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IRON PRODUCTION LOGISTIC ASPECTS

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Abstract: Pig iron production is a technologically and organizationally demanding process. A blast furnace plant consists of a great number of support processes that are necessary for the continuous operation of the given blast furnace. The iron production process involves a huge volume of input raw and other materials and manufactured products. Various transportation types are used for the given material transport. The logistic demands of individual processes often differ based on a given blast furnace plant. The conducted research included an analysis of the logistic demands of individual parts of a blast furnace plant. The possibility of utilizing various transportation types and individual application options of the selected instruments has also been assessed. The research took place under the conditions of a selected iron manufacturer in the Czech Republic. This article analyzes the key aspects of the conducted research. The research was carried out in 2018-2019. The data were processed for the logistics and production part.

1 Introduction - Production processes used for pig iron production

Blast furnace iron production is a set of many physical, chemical, mechanical and thermal processes. The actual iron production that takes place in a blast furnace is subject to properly-functioning related processes. A blast furnace plant does not only include the operation of the blast furnaces themselves, but also many preparation and auxiliary operations [1]. A general diagram of a blast furnace plant is showed as part of Figure 1. The blast furnace operation is continuous. The furnaces operate without any interruption for a period of 10-15 years [2]. In order to ensure such uninterrupted operation of a blast furnace, input raw materials have to be continuously prepared and added and pig iron needs to be tapped in regular intervals [1].

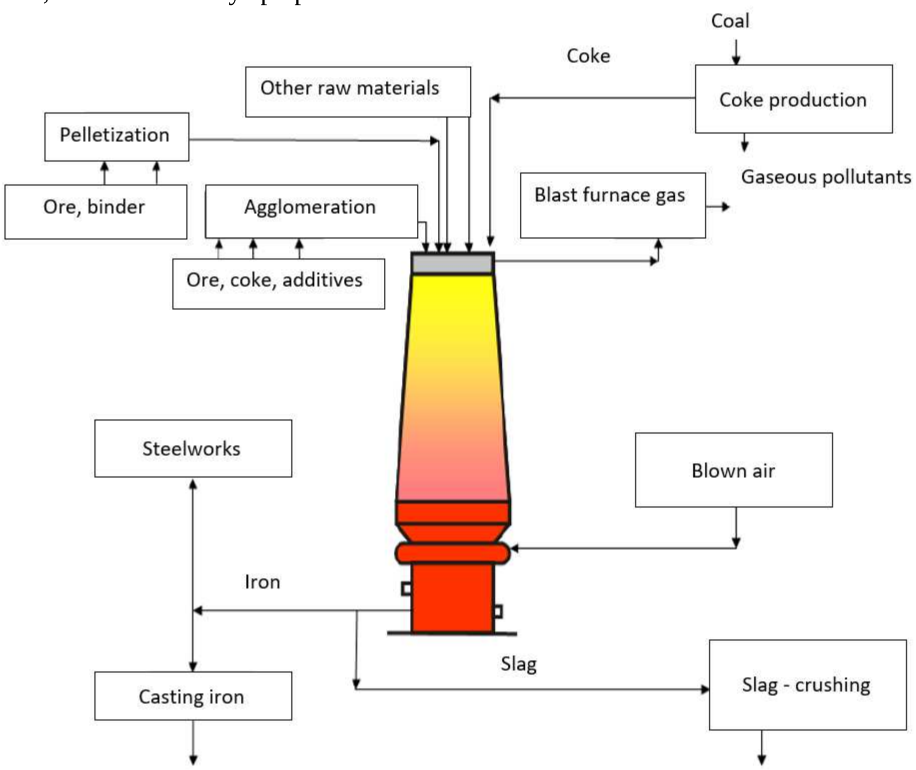

Figure 1 Blast furnace plant diagram [modified according to 2]

Apart from the actual production technology control in the blast furnace, other operations are also fundamentally important. These operations are linked to material preparation, transport, product processing and other related activities. A separate part of a given production plant is used for processing and preparing the given metalbearing component (especially ore). Agglomeration as well as palletization procedures are used for processing and modifying raw ore materials [3].

One of the most important processes in the Czech Republic is ore sintering. One of the input raw materials used in blast furnaces are pellets. However, they are usually produced at the iron ore mining locations. They are subsequently imported to the Czech Republic in the form of ready-to-use input material. Generally speaking, agglomeration or iron ore sintering is the heating of a dust agglomeration mixture (ore part, fuel, additives) to a temperature at which the surface of the individual grain of the burden is set and the formed smelt creates liquid bridges among the grains, which, once they solidify, create a solid porous material (agglomerate). The production takes place in a continuous manner and the final agglomerate is subsequently taken to reservoirs, from which the raw material is batched to the given blast furnace. Based on their character, individual agglomeration processes can be generally divided into cold and hot segments. The cold segment is used for supplying raw materials and granularity adjustments and for averaging the chemical composition of the material (tippers, grinders, screeners, homogenization dump sites). The task of the hot segment is to produce an agglomerate of the required quality from the supplied ores, concentrates, fuel and additives. The ore sintering hot segment particularly includes daily reservoirs, mixture batchers, raw material homogenization, sintering belts and also agglomerate cooling and modifications of its granulometric composition. The primary fuel for blast furnaces is blast furnace coke. Coke can be characterized as a firm, porous and degassed residue from the coal carbonization process.

Coal thermal processing takes place at temperatures of 900-1100 °C [4] without oxygen access. Cinder-forming additives are mostly limestone-based (dolomitic limestone and dolomite).

These substances subsequently create cinder during the transition to the liquid phase for the purpose of permanently binding the acidic hypogene elements of the ore components. Harmful cinder elements from the blast furnace processes are also allocated [5].

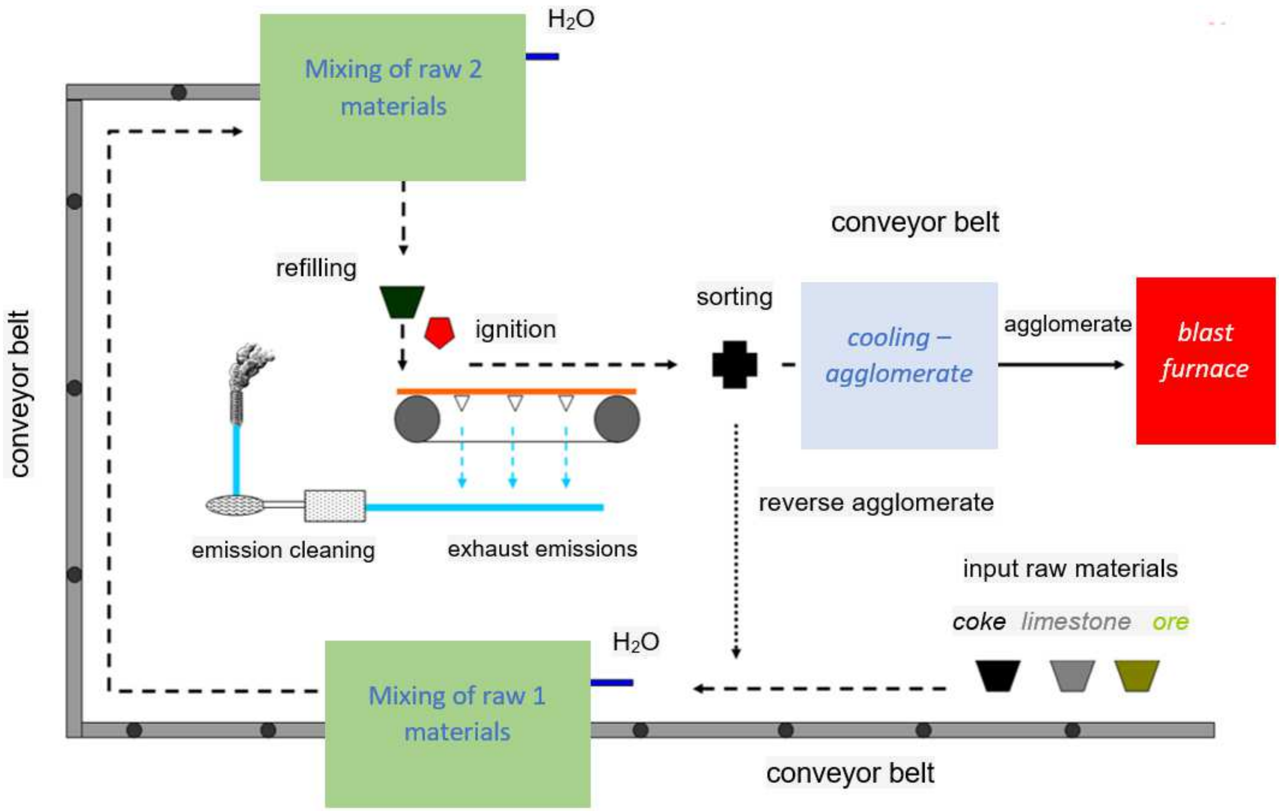

Figure 2 Agglomeration process diagram [modified according to 2]

The blast furnace profile and its size are modified pursuant to the given production technology. The bottom cylindrical part of the profile is called the hearth. Pig iron and cinder are collected here [6]. Iron and cinder are periodically tapped and discharged from the hearth. Blowpipes are installed at the upper part of the hearth.

They blow hot air and additive fuels [7]. The blown air is also moistened. The hearth is linked to a seat of a truncated cone shape with a wider top base. This shape ensures the necessary diversion of glowing gas currents from the oxidation areas from the furnace lining, which would otherwise become prematurely damaged [8]. The gradual crossing of the seat to the shaft in ensured by a belly. The most voluminous part of a blast furnace is a shaft in the shape of a truncated cone or two truncated cones. The shaft is used for preheating raw materials, the decomposition of carbonates and indirect reduction [9]. The upper part of the blast furnace is called the throat. It is used for filling the furnace with burden and for discharging throat gas from the furnace. Output products and waste (agglomeration dust, blast furnace flue-dust emissions, blast furnace sediments and cinder) are also processed. Waste processing is based on the possibilities of its further utilization in other industrial areas, but also on its possible repeated use for iron production. Waste production and processing are also demanding due to its quantity. The volume of cinder, for example, amounts to 200-400 kg [10] per one ton of the produced pig iron.

From the perspective of logistic processes, a significant part of a blast furnace plant is used for agglomeration [11]. This is where iron ore is being sintered while using coke and basic additives. Figure 2 shows the main parts of the entire process. As part of the first step, the input raw material is batched onto the conveyor belt. From the perspective of the entire process, this type of transport represents a key operation since it allows for transporting a huge quantity of material. The input raw materials are then stirred in homogenization drums, where they are also moisturized. This mixture is subsequently batched on the sintering transportation belt, onto which the mixture is processed thermally. Once the processing is completed, the agglomerate is modified from the granulometric point of view. The agglomerate is then transported to the blast furnace reservoirs. All of this is also implemented using conveyor belts. From the agglomerate production perspective, conveyor belt transport is thus a key requirement and it is very difficult to substitute it with any other form of transportation.

2 Logistics of metallurgical products

Steel products are manufactured in huge volumes. Their transport to end customers represents a significant logistics problem [12]. Their production in the Czech Republic amounts to millions of tons in the form of several thousand metallurgical product items (in relation to chemical analyses, thermal processing, shapes, dimensions or possible surface treatments). The consumers of metallurgical products can be from several areas [13]. Some of the most important ones include the construction industry, mechanical engineering and the automotive industry. When it comes to the character of individual deliveries, we can identify two possibilities. The first one can be characterized as regular and continuous deliveries of a large number of metallurgical materials for mechanical engineering companies, construction projects and the automotive industry. The other possibility is related to deliveries to a network of warehouse businesses that provide distribution for certain areas (regions) [14]. When it comes to direct deliveries from metallurgical companies to consumers (companies), the whole process is usually implemented without any other intermediaries. In the other case, the deliveries are supplied to a wide range of customers from various areas via wholesale networks. In This case, the volume of the supplied goods can be of a small to medium volume. These customers cannot satisfy their needs for the given metallurgical material directly from metallurgical companies, where such requirements would accumulate [15]. From the point of view of the planning of metallurgical campaigns and production capacities, this principle is not possible from the technological and cost perspective. Due to these facts, the rolling campaigns have been getting gradually shorter. In comparison with blast furnace production, they allow for more individual control. The sales system of metallurgical products can be classified pursuant to the following structure [16]:

- Final sellers to end customers (minimal supplies),
- Regional warehouse centres,
- Local warehouse shops (complete assortment of metallurgical materials).

The demand for individual steel product types (number of sales, size of the orders, sale regularity) is also monitored in detail these days. Individual business areas behave as relatively stabilized customers, provided a certain minimal limit, determined by a given set of customers, is reached. That is why the consumption prognoses for such areas are very accurate. Consumption fluctuations are resolved by the mutual cooperation of local warehouses, making sure there is a sufficient volume of all metallurgical products in the given area. Cooperation among individual warehouses can also correct errors in the given future consumption prognoses. Local warehouses form the most important nodes of the entire distribution network. They represent the main location for statistic assessments of the steel consumption pursuant to individual products.

3 Used transport types and their use in the metallurgical industry

Transport can be understood as a set of all activities used for moving means of transportation along transport routes and for moving material or people by the means of transportation or devices. Transport represents activities and technical means designated for transporting people and cargo [17]. Transport logistics then coordinate, synchronize and optimize the movement of goods and raw materials within the transportation network, utilizing one or several transport types. The main objective of transport logistics is not only primarily to make transport easier, but, most of all, to flexibly and economically satisfy the needs of individual customers. We can then perceive customers not only as external users of the provided services, but also as an internal, company material consumption within different production centers [13]. A reduction of the extent of the movement of individual means of transportation, necessary for implementing a certain material logistic chain, is also achieved by making the corresponding transports easier. This is due to the main principle of the transport logistics, which strives to minimize all purposeless physical movement and material flows when moving material, raw materials or finished products. The end goal of this process is to not only reduce the cost, but also the corresponding environmental burden, while improving transport quality and reliability.

Considering the volume of the transported material and raw material, metallurgical production is an extremely demanding process. Iron manufacturers in the Czech Republic produce over 5 million tons of crude metal annually. When it comes to ore raw materials, one needs 1900 to 2100 kg of the ore component for the production of one ton of pig iron. The volume of coke (which is used as a dominant source of thermal energy) needed for one ton of the produced pig iron, amounts to 300-400 tons [18]. The needed volume of the basic additives mostly depends on the alkalinity or acidity of the ore component. Iron manufacturers in the Czech Republic use mostly acidic ore raw material, which require the use of a greater quantity of the basic additives. The volume of the used alkalis can then be between 300 and 400 kg [19] per one ton of the produced iron. The total volume of the used raw materials that pass through a metallurgical company in a single year amount to several million tons. This huge quantity then results in great demands on the transport and optimization of all related logistic processes.

4 Basic characteristics of individual cargo transport types

The current logistic processes allow for utilizing a wide spectrum of the transport types. Each transport type has several specifics and limitations from the perspective of the transported medium, transport cost or suitable transport distance. Some of the basic transport types include road, railroad, water, pipeline, aerial, conveyor or funicular transports [13].

These transport types can mutually complement one another and can be used in a sequence or simultaneously. We can then call it combined transport (the most common scenario is railroad – road, truck transport). A basic condition of transport efficiency is the requirement that the implementation of the given moving consumes the corresponding use value [20]. Incompliance with this condition results in losses that are equal to the given moving cost. Moreover, should a given shipment not be used at all, additional losses are incurred amounting to the production cost of the unused values. We can evaluate transports based on several key criteria. Some of the main ones include transport performance, transport time, transport cost, transport frequency, network availability, flexibility, reliability and also environmental consequences. Individual customer requirements also play an important role when it comes to the distribution of metallurgical products. Apart from other things, such requirements result in a higher transport frequency or various weights of the transported cargo.

The following are the key transport types for metallurgical processes:

- road,
- railroad,
- pipeline,
- conveyor.

Road transport is irreplaceable when it comes to speed and operability, however, it has a negative impact on the environment caused by exhaust gases, noise and vibrations [21]. The advantages of this transport type include a dense network of roads, house-to-house transport, high flexibility, adjustability to given delivery times, time savings, shorter downtime and shorter waiting times [13]. Road (truck) transport in the area of metallurgical production is particularly used for transporting metallurgical products and semi-finished products, such as ingot slabs, sheet metal, belts, fired products, etc. Some of the main road transport disadvantages include harmful impacts on the environment, limited transported volumes by a single vehicle, limited loading ability or congestion. The share of the loads transported on the road in the Czech Republic is the highest among all transport types and the share keeps increasing. This stipulation applies to metallurgical products as well.

The second most important transport type from the metallurgical production perspective is railroad transport. This transport field is suitable for transporting greater cargo volumes for longer distances. Its advantages include the possibility to transport very heavy cargo shipments, independence on particular road traffic intensity, precise timetables, low costs for long distances and high material loads. In the metallurgical production field, railroad transport can be used for two large areas [22]. The first one applies to the transport of metallurgical semi-finished products for long distances. Another option is the transport of large volumes of input raw materials, such as ore, coal and alkaline additives. When it comes to ores, railroad transport is really the only transport option due to the used ore volumes and distances from individual ore deposits, provided we do not take into account ores from other continents, such as Australia or South and North America. Disadvantages of railroad transport especially include its limited shunting and maneuvering ability, the impossibility to transport cargos directly from one company to another, the dependability on timetables and smaller flexibility.

Pipeline transports in the context of metallurgical production can be perceived to be rather secondary. When it comes to pipeline transport, transportation containers, transport means and transport routes merge into a single unit. This transport field is very specific. It is used for transporting liquids, gases and sometimes also chemicals for long distances [13]. The utilization of pipeline transport as a part of the blast furnace process can be perceived to be specific. It mostly involves the transport of gases and combustion products that occur during the related production processes. Nevertheless, considering the further use and processing of these blast furnace products, pipeline transport represents a significant element. Some of the advantages of pipeline transport include reliability and safety, minimal pollution threats and continuous operation. As for disadvantages, we can mention the high financial cost of building such systems and limitations from the perspective of the transported medium.

Conveyor transport represents the most important transport type on the premises of blast furnace plants. This transport type is used for transporting ore raw materials and as a part of their processing, and also as a part of the agglomeration process, the transport of input raw materials to individual reservoirs and other processes. Conveyor transport allows for transporting huge volumes of material used in blast furnaces. We can generally say that this is the fundamental benefit of conveyor transport, which provides high performance and allows for transporting up to 6000 tons of material per hour. Due to significant acquisition expenses, which quickly increase with increased capacity, conveyor transport is particularly suitable for shorter distances. However, when transporting large volumes of raw materials, it can be economical even for longer distances (several kilometers). Its use is significant for the processes that use large volumes of input raw materials (Table 1).

Table 1 Assessment of the use of individual transport types for metallurgical processes

Transport type	Usability	Usage – in the plant / outside the plant	Character	Importance for blast furnace plants
Road	Yes	Outside the plant	Product transport to customers	7
Railroad	Yes	Outside the plant	Transport of raw materials	9
Water	No	-	-	0
Pipeline	Yes	In the plant	Transport of gaseous materials	8
Aerial	No	-	-	0
Conveyor	Yes	In the plant	Transport of input raw materials	10
Funicular	No	-	-	0

5 Characteristics of the potentially usable methods

The logistic tools and methods that are used these days are often linked to lean production principles. It is generally given by the character of the individual logistic objectives, which are, due to their nature, tightly related to the process of increasing the process efficiency [23]. Lean production and its principles cannot be understood as an exactly defined and closed system. As a part of this philosophy, several methods and instruments can be applied and their implementation manner can vary. Lean production implementation is then most often a reaction to a certain type of problem at a given company. That is why, when introducing the lean production principles, a procedure that is based on an initial audit of the lean production main parameters is often recommended. The values of selected indicators can be set as part of such a procedure [24]. Many lean production instruments originally came from the automotive industry. However, as these principles have been gradually developing and expanding to other industrial areas, other methods and instruments have been added and used. That is why it is not currently possible to provide a complete and comprehensive list of all the used methods since they are being continuously amended and modified. Nevertheless, some of the typical and frequently used lean production instruments include:

- TPM
- 5S – good management principles,
- Visual control,
- Team problem solutions,
- Management of bottleneck locations,
- Lean administration,
- Kaizen,
- Poka – Yoke,
- Jidoka,
- Heijunka,
- Kanban,
- Genchi genbutsu,
- SMED
- Multicriterial problem solutions.

Metallurgical production is quite specific and very different from large-series car production. Despite of that, some of the aforementioned methods and instruments can be successfully used for it as well. Table 2 shows selected methods that have been successfully used outside of the automotive industry and the possibilities of their application in metallurgical production.

Table 2 Selected lean production tools and their use

Transport	Usability	Area
TPM	Yes	Mainly secondary metallurgy
5S	Yes	All production areas
Kaizen	Yes	Production as well as nonproduction spheres
Lean administration	Yes	Administrative processes
Poka – Yoke	Limited	Selected segments, especially linked to improving safety
SMED	Limited	Mainly secondary metallurgy
Multicriterial evaluations	Yes	Supporting managerial decisions

The tools for supporting managerial decisions are especially universal [25]. Metallurgical processes are very demanding from the perspective of precise assessments of raw material quality, processes and individual activities. The quality of input raw materials fundamentally influences the blast furnace process with regard to individual ore components, fuel or alkaline additives. The problem of selecting a suitable contractor is created by a large number of the monitored criteria. A typical example can be the selection process of suppliers of basic additives. Completely different criteria can all play a role here and it is difficult to synthetize them into a single indicator. In order to find a suitable variant, it is very convenient to use a system that is based on a multidimensional base, which allows for considering multiple relevant characteristics. The criteria can be of a chemical, physical, logistic or economic character. Table 3 shows the selected criteria for assessing basic raw materials. Iron manufacturers cooperate with suppliers with many countries. They often need to adopt decisions related to the selection of suitable raw materials.

As part of the project solution, the quality of three types (suppliers) of the basic raw materials (dolomite – $CaCO_3$) was assessed. Four key criteria were selected for the assessment: basicity, price, storage volume and lumpiness. Based on the character of the stated criteria, it is clear that they represent quite different factors. It is thus very convenient to use multicriterial decision-making tools for assessing these data. The assessed criteria are of a different character, but also of a different significance. Basicity is a key criterion for alkaline additives since it expresses the share of alkaline and acidic components. The second criterion is the price of the basic raw material. Input raw material expenses fundamentally influence the final price of the given produced metal. The third criterion is the storage volume that is immediately available from a supplier. Blast furnace production is of a continuous character and it is thus important to make sure that all the related raw materials are operatively available. The last criterion applies to lumpiness. It tells us how homogenous given material is from the granulometric perspective.

Table 3 Dolomite criteria from potential suppliers

Criteria		Dolomite suppliers		
		Poland	Ukraine	Czech Republic
K_1	Basicity (%)	4.1	3.7	3.5
K_2	Cena ($)	20.1	18.8	19.6
K_3	Storage volume (t)	2,500	4,500	1,800
K_4	Lumpiness (%)	75	74	81

To compare dolomite suppliers from Poland, Ukraine and the Czech Republic, the method that assesses distances from a given fictious alternative was used. The method is based on determining the Euclidean distance. All the criteria values are compared with the best alternative and the final assessment is formed by a synthesis of all the monitored criteria. The fictious alternative then represents an alternative, in which the values of all the criteria are ideal [26, 27]. Formulas (1) and (2) are used for calculating the ideal alternative.

$$D_j = \sqrt{d_j} \tag{1}$$

$$d_j = \sum_{i=1}^{n} v_i \times \left(\frac{x_i^* - x_{ij}}{x_i^* - x_i^0} \right)^2 \tag{2}$$

Where:

D_j - distance from the ideal variant,
x_i^* - the length of action,
x_{ij} - the mean width of the elongated bar,
x_i^0 - the mean width of the elongated bar,
v_i - the weight of the criteria.

First, each criterion was assigned its respective weight. This weight represents the significance and importance of each criterion. The weight was determined by means of a binomial comparison of individual criteria. The determined values are then based on the executed pair decisions. Table 4, in which the distances from the fictitious alternatives are determined, also presents the weights of all the criteria (column v_i).

Table 4 Determining the ideal alternative

Criteria		v_i	x_i^*	x_i^0	d_{ij}		
					Poland	Ukraine	Czech Republic
K_1	Basicity (%)	0.450	4.1	3.5	0	0.200	0.450
K_2	Price ($)	0.250	18.8	20.1	0.250	0	0.095
K_3	Storage volume (t)	0.100	4500	1800	0.055	0	0.100
K_4	Lumpiness ($)	0.200	81	74	0.147	0.200	0
				$\sum$	0.452	0.400	0.645
				D_j	0.672	0.632	0.803
				Sequence	2.	1.	3.

The determined distance from the fictitious alternative then basically represents the sum of the deviances of individual criteria from the best alternative [28]. Its values for the basic raw materials from Poland, Ukraine and the Czech Republic were calculated using formulas 1 and 2. Based on the used evaluation principle, the lower the value, the more suitable the alternative. The distance from the fictitious alternative is shown in Table 4 in row D_j. Based on this value, we can assess the quality of the given basic raw material from the monitored suppliers. Pursuant to the values of individual criteria, we can sort the monitored suppliers in a descending order in the following manner: 1st Ukraine, 2nd Poland, 3rd Czech Republic. The determined assessment, applied using a multicriterial decision-making process, can form a basis for a potential managerial decision when selecting a supplier. Due to its universality, the applied method can be used for a wide spectrum of processes.

6 Assessment and conclusion

Iron production is a technologically demanding and complex process. A huge volume of raw materials is transported within the given metallurgical plant. Some of the greatest demands are particularly put on the efficiency of logistic processes. From the iron ore sintering perspective, the key transport type is represented by conveyor belts. They enable the delivery of input raw materials, material transport during the sintering process and also material transport to the given blast furnace. From among the other transport types, road, railroad and pipeline transports represent the important ones for metallurgical processes. Truck transport represents a key transport type in the area of the distribution of metallurgical products and semi-finished products to customers or intermediate warehouses. Railroad transport provides, apart from other things, transportation of all relevant input raw materials. It is also used for transporting metallurgical products over long distances. As part of the conducted research, we also examined the use of logistic tools based on the lean production principles in metallurgical processes. Despite the fact that these tools and methods were primarily used in other production systems, they can also be applied in the metallurgical industry. Apart from the traditional methods, such as 5S or Kaizen, exact logistic tools for supporting the managerial decision-making processes can be also used. As part of the implemented project, multicriterial decision-making methods were used for comparing the basic raw materials. The conducted assessment allows for quantifying categorically different criteria. It also offers the possibility of comparisons in the form of a single indicator. Several traditional logistic methods and tools can be used not only in the area of the production process itself, but also in the area of managerial decisions.

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