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The hybrid mathematical model for the evaluation and selection of iron ore raw materials in the context of the European Green Deal

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Abstract

The actual scientific research on the development of the hybrid mathematical model for evaluating and selecting iron ore raw materials in the context of the EU Green Deal is carried out. The necessity of developing decision support systems within the framework of the EU Green Deal concept is substantiated, in order to increase the degree of validity of decision-making in the evaluation space, regarding the green course and achieving the goals of the green agreement. For the first time, a systematic theoretical-multiple model of the problem of evaluation and selection of iron ore raw materials, according to the proposed factors of chemical composition, cost, and environmental policy of the manufacturer. The problem of multi-criteria selection of alternatives based on the imaginary alternative of the "satisfaction point" of the decision-makers (DM) requirements using the information model of criteria for evaluating the properties of the object of study on the chemical composition of iron ore raw materials. For the first time, a hybrid mathematical model of multi-criteria evaluation of iron ore raw materials with target needs was developed: quality of chemical composition of iron ore raw materials; the cost of iron ore; environmental policy and environmental impact in the extraction and/or enrichment of iron ore raw materials. The results of a study on a real example of evaluation and selection of iron ore concentrate for six alternatives implemented by Metinvest (Ukraine) were tested. The general step-by-step algorithm of the evaluation concept is described, which can be quickly implemented in the software product for the application. The developed model will be a useful tool for various programs of state support/business assistance in the procurement of iron ore raw materials by reasonably choosing a supplier using targeted needs in the context of synchronization with the EU Green Deal initiative. Raw material extraction and subsequent transport logistics are especially important for the engineering industry, the electrical engineering industry, and the automotive industry, with strong potential for the aeronautics and aerospace industry.

Keywords

iron ore raw materials, iron ore concentrate, EU Green Deal, decision-making, hybrid model, fuzzy mathematics.

Introduction

Each mining company sells and sells its products to processing entities under agreements concluded with them, in accordance with the planned volumes of mining. To reduce the amount of greenhouse gases, the metallurgical industry is changing every day through new environmental methods of its work. Management decision support systems are no exception. Of course, after the industrial revolution, the world economy was based on the consumption of fossil iron ore raw materials. It was mainly coal used as technological, energy, and energy raw materials in the production of coke and semi-coke to obtain many chemicals (naphthalene, phenols, pitch, etc.), which are used to obtain fertilizers, plastics, synthetic fibers, varnishes, paints, etc. (Xu et al., 2020).

Today, in the European Union, there is a transformation of the extraction, processing, and disposal of iron ore according to the principles and implementation of the European Green Deal.

Iron ore raw materials are iron-containing ore materials prepared for further processing into cast iron, direct reduction iron, and ferroalloys. The source for the production of iron ore is iron ore - a rock that contains iron in such quantities that the ore is profitable to process (Metinvest, 2022).

The European Green Deal is the most comprehensive and ambitious climate and environmental protection program launched by the EU (EU climate action and the European Green Deal, 2022; Green Deal In The EU And Ukraine: What Challenges Arise, 2022). The idea of this strategy is to turn the EU into a resource-efficient economy aimed at implementing it by 2050.

The reason for the green policy is too rapid climate change due to the anthropogenic increase in greenhouse gas emissions in the 20th century. The European Green Deal is part of an international effort on climate change. The idea behind the agreement is to be a role model for other countries. This requires a lot of effort, resources, innovation, and the development of new methodologies in the ecosystem of a resource-efficient economy. One of the elements of such an ecosystem is the development of a decision support system based not only on the criteria that ensure the ecological green course but also on the objectives of environmental policy.

The development of decision support systems under the European Green Deal is an extremely complex, innovative, interdisciplinary task that opens up large areas of new research, development, and implementation, the main purpose of which is to increase the validity of decision-making in the evaluation space on the green course and to achieve the goals of the green agreement.

The European Green Deal defines the following: if the European Union can achieve sustainable growth while providing a cleaner and safer planet for our children, others will do the same.

As Ukraine's associate member, it plans to join the agreement and declare carbon neutrality until 2060 in its National Economic Strategy (National Economic Strategy until 2030, 2021). However, for Ukraine, such a transition is very difficult due to outdated industry technologies and poor quality of management of the management of production, processing, and disposal of iron ore raw materials.

In response to all these facts, it was decided to conduct a topical scientific study, the main purpose of which is to develop a hybrid mathematical model for evaluating and selecting iron ore raw materials for businesses (metal producers) on target needs, taking into account the expert opinion of environmental policy, in the extraction/enrichment of iron ore raw materials. This study will be the basis for the development of the methodology of decision support systems within the concept of synchronization with the initiative of the European Green Deal.

The relevance of this study is confirmed by the need to develop new decision support systems in the management of management processes in the ecosystem of extraction, processing, and disposal of iron ore, in the context of the European Green Deal. In addition, the study's relevance is confirmed by the European Data Strategy for its implementation until 2030, to implement in the EU models of data and knowledge assessment for sound decision-making in business and the public sector (A European strategy for data, 2020).

Literature review

Let us perform an analytical review of multi-criteria evaluation tasks in the metallurgical industry to support decision-making.

Modern decision-making theory is based on a complex concept (Zaychenko, 2014), which takes into account all factors of the problem situation, and relies on the rational integration of logical thinking and material and technical means. First, DM and decision-making experts meaningfully analyze the problem situation and, based on their logic and intuition, formulate a goal, the achievement of which should solve the problem. A detailed presentation of the goal and their own preferences allows one to formulate ways to achieve it. The end result is a reasonable choice, which in the opinion of DM, is considered the best.

The application of different mathematical approaches begins after the formulation of the goal and ends with the search for the optimal solution that provides the best value of the criterion or all criteria. The decision-making process is to choose the best (optimal) among a set of possible alternatives based on complex decisions. Finding effective strategies or methods to facilitate this process is not an easy task due to the complexity of the problems.

The literature suggests many methods of decision-making and their extension, for example, techniques for ordering preferences by similarity to the ideal solution: the method TOPSIS (Behzadian et al., 2012; Paradowski et al., 2020) and method VIKOR (Więckowski et al., 2020). Method of organizing preferences for benefits to enrich estimates (PROMETHEE II) (Palczewski et al., 2019), analytical process of the hierarchy (AHP) (Vaidya & Kumar, 2006), analytical network process (Becker et al., 2017; Kheybari et al., 2020), complex proportional assessment (COPRAS) (Stefano et al., 2015), ELECTRE (Akram et al., 2020; Wan et al., 2017), characteristic object method (COMET) (Więckowski & Kołodziejczyk, 2020), the best is the worst method (Faizi et al., 2020) and other.

Many authors (Durnyak et al., 2021; Fazlollahtabar et al., 2019; Zaychenko, 2014) consider different stages of decision-making, but all of them can be reduced to the following analytical procedures: diagnosis of the problem; formulation of restrictions (definition of sets of alternatives and criteria, temporary restrictions); evaluation and selection of alternatives.

Regarding the application of different models of decision support in the metallurgical industry, we can note the following. The paper (Shrikrushna et al., 2018) used the TOPSIS method for multi-criteria decision-making on the choice of material composition for the powder metallurgy process. The paper (Polishchuk et al., 2021) developed a fuzzy mathematical model of the decision support system for assessing the creditworthiness of the coal industry of Ukraine. Aksvonov & Antonova, 2018 developed a Hybrid decision-making method based on a simulation-genetic algorithm in a web-oriented metallurgical enterprise information system. Maleki et al., 2020 developed a mining planning model to identify and minimize risk, obtain valuable information on the content and quality of ore in the early stages of the mining project, as well as improve decision-making on deterministic production planning. In (Milentijević et al., 2016), the methods of multi-criteria analysis of AHP and PROMETHEE were used to rank the degree of negative impact on the environment of tailings.

Increasingly, modern decision support systems use the conclusions of experts based on their experience, competencies, and knowledge. Such systems are called intelligent decision-making systems. However, if such systems are combined with quantitative estimates, then they are called hybrids. Examples of hybrid models of decision support in different areas of application are: a complex expert model for obtaining a quantitative assessment of the safety risk of implementation of environmental projects in the aviation sector (Kelemen et al., 2020); a hybrid fuzzy model for assessing the competencies of specialists in the smart city system (Kelemen et al., 2021); Expert Model for Evaluation of the Civil Airport NIS Security to Support the Security Management and the Cyber Criminology for Flight Safety (Kelemen et al., 2020), etc.

However, modern decision support systems are designed for the safe use of systems and do not take into account environmental factors in the context of the European Green Agreement. To date, no comprehensive study has been presented for the evaluation and selection of iron ore in the context of the European Green Deal, based on a hybrid model, taking into account both quantitative indicators and qualitative targets.

Material and Methods

Decision-making takes place over time, so the concept of the decision-making process is used, which consists of successive stages and procedures aimed at eliminating the problem situation. The decision-making process is presented in the form of some iterative procedures, which largely use both purely mathematical and heuristic approaches. It is expressed in the receipt, processing, and transmission of information, starting with the problem situation and ending with the choice of solution, that is, actions to solve the problem situation. The decision-making process aims to find the best alternative (group of alternatives), considering many local objectives, goals, research objects, criteria, and other important factors. The set of elements to be studied is divided into groups according to certain characteristics. These groups or their typical representatives are then studied as elements of a new level in the general system. These typical representatives, in turn, can be grouped according to certain characteristics and so, rising to a higher level, reaches the top, which is commonly called the purpose of decision-making.

Formal problem statement. Suppose that there are many alternatives on the market for the selection of iron ore raw materials $X = (X_1, X_2, \ldots, X_n)$, which must be evaluated and selected by the business entity (manufacturer of metal products) according to target needs: quality of chemical composition of raw materials, cost of raw materials, and producer's environmental policy (extraction/enrichment). From a mathematical point of view, this set of alternatives is considered finite. Therefore, the allowable alternatives can be listed. System theoretical-multiple model of the problem of evaluation and selection of iron ore, according to factors of chemical composition, cost, and environmental policy of the manufacturer, can be represented as follows:

$$\{X, K, M, P, E | Y\}. \tag{1}$$

In this model, we have the following variables:

- X – the object of study, this is alternatives to iron ore raw materials;

- K – the information model of criteria for evaluating the properties of the object of study on the chemical composition of iron ore raw materials. Let $K = \{K_i, i = 1,2,\ldots,m\}$ be the set of criteria that characterizes the chemical composition of iron ore raw materials. Moreover, K_i is the value of the i-th criterion, $i = 1,2,\ldots,m$;
- M – mathematical multi-criteria evaluation model based on an imaginary alternative;
- P – the cost of iron ore raw materials;
- E – an expert opinion on environmental policy and environmental impact in the extraction/enrichment of iron ore raw materials.

As a result, we obtain an initial estimate of Y, which determines the best alternative X^* taking into account factors of chemical composition, cost, and environmental policy.

Hybrid mathematical model of multi-criteria evaluation with target needs.

The solution to evaluating and selecting iron ore raw materials is divided into two stages.

In the first stage, it is necessary to solve the problem of multi-criteria choice of alternatives using the information model of criteria for evaluating the properties of the object of study on the chemical composition of iron ore and evaluation model based on an imaginary alternative.

To solve the second stage, we propose a hybrid mathematical model for choosing an alternative to target needs. For this task, we have the following goals: G_1 the quality of the chemical composition of iron ore raw materials; G_2 the cost of iron ore raw materials; G_3 expert opinion on environmental policy and environmental impact in the extraction and/or enrichment of iron ore raw materials. The model for obtaining an aggregate estimate will be presented in the form:

$$HM(G_1(\mu(g_1),\ldots,\mu(g_n)); G_2(\mu(p_1),\ldots,\mu(p_n)); G_3(\mu(e_1),\ldots,\mu(e_n))) \to Y^*. \quad (2)$$

As a result, for each alternative $X = (X_1, X_2, \ldots, X_n)$, there are normalized estimates based on which the best alternative Y^* is determined. We have $\mu(g_1), \mu(g_2), \ldots, \mu(g_n)$ aggregate estimates of the corresponding alternatives of iron ore raw materials $X = (X_1, X_2, \ldots, X_n)$ for the goal G_1; $\mu(p_1), \mu(p_2), \ldots, \mu(p_n)$ – cost estimates for goal G_2 and $\mu(e_1), \mu(e_2), \ldots, \mu(e_n)$ environmental policy expert opinion for goal G_3.

Consider the first stage of solving the problem.

A multi-criteria evaluation model based on an imaginary alternative can be presented in Table 1.

Tab. 1. Criterion estimates of values for alternative iron ore raw materials

№	X_1	X_2	...	X_n
K_1	O_{11}	O_{12}	…	O_{1n}
K_2	O_{21}	O_{22}	…	O_{2n}
…	…	…	…	…
K_m	O_{m1}	O_{m2}	…	O_{mn}

Or a matrix of solutions:

$$O = (O_{ij}), i = \overline{1,m}; j = \overline{1,n}. \quad (3)$$

where O_{ij} is an estimate of the j-th alternative of iron ore raw materials according to the i-th criterion.

Let us consider the point $T = \{t_i, i = 1,2,\ldots,m\}$, $\forall t \in T \subset R_{++}^m$, which is a closed convex subset on the half-axis R_{++}^m.

Definition 1. The "point of satisfaction" T of DM requirements is an imaginary alternative in which scores on all criteria could satisfy DM.

The set of "satisfaction points" $T = \{t_i, i = 1,2,\ldots,m\}$ the expert will choose independently, analyzing each criterion and choosing the optimal value. Those indicators are best suited to the entity for the manufacture of a product from iron ore raw materials or possibly the technological capabilities of the entity.

The question of constructing membership functions is one of the most important questions in the theory of blurred sets. We describe the approach to constructing the membership function $\mu_A(g_j), j = 1,2,\ldots,n$. (Polishchuk et al., 2021). Assume that we know the matrix of solutions (3) and given the "satisfaction point" T. Determine the set of values that are the relative estimate of the proximity of the element of the matrix (3) to the corresponding element of the "point of satisfaction":

$$z_{ij} = 1 - \frac{|t_i - O_{ij}|}{max\left\{t_i - \min_j O_{ij}; \max_j O_{ij} - t_i\right\}}, i = \overline{1,m}, j = \overline{1,n}. \quad (4)$$

Since each alternative is a point in the space R_{++}^{m}, then the defined matrix $Z = \{z_{ij}\}$ characterizes in columns the relative estimates of the proximity of the alternative X_j to the "point of satisfaction" T for each criterion and removes the question of different rating scales.

If we have more than one evaluation criterion, then they are of different importance. In this regard, DM sets the weights for each evaluation criterion $\{p_1, p_2, \ldots, p_m\}$, for example from the interval [1; 10]. For further calculations, we carry out their rationing:

$$w_i = \frac{p_i}{\sum_{i=1}^{m} p_i}, i = \overline{1,m}; \; w_i \in [0,1]. \tag{5}$$

Where the condition $\sum_{i=1}^{m} w_i = 1$ is satisfied.

The next step is to derive an aggregate assessment of alternatives. To do this, we build a membership function as one of the proposed convolutions (Polishchuk et al., 2020):

$$\mu_A^2(g_j) = \frac{1}{\sum_{i=1}^{m} \frac{w_i}{z_{ij}}} \text{ – pessimistic;} \tag{6}$$

$$\mu_A^3(g_j) = \prod_{i=1}^{m} (z_{ij})^{w_i} \text{ – careful;} \tag{7}$$

$$\mu_A^4(g_j) = \sum_{i=1}^{m} w_i z_{ij} \text{ – average;} \tag{8}$$

$$\mu_A^5(g_j) = \sqrt{\sum_{i=1}^{m} w_i (z_{ij})^2} \text{ – optimistic.} \tag{9}$$

Where w_i $(i = \overline{1,m})$ normalized weights for each criterion.

There is the following subordination between them: $\mu_A^2(g) \le \mu_A^3(g) \le \mu_A^4(g) \le \mu_A^5(g)$.

Consider the second stage of solving the problem.

Suppose we have a set of alternative choices of iron ore raw materials $X = (X_1, X_2, \ldots, X_n)$, which is evaluated according to factors of chemical composition, cost, and environmental policy of the manufacturer, for many goals G_1, G_2, G_3 and the output gives estimates in the interval [0; 1].

At the first stage of solving the problem, we obtained normalized estimates of alternatives for iron ore raw materials $\{\mu(g_1), \mu(g_2), \ldots, \mu(g_n)\}$. Now it is necessary to evaluate alternatives according to the cost and environmental policy of the manufacturer.

Let the cost of iron ore raw materials $P = \{p_1, p_2, \ldots, p_n\}$, be known, which is quantified in some monetary units. For comparison and further calculations, it is necessary to have normalized estimates at the output. Therefore, to normalize the cost, we use the following formula:

$$\mu(p_j) = \frac{\min_j p_j}{p_j}, j = \overline{1,n}. \tag{10}$$

The meaning of this rationing is as follows: if the value of $\mu(p_j)$ will go to 1; it will mean that the cost of alternative j is the lowest.

Outdated industry technologies and poor-quality management of iron ore mining and/or enrichment lead to significant negative impacts on the environment. Therefore, it is necessary to develop comprehensive, innovative approaches, not only technical, technological, but also managerial. In the context of a hybrid fuzzy evaluation model, it is proposed to introduce an expert opinion on environmental policy and environmental impact in the extraction/enrichment of iron ore by the manufacturer, respectively, according to alternatives $E=\{e_1, e_2, \ldots, e_n\}$. This expert opinion will influence the choice of an alternative option for the purchase of iron ore raw materials. Each alternative iron ore is evaluated by an expert using the linguistic variable T. For example, we propose the following term set of linguistic variables on the expert opinion of the environmental policy of extraction and/or enrichment of iron ore raw materials $T = \{T_1; \; T_2; \; T_3; \; T_4; \; T_5\}$, where: T_1 – «low level of environmental policy»; T_2 – «the level of the environmental policy below average»; T_3 – «average level of environmental policy»; T_4 – «environmental policy level above average»; T_5 – «high level of environmental policy». Also, for each assessment, the expert puts a "coefficient of confidence" d in assigning him an assessment from the interval [0; 1] (Kelemen et al., 2021). Then the expert opinion will consist of linguistic and quantitative assessments $e_j = (T_{jf}; d_j), j = \overline{1,n}; \; f = \overline{1,5}$.

Since the model is based on the term set of linguistic variables $T = \{T_1; \; T_2; \; T_3; \; T_4; \; T_5\}$, then the numerical interval $[a_1; a_6] = [0; 1]$, is chosen, where $T_1 \in [a_1; a_2]$, $T_2 \in [a_2; a_3]$, $T_3 \in [a_3; a_4]$, $T_4 \in [a_4; a_5]$, $T_5 \in [a_4; a_6]$. Next, perform fuzzification to obtain estimates $\mu(e_1), \mu(e_2), \ldots, \mu(e_n)$, using linguistic variables T, "coefficient of confidence" of the expert on their assignment d and the value of the partition interval $[a_1; a_6]$, using the following membership functions:

$$\mu(e_j) = \begin{cases} a_2 \cdot d_j, & if \quad T_j \in T_1; \\ a_3 \cdot d_j, & if \quad T_j \in T_2; \\ a_4 \cdot d_j, & if \quad T_j \in T_3; \\ a_5 \cdot d_j, & if \quad T_j \in T_4; \\ a_6 \cdot d_j, & if \quad T_j \in T_5. \end{cases} \tag{11}$$

This will make it possible to adjust the assessments regarding the expert's confidence in their assignment.

Since we have the problem of estimating and choosing alternatives to the target needs, then we denote the vectors $\overline{\mathrm{Q}} = \{\mu(g_1), \mu(g_2), \dots, \mu(g_n)\}$, $\overline{\mathrm{P}} = \{\mu(p_1), \mu(p_2), \dots, \mu(p_n)\}$ and $\bar{E} = \{\mu(e_1), \mu(e_2), \dots, \mu(e_n)\}$. We design them on a three-dimensional coordinate system, where the values of $\overline{\mathrm{Q}}$ are the values plotted on the *x*-axis, $\overline{\mathrm{P}}$ is the *y*-axis, and $\overline{\mathrm{E}}$ is the *z*-axis. For each alternative, we obtain the coordinates of the goals G_1, G_2, G_3 in the following form: $(\mu(g_1), \mu(p_1), \mu(e_1))$, $(\mu(g_2), \mu(p_2), \mu(e_2))$,…, $(\mu(g_n), \mu(p_n), \mu(e_n))$.

Next, we consider a three-dimensional "vector of satisfaction" of DM requirements $T^* = (A_1, A_2, A_3)$, which takes into account the wishes of DM on the importance of alternatives according to the objectives G_1, G_2, G_3.

Definition 2. "Vector of satisfaction" is an imaginary alternative in which the coordinates of the goals satisfy the decision-maker.

We model the "vector of satisfaction" as follows (Kelemen et al., 2020). Let us analyze an object with three inputs and one output:

$$U = (A_1, A_2, A_3), \tag{12}$$

where U is the vector of the initial estimate (u_1, u_2, u_3), the components of which take one of the values {0,2; 0,4; 0,6; 0,8; 1}, A_1, A_2, A_3 are the input linguistic variables.

To evaluate the linguistic variables A_1, A_2, A_3 we use qualitative terms from such term sets:

$$A_1 = (a_{11}, a_{12}, \dots, a_{1t}),\ A_2 = (a_{21}, a_{22}, \dots, a_{2t}),\ A_3 = (a_{31}, a_{32}, \dots, a_{3t}), \tag{13}$$

Knowledge of the "vector of satisfaction" $T = (t_1, t_2, t_3)$ is obtained from the base of fuzzy knowledge, consisting of systems of logical expressions - "If - Then, Else", which link the values of input variables A_1, A_2, A_3 with one of the possible values U (Kelemen et al., 2020).

$$\text{If } A_1 = a_{1t} \text{ and } A_2 = a_{2t} \text{ and } A_3 = a_{3t} \text{ Then } U = (u_1, u_2, u_3) \text{ Else } \dots \tag{14}$$

Thus, DM sets the linguistic wish of the "vector of satisfaction", which is translated into the vector of the original quantitative and normalized estimate (u_1, u_2, u_3), which is denoted accordingly $(u_1, u_2, u_3) = (t_1, t_2, t_3)$.

A fuzzy knowledge base can be formulated as follows:

IF we have goals:

the quality of the chemical composition of iron ore raw materials (goal G_1):

- a_{11} there is a need for iron raw materials content in ores from 10% to 30%, then $u_1 = 0.2$;
- a_{12} there is a need for iron raw materials content in ores from30% to 40%, then $u_1 = 0.4$;
- a_{13} there is a need for iron raw materials content in ores from40% to 50%, then $u_1 = 0.6$;
- a_{14} there is a need for iron raw materials content in ores from50% to 60%, then $u_1 = 0.8$;
- a_{15} there is a need for iron raw materials content in ores from60% to 72%, then $u_1 = 1$.

AND the cost of iron ore raw materials (goal G_2):

- a_{21} above market value, then $u_2 = 0.2$;
- a_{22} market value, then $u_2 = 0.4$;
- a_{23} slightly below market value, then $u_2 = 0.6$;
- a_{24} below market value, then $u_2 = 0.8$;
- a_{25} is much lower than the market value, then $u_2 = 1$.

AND expert opinion on environmental policy and environmental impact in the extraction and/or enrichment of iron ore raw materials (goal G_3):

- a_{31} very low controllability of the environmental policy of the entity, then $u_3 = 0.2$;
- a_{32} low controllability of the environmental policy of the entity, then $u_3 = 0.4$;

- a_{33} average manageability of the environmental policy of the entity, then $u_3 = 0.6$;
- a_{34} controllability of the environmental policy of the business entity above the average, then $u_3 = 0.8$;
- a_{35} the highest manageability of the entity's environmental policy at that time, then $u_3 = 1$.

THEN the logical statement can be formulated as follows:

If we need the quality of the chemical composition of iron ore raw materials A_1, the cost of iron ore raw materials A_2 and expert opinion on environmental policy and environmental impact in the extraction and/or enrichment of iron ore raw materials A_3 then $U = (u_1, u_2, u_3)$.

The knowledge base is open, regardless of the number of rules for the purpose. A system's analyst can always change quantitative levels and rules for purposes. In addition, without reducing the generality, this task is considered for three purposes, but the number of objectives can be increased if necessary.

The following approach is proposed for the construction of an aggregate series and the choice of alternatives for iron ore raw materials.

First, we find the values of $Z_j = (z_{1j}, z_{2j}, z_{3j}), j = \overline{1,n}$, which characterize the relative estimates of the proximity of alternatives to the "vector of satisfaction" for each goal G_1, G_2, G_3, thus removing the issue of different scales evaluation (Kelemen et al., 2020):

$$Z_j = (1;1;1) - (\mu(f_{1j}); \mu(f_{2j}); \mu(f_{3j})). \tag{15}$$

Where $\mu(f_{1j}),\ \mu(f_{2j}),\ \mu(f_{3j}), j = \overline{1,n}$, the membership functions of the proximity of alternatives to the "vector of satisfaction" are as follows:

$$\mu(f_{1j}) = \frac{|u_1 - \mu(g_j)|}{max\left\{u_1 - \min_j \mu(g_j);\ \max_j \mu(g_j) - u_1\right\}}, \tag{16}$$

$$\mu(f_{2j}) = \frac{|u_2 - \mu(p_j)|}{max\left\{u_2 - \min_j \mu(p_j);\ \max_j \mu(p_j) - u_2\right\}}, \tag{17}$$

$$\mu(f_{3j}) = \frac{|u_3 - \mu(e_j)|}{max\left\{u_3 - \min_j \mu(e_j);\ \max_j \mu(e_j) - u_3\right\}}. \tag{18}$$

Let the decision-maker set the weights for each evaluation factor $\{\alpha_1, \alpha_2, \alpha_3\}$, for example from the interval [1,10]. For further calculations, we carry out their rationing:

$$w_1 = \frac{\alpha_1}{\alpha_1+\alpha_2+\alpha_3}, w_2 = \frac{\alpha_2}{\alpha_1+\alpha_2+\alpha_3}, w_3 = \frac{\alpha_3}{\alpha_1+\alpha_2+\alpha_3}. \tag{19}$$

With the help of weighted average convolution, we will build an aggregate assessment of alternative choices of iron ore raw materials:

$$Y_j = w_1 \cdot z_{1j} + w_2 \cdot z_{2j} + w_3 \cdot z_{3j}, j = \overline{1,n}. \tag{20}$$

Based on the obtained estimates, we build a ranking series and choose the best alternative for iron ore raw materials, taking into account the goals of DM:

$$X^* = \max_j Y_j, \quad j = \overline{1,n}. \tag{21}$$

Thus, the best alternative solution will be the closest to the "vector of satisfaction" for the goals corresponding to the goals G_1, G_2, G_3.

Result

We test the results of the study on the example of evaluation and selection of iron ore raw materials concentrate that sells Metinvest enterprise (Metinvest, 2022).

Iron ore concentrate - a product of ore beneficiaries, the content of elements and mineralogical composition of which meet the requirements of further metallurgical processing. The concentrate is supplied as a marketable product and is used as a semi-finished product for the production of blast furnace pellets and pellets for metallization, and can also be used for the manufacture of iron-containing briquettes (Metinvest, 2022).

We use an information model based on nine criteria for evaluating the properties of the object of study on the chemical composition of iron ore concentrate. The values of the criteria according to the criteria for the six alternatives are shown in Table 2 (Metinvest, 2022). Let the DM determine the "point of satisfaction" T, as well as the weights for each evaluation criterion from the interval $[1;\ 10]$. The result is shown in table 2.

Tab. 2. The value of estimates according to the criteria of the chemical composition of iron ore concentrate of Metinvest enterprises

Criterion	Name (chemical composition)	T	p	X_1 concentrate	X_2 concentrate MMC	X_3 concentrate МФО	X_4 concentrate МФО+	X_5 concentrate A-1	X_6 concentrate К3
K_1	Fe	67	10	65.43	65	67	68.5	68.24	65.12
K_2	Fe2O3	65	9	63.72	59.77	65.21	66.21	64.36	61.86
K_3	SiO2	7	7	7.77	8	5.55	4.1	4.36	8.48
K_4	Al2O3	0.2	8	0.09	0.32	0.2	0.18	0.04	0.16
K_5	CaO	0.3	9	0.22	0.18	0.3	0.21	0.04	0.17
K_6	MgO	0.5	7	0.24	0.86	0.51	0.39	0.10	0.30
K_7	S	0.1	6	0.055	0.221	0.052	0.03	0.09	0.03
K_8	P	0.02	7	0.01	0.024	0.014	0.015	0.002	0.006
K_9	Moisture Less	10	5	10.5	10.5	10	10	10	10.5

Table 3 shows the following input data: P – test value of iron ore and E – an expert opinion on environmental policy and environmental impact in the extraction/enrichment of iron ore raw materials.

Tab. 3. Cost and conclusion on the environmental policy of Metinvest enterprises iron ore concentrate

Input data			X_1 concentrate	X_2 concentrate MMC	X_3 concentrate МФО	X_4 concentrate МФО+	X_5 concentrate A-1	X_6 concentrate К3
P	Cost (Eur. For 1 ton)		180	200	190	210	220	190
E	Expert opinion	Linguistic variable	T_4	T_5	T_3	T_4	T_4	T_5
		Coefficient of confidence	0.9	0.8	0.7	0.9	0.9	0.8

Therefore, based on input and expert data, it is necessary to evaluate and build a ranking of alternatives to iron ore concentrate.

Computations based on a hybrid mathematical model of multi-criteria estimation with target needs will be presented in the form of a step-by-step algorithm.

1st step. Determine the set of values that are the relative estimate of the proximity of the elements of the input estimates O by the criteria to the corresponding element "satisfaction point" by formula (4), table 4.

Tab. 4. Matrix of assessments of the proximity of assessments by criteria to the corresponding element of "satisfaction point."

Criterion	X_1 concentrate	X_2 concentrate MMC	X_3 concentrate МФО	X_4 concentrate МФО+	X_5 concentrate A-1	X_6 concentrate К3
K_1	0.215	0	1	0.25	0.38	0.06
K_2	0.755	0	0.96	0.769	0.878	0.4
K_3	0.734	0.655	0.5	0	0.09	0.49
K_4	0.313	0.25	1	0.875	0	0.75
K_5	0.692	0.538	1	0.654	0	0.5
K_6	0.35	0.1	0.975	0.725	0	0.5
K_7	0.628	0	0.603	0.421	0.917	0.421
K_8	0.444	0.778	0.667	0.722	0	0.222
K_9	0	0	1	1	1	0

2nd step. The rationing of weights according to the formula is carried out (5): w *={0.15; 0.13; 0.1; 0.12; 0.13; 0.1; 0.09; 0.1; 0.08}.*

3rd step. Derivation of aggregate assessment. To do this, take, for example, the average convolution to construct the membership function by the formula (8): $\mu_A^4(g)$ *={ 0.467; 0.253; 0.873; 0.590; 0.343; 0.375}.*

4th step. Normalization of the cost of iron ore according to the formula (10): $\mu(p)$ *={ 1; 0.9; 0.947; 0.857; 0.818; 0.947}.*

5th step. Fuzzification of the expert opinion of environmental policy. Let the DM choose the following partition of the numerical interval $[a_1; a_6] = [0; 1]$: $T_1 \in [0; 0.2]$, $T_2 \in [0.2; 0.4]$, $T_3 \in [0.4; 0.6]$, $T_4 \in [0.6; 0.8]$, $T_5 \in [0.8; 1]$. Next, the estimates $\mu(e_1), \mu(e_2), \dots, \mu(e_6)$ are calculated by the formula (11): $\mu(e)$ *={ 0.72; 0.8; 0.42; 0.72; 0.72; 0.8}.*

6th step. The values of the goals G_1, G_2, G_3 are selected. Let the DM choose one of the values for each of the goals, such as a logical statement of the following:

IF we need the quality of the chemical composition of iron ore raw materials:

$A_1 = a_{14}$ {there is a need for iron raw materials content in ores from 50% to 60%}

AND the cost of iron ore raw materials

$A_2 = a_{25}$ {is much lower than the market value}

AND expert opinion on environmental policy and environmental impact in the extraction and/or enrichment of iron ore raw materials

$A_3 = a_{35}$ {the highest manageability of the entity's environmental policy at that time} **THEN** $U = (0.8, 1, 1)$.

7th step. We find the values of Z, which characterize the relative estimates of the proximity of alternatives to the "vector of satisfaction" for each individual goal G_1, G_2, G_3.

To do this, first calculate the membership functions of proximity by formulas (16)-(18): $\mu(f_1) = (0.608;\ 1;\ 0.211)$; $\mu(f_2) = (1;\ 0.5;\ 0)$; $\mu(f_3) = (0.134;\ 0.737;\ 1)$; $\mu(f_4) = (0.384;\ 0.286;\ 0.211)$; $\mu(f_5) = (0.837;\ 0.091;\ 0.211)$; $\mu(f_6) = (0.777;\ 0.737;\ 0)$.

By formula (15), we find the values of quantities Z: $Z_1 = (0.392;\ 0;\ 0.789)$; $Z_2 = (0;\ 0.5;\ 1)$; $Z_3 = (0.866;\ 0.263; 0)$; $Z_4 = (0.616;\ 0.714;\ 0.789)$; $Z_5 = (0.163;\ 0.909;\ 0.789)$; $Z_6 = (0.223;\ 0.263;\ 1)$.

8th step. Normalization of weights for each evaluation factor. Let the DM set the weights for each evaluation factor $\{9; 8; 10\}$; we ration them according to the formula (19): $w_1 = 0.33$; $w_2 = 0.3$; $w_3 = 0.37$.

9th step. Construction of an aggregate assessment of alternatives for the selection of iron ore raw materials according to the formula (20): $Y_1 = 0.33 \cdot 0.392 + 0.3 \cdot 0 + 0.37 \cdot 0.789 = 0.423$; $Y_2 = 0.519$; $Y_3 = 0.367$; $Y_4 = 0.709$; $Y_5 = 0.616$; $Y_6 = 0.523$.

10th step. Construction of the ranking series and choosing the best alternative: $(X_4;\ X_5; X_6;\ X_2;\ X_1;\ X_3)$. We conclude that the best iron ore concentrate sold by Metinvest enterprises, taking into account the wishes of DM regarding the quality of the chemical composition of raw materials, target needs for the cost of raw materials, and environmental policy of the manufacturer (mining/enrichment) – X_4.

The decision-making infrastructure for the implementation of the Green Deal in Ukraine is at a very early stage of development. Ukraine has a Deputy Prime Minister for European Integration and is responsible for international cooperation, but there is no one responsible for implementing a green policy in Ukraine. The outdated industry is a big challenge for Ukraine. Another topical issue is funding. There is a plan to create a fund that would accumulate contributions from international partners and then allocate money to environmentally friendly projects and policies. The European Commission plans to present financial instruments that will be available for Ukraine, as well as for the other 30 countries, in the framework of the EU Green Deal (EU climate action and the European Green Deal, 2022; Green Deal In The EU And Ukraine: What Challenges Arise, 2022).

Discussion

The developed model will be a useful tool for various government support/business assistance programs in iron ore procurement by reasonably selecting a supplier using targeted needs in the context of synchronization with the EU Green Deal. That is, the state announces target needs, on the basis of which there is an assessment of alternatives to iron ore raw materials. When purchasing iron ore raw materials, the state supports enterprises in choosing the best positions on the market in accordance with the announced target needs of the state. Such support can come through a variety of funding models. Of course, in a complex system of operation of mining, enrichment, and processing of iron ore by various economic entities, the study does not solve the fundamental problem of the green industry. However, it will draw attention to this issue and make informed decisions, through the introduction of hybrid technologies of decision support systems, in order to invest in a green economy, taking into account environmental policy and environmental impact in the extraction and/or enrichment of iron ore raw materials.

On the example of Ukraine, in 2020, a law was adopted that opens new opportunities for the development of green procurement. Green public procurement is becoming more common. It is important to focus not only on the current price but also on the product's entire life cycle, including side effects and external factors that will be covered by the state budget. Green public procurement can be more effective if used in combination than simply from an economic point of view.

The built hybrid mathematical model of evaluation and selection of iron ore raw materials in the context of the EU Green Deal has a number of advantages, namely: derives an aggregate assessment of alternatives to iron ore raw materials in terms of chemical composition and using the "satisfaction point" of DM requirements; expert opinion of environmental policy is introduced in the form of linguistic and quantitative assessment, which improves the expert's confidence in their provision; a number of alternatives are being built, taking into account the targeted needs of DM, such as the quality of the chemical composition of iron ore, the cost of iron ore and environmental policy and environmental impact, in the extraction and/or enrichment of iron ore raw materials. The results of the study describe the general step-by-step algorithm of the evaluation concept, which can be quickly implemented in a software product for the application.

Disadvantages of this approach include the use of different models of convolutions to obtain an aggregate estimate, data fuzzification models, and values breaking the interval of expert opinions, which can lead to ambiguity of the final results.

Conclusions

Scientific research of the current innovative task of developing a hybrid mathematical model for evaluating and selecting iron ore raw materials for businesses (metal producers) according to goal needs, taking into account the expert opinion of environmental policy on environmental impact in mining/enrichment of iron ore raw materials. At the same time, the following results were obtained for the first time:

- the system set-theoretical model, tasks of estimation and choice of iron ore raw materials, according to the offered factors of chemical composition, cost, and ecological policy of the manufacturer have resulted;
- the problem of multi-criteria selection of alternatives based on the imaginary alternative of the "satisfaction point" of DM requirements was further developed, using the information model of criteria for evaluating the properties of the object of study on the chemical composition of iron ore raw materials;
- within the framework of the EU Green Deal concept, a hybrid mathematical model of multi-criteria evaluation of iron ore raw materials with goal needs has been developed: the quality of the chemical composition of iron ore raw materials; the cost of iron ore; environmental policy and impact on the environment, in the extraction and/or enrichment of iron ore raw materials. In the context of this model, it is proposed to introduce an expert opinion on environmental policy for the extraction/enrichment of iron ore raw materials based on linguistic variables and quantification of the "coefficient of confidence" of the expert to provide an opinion. The model is based on modern principles of fuzzy mathematics, intellectual analysis of knowledge, and systems approach. In the end, we get a normalized estimate of the alternative choice of iron ore and the ranking range to choose the best alternative;
- the results of a study on a real example of evaluation and selection of iron ore concentrate for six alternatives implemented by Metinvest (Ukraine) were tested. The general step-by-step algorithm of the evaluation concept is described, which can be quickly implemented in the software product for the application.

The rationality of the obtained initial assessment of iron ore in the context of the EU Green Deal proves the advantages of the developed hybrid model. The reliability of the obtained results is ensured by the correct use of the modern apparatus of fuzzy mathematics, intellectual analysis of knowledge, and a systematic approach, which is confirmed by the results of research.

Further research is seen in the development of other decision support systems within the concept of synchronization with the EU Green Deal initiative for various applications in order to increase the validity of management decisions in the ecosystem of a resource-efficient economy. Also, for the practical use of a hybrid mathematical model for evaluating and selecting iron ore raw materials in the context of the EU Green Deal, software development is planned.

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