will signal that the next order needs to be issued, when this system is used. At the moment this point is reached, it will be necessary to order the
fixed order quantity. The fixed order-quantity system works with the following parameters used for inventory control: Fixed order quantity - $Q$, Reorder point – $B$. The reorder point value will depend on lead time $R$ and the expected daily demand $D$ [6].

EOQ model and Harris-Wilson formula (1) are used to determine the fixed order quantity, i.e. $Q = Q_{opt}$. The formula for setting the reorder point has the following form [4]:

$$B = D \cdot \bar{R} + PZ$$  \hspace{1cm} (2)

Where:
- $\bar{R}$ – average length of lead time
- $D$ – average daily demand quantity of the product
- $PZ$ – safety stock

The term $D \cdot \bar{R}$ expresses an average amount of demand during the lead time. The following procedures can be used in order to determine the safety stock: intuitive – in real life, very simple ways of setting the safety stock amount are often used, for ex. half of order quantity; statistic; simulation.

The statistic procedure will be used in the following part of this work so as to formulate the safety stock. Scholarly literature recommends using quite a large number of formulas to calculate the safety stock based on statistic procedures. The following formula can serve as an example [7], [8]:

$$PZ = k \cdot \sigma_{DR}$$  \hspace{1cm} (3)

Where:
- $\sigma_{DR}$ – standard deviation of the demand during the lead time
- $k$ – service factor

Standard deviation of the demand during the lead time $\sigma_{DR}$ can be defined using formula [9], [10]:

$$\sigma_{DR} = \sqrt{\bar{R} \cdot \sigma_D^2 + \bar{D}^2 \cdot \sigma_R^2}$$  \hspace{1cm} (4)

Where:
- $\bar{R}$ – average length of lead time
- $\sigma_D$ – standard deviation of the daily demand
- $\bar{D}$ – average daily demand
- $\sigma_R$ – standard deviation of the lead time

### 2.2 Fixed order-period system

The fixed order-period system results from the same assumptions as the fixed order-quantity system. Unlike the fixed order-quantity system, in case of which the time among the individual orders differs, the fixed order-period system is based on issuing the orders at regular points, i.e. in fixed order cycles. The order quantity is then specified as a variation between the maximum inventory level defined in advance and the actual inventory level in a warehouse at the moment the order is being issued. With regards to the development of demand, different quantity of products will be ordered in each order cycle. That is why the fixed order-period
system works with the following parameters of inventory management: Fixed order cycle \( C \), Maximum inventory level \( S \) [6].

The Economic Order Quantity (EOQ) model and Harris-Wilson formula (1) can, again, be used to determine the fixed order cycle. The first step is the calculation of the Economic Order Quantity \( Q_{opt} \). Subsequently, the optimal order cycle is derived from it. If the number of orders during a year is \( P / Q_{OPT} \), the fixed order cycle \( C \) for 365 days of a year will be set this way:

\[
C = C_{opt} = \frac{365}{P} \cdot \frac{Q_{opt}}{P} = \frac{365 \cdot Q_{opt}}{Q_{opt}} \tag{5}
\]

The maximum inventory level is calculated in such a way to meet the demand in the period which includes the existing optimal order cycle and the lead time \( (C_{opt} + \bar{R}) \). As the demand and lead time are random variables, the fixed order-period system must also make provision for creation of the safety stock. If it is defined according to formulas (3) and (4), the following formula can be used in order to calculate the maximum inventory level [4]:

\[
S = D \cdot (Q_{opt} + \bar{R} + k \cdot \sqrt{Q_{opt} + \bar{R} \cdot D + 2 \cdot D^2 + R^2}) \tag{6}
\]

3. CASE STUDY

An algorithm schematically shown in Figure 2 was created for potential application of the described inventory control systems for ordering and replenishment.

**Fig. 2 Methodology for comparative analysis of inventory control systems**

The input data used to establish the rules for the individual inventory management systems, whose entry into the analysis is shown in Figure 2 and marked by red arrows, were provided by a concrete electric arc furnace.
plant, but the data had been modified by the authors of the article due to their sensitive nature. These modifications were made so that there is no deterioration of the outputs or partial calculations. The input data include the values of the following variables.

Parameters of electrodes:
- \( d_e \) – diameter of electrode (mm).
- \( l_e \) – length of electrode (mm).
- \( \rho_e \) – density of electrode (g·cm\(^{-3}\)).
- \( c_e \) – price of electrodes (€·kg\(^{-1}\)).

Parameters of the monitored period:
- \( T_c \) – planning horizon (years).
- \( x_{ci} \) – planning interval (weeks).

The individual blocks of activities from the flowsheet (figure 2) have the following description:

1. **Determination of the volume and weight of one electrode** – The need for calculations of the parameters is given by the nature of the logistic process, where in certain places / situations electrodes are counted in pieces or, on the contrary, in weight units. The calculations used basic formulas with the assumption of cylindrical shape of electrodes.

2. **Determination of yearly/weekly demand for electrodes** – The calculation is based on the same problem as point one, when production provides information on spent tonnes, but the supplier accepts order in pieces.

3. **Calculation of average values and standard deviations of consumption and supply cycles** – These are sub-calculations of variables, which are subsequently included in the formulas used for calculation of the parameters that are used to set both systems. Their calculation will ideally use a spreadsheet because of potentially large scale of the analysed data.

4. **Calculation of safety stock** – It is given by formula (4). In this study, parameter \( k \) was chosen for the limit of 95% of security due to high losses during unplanned downtime of electric arc furnace.

5. **Calculation of costs per single order and unit storage costs** – The calculation can use different variables, which are associated with the costs and are subject to change when the ordering system of electrodes is changed. The variable used in this study were \( p_{km}, s_d, \pi \). Determination of these costs are often difficult in practice, therefore the authors recommended the use of cost management [11] or ABC method [12].

6. **Calculation of EOQ** – the calculation formula is (1).

7. **Calculation B – reorder point** – The calculation formula is (2) and the result is used to set-up the ordering system of electrodes following the logic of Fixed order-quantity system.

8. and 9. **Calculation C – fixed order cycle and S – maximum inventory level** – The calculation formulas are (5) and (6) and the result is used to set-up the ordering system of electrodes following the logic of Fixed order-quantity system.

10. and 11. **Setting the order, delivery days and simulation of the system** – Once the calculations of the parameters have been completed, it is possible to determine the order or delivery days and to simulate the behaviour of the whole ordering system of electrodes for electric arc furnace. The study simulated a
yearlong operation of the electric arc furnace. Based on this simulation, it was possible to determine the average inventory level $\bar{Z}$ and the number of orders per year $P/Q$.

12. **Economic evaluation of the systems** – Thanks to the data obtained from the simulation of the systems, it is possible to evaluate both systems and to determine their cost demands. The total monitored costs of the system were determined using the equation (7).

$$N_{c1} = \pi \cdot h \cdot \bar{Z} + n_o \cdot \frac{P}{Q}$$

The courses of inventory replenishment and consumption for both ordering systems are shown in Figures 3 and 4, and they are presented by time graphs.

Economic evaluation of the systems and their comparison is illustrated in Table 1.

**Tab. 1 Comparison of the inventory control methods**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fixed order-quantity system</th>
<th>Fixed order-period system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average inventory level (pcs)</td>
<td>176</td>
<td>222</td>
</tr>
<tr>
<td>Annual inventory holding costs (€)</td>
<td>19 882</td>
<td>25 053</td>
</tr>
<tr>
<td>Annual ordering costs (€)</td>
<td>16 800</td>
<td>16 800</td>
</tr>
<tr>
<td>Total monitored costs (€)</td>
<td>36 682</td>
<td>41 853</td>
</tr>
</tbody>
</table>

When you look at the table of economic evaluation, it suggests that, for a given operation, the Fixed order-quantity system appears to be more cost effective, because it will save € 5,171 a year compared to the Fixed order-period system. However, the practical application of this model requires continuous inventory control, which is usually connected with higher labour input and additional costs (for example for implementation of automatic identification system or specialized software) [6]. That is why before the decision about real changes in the ordering system of electrodes is taken, the authors recommend performing a feasibility study that will include a broader look at the economy of the individual options under consideration. For similar reasons, it is necessary to analyse the related logistics activities [13]. For analysis can be use classical mathematical and statistical methods or simulation techniques [14].

**CONCLUSION**

The study has shown that these systems can be practically applied in the area of metallurgy, but only for inventories with relatively stable consumption. The stability analysis can use for example XYZ analysis.
Suitable inventories include especially those from category X, while the inventories in categories Y and Z lead to disproportionately high safety stock, which makes the whole system cost-ineffective. At the same time, the authors recommended using these systems for strategic raw materials that form the basis of the finished products, since the systems take into account some simplifications that eliminate the effects of seasonality or price.

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REFERENCES


