CURRENT REQUIREMENTS OF METALLURGICAL PRODUCTION ON THE USE OF LOGISTIC TOOLS IN PROCESS OPTIMIZATION

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Abstract

The blast furnace process is a collection of a large number of physicochemical, thermal and mechanical processes. All processes do not run in isolation, but in parallel and in a certain interaction. The input raw material includes ores, basic additives and fuel. The output products of the blast furnace process are pig iron, slag and blast furnace gas. The current highly competitive environment forces iron manufacturers to monitor in detail the quality of all input raw material and internal processes. An important aspect is the quality of ore raw materials, which fundamentally affects the technological production process, but also the quality of the metal produced. Ore materials can be assessed using a wide range of criteria - chemical, physical, mechanical, technological. In each category we can find a large number of specific parameters. The evaluation can then be carried out for tens of different ore materials. This multi-criteria character offers the possibility to use logistic tools to support decision-making. The article deals with experimental use of logistic tools of multi-criteria decision making for evaluation of ore materials. The article analyzes the results of the research, which was executed in the conditions of the company TŘINECKÉ ŽELEZÁRNY, a. s. The research was focused on possibilities of determination of complex quality of ore raw materials in relation to blast furnace process.

Keywords: Logistics, evaluation, quality, ore

1. INTRODUCTION

In today´s dynamic environment the logistics fundamentally affects the competitiveness of companies. The logistic approach to optimization of production processes is primarily based on the elimination of all forms of waste. Essentially the main logistic objectives are closely tied with the principles of lean production [1].

Lean production cannot be understood as a closed clearly defined system. It has roots in the automotive industry and initially was focused only on improving the quality of production and thus minimizing substandard production. Demands for increasing efficiency of production and ever-increasing customer requirements led to the extension of the principles of lean production to other areas of activity of manufacturing companies. Currently, we are talking about a lean business. Its integral parts are lean production, lean logistics, lean administration, but also lean development and Innovation [2]. Today, we understand the principle of lean production as an overall philosophy, which aims to reduce the lead time and to eliminate all forms of waste. Nowadays, the principles of lean production affect all departments of the company, from purchasing raw materials to customer marketing service and product distribution. In the same way, the used methods and tools continued to develop. For example, in the optimization of logistics processes a wide range of different methods and tools can be applied. Some of the frequently used tools are the optimization of logistics routes, cooperation with suppliers, value flow management, standardization of logistic processes and use of mathematical tools for multicriteria decision making [3].

Within the logistics processes we often deal with the problem of finding the optimal solution based on a wide range of parameters. This is especially typical for production areas, which are based on parallel progress of categorically different processes. For these cases it is very suitable to use multicriteria decision-making tools. An interesting area with regard to above mentioned facts is the metallurgical production and related processes.

Iron production consists of number of complex processes such as chemical, physical, thermal or mechanical processes. These do not take place separately but in certain interdependencies. These sub-phenomena are the reduction of iron oxides and accompanying elements, fuel combustion, gas and batch counter current, dissociation processes and solid and liquid phase reactions [4].

The basic raw materials include the metal-bearing part (mainly ore), fuel and alkaline additives. Iron ore is one of the most widespread minerals. Sources of this raw material can be found in virtually all parts of the world. However, only certain selected sites contain a raw material suitable for use in a blast furnace. The primary parameter will always be the iron content. The metal content for rich magnetite and hematite ores ranges from 55 to 70 % [5]. The producers of rich raw iron ore are countries such as Australia, China, Russia, Brazil and India. Besides the iron content in the raw ore, there are also other important criteria. In general, we can divide the properties of raw ore into three basic categories - chemical, physical and technological. The chemical properties are related to the specific chemical composition of the ore. The content of harmful elements such as sulphur, phosphorus or zinc also plays a role here. One of the chemical properties is also alkalinity. The evaluated physical properties of raw ore are primarily moisture, lumpiness, porosity and magnetic properties. The technological properties or raw ore are related to criteria, that monitor the behavior of the raw ore in the blast furnace process [6]. Some of these criteria are strength characteristics, ore reduction degree and thermoplastic properties. The aim of the article is to analyse the possibilities of application of selected logistic tools based on multicriteria decision making in metallurgical processes. In the frame of long-term research, the possibility of application of multicriteria decision making tools for the comparison of raw ore material was verified. The purpose of the research was to create the methodology for evaluation of raw ore materials, which would allow to gain data for long-term management decisions. The article deals with analysis of the results of the research.

2. PROBLEM FORMULATION

The problematic of the evaluation of raw ore materials is complicated, because of the wide range of relevant criteria, which considers completely different characteristics. And moreover, these are measured in different units. Nowadays, the standardized evaluation system for the comparison of ores, which would be used worldwide by both customers and suppliers is completely absent. In the framework of realized research in the company TŘINECKÉ ŽELEZÁRNY, a. s. the overall quality of eleven selected raw ore materials was evaluated. The multicriteria decision making tools were used for the evaluation. The ores from major European suppliers, who are regular suppliers of raw input materials for metallurgical enterprises, were included into the evaluation. The purchasing department and company management must evaluate and compare the offered raw materials on regular basis, The fundamental issue lays in the character and range of parameters for evaluation of the quality of raw ore materials. A total of 25 criteria for the evaluation of ore raw materials were assessed. During the operative comparison of the specific offers, it is often necessary to deal with the issue of the inconsistent provided information. Therefore, it was decided, during the definition of the research objectives, that the set of the evaluated criteria should be limited only to the key criteria. The availability of data from all suppliers was also one of the reasons for this limitation. Due to these facts, the original set of 25 criteria was reduced to 16. Furthermore, the 7 criteria were selected from these 16 criteria via brainstorming. The criteria included into evaluation were from the following areas: chemical, physical and technological. The list of further used selected criteria is as follows:

1) Price of ore ($/ton)
2) Iron content (%)
3) Strength of ore (after drum test, according to ISO) (%)
4) Homogenity of lumpiness (V_x, %)
5) Phosphorus content (%)
6) Reducibility (%)
7) Humidity (%)

The selected criteria are among the most important. At the same time, these criteria are difficultly listed by the majority of input raw material suppliers. The values of all criteria for the evaluated raw ore materials are listed in **Table 1**. The raw ore materials were marked with a placeholder in the form of numbers. On the basis of these data the raw ore materials were compared using multicriterial decision-making methods.

Table 1 Input parameters for the evaluation of ores

Raw ore material	**K_1** **Price of ore** **($/t)**	**K_2** **Iron content** **(%)**	**K_3** **Strength of ore** **(%)**	**K_4** **Homogenity** **(%)**	**K_5** **Phosphorus content** **(%)**	**K_6** **Reducibility** **(%)**	**K_7** **Humidity** **(%)**
Ore 1	151	62	75	95	0.05	48	5.2
Ore 2	143	63	76	92	0.04	55	6.8
Ore 3	142	64	74	90	0.04	65	1.4
Ore 4	141	67	83	48	0.02	64	2.3
Ore 5	140	61	79	79	0.03	66	6.2
Ore 6	139	65	74	90	0.05	64	4.7
Ore 7	142	66	82	52	0.01	69	2.9
Ore 8	138	63	75	122	0.04	61	3.3
Ore 9	149	64	77	89	0.04	63	3.9
Ore 10	148	61	80	96	0.04	64	5.1
Ore 11	152	62	75	91	0.05	62	4.2

3. EXPERIMNETAL WORK

Within the realized research concerning the use of logistic tools in metallurgical processes was evaluated the quality of eleven types of ore raw materials. A total of seven criteria were used for their evaluation. In the first step we determined the weights of individual criteria. For their determination was used the method of gradual-priority weighting. This method is usually used to evaluate a larger set of criteria. The criteria are classified into individual groups according to their kinship. The weights of specific criteria are then determined in several steps. First, we determine the weight of the criteria groups themselves. The weights of the criteria groups are determined by the formula (1), which is based on the quantification of their order.

$$v_i = \frac{b_i}{\sum_{i=1}^{k} b_i} \tag{1}$$

vi - weight of group or criteria

bi - point value of the specified order

In the same way is determined the order of the criteria within each group and their weight. The resulting criteria weight values are determined based on the observed weight of a particular group and the partial weight of the criterion in that group. In the framework of the evaluation of the quality of ore raw materials the monitored criteria were divided into four groups:

I. K_2 - iron content, K_5 - phosphorus content
II. K_3 - strength of ores, K_4 - homogeneity of lumpiness
III. K_6 - reducibility, K_7 - humidity
IV. K_1 - price of ore

Table 2 shows the principle and the whole procedure. In the first step was compiled the order (importance) of the groups. A record of the made decisions is in the ranking column. The order is then converted to a score. In the case of the four monitored groups, the group is ranked first with four points. Other groups are ranked in descending order according to the stated principle. The weight of the group is calculated according to (1). An example of the calculation (2) of a weight for group I. can be written as follows:

$$v_i = \frac{b_i}{\sum_{i=1}^{k} b_i} = \frac{4}{10} = 0.400 \tag{2}$$

The weight of all other groups is determined in a similar way. In the second step were determined the weights of specific criteria within each group. The principle is similar when the ranking of criteria was determined within individual groups. For example, the calculation of the partial weight of criterion K_2 can be written in the following form (3):

$$v_i = \frac{b_i}{\sum_{i=1}^{k} b_i} = \frac{2}{3} = 0.667 \tag{3}$$

The last step of the calculation is to compare the weights of individual groups and partial weights of criteria in the group. This is realized by multiplication of both values and the result represents the final weight of the criterion. For example, for criterion K_2, we calculate the final weight as follows:

$$v_2 = 0.400 \cdot 0.667 = 0.267 \tag{4}$$

Table 2 Determination of weights for evaluation of ores by gradual-priority method

Group of criteria	Criteria	Rank	Value	Weight - group	Rank	Value	Weight - criteria	Weight final
I.	K_2	1.	4	0.400	1.	2	0.667	0.267
	K_5				2.	1	0.333	0.133
II.	K_3	2.	3	0.300	1.	2	0.667	0.200
	K_4				2.	1	0.333	0.099
III.	K_6	4.	1	0.100	1.	1	0.333	0.033
	K_7				2.	2	0.667	0.068
IV.	K_1	3.	2	0.200	1.	1	0.200	0.200

The resulting weights are shown in **Table 2**. The K_2 criterion was evaluated as the most important, which has a final weight value of 0.267. Criteria K_1 and K_3 ranked second. In both cases the weight is 0.200. Other criteria can be classified as less significant based on the values given. The weightings of the criteria thus determined will be used in the actual evaluation of the ores. For their comparison was used the gradual-priority method. This is characterized by an effort to find the overall value of each variant. The method is based on the quantification of the order in which the individual variants were sorted according to the relevant criteria. **Table 1** shows the primary values of the criteria. These were ranked in descending order according to specific criteria values. **Table 3** shows the ranking. The next step is to calculate the partial evaluation of each option in terms of each criterion according to the following formula (5):

$h_{ij} = m + 1 - p_{ij}$ (5)

h_{ij} - partial evaluation of variants from the perspective of each criterion
m - total number of variants
p_{ij} - specific determined order according to a given criterion

Furthermore, the total value of individual variants (ores) was determined by means of a relation (6):

$$H_j = \sum_{i=1}^{n} v_i \times h_{ij} \tag{6}$$

n - total number of criteria
v_i - weight of the specific criterion

Determination of the best variant of the ore is then based on the comparison of the total value of the given variant (H_j). The ore materials were then ranked in descending order of calculated value.

Table 3 Order of criteria for monitored ores

Ore raw materials	**Criteria**						
	K_1	**K_2**	**K_3**	**K_4**	**K_5**	**K_6**	**K_7**
Ore 1	8.	6.	7.	8.	5.	9.	9.
Ore 2	5.	5.	6.	7.	4.	8.	11.
Ore 3	4.	4.	8.	5.	4.	3.	1.
Ore 4	3.	1.	1.	1.	2.	4.	2.
Ore 5	2.	7.	4.	3.	3.	2.	10.
Ore 6	1.	3.	8.	5.	5.	4.	7.
Ore 7	4.	2.	2.	2.	1.	1.	3.
Ore 8	2.	5.	7.	10.	4.	7.	4.
Ore 9	7.	4.	5.	4.	4.	5.	5.
Ore 10	6.	7.	3.	9.	4.	4.	8.
Ore 11	9.	6.	7.	6.	5.	6.	6.

Table 3 shows the order of the individual ore materials in relation to the criteria used. The order was created on the basis of input data on ore materials. Based on the transformation of the above data was executed a calculation to assess the quality of all ores, using relations (5), (6). An example of the calculation for ore 1 is shown in **Table 4**, line K_1. The weights given in column vi were determined using the gradual weighting method. The calculation of the partial values for the ore material no.1 from the viewpoint of criterion no.1 can be written as follows (7), (8):

$h_{i1} = m + 1 - p_{ij} = 11 + 1 - 8 = 4$ (7)

$$H_j = v_i \cdot h_i = 0.200 \cdot 4 = 0.800 \tag{8}$$

The total sum of weights for each criterion is determined by the formula (6) and represents the final value of the quality of the ore. Its value, which is shown in **Table 4**, is for that ore 5.032.

Table 4 Determination of the weighted order value for the selected ore component

Criteria	v_i	Ore 1		
		p_{i1}	h_{i1}	$v_i\,h_{i1}$
K_1	0.200	8.	4	0.800
K_2	0.267	6.	6	1.602
K_3	0.200	7.	5	1.000
K_4	0.099	8.	4	0.396
K_5	0.133	5.	7	0.931
K_6	0.033	9.	3	0.099
K_7	0.068	9.	3	0.204
∑				5.032

The value was determined in the same way for the other monitored ore components. Complete results are shown in **Table 5**. For each ore, a specific calculated value is reported using the weighted order method. This represents the final quality value of the ore.

Table 5 Final order of ores according to the found values

Rank	Ore	Total value	Quality groups
1.	Ore 4	10.050	I.
2.	Ore 3	7.890	II.
3.	Ore 5	7336	
4.	Ore 9	7.010	
5.	Ore 8	6.942	
6.	Ore 10	5.989	III.
7.	Ore 2	5.704	
8.	Ore 11	5.344	
9.	Ore 1	5.032	
10.	Ore 7	1.328	IV.
11.	Ore 6	0.142	

4. RESULTS AND DISCUSSION

To determine the quality of the ore raw materials were used the gradual weighting method and the weighted order method. The final results are shown in **Table 5**. The ore raw material identified by number 4 was identified as the best. This ore received a final rating of 10.050. The ores No. 3, 5, 9, 8 were placed on the second to fifth place. These ore components were evaluated in the interval 7.890 - 6.942. They can therefore be considered as very qualitatively similar. On the sixth to ninth place are ores No. 10, 2, 11, 1. These ore components have a rating in the range of 5.989 - 5.032. The last two places are ores No. 7, 6 (rating 1.328, 0.142). Quality groups can be created for this evaluation. Each group will then contain ore materials of comparable quality. The specific distribution corresponds to the given classification and is shown in **Table 5**. Ideally from the manufacturer's point of view is to use the ore within category I. Based on the evaluation carried out, this is the best option. Another option is to use one of the ores from the second category. Thus, defined groups also offer an alternative in the event of a supplier failure or the need to change raw materials.

5. CONCLUSION

The use of managerial logistics tools in metallurgical conditions enables complex evaluation of complicated processes. The choice of the supplier of ore materials can have a major impact on the entire production process. The application of the methods used then allows to evaluate the complex quality of ores on the basis of a wide range of criteria. The procedure used can be easily implemented in electronic form and the evaluation can be performed continuously. The results can serve to increase the efficiency of purchasing and logistics processes in relation to negotiations with suppliers. Within the research carried out in the monitored company, the evaluation was the basis for the upcoming managerial decision on future supplier contracts. The evaluation procedure and methodology used is also easily applicable to other types of materials and raw materials.

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REFERENCES

[1] PERNICA, Petr. *Logistika pro 21. století*, 2. díl. Praha: Radix, s. r. o., 2005. p. 560.

[2] WILSON, Lonnie. *How to implement Lean Manufacturing*. McGrawHill Professional, 2009. p. 416.

[3] KOŠTURIAK Ján and FROLÍK, Zbyněk. *Štíhlý a inovativní podnik*. Praha: Alfa Publishing, 2006. p. 237.

[4] BROŽ, Ludvík. *Hutnictví železa*. Praha: SNTL - Nakladatelství technické literatury, 1988. p. 460.

[5] YIN, Ruiyu. *Metallurgical Process Engineering*. Berlin: Springer-Verlag Berlin Heidelberg, 2011. p. 400.

[6] VIGNES, Alan. *Extractive Metallurgy 1: Basic Thermodynamics and Kinetics*. New York: John Wiley & Sohn, 2013. p. 344.