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THE LOGISTIC ASPECTS OF SUPPLY MANAGEMENT IN A METALLURGICAL ENTERPRISE

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Using logistic approach in an enterprise by organizing optimal material streams becomes an essential instrument of rationalization of storage and supply management processes. The application of proper, solutions based on logistic rules in supply administration becomes indispensable considering necessity of storage cost reduction. Optimal management in procurement sphere demands a considering a lot of parameters impacting on supply level. In this paper chosen aspects of supply management of materials and raw materials, which are subjects of supplying in a steelmaking plant, are described.

Key words: *steelmaking plant, inventory-keeping strategies, material supplies, forecasting, optimal supply volumes and frequencies*

Oblici upravljanja snabdijevanja robom u metalurškim poduzećima. Uporaba logističkog pristupa u poduzeću organiziranjem optimalnih materijalnih tokova postaje bitni instrument racionalizacije procesa upravljanja skaldištenjem i dopremom robe. Primjenjivanje odgovarajućih rješenja temeljenih na logističkim propisima o snabdijevanju robom je neophodno za upravu odjela za snabdijevanje robom ako se vodi računa o tome da se troškovi skladištenja moraju nužno smanjivati. Optimalno upravljanje u području nabave podrazumijeva mnoštvo parametara koji utječu na razinu snabdijevanja. U ovom radu se opisuju odabrani aspekti upravljanja nabavom materijala i sirovina kojima se opremaju čeličane.

Ključne riječi: *čeličana, strategija održavanja inventara, snabdijevanje materijalom, predviđanje, količina i učestalost optimalnog snabdijevanja*

MATERIAL INVENTORY MANAGEMENT IN A METALLURGICAL ENTERPRISE

Inventory management constitutes an important element of the activity of an enterprise owing to its effect on the enterprise's profitability. Moreover, flexibility and reliability in the sphere of supplies allows the reduction of stock in the supply of production. A low inventory level of supply goods influences production flexibility and, indirectly, the level of finished product inventory and the customer service level. In addition, the necessity of inventory reduction compels the purchasing functions to undertake activities aimed at the integration with the activity of the entire enterprise's system, since there is no possibility of assuring a relative continuity in meeting the needs thanks to the stored stock.

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A favourable effect on proper inventory management is exerted by the following factors:
- close cooperation with suppliers,
- an efficient information system enabling the inventories to be closely monitored,
- proper planning, and
- an integrated organizational structure facilitating comprehensive logistic management.

Among the decision making problems in the sphere of inventory management, the following are of particular importance:
- the selection of items, the stock of which should be kept,
- the determination of ordered batches and the time of placing an order,
- the determination of an inventory control system,
- proper forecasting of demand.

Also important is the determination of inventory values by paying special attention to the product range of

primary importance for production. Owing to this, stocks of the following characteristics can be distinguished:
- critical stock, which may not become depleted due to its particular importance for production,
- essential stock, of a limited inventory level,
- necessary stock (occasionally limited), for which depletion is permissible,
- desirable stock, for which depletion is allowable
- stock that can become useless due to a change of modernization of production.

MAIN INVENTORY-KEEPING STRATEGIES

In practice, accurate forecasting of demand is a very difficult issue, as there is a lot of factors affecting the accuracy of forecast. A consequence is usually the maintaining of a safety stock.

The control of stock in the conditions of uncertainty may be based on classical models (strategies) of inventory control. These models serve for determining the time and volume of orders placed with suppliers in order to make up the stock level [1, 2].

Time-oriented strategies are related to the cycle (rhythm) of ordering. In these models, it is not necessary to monitor the inventory level on an ongoing basis, but only at specified points of time resulting from the optimal cycle of purchasing. Owing to this, the system is easy to implementation. Besides, there is a possibility of combin-ing orders for different materials and organizing joint carriage trips, which will allow quantitative discounts and savings on transport costs to be achieved. Time-oriented strategies are the best solution in a situation, where the size of needs and the length of order delivery time are known. If either the size of needs or order delivery time (or both) changes, then the choice of supply strategy must take account of potential consequences of occurred shortage. Adopting a time-oriented strategy requires that variations in sale volumes be analyzed and forecasts be made. Usually, however, using a time-oriented strategy is associated with a necessity of maintaining a higher safety stock level. So, these strategies constitute the best solution in the case of purchasing cheap materials, and particularly small-sized items.

A second group of inventory-keeping strategies includes models that are quantitatively oriented in character, where the primary issue is setting the point of placing orders or the stock level that determine the submission of a requisition for the next supply. Important control norms are thus an optimal purchased batch and an optimal safety stock level. In the system of fixed ordering level, different stocks can be approached individually. The safety stock may also have a lower level, since the planning covers a shorter period.

Due to the fact that one of the control norms in the ordering level system is the alarm stock level, the determination of its magnitude is a primary issue. This magnitude depends on the average demand (arithmetic mean) and the standard deviation (variability) during the period or order performance. If the forecast is made, then the mean value forecast and the standard forecast error can be used for the determination of the safety stock level.

The business processes are random, or not entirely foreseeable processes. Any plans are more or less burdened with forecasting errors. Therefore, any values must be expressed in a certain numerical interval with a specified degree of confidence. Creating a large safety stock is connected with an additional cost of its maintaining; it is therefore necessary to estimate the probability of occurrence of needs greater than average ones (or the mean value forecast). In the case of the enterprise under study, the examination of the distribution of needs, and particularly the normal distribution, proved useful for establishing the probability of occurrence of needs greater than the mean values, enabling the determination of the intervals of confidence for some materials for the average magnitudes of expenditures, allowing the proper formation of safety stocks.

The basic data in inventory control in the case of materials, for which the distribution of demand cannot be described by the normal distribution, may be descriptive statistical data. In addition, the mean forecast value and the standard forecast error should be taken into account.

DETERMINATION OF THE RATIONAL VOLUMES AND FREQUENCY OF SUPPLIES

One of the basic logistic decisions is the determi-nation of the size of a supply batch. In practice, the use of the economical order volume concept may prove useful. This method relies on searching for an optimum between the inventory-keeping costs and the order placement costs.

The basic tool is the formula for the optimal order volume, having the following form [3]:

$$Q = \sqrt{\frac{2PK_z}{K_u}} \tag{1}$$

where:

Q - size of the ordered batch,
K_z - fixed order (purchase) cost of one batch of material, independent of its size
P - magnitude of annual consumption,
K_u - annual cost of maintain a single unit of a given material in stock, mostly defined as a fraction r (rate) of the purchase price, C_z, (or $K_u = rC_z$).

The determination of the optimal supply batch can be a basic standard for conducting purchasing policy and inven-

Table 1. **Levels of annual needs for selected material, actual number of orders and other data related to inventory control**
Tablica 1. **Razine godišnjih poterba odabranog materijala, stvarni broj narudžbi i drugi podaci temeljeni na kontroli inventara**

No	Material	n_i	P_i	$C_{z,i}$	$P_{z,i} \cdot C_{z,i}$	$q_i \cdot C_{z,i}$	$(q_i \cdot C_{z,i})/2$
1	Pig iron	127	18740	552	10344480	81452,6	40726,30
2	Silicomanganese Si-17 % Mn-69,3 %	49	4925	2284	11248700	229565,3	114782,65
3	Ferrosilicon Si-75,5 % Al 2,51 %	58	2211	2599	5746389	99075,7	49537,84
4	Ferromanganese Mn-78,50 %	98	2028	1915	3883620	39628,8	19814,39
5	Aluminium Pig Sows	79	555	5400	2997000	37936,7	18968,35
6	CaSi Powder in Flux-Cored Wire	19	239	6300	1505700	79247,4	39623,68
7	Burnt lime	247	32576	133	4332608	17540,9	8770,46
8	Slag frothing agent	252	3993	428	1709004	6781,8	3390,88
9	Dolomite lime	244	9640	149	1436360	5886,7	2943,36
10	Graphite electrodes ∅ 610	48	1368	8900	12175200	253650,0	126825,00
11	Electrodes 457 mm	20	209	8500	1776500	88825,0	44412,50
12	Dossolitr Mix	30	762	1474	1123188	37439,6	18719,80
13	Wedges DK 35 4P12	125	1604	1269	2035476	16283,8	8141,90
14	UM/Z Mix	73	1779	753	1339587	18350,5	9175,25
15	UM MIX	20	460	1080	496800	24840,0	12420,00
16	Wedges DMC40 3P10	55	491	1593	782163	14221,1	7110,57
17	Wedges DMC40 4P12	87	442	1591	703222	8083,0	4041,51
Total		1631					529404,45

tory control to be used in different stock level shaping models. However, despite a considerable value and purposefulness of using formulas for calculation of the optimal order volume, the determination of some cost components, such as the costs of creation and maintenance of inventories, was rather difficult in the studied enterprise, because of recording system solutions. Than all discourages the workers from determining optimal supply batches.

For rational inventory control, a practical method of estimating the costs of creation and maintenance of stock was applied, based on the rational frequency of ordering and proper purchased batches. A method based on the determined total annual number of orders was used, which enabled the determination of the volume of orders minimizing the overall costs of purchases and stock-keeping [4].

Purchasing the chosen i-th material should assure the minimization of the combined costs of creation and maintenance of stocks ($ŁKZ_i$); this can be expressed as below:

$$\text{(min) } ŁKZ = \frac{P_i}{Q_{opt,i}} K_z + \frac{Q_{opt,i}}{2} r \cdot C_{z,i} \tag{2}$$

where:

- $Q_{opt,i}$ - optimal size of the ordered batch of the i-th material,
- K_z - fixed order (purchase) cost of one batch of material, independent of its size
- P_i - magnitude of consumption of the i-th material in a year,
- $C_{z,i}$ - purchase price of a material unit,
- r - annual percentage rate of keeping the stock.

After substitution of formula (2) to formula (1) and transformations, we obtain:

$$\text{(min) } ŁKZ = \sqrt{2K_z \cdot r} \cdot \sqrt{P_i \cdot C_{z,i}} \tag{3}$$

Independently of the fixed value of the first term of the formula, the total cost of the stock of this material is proportional to the square root of the value of its consumption. This can be utilized for the rational inventory control, although not knowing the cost of stock creation (K_z) and maintenance (K_u). Taking into account the formulated condition of joint number of purchases for the considered group of materials, we can write:

$$\frac{\text{(min) } ŁKZ_i}{\text{(min) } \sum_i ŁKZ_i} = \frac{\sqrt{P_i \cdot C_{z,i}}}{\sum_i \sqrt{P_i \cdot C_{z,i}}} = \frac{n_{opt,i}}{\sum_i n_{opt,i}} \tag{4}$$

The share of total costs of stocks of particular material items in the overall costs for the whole group is described by the formula (5):

$$(\min) \sum_i ŁKZ_i = \sqrt{2K_z \cdot r} \cdot \sum_i \sqrt{P_i \cdot C_{z,i}} \qquad (5)$$

where:

$n_{opt,i}$ - rational frequency of ordering the i-th material.

The levels of annual needs for selected material items in the studied enterprise, their prices and other data are given in Table 1., where:

n_i - actual number of orders in a year,
P_i - annual needs (natural units - tons),
$C_{z,i}$ - unit price (zł),
P_i, $C_{z,i}$ - annual needs (zł),

q_i, $C_{z,i} = \frac{P_i \cdot C_{z,i}}{n_i}$ - ordered batch (zł),

$\frac{q_i \cdot C_{z,i}}{2}$ - average value of stock (zł).

With 1631 deliveries actually made in the year, the average value of stock for selected materials was Zl 529404.45.

The method of determining the rational number of purchases and the ordered batch of purchases of particular material items are given in Table 2., where:

$$n_{rac,i} = \sum_i n_i \frac{\sqrt{P_i \cdot C_{z,i}}}{\sum_i \sqrt{P_i \cdot C_{z,i}}} \qquad (6)$$

is rational number of purchases, and

$$q_{i,rac} \cdot C_{z,i} = \frac{P_i}{n_{rac,i}} \cdot C_{z,i} \qquad (7)$$

is rational ordered batch.

Changing the frequencies of purchasing particular material, in accordance with the indications of the method applied, may bring about a reduction of the average value of stock from Zl 529404.45 down to Zl 264572.21. Although the applied method does not guarantee optimal, but only rational solutions, these results can be regarded as satisfactory. Besides, it should be noted that the problem of estimating the costs of stock creation and maintenance has been omitted.

FORECASTING MATERIAL DEMAND

An important element in inventory control is forecasting material demand. A high accuracy of forecast allows the safety stock level to be reduced. Therefore, it is purposeful to examine the possibility of using selected forecasting

Table 2. **Calculation of the rational frequencies of ordering**
Tablica 2. **Izračun racionalne učestalosti pisanja narudžbi**

No	Material	$\sqrt{P_i\ C_{z,i}}$	$\frac{\sqrt{P_i\ C_{z,i}}}{\sum_i \sqrt{P_i\ C_{z,i}}}$	$n_{rac,i}$	$q_{rac,i} \cdot C_{z,i}$	$(q_{i,rac} \cdot C_{z,i})/2$
1	Pig iron	3216,28	0,109	179	57931,46	28965,73
2	Silicomanganese Si-17 % Mn-69,3 %	3353,91	0,114	186	60410,34	30205,17
3	Ferrosilicon Si-75,5 % Al 2,51 %	2397,16	0,082	133	43177,51	21588,76
4	Ferromanganese Mn-78,50 %	1970,69	0,067	109	35495,92	17747,96
5	Aluminium pig sows	1731,18	0,059	96	31181,97	15590,98
6	CaSi Powder in Flux-Cored Wire	1227,07	0,042	68	22101,89	11050,94
7	Burnt lime	2081,49	0,071	116	37491,67	18745,84
8	Slag frothing agent	1307,29	0,044	73	23546,79	11773,39
9	Dolomite lime	1198,48	0,041	67	21586,97	10793,49
10	Graphite electrodes ∅ 610	3489,30	0,119	194	62848,97	31424,49
11	Electrodes 457 mm	1332,85	0,045	74	24007,27	12003,63
12	Dossolitr Mix	1059,81	0,036	59	19089,14	9544,57
13	Wedges DK 35 4P12	1426,70	0,049	79	25697,63	12848,82
14	UM/Z Mix	1157,41	0,039	64	20847,10	10423,55
15	UM MIX	704,84	0,024	39	12695,53	6347,77
16	Wedges DMC40 3P10	884,40	0,030	49	15929,74	7964,87
17	Wedges DMC40 4P12	838,58	0,029	47	15104,50	7552,25
Total		29377,4	1,000	1631		264572,21

methods and the choice of a method optimal for the specific nature of the steelmaking plant's material demand.

When making forecasts of material demands in the steelmaking plant, it should be remembered that the higher demand forecast and forecast error, the larger safety stocks have to be.

The basic measures of forecast errors were: the mean forecast error, the standard forecast error and the coefficient of relative variation.

One of the applied forecasting models, based on exponential equalization, was the Brown model. For product-range items, whose consumption magnitude shows a high regularity and small, fairly slow changes in the trend. This model has a considerable application value. This is evidenced, among other things, by low values of mean forecast errors. For other materials, whose mean value changes significantly, the model required revision and searching for a model that would take account of the nonstationary character of material consumption.

One of the models that consider significant variations in the trend is the Holt model. The basic measures of forecasts obtained as a result of using this model indicate that there are no grounds for using forecasting models which take into account substantial variations in the trend.

In addition to significant trend variations, repeating cyclic fluctuations may occur in the time series. If these occur in yearly cycles, then they indicate a seasonality phenomenon. Failing to consider possible seasonality is a base for the occurrence of systematic errors, and results in excessive stock levels in some months and insufficient in the others. For the determination of seasonal fluctuations, the classical linear trend model proved helpful. For the consumption of steel scrap, estimated on data based from a two-year period, the classical linear trend model had the following form:

$$\hat{y}_t = 55816 + 914,27t \quad / \mathrm{s} \tag{8}$$

where:

$\hat{y}_t$ - dependent change (material demands in established range of time).

Calculated differences between the actual demand and the values estimated from the classical linear trend indicated the occurrence of a seasonality phenomenon in the time series analyzed.

Finding the existence of seasonal fluctuations was a basis for inferring that there was a need of determining the indices of seasonality. To determine the indices of seasonality of scrap consumption, a method was employed, which considered a so-called multiplicative seasonality, i.e. the one, in which the variation in oscillation amplitude magnitude occurs in approximately the same ratio [5 s. 71]. The determination of the required seasonality indices:

- the estimation of the initial average monthly increment in the development trend, b_0, or:

$$b_0 = \frac{\bar{y}_I - \bar{y}_{II}}{12} = 767,045 \tag{9}$$

where:

$\bar{y}_I$, $\bar{y}_{II}$ - average value for studied timeseries for I and II year;

- the estimation of initial raw seasonality indices, c_t, using the following formula:

$$c_t = \frac{y_t}{\bar{y}^{(i)} - \left(\frac{K+1}{2} - j\right) b_0} \tag{10}$$

where:

i - successive year (i = 1, 2),
j - monomial periods (for months j = 1, 2, ..., 12),
K - seasonality cycle (for monthly data K = 12).

Seasonality indices calculated from formula (10) are given in Table 3.

Table 3. **Net seasonality indices of scrap consumption**
Tablica 3. **Mreža indeksa sezonske potrošnje otpada**

c_1	c_2	c_3	c_4	c_5	c_6
0,775	0,903	1,063	1,196	1,350	1,230
c_7	c_8	c_9	c_{10}	c_{11}	c_{12}
1,157	1,252	1,039	0,632	0,737	0,704

The supply of scrap for the steelmaking plant under study - similarly as for many other domestic steelworks - showed a clear seasonal diversification. This diversification can reach values as high as up to 200% in 2 to 6 month cycles. The main causes of these fluctuations include:

- variable demand for steel finished and semi-finished products from the group of so-called long products; this demand is much higher in spring-summer months compared to winter months,
- considering the Polish climatic conditions and the fact that a considerable share in the "structure" of scrap suppliers belongs to private suppliers, who often do not have adequate technical (appropriate facilities for initial scrap preparation) and personnel (frequent use of seasonal workers) resources, it should be noted that the winter

period is characterized by limitations in the acquisition of scrap in general, and in the preparation of so-called charge scrap,
- marketing and trading connections of Polish scrap enterprises with some countries, e.g. from the European Union, and the trends in international scrap prices cause Polish steelmaking plants, equipped with electric arc furnaces, experience clear shortages in scrap supplies in a cyclic manner, too,
- over the period of recent years, the available mass of so-called in-house scrap (steel wastes from the steelworks' own steel production of processing departments) has substantially diminished; this trend aggravates, as advanced technologies and equipment providing a very high yield of finished product and a very low waste level are used.

Fluctuations in the consumption of metallized pellets (DRI) or pig iron are more complex, because they are subject to a considerable number of market conditions.

The use of pellets and pig iron will thus depend, above all, on:
- the mass of produced steel,
- the grades and required properties of steel, and
- scrap supply.

In the case of a scrap deficit, additions of pellets or pig iron grow to make up for the required iron mass.

The magnitude of fluctuations for DRI may also be influenced by the regularity of deliveries, as in an imported material.

In the case of most other auxiliary materials, their consumption is primarily dependent on the volume and product-range of production.

Finding the occurrence of seasonality was a basis for considering it purposeful to perform the analysis of the application of forecasting models that would take this phenomenon into account. One of such models was the Winter model.

SUMMARY

On the basis of the carried out studies it can be found that no material supply objective could be formulated in the way, that the supplies of all materials would take place in a system synchronized with the production process. For a definite majority of product-range items, the supply system must be implemented based on a proper inventory management strategy.

Inventory management must be closely connected with shaping the optimal safety stock level based on activities including:
- the use of a time-oriented strategy and a quantity-oriented strategy,
- the estimation of demand distribution in the event, where the demand can be described by the normal distribution,
- the use of descriptive statistical data, while considering the mean forecast value and the standard forecast error,
- the application of forecasting methods appropriate to the specific character of the steelmaking plant's needs, and
- the determination of the optimal volumes and frequencies of deliveries.

Making purchases based on the change of purchasing frequency and the rational supply batch allows a reduction of the average stock value. This method is a valuable tool in conducting purchasing policy, which permits the problem of estimating the costs of stock creation and maintenance to be omitted.

The occurrence of the phenomenon of seasonality in demand for materials indicates a need of accounting for cyclic fluctuations in the supply process to avoid excessive stock levels or possible shortages. The determination of the seasonality indices should perhaps be a basic norm in supply control.

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