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FUZZY SYSTEM FOR DECISION SUPPORT OF POST-MINING REGIONS RECLAMATION (FSDR)

SYSTEM ROZMYTY DO WSPOMAGANIA DECYZJI W ZAKRESIE REKULTYWACJI TERENÓW POGÓRNICZYCH

Open pit mining of rock minerals and the affected areas requiring further development are a serious challenge for shaping the positive image of the mining industry among the public. The direction and method of post-mining land reclamation are important for this image, which should take into account various factors describing the mining area, including social preferences. The article presents an example solution – fuzzy system (FSDR) – which supports the selection of the direction of reclamation of post-mining areas created after the termination of operations of open pit gravel and sand natural aggregate mines. The article presents selected factors determining the selection of the direction and possible reclamation variants as input and output data of the fuzzy system. The rules base of the developed system, as well as the mechanisms of inference and defuzzification, were also characterized. The application of the developed system is presented on selected examples.

Keywords: reclamation, post-mining regions, fuzzy system, decision-making support

Eksploatacja surowców skalnych metodą odkrywkową oraz pozostające po niej tereny wymagające dalszego zagospodarowania stanowią poważne wyzwanie dla kształtowania pozytywnego wizerunku branży górniczej w odbiorze społecznym. Dla tego wizerunku istotnym jest przede wszystkim kierunek i sposób rekultywacji terenu poeksploatacyjnego, który powinien brać pod uwagę różne czynniki charakteryzujące teren pogórniczy, w tym preferencje społeczne. W artykule zaprezentowano przykład opracowanego rozwiązania – systemu rozmytego (FSDR) – który wspomaga wybór kierunku rekultywacji terenów pogórniczych powstałych po zakończeniu działalności kopalń odkrywkowych kruszyw naturalnych żwirowo – piaszczystych. W artykule przedstawiono wybrane czynniki determinujące wybór kierunku i możliwe warianty rekultywacji jako dane wejściowe i wyjściowe systemu rozmytego. Scharakteryzowano również bazę reguł opracowanego systemu oraz mechanizm wnioskowania i defuzyfikacji. Przedstawiono zastosowanie opracowanego systemu na wybranych przykładach.

Słowa kluczowe: rekultywacja, tereny pogórnicze, system rozmyty, wspomaganie decyzji

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1. Introduction

Mining is perceived negatively by society due to the scale of the transformations it causes. The effects of open pit mining operations are particularly noticeable in the form of workings requiring further management.

Due to the large number of open pit mines and the prevalence of rock minerals mining in this form, the reclamation process is of great importance for the proper shaping of the image of the mining industry among the public.

The issue of reclamation of the post-mining areas is the subject of a number of papers determining the technical, technological and biological procedures for carrying out the process of reclamation (Cairns, 1972; Alexander, 1998; Bell, 2001; Cao, 2007; Drummond & Loveland, 2010; Dolezalova et al, 2012; Karan et al., 2016).

Problems occurring at the moment of undertaking the reclamation activities are preceded by the process of physical decommissioning of mining plants, which involves the use of original technologies and technical means. The reclamation of post-mining areas involves solving a number of complex technical and organisational problems, taking into account the characteristic features of reclaimed areas (Davis & Margolis, 1979; Brodie, 1995; Buchanan, 2005; Sklenička et al., 2004). An interdisciplinary approach to the methods of reclamation of post-mining areas, taking into account environmental and social factors is presented, for example, by Coppin and Bradshaw (1982), Glen (1994), Ricks (1995), Schaaf (2001) as well as Sklenička and Lhota (2002). Details of the reclamation process are also presented by Hancock (2004) while pointing out that the issue of reclamation varies considerably among countries and regions, as also evidenced by (Miao et al., 2000; Parrota & Knowles, 2001; Wiegleb & Felinks, 2001; Brown, 2005; Hendrychova, 2008; Hao et al., 2010; Mishra et al., 2012, Skousen & Zipper, 2014).

The process of selecting the direction of reclamation of the post-mining site is based on multiple criteria. The objectivity of choosing a reclamation variant can be ensured by using methods which take into account the specificity of the issue and use the accumulated knowledge to reach (optimal) decisions. Various solutions have been developed to support the reclamation decision process, with the use of AHP method (Uberman & Ostrega, 2005; Bascetin, 2007; Ebrahimabadi, 2017), TOPSIS method (Soltanmohammadi et al., 2010, Narrei & Osanloo, 2011), neural networks (Górniak-Zimroz & Malewski, 2004) or evolutionary algorithms (Palogos et al., 2017).

During the selection of the reclamation direction, the complexity of the processes does not allow for a clear and reliable identification of the factors that favour or fully exclude any particular reclamation variant. The absence of such functional dependencies does not contradict the fact that there are experienced individuals, experts, whose intuitive knowledge in this field can be applied. The analysis of qualitative factors, as well as imprecision and ambiguity of information used in the complex evaluation of the method of reclamation, can be interpreted using the fuzzy set theory, which was also used in the extension of existing methods (Alavi & Alinead-Rokny, 2011; Masoumi et al., 2014) or as a basis for new solutions (Bandopadhyay & Chattopadhyay, 1986; Sweigard & Ramani, 1988; Burrough, 1989; Cheng et al., 2017), including the system presented in this paper.

The literature also presents other systems for supporting the decision-making process (Pavloudakis et al., 2009; Zimmerman, 2016) which are used in specific conditions regarding the land intended for reclamation.

This article presents an original solution designed to support the process of selecting the direction of reclamation for open pit mines of natural gravel and sand aggregates (Król-Korczak, 2016).

The reasons for developing this type of solution were, first of all, the characteristic features of this minerals base with great economic importance, the large number of deposits in the world, as well as their attractiveness for various forms of use in building construction, road construction and various possibilities of reclamation of the post-mining areas.

The paper is structured as follows. In Section 2 characteristic of fuzzy system FSDR is presented, according to its development stages. Results of system execution for various mining plant examples are presented in Section 3. Section 4 concludes the paper and provides remarks for system usage.

2. Development of fuzzy system for decision support of post-mining regions reclamation (FSDR)

The early concept of an expert system supporting the decision regarding selection of reclamation direction after mining of natural gravel and sand aggregates was described in (Bielecka & Korczak-Król, 2010). In the process of improving the mentioned solution, the inference tree was abandoned and the determined choices were replaced with fuzzy rules. In addition, other possible directions of reclamation were introduced, e.g. agricultural or commercial, which made it possible to create a more universal system for the various conditions typical for the excavations of natural gravel and sand aggregates. New linguistic variables were also introduced.

The work on the system was divided into the following stages:

1) In the first stage, the factors determining the selection of reclamation direction were found – input data to the fuzzy system were specified.
2) Then, possible reclamation alternatives were identified – output data to the fuzzy system were specified.
3) The foundations of the fuzzy system were developed in the following scope:
   – defining the fuzzy sets describing the input and output data,
   – preparing the fuzzy rules base,
   – selecting the fuzzy inference scheme and the method of defuzzification of the results.
4) Then the developed fuzzy system was implemented into the MATLAB environment and sample calculations were performed.

2.1. Identification of factors determining the selection of the direction of reclamation

The following factors were chosen for the main elements characterising the mining plant affecting the direction of reclamation:

1) Economic – in terms of financial resources at the disposal of the entrepreneur, used to carry out the reclamation.
2) Social – social aspects were characterised in terms of current and potential users of a given area. Assuming the local community as the main potential beneficiaries of the reclaimed area, the basis for the proper selection is the analysis of data on demography, entrepreneurship or recreation interests. The following variables were selected in this respect:
   – demographic conditions – expressed in terms of population density,

- entrepreneurship – expressed as entrepreneurship factor, defined as "the number of economic entities registered in the REGON system per 1000 residents",
- sports facilities – expressed in terms of a set of facilities with public functions for sports,
- interest in recreation and fishing – expressed by the results of surveys describing local community preferences in this area,
- traditions and customs, social needs, farming and commercial traditions – as expressed by the results of the analysis of the historic structure of a given region and the formulation of the occurrence or absence of traditions, customs or social needs,
- social acceptance (position) – expressed by the results of surveys defining the preferences of the local community, especially with respect to the possible economic direction of reclamation.

3) Formal and legal – a point of verification of formal and legal factors may be the provisions of e.g. the commune's local spatial development plan, the provisions of the commune's development strategy, which would result in the permitted designation of areas and, among other things, the principles of reclamation. These factors include, for example, the existence of any forms of nature conservation in a given area. Various forms of legal protection may also include valuable plants, animals and other distinctive features, e.g. geological formations. Therefore, the following factor was identified in this group:
   - protected plant and animal species – expressed in terms of the number of protected plant and animal species that are considered to be valuable and/or threatened by extinction.
4) Environmental – in order to check the contribution of the environmental factors in determining the direction of reclamation, it is necessary to analyse the natural environment from the point of view of vegetation in the mining area of the analysed plant, fauna and flora. The following characteristics were selected from the group of environmental factors:
   - landscape value – expressed in a 1–10 numerical scale rating, determined on the basis of partial measures such as conservation status, landscape diversity, harmony, distinctiveness,
   - environmental attractiveness – expressed in a 1–10 numerical scale rating, determined on the basis of partial measures such as natural values and the state of development,
   - forest cover – expressed as the share of forest complexes in the total surface area of the region.
5) Spatial – in terms of spatial factors, the analysis should take into account whether a given mining plant has a favourable and satisfactory system of external transport infrastructure. The following variables were selected in this respect:
   - transport access – the frequency of public transport connections,
   - distance from residential areas – expressed in terms of distance from residential development areas.
6) Hydrological and hydrogeological – water accumulation and water quality class are crucial in terms of this factor. Therefore, the following variables were identified in this group:
   - water purity status – expressed by water quality class,
   - excavation flooding – expressed as the share of water in the excavation cross-section.

7) Geological and engineering – in terms of geological and engineering (technical) factors, the following characteristics were taken into account:
   – excavation depth,
   – pitch and stability of the end slopes.

2.2. Identification of possible reclamation variants

Output data (possible reclamation directions) for the developed method were determined based on the characteristics of factors relevant to the selection of the reclamation direction.

Five reclamation variants have been identified:

- variant I – reclamation in the agricultural direction (with eventual construction of water reservoirs for fish husbandry),
- variant II – reclamation in the water direction (with the creation of pools for swimming and water sports or reservoirs for drinking water, water retention and fisheries),
- variant III – reclamation in the forest direction (creation of walking areas for local residents and tourists),
- variant IV – reclamation in the environmental direction (may be preferred due to the existing water birds and amphibian habitats),
- variant V – reclamation in the commercial direction (for storage of non-hazardous waste in the unflooded part of the excavation or for reducing the depth of the flooded excavation).

2.3. Development of the foundation for the FSDR fuzzy system

For the needs of the FSDR fuzzy system, the selected factors (input data) are expressed as linguistic variables. Linguistic variables assume certain values expressed as fuzzy sets with defined membership functions.

Fuzzy set A in a particular (non-empty) X space, with notation as $A \subseteq X$, is the name for a set of pairs (Cox, 1994):

$$A = \{(x, \mu_A(x)); x \in \mathbf{X}\}$$

where:

$\mu_A : \mathbf{X} \to [0,1]$ is a membership function for fuzzy set A. This function, to each element $x \in X$ assigns the degree of membership in fuzzy set A, with 3 cases of membership degree to be distinguished:

$\mu_A(x) = 1$ stands for full membership in fuzzy set A, i.e. $x \in A$,

$\mu_A(x) = 0$ stands for no membership of element x to fuzzy set A, i.e. $x \in A$,

$0 < \mu_A(x) < 1$ stands for partial membership of element x to fuzzy set A.

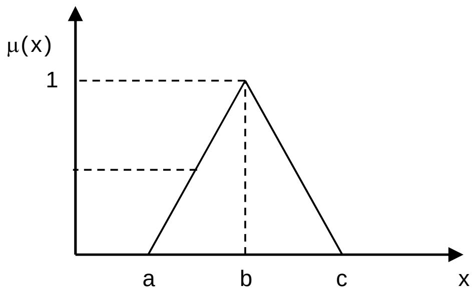
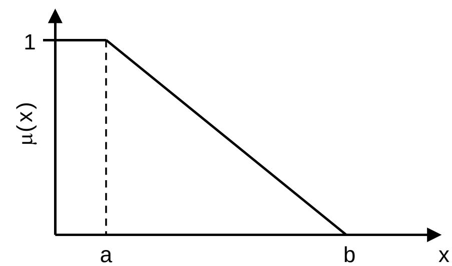
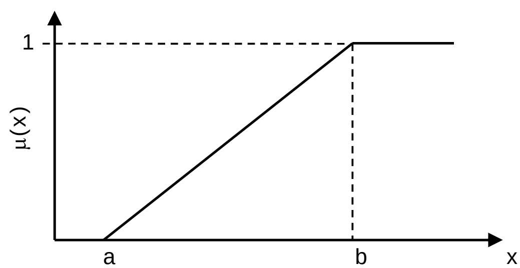
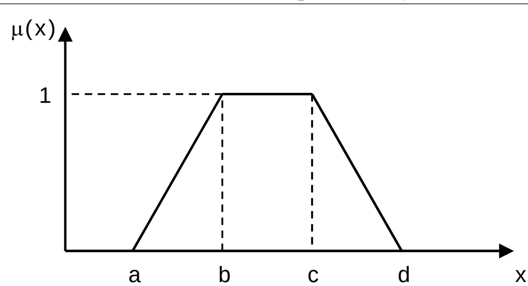
In the designed fuzzy system, the membership functions presented in Table 1 were used to define fuzzy sets.

In all cases, multiple-angle functions were used, as their advantage is the ease of modifying the membership function parameters based on the measurement input-output data for the system.

For most linguistic variables, their values are described by fuzzy sets with symmetrical membership function L and γ (Table 2), with the exception of variables: “water quality class” and “excavation depth”, with descriptions using triangular and trapezoidal functions (Table 3).

TABLE 1

Selected fuzzy sets membership functions

Function symbol	Membership function formula	Graphic form and name
T	$\mu(x)=\begin{cases} 0 & \text{for} \quad x \le a \\ \dfrac{x-a}{b-a} & \text{for} \quad a \le x \le b \\ \dfrac{c-x}{c-b} & \text{for} \quad b \le x \le c \\ 0 & \text{for} \quad x \ge c \end{cases}$	 Triangular membership function
L	$\mu(x)=\begin{cases} 0 & \text{for} \quad x \le a \\ \dfrac{b-x}{b-a} & \text{for} \quad a < x \le b \\ 1 & \text{for} \quad x \ge b \end{cases}$	 L-class membership function
γ	$\mu(x)=\begin{cases} 0 & \text{for} \quad x \le a \\ \dfrac{x-a}{b-a} & \text{for} \quad a < x \le b \\ 1 & \text{for} \quad x \ge b \end{cases}$	 Class membership function γ
TR	$\mu(x)=\begin{cases} 0 & \text{for} \quad x \le a \\ \dfrac{x-a}{b-a} & \text{for} \quad a < x \le b \\ 1 & \text{for} \quad b < x \le c \\ \dfrac{d-x}{d-c} & \text{for} \quad c < x < d \\ 0 & \text{for} \quad x > d \end{cases}$	 Trapezoidal membership function

Surce: based on (Piegat, 1999)

TABLE 2

Definition of fuzzy sets in the FSDR system – part 1

Name and symbol of the linguistic variable	**Value of the linguistic variable**	**Type of fuzzy set membership function**	**a**	**b**	**Unit**
financial resources of the entrepreneur	small	L	59	89	thousand PLN/ha
	big	γ			
demography	small	L	59	373	persons/km^2
	big	γ			
entrepreneurship	small	L	67	125	number of entities / 1000 residents
	big	γ			
sports facilities	bad	L	2	5	number of facilities / 1000 residents
	good	γ			
interest in recreation	small	L	30	50	%
	big	γ			
interest in fishing	small	L	30	50	%
	big	γ			
farming and commercial traditions	small	L	15	55	%
	big	γ			
social acceptance	small	L	10	30	%
	big	γ			
protected plant and animal species	small	L	10	30	number of protected species
	big	γ			
landscape value	small	L	1	9	score
	big	γ			
environmental attractiveness	small	L	1	9	score
	big	γ			
forest cover	small	L	21	49	%
	big	γ			
transport access	good	L	0.5	2	h
	bad	γ			
distance from residential areas	close	L	200	1000	m
	far	γ			
excavation flooding	small	L	25	50	%
	big	γ			
slope pitch	small	L	22	45	^{0}
	big	γ			

The system output values (reclamation directions) are expressed as a linguistic variable with values I, II, III, IV and V. They are expressed by fuzzy sets with triangular membership functions (Fig. 1).

TABLE 3

Definition of fuzzy sets in the FSDR system – part 2

Name and symbol of the linguistic variable	Value of the linguistic variable	Type of fuzzy set membership function	a	b	c	d	Unit
water quality class	high	*L*	3	4	—	—	—
	medium	*T*	3	4	5	—	
	low	γ	4	5	—	—	
excavation depth	very small	*L*	1	2	—	—	m
	small	TR	1	2	3	4	
	big	γ	3	4	—	—	

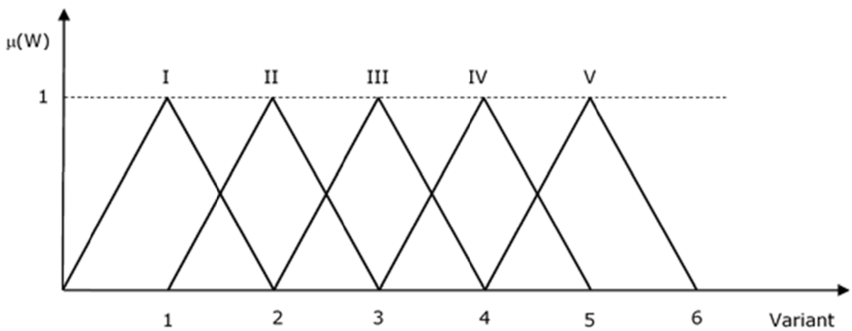


Fig. 1. Membership functions for FSDR system output values

2.4. Fuzzy rules base and inference principles

Defined fuzzy sets became the basis for the formulation of the rules base. From each possible input data pair (a, b) and the output value (c) one rule can be obtained, resulting in 681 simple rules in the following form:

$$\text{IF } a = X \text{ and } b = Y \text{ THEN } c = W.$$

In order to avoid redundancy in the rule base, rules composed by a combination of rules with the same rationale and/or conclusions were created. As a result, a set of 26 complex rules was obtained, out of which selected rules are presented below:

1. If (financial_resources is big) and (demography is big) and (entrepreneurship is small) and (sports_facilities is good) and (interest_in_recreation is small) and (interest_in_fishing is small) then (variant is I),
2. If (transport_access is good) and (distance_from_residential_areas is small) and (excavation_flooding is big) and (water_quality_class is high) and (excavation_depth is small) and (slope_pitch is small) then (variant is II),
3. If (farming_commercial_traidtions is small) and (social_acceptance is small) and (protected_species is big) and (landscape_value is big) and (environmental_attractiveness is big) and (forest_cover is small) then (variant is III),

4. If (financial_resources is big) and (demography is small) and (entrepreneurship is big) and (sports_facilities is bad) and (interest_in_recreation is big) and (interest_in_fishing is small) then (variant is III),
5. If (transport_access is good) and (distance_from_residential_areas is small) and (excavation_flooding is small) and (water_quality_class is medium) and (excavation_depth is big) and (slope_pitch is big) then (variant is III),
6. If (financial_resources is small) and (demography is big) and (entrepreneurship is big) and (sports_facilities is bad) and (interest_in_recreation is big) and (interest_in_fishing is small) then (variant is IV),
7. If (transport_access is bad) and (distance_from_residential_areas is big) and (excavation_flooding is big) and (water_quality_class is low) and (excavation_depth is big) and (slope_pitch is big) then (variant is V),
8. If (farming_commercial_traidtions is small) and (social_acceptance is big) and (protected_species is small) and (landscape_value is small) and (environmental_attractiveness is small) and (forest_cover is big) then (variant is V).

All system rules are used for inference. As a result, as many activated baselines are obtained, which constitute the conclusion of each rule, as the number of rules activated in the process of inference. Thus, the final fuzzy set in the variable output space remains, which arises after the accumulation of all activated conclusions contained in the rules base, remains to be determined. This is done in the aggregation block of the inference system.

The developed FSDR fuzzy system proposed the use of Mamdani-type inference (Cox, 1994). The operators of aggregation of complex premises and accumulation as well as the method of defuzzification were also selected:

- the rationale for the rules includes conjunction – the product of two fuzzy sets, the MIN operator was assumed as the operator – i.e. the fulfilment of the entire condition shall be calculated as a minimum from membership in particular components,
- the MIN operator has been selected as the implication operator, which determines the membership in the resulting fuzzy set,
- each set of sharp input variable values can activate several rules and, as a result, several fuzzy sets can be obtained – these sets are then added together and MAX operator is the operator to carry out the accumulation,
- the COG method, which involves calculating the centre of gravity of the set, was proposed as a method of defuzzification.

The developed FSDR fuzzy system was implemented in the MATLAB Fuzzy Logic Toolbox software.

3. Results and discussion

In order to verify and confirm the correctness of the method used to support the decision on the direction of reclamation, a mining plant which had completed the extraction of gravel and sand aggregates in one of the communes of Małopolska (Lesser Poland region) was selected as the subject of the study.

The surface area of the commune amounts to approx. 52 km^2, of which 20% is constituted by fish husbandry ponds and approx. 33% of the total area of the commune is covered by forests and forest areas belonging to the first attractiveness zone of the highest environmental values. The forms of nature protection in the area are represented by environmental conservation reserves, e.g. a forest-water-ornithological nature reserve. The picturesque areas of the commune determine its agritourism-focused character. The structure of the ponds and the way in which they are managed determines their extraordinary biodiversity, which is manifested by the presence of rare and endangered bird species (night heron). The surrounding gravel mines and post-mining areas increase the diversity of breeding and feeding habitats, and the entire habitat system creates an attractive place for bird watchers. The dense network of roads is ideal for cycling tourism. These qualities suggest that the preferred way of development of the commune should be recreation, as well as protection of environmental values.

The described mining plant is an establishment forming part of a multi-industry company established in the 1950s, which now forms a joint-stock company. According to preliminary estimates, the mining plant selected from the 10 other plants belonging to the same company shows potential for improvement of works related to the reclamation of post-mining areas in view of the increasing financial problems of the company.

Input data for the selected mining plant X have been entered into the FSDR system and then subjected to the fuzzification process, as shown in Table 4.

TABLE 4

FSDR system input data for plant X and their linguistic values

Variable name	Unit	Input data	Linguistic value
financial resources of the entrepreneur	[PLN/ha]	67,300	small
demography	[persons/km2]	179	small
entrepreneurship	[number of entities / 1000 residents]	68	small
sports facilities	[number of facilities / 1000 residents]	2	bad
interest in recreation	[%]	70	big
interest in fishing	[%]	69	big
farming and commercial traditions	[%]	64	big
social acceptance	[%]	5	small
protected plant and animal species	[number of protected species]	21	big
landscape value	[score]	10	big
environmental attractiveness	[score]	10	big
forest cover	[%]	5	small
transport access	[h]	0.75	good
distance from residential areas	[m]	200	small
excavation flooding	[%]	75	big
water quality class	[class]	2	high
excavation depth	[m]	3	small
slope pitch	[°]	35	big

After entering the input data and their fuzzification, the inference process was performed following the rules base, as shown in Figure 2.

The inference process was conducted with a rules base containing 26 linguistic rules. In the figure, one can see the activated membership functions for the conclusions of particular rules and the assigned membership function of the resulting fuzzy set of conclusions for the entire rules base, which is presented in the last line of the list.

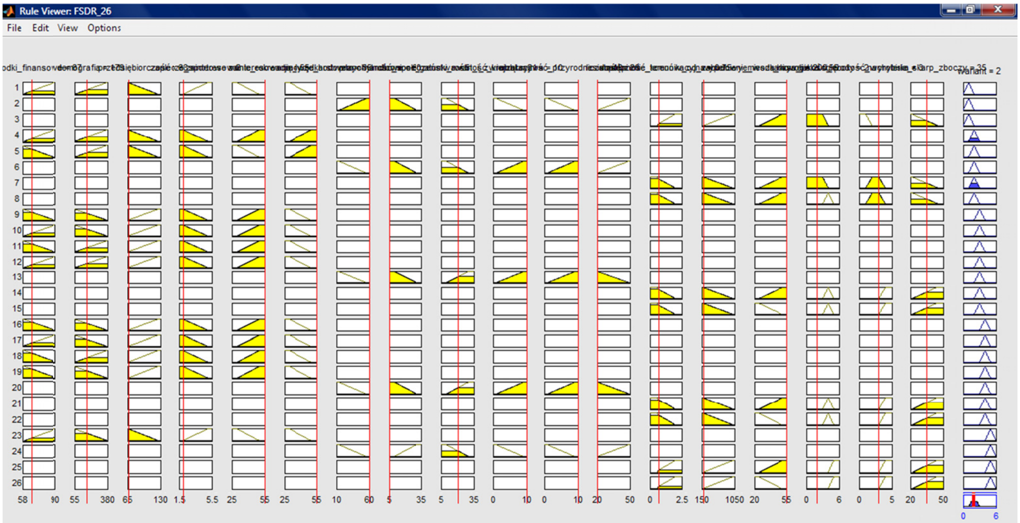


Fig. 2. Inference process in the FSDR fuzzy system. *Surce:* (Król-Korczak, 2016)

Sharp input values in the FSDR fuzzy system are presented in the form of vertical lines. Each input variable is described by two to three linguistic values. Both the premises and conclusions are fulfilled to some extent what is illustrated by filling in only a part of the fuzzy set with colour – the height of the filling corresponds to the membership degree value. The applied conjunction operator is the MIN operator, whose advantage is revealed when multiple input variables are taken into account, because its operation does not "drastically" decrease the resulting level of activation of the premises, as in the case of the PROD operator, for example.

In order to assess the fulfilment of the premise, the mechanism of implications was introduced and the result of conclusion fulfilment degree was calculated.

As a result of the simulation carried out in the selected example, the resulting set of fuzzy conclusions was obtained for the entire rules base. As a result of the inference process using the centre of gravity method, a sharp value W = **2.0** was obtained, which indicates the water direction reclamation – variant II – with membership degree of 1 (Fig. 3).

It is worth noting that the proposed direction coincides with the actions taken by the entrepreneur (Fig. 4).

The simulation of the developed fuzzy system supporting the decision on the direction of reclamation was extended by additional examples, taking into account the change in the values of particular linguistic variables in terms of analysing the applicability of the FSDR system for other mining companies and the completeness of the proposed rules base. Table 5 presents input data for sample natural aggregate mining plants from the Małopolskie (Lesser Poland) Voivodeship, which differ from the analysed mining plant "X".

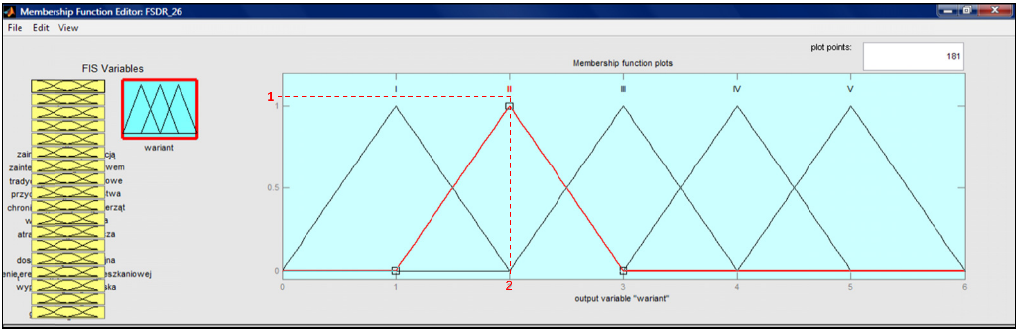


Fig. 3. Membership functions for the resulting value of the FSDR system. *Surce:* (Król-Korczak, 2016)

Fig. 4. View of the reclaimed post-mining area. *Surce:* (Król-Korczak, 2016)

The units used to verify the method supporting the selection of the reclamation direction were four mining plants operating in sand and gravel aggregate deposits. These plants have been named for the purposes of this paper: "A", "B", "C" and "D" (Table 5).

Mining plants „A",„B" and „C" are owned by individual entrepreneurs. The owner of mining plant "A" has been involved in the mining industry for over a dozen years. Thus, the action plan for reclamation has already been developed by the entrepreneur to some extent. Furthermore, these plants have a similar surface area to the analysed mining plant. Mining plant "D" is part of a large mining company and is located on a surface area of more than 20 ha.

As a result of the conclusion made for individual mining plants: „A", „B", „C", „D", the FSDR system proposed reclamation directions with a certain membership degree – the results are summarised in Table 6.

On the basis of the above analyses, it should be stated that in each of the five mining plants (with different input data), the system suggested different solutions. It is worth noting that for each of the presented examples, different variables have lesser or greater impact on the results of aggregation and defuzzification. This mean that the system is sensitive on variables change and can be used for different conditions of natural gravel and sand aggregate mining plants.

TABLE 5

Input data to the FSDR system for the sample mining plants

No.	Mining plants	Linguistic variable values for individual plants																	
		Financial resources of the entrepreneur	**Demography**	**Entrepreneurship**	**Sports facilities**	**Interest in recreation**	**Interest in fishing**	**Farming and commercial traditions**	**Social acceptance**	**Protected plant and animal species**	**Landscape value**	**Environmental attractiveness**	**Forest cover**	**Transport access**	**Distance from residential areas**	**Flooding**	**Water quality class**	**Excavation depth**	**Slope pitch**
1.	Mining plant “A”	74	235	125	2	28	41	35	25	22	6	1	10	2	950	39	3	1	30
2.	Mining plant “B”	58	300	110	3	33.5	45	60	28	25	8.8	4	29	2	800	48	4	5	23
3.	Mining plant “C”	78	265	100	3	42	60	35	22	13	9	4	49	2.5	800	49	4	4	39
4.	Mining plant “D”	84	288	123	4	92	85	60	24	35	10	10	19	2.5	1050	55	5	5	50

Surce: based on (Król-Korczak, 2016)

TABLE 6

Results of the FSDR system for the analysed mining plants

No.	Plant	Defuzzification result (sharp value)	Reclamation variant with membership degree
1.	Mining plant “X”	**2.00**	**II** – 1.00
2.	Mining plant “A”	**1.01**	**I** – 0.99
3.	Mining plant “B”	**2.77**	**III** – 0.77
4.	Mining plant “C”	**3.72**	**IV** – 0.72
5.	Mining plant “D”	**4.81**	**V** – 0.82

Surce: based on (Król-Korczak, 2016)

4. Conclusions

Supporting the decision to select the reclamation direction is particularly important in the case open pit gravel and sand aggregate mines, which carry out the mining process under certain conditions. These conditions refer to plant-specific factors, and in particular relate to economic, social, formal and legal, environmental, spatial, hydrological, hydrogeological and geological characteristics.

This specificity and low repeatability of identical conditions in terms of factors characteristic for natural aggregate mining plants require focusing attention on previous experience and knowledge accumulated as a result of reclamation works in the decision-making process related to the selection of the direction of reclamation.

In the conditions of knowledge-based economy and the dynamic development of computer science, there is a possibility to support the process of making the decision regarding the selection of the direction of reclamation with modern tools, which can significantly influence its effectiveness and the quality of obtained solutions. One example of such tools is fuzzy systems, which enable the collection and repeated use of the knowledge of experts.

The FSDR system developed for the purpose of supporting the decision regarding the selection of the direction of reclamation was verified based on the example of the open-pit mining gravel and sand aggregate mining plant in one of the communes of Małopolska (Lesser Poland region), where the direction of reclamation was provided as a result of the input data entered – namely, reclamation in the water direction (fishing). This is also the direction currently pursued by the entrepreneur.

The developed fuzzy system creates new possibilities to support engineers and entrepreneurs in solving problems which require taking into account fuzzy categories. The results provided by the system can support, among other things, a rational approach in the case of selecting the direction of reclamation of post-aggregate mining areas by taking into account various factors characteristic of the given mining area. They can also facilitate the work of the engineer in planning a specific method of reclamation of the post-mining areas.

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