Hybrid expert system aiding design of post-mining regions restoration

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ABSTRACT

Reclamation as one of the stages in the life cycle of a mine is realized using different techniques and technology adapted to the unique characteristics for any given mining institution. Restoration of terrain from open-cast mining is influenced by many factors and processes; the results are open to interpretation and are not predictable. Most of the aforementioned factors have qualitative characteristics. The number and complex connections among these factors make the analysis of post-mining terrain restoration expensive and time-consuming. Therefore the automation of the decision making is desirable. In this paper, a fuzzy decision support system design is proposed for the restoration of post-mining regions. The system was applied to the testing of decision making concerning the direction of revitalization in an open-cast mining institution in Zator community, southern Poland. The considered gravel mine has worked since 1951 and belongs to the Cracow Aggregate Exploitation Company.

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1. Introduction

The mining of mineral materials affects the environment in special ways – degrading or destroying the scenery, altering and changing the terrain and removing considerable areas of agricultural soil and forest. Open-cast mines excavate the soil to exploit the natural resources, giving rise to the problem of either redevelopment or restoration of the excavations when the exploitation is complete.

Numerous papers provide guidelines on land reclamation methods for modern open-cast sites (Coppen and Bradshaw, 1982; Glen, 1994; Ricks, 1995; Prach et al., 1999; Schaaf, 2001; Skleniška and Lhota, 2002). The development of the reclamation strategy, after-use possibilities and the constraints to plant growth and soil development, taking environmental problems into account, are discussed by Andres and Mateos (2006). Details concerning reclamation procedures and techniques available are considered as are the practical guidelines for each (Hancock, 2004). These details vary regionally, so each region has its own specificity, such as the USA (Brown, 2005), South America (Parrotta and Knowles, 2001), U.K. (Cloke et al., 1996), continental Europe (Hendrychová, 2008; Prach et al., 1999; Skleniška et al., 2004; Wiegley and Felinks, 2001), Asia (Agarwal and Shanker, 2004) and Australia (Bell, 2001). Alternative details for various climatic regions should be taken into consideration by combining local knowledge with the general details and criteria.

Reclamation, as one of the stages in the life cycle of a mine, is realized using different techniques and technology, adapted to the unique characteristics for any given mining institution. It is influenced by many factors and processes so the results are hard to predict. Therefore, it is extremely important to have tools aiding decisions concerning the revitalization of regions, the more so because most of the experts are educated in specialized fields – hydrologists, geologists, ecologists, economists.

According to Polish law, the person or institution responsible for the destruction of the environment is obliged to obtain agreement on the restoration required and perform the repairs. There is no detailed legal description for redevelopment except for the definition. Currently, the definition for executing basic reclamation is return the terrain to the same use as the local surrounding terrain. Companies are required to take account of the complexity and many alternative revitalization processes that characterize post-mining terrain restoration.

Realizing the difficulty of making decisions for the future functions of a post-exploitation area, the authors present and test an algorithmic aid for an analysis of the optimum choices for revitalization. Since some factors characterizing excavation sites have a qualitative character, they cannot be expressed numerically. Therefore, the inference tree, being the decision-making algorithm description, is aided by fuzzy inference moduli.

This paper is organized in the following way. The systematization of factors characterizing excavation sites, objects and
post-industrial areas are presented in Section 2. The implemented expert system, a hybrid rule system with fuzzy moduli, is introduced in Section 3. The introduced system is tested in the process of making a decision about revitalization direction in an open-cast mining institution in southern Poland – see Section 4.

2. The problem description

The decision process concerning the optimum form of reclamation and redevelopment is an essential component of the terrain restoration after the open-cast mining of natural resources. It should be characterized by the most important factors and criteria of the revitalization. The exact analysis and profile of environmental protection factors should include cultural values, traditions and societal expectations. The practical basis for reclamation should take into consideration both economic issues and social acceptability.

The process of making choices in directions for the developments of terrains post-exploitation is preceded by inventorying of the characteristic factors for a given region. This enables us to specify and analyse a profile of factors and to create a criterion that defines the limitation and choice for the form of revitalization.

The factors characterizing the excavation, objects and terrains post-exploitation, as well as the criteria for selecting the optimum direction of reclamation and redevelopment are presented on the

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Classification of factors characterising open-cast mining excavation sites, objects and post-industrial areas and criteria determining a choice of an optimal mode of reclamation and redevelopment.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factors</td>
<td>Possible factors characterizing excavations and commentary</td>
</tr>
<tr>
<td>Economical</td>
<td>The direction of reclamation and development depends on the level of predicted expenses to be incurred in liquidation and reclamation, as well as later maintenance of the post-mining areas. The costs determine the function of natural resource post-mining region. The correct choice of direction in reclamation decisions, based on analysed factors in projecting phases of the exploitation, shapes the final excavation form, along with the bingstead or wastes.</td>
</tr>
<tr>
<td>Social</td>
<td>The demography of a local community, its wealth, level of education, traditions and customs, social preferences and needs will be considered in case of commercial ventures, in planning demand on products, or services. The optimal choice could be, therefore, a local opinion poll of community and council to discover their preferences for the utilization of the post-mining terrains.</td>
</tr>
<tr>
<td>Formal-legal</td>
<td>These are: obligation to conduct reclamation and development forms of protection for example the protection of nature, relics, structure of property of soils, and the local plan of spatial development.</td>
</tr>
<tr>
<td>Environmental</td>
<td>This includes geological formations, landscape and indigenous plants and animals. The value placed on specific natural resources should determine relevant environmental protection policies such as: maintenance of ecological processes, stability of ecosystems, maintaining biodiversity, habitat, geological heritage and the education of the local community.</td>
</tr>
<tr>
<td>Spatial</td>
<td>The degree of the terrain urbanization, shape of the communication infrastructure, distance to protected terrains, distance to industrial institutions and the possibility of the individual commuting using private or public transport.</td>
</tr>
<tr>
<td>Hydro geological</td>
<td>The presence or absence of water on the bottom of an excavation, water quality, the depth of underground water; thickness of impermeable geological layers as well as the hydro geological connections.</td>
</tr>
<tr>
<td>Geological-engineering</td>
<td>Measurement and description of an excavation post-mining: The base – type of rock, penetrability of the base, tectonic phenomena (offsets and fissures) and karst and the morphology. The slopes – type of rock and stability, angle of inclination. These factors include type of excavation, shape, depth and surface, quantity of groundwater exploitation, size of external and internal bingstead, type of stored material, shape and inclination of the final slopes.</td>
</tr>
<tr>
<td>Cultural</td>
<td>The objects of technique and material culture, for example: the old mines, buildings, workshops, constructions, tools, machines, transportation, illustrating technical progress. Also included are historical and spiritual monuments, for example: places of martyrdom, tombs, and extermination camps.</td>
</tr>
</tbody>
</table>
Table 2
Examples of opportunities for mining-related reclamation and development.

<table>
<thead>
<tr>
<th>General</th>
<th>Detailed specification of reclamation directions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural</td>
<td>Breeding: animals, fish, poultry</td>
</tr>
<tr>
<td></td>
<td>Cultivation: arable land, orchards, meadows and gardens</td>
</tr>
<tr>
<td>Forest</td>
<td>Protected forest</td>
</tr>
<tr>
<td></td>
<td>Commercial woodland</td>
</tr>
<tr>
<td></td>
<td>Recreation: tourist routes, parks, paths, cycling routes, health routes, forest promotion complexes</td>
</tr>
<tr>
<td>Natural</td>
<td>Different forms of protection depending on the nature value e.g., wild life habitats, ecological parks, geological heritage sites, etc.</td>
</tr>
<tr>
<td>Water</td>
<td>Recreation: artificial lakes, water sports</td>
</tr>
<tr>
<td></td>
<td>Economic: storage reservoirs, drinking water reservoirs, fish ponds</td>
</tr>
<tr>
<td>Economic</td>
<td>Housing building, campuses, garages</td>
</tr>
<tr>
<td></td>
<td>Industry</td>
</tr>
<tr>
<td></td>
<td>Services: incubators, warehouses, stores, parking areas</td>
</tr>
<tr>
<td></td>
<td>Waste storage yards</td>
</tr>
<tr>
<td>Cultural</td>
<td>Educational: thematic routes, museums (including industrial museums), heritage parks, laboratories, computer labs, conference halls</td>
</tr>
<tr>
<td></td>
<td>Contemplative: memory parks</td>
</tr>
<tr>
<td></td>
<td>Artistic: expositions, exhibition and concert halls</td>
</tr>
<tr>
<td></td>
<td>galleries, stages, cinemas, theatres</td>
</tr>
</tbody>
</table>

The decision process concerning directions of post-mining restoration can be algorithmized. However, a few variables cannot be expressed in terms of two-valued logic. Therefore, the fuzzy inference, based on type-1 fuzzy sets (Zadeh, 1965), is applied as a part of the inference process (Fig. 2). The increasing popular fuzzy logic technology has achieved impressive achievements in engineering applications. The basic nature of post-mining decision process fits well into a fuzzy logic application that includes using membership functions, fuzzy rules, fuzzification and defuzzification processes. Membership functions are used to convert the linguistic descriptions of the problem into membership values, which are appropriate for computer implementation. Since there was no training set, the basis of knowledge has been created basing on expert knowledge, statistical data and general principles and laws, tracing the approach described in Chow and Tram (1997).

3.1. Fuzzy inference moduli

In fuzzy moduli the following variables were used as premises in inference rules:

(a) Population is described by two fuzzy sets: small and large.
(b) Interest in recreation is described by two fuzzy sets: small and large.
(c) Level of unemployment is described by two fuzzy sets: small and large.
(d) Traditional economic activity is described by two fuzzy sets: small and large.
(e) Enterprise is described by two fuzzy sets: small and large.
(f) Possibility of introduction of protected plants and animals is described by a singleton.
(g) Water purity class is described by three fuzzy sets: I, II and III.

![Fig. 1. Factors that account for the data entrance and possible directions of reclamation which are the data exit.](image-url)
Fig. 2. The inference tree.

(h) Slope gradient of excavation is described by two fuzzy sets: small and large.
(i) Depth of excavation is described by three fuzzy sets: very small, small and large.
(j) Interest in angling is described by two fuzzy sets: small and large.
(k) The quality of public transport is described by two fuzzy sets: good and bad.
(l) Interesting geological conditions are described by a singleton.
(m) Number of schools is described by a singleton.
(n) Number of sports facilities is described by a singleton.
(o) Social approval is described by two fuzzy sets: small and large.

In fuzzy inference moduli, a few types of fuzzy sets have been used. Variables described in points (a)–(e), (h)–(j) and (o) are characterized by fuzzy sets, small and large, of which membership function are shown in Fig. 3.

In the case of the point (g), three classes of purity of water have been used – see Fig. 4.

In the case of the point (i), three fuzzy sets have been used for variable description: very small depth of open-cast mining (VS), small (S) and large (L) see Fig. 5.

Fig. 3. The membership functions of fuzzy sets “small” and “large”.

Fig. 4. The membership functions of water purity.

In the case of points (f) and (l)–(n), instead of singletons very narrow triangular functions have been used.

In the fuzzy module 1 there are six answers concerning adaptation possibilities of the post-mining area:

(1) Lido construction.
(2) Reservoir creation for angling.
(3) Fish farm creation.
(4) Water-forest recreational park creation.
(5) Formation of a nature reserve.
(6) Salmon fish farm creation.

Fig. 5. The membership functions of depth of excavation.
In the fuzzy module 2 there are four answers concerning adaptation possibilities of the post-mining area.

(1) Forest park having recreational and sport character.
(2) Nature reserve creation.
(3) Geological reserve creation.
(4) Water-forest recreational park creation.
(5) Forest.

The forest direction (point 5) is implemented if activation of all first six rules in the second modulus is low – see moduli rules specified below. Therefore, the membership function for output values for the second module consist of four modals – the fifth possibility is realized outside the Mamdani system.

In the fuzzy module 3 there are two answers concerning adaptation possibilities of the post-mining area.

(1) Economic direction of adaption.
(2) Forestation.

The fuzzy module 1 consists of the following nineteen if-then rules.

(i) If the level of demography is large and the interest in recreation likewise, then mode of the revitalisation is recreational water (lido).
(ii) If the level of interest in fishing is large, then mode of the revitalisation is recreational water (angling).
(iii) If the level of unemployment is large and the large traditional farm-commercial-process, likewise then mode of the revitalisation is agricultural (fish farming).
(iv) If the level of unemployment is large and the traditional farm-commercial-process is small, then mode of the revitalisation is recreational (lido).
(v) If the level of enterprise is large and there is large interest in recreation, then mode of the revitalisation is recreational (lido).
(vi) If the level of enterprise is large and small interest in recreation, then mode of the revitalisation is agricultural (fish farming).
(vii) If entrepreneurship is small and large interest in angling, then mode of the revitalisation is recreational (fishery).
(viii) If the level of enterprise is small and interest in recreation is small, then mode of the revitalisation is water-forest recreational park.
(ix) If there is lack of traditions and interest in angling is large, then mode of the revitalisation is recreational (lido).
(x) If water purity is first class and there is large traditional farm-commercial-process, then mode of the revitalisation is agricultural (salmon fish farming).
(xi) If water purity is second class and there is large traditional farm-commercial-process, then mode of the revitalisation is agricultural (fish farming).
(xii) If there is lack of traditions and interest in angling is large, then mode of the revitalisation is recreational (fishery).
(xiii) If there is small depth of excavation, then mode of the revitalisation is agricultural (fish farming).
(xiv) If there is very small depth of excavation and the slope gradient of excavation is small, then mode of the revitalisation is recreational (lido).
(xv) If there is large depth of excavation and small interest in angling, then mode of the revitalisation is recreational (fishery).
(xvi) If there is large depth of excavation and small interest in angling then mode of the revitalisation is water/forest (recreational park).
(xvii) If there is small depth of excavation and the slope gradient of excavation is large then mode of the revitalisation is water-forest (recreational park).
(xviii) If there is bad public transport and lack of interest in recreation then mode of the revitalisation is natural (nature reserve) or water/forest (recreational park).
(xix) If there is good public transport and large interest in recreation then mode of the revitalisation is water recreational (lido).

The fuzzy module 2 consists of the following seven if-then rules.

(i) If the level of population is large and there is large interest in recreation then mode of the revitalisation is forest recreational (sporting grounds).
(ii) If there are protected species then mode of the revitalisation is natural (nature reserve).
(iii) If there are interesting geological conditions then mode of the revitalisation is natural (geological reserve).
(iv) If there is bad public transport and lack of interest in recreation then mode of the revitalisation is natural (reservation) or forest recreational (sporting grounds).

Fig. 6. The membership function for output values. (a) The membership functions for output values for the first module. (b) The membership functions for output values for the second module. (c) The membership functions for output values for the third module.
(v) If there is good public transport and interest in recreation, then mode of the revitalisation is forest recreational (sporting grounds).
(vi) If there are many schools and lack of sports facilities, then mode of the revitalisation is water-forest recreational park.
(vii) If rules (I)-(VI) have low activation level values, then mode of the revitalisation is forest.

The fuzzy module 3 consists of the following two if-then rules.

(i) If there is large societal approval, then mode of the revitalisation is economic (industrial waste lagoon).
(ii) If there is small societal approval, then mode of the revitalisation is forest.

3.2. Inference process in fuzzy moduli

The inference process is based on the approach proposed by Mamdani (1974, 1976). In this paper, the singleton fuzzifier is used. The fuzzy rule base consists of a collection of fuzzy if-then rules \( R^{(k)} \) of the form:

\[ R^{(k)} : \text{If } (x_1 \text{ is } A^{(k)}_1 \text{ and } \ldots \text{ and } x_n \text{ is } A^{(k)}_n), \text{ then } y \text{ is } B^k \]

where \( A^{(k)}_1, A^{(k)}_2, \ldots, A^{(k)}_n \) are fuzzy sets characterized by membership functions \( \mu_{A^{(k)}_i}(x_i) \), whereas \( B^k \) are fuzzy sets characterized by a membership function \( \mu_{B^k}(y) \). The firing strength of rules is given by:

\[ \mu_{A^k}(x) = \frac{1}{n} \sum_{i=1}^{n} \mu_{A^{(k)}_i}(x_i) \]

Each of rules determines a fuzzy set \( \tilde{B}^k \) given by composition rule of inference:

\[ \tilde{B}^k = A' \circ (A^k \rightarrow B^k) \]

where \( A^k = A^{(k)}_1 \times A^{(k)}_2 \times \ldots \times A^{(k)}_n \). Fuzzy set \( \tilde{B}^k \) is characterized by membership function:

\[ \mu_{\tilde{B}^k}(y) = \mu_{A^k \rightarrow B^k}(x, y) = T(\mu_{A^k}(x), \mu_{B^k}(y)) \]

where \( T \) is a t-norm, in this case it is a product operator.

3.3. Defuzzification process

In all three moduli defuzzification was performed in the following way. The output possibilities were encoded as triangular fuzzy sets with maxima in natural numbers representing the output possibilities – see Fig. 6. After calculating the output fuzzy set, the value of \( x \)-coordinate of its membership function maximum,
say $x_0$ is checked. Then, this output possibility is chosen which is
encoded by the number nearest to $x_0$. If the calculated membership
function of the output fuzzy set has a few maxima in which its
values are equal to one, then the alternative concerning all pointed
solutions is put as the system answer.

4. Results

Nowadays, the institution exploiting a mine is obliged by Polish law to restore the post-mining terrain. However, there are numerous old open-cast mines which were abandoned when the exploitation was over. In such a case, usually, excavations were flooded and ponds or lakes were naturally created. Surrounding terrains became usually naturally afforested or bush-covered. Such environments became rich water and water-land biocenoses. Now they are wildlife sanctuaries, breeding grounds, watering places and winter habitats. Old abandoned gravel mines at the Nysa Klodzka river can be put as examples of such natural post-mining restoration processes in Poland. However, abandoned post-mining terrains can be dangerous for posterior users. Zakrzówek, the abandoned gravel mine near the borders of Cracow City is an example of such a risk because of its afforested, vertical, high rocky walls. Therefore, contemporarily, post-mining terrains are restored according to certain standard procedures.

The introduced inference system is applied to make a decision of revitalization direction in the gravel mine which has worked since 1951 and belongs to the Cracow Aggregate Exploitation Company. The area of the mine is 50 ha. It is located in the Zator district, southern Poland.

The Zator commune is situated 46 km west from Cracow and 48 km from Katowice. Good public communication – the railway and buses – made Zator a potential region for development. This is an attractive location, especially for a weekend getaway for occupants from Silesia and Cracow. The area of the Zator community is about 52 km². The Zator community consists of 20% fishing ponds, and approximately 33% of the remaining general surface is forest terrain. The forest terrain is part of the number “I Zone” for both attractiveness and the highest natural values. The area formation is represented by forest-water – ornithological reserves, as well as Nature 2000 and the White Park. The picturesque terrains of the Zator community determine its agro-touristic character. The structure of the ponds is determined in large part by the fishing economy. This economic determination is reflected in the unusual biodiversity, as manifested by the occurrence of rare and endangered bird’s species, for instance Gorsachius leucopterus. The adjoining gravel pits and post-mining terrains increase the variety of nesting and feeding sites. The whole nesting system creates an attractive spot for ornithology lovers. The thick net of roads is suitable for bicycle tourism. Green bushes, ponds and numerous nesting sites of water fowl make this terrain the “frog’s country” and one of the favourite places for walks, not only for local occupants but also visitors looking for silence and contact with nature. These imply that the preferred way of development is recreation and protection of natural values.

Fig. 8. Fuzzy inference for the second case.
The above description implies that the post-mining area is waterlogged with water purity of the first class. Therefore, in the inference tree – see Fig. 2, the fuzzy module 1 is activated. The following values of input variables should be assumed:

- The level of population is 175 where the interval of values is (90:216).
- The level of unemployment is 10.6% where the interval of values is (9:14.3).
- The enterprise is 66 where the interval of values is (0:94).
- There is water purity of the first class.
- The depth of excavation is 8.8 where the interval of values is (1:20).
- The slope gradient of excavation is about 30° where the interval of values is over 5°.
- There is a possibility of the introduction of protected plants and animals.
- The public transport is good where the interval of values is (0 h:2 h).

The values of the rest of the variables cannot be deduced from accessible information concerning Zator community. The following variants were assumed:

- **The first case**
  - The interest in recreation is 5.5 where the interval of values is (1:10).
  - The traditional farm-commercial-process is 5 where the interval of values is (1:10).
  - The interest in angling is 5 where the interval of values is (1:10).

  In this case the result of the fuzzy interference is a lido – see Fig. 7.

- **The second case**
  - The interest in recreation is 3.17 where the interval of values is (1:10).
  - The traditional farm-commercial-process is 6.61 where the interval of values is (1:10).
  - The interest in angling is 7.22 where the interval of values is (1:10).

  In this case the result of the fuzzy interference is a reservoir for angling or salmon fish farming – see Fig. 8.

- **The third case**
  - The interest in recreation is 3.17 where the interval of values is (1:10).
  - The traditional farm-commercial-process is 6.61 where the interval of values is (1:10).
  - The interest in angling is 2.78 where the interval of values is (1:10).

  In this case the result of the fuzzy interference is a water-forest recreational park or salmon fish farm – see Fig. 9.

The results obtained from the implemented hybrid inference system coincide with the direction of the applied restoration in Zator community. Generally, water development was utilized.
mining area both during exploitation and after restoration is presented in Fig. 10.

5. Concluding remarks

The exact analysis and profile protection of the environmental factors should take into account engineering and economic conditions, cultural values and the traditions and expectations of the society. The practical basis for reclamation must consider both the economic and social acceptance issues. The main problems for consideration are:

- Settlement and function of the water reservoir.
- Qualification of shape and dimensions of final excavation; the documentary evidence referring to mining activity in the region and the state of the environment, with regard to the proposed location of the future reservoir.
- Preparation of hydrological shape and dimensions of final excavation based on geological conditions.
- Study of ways of protecting the geological-engineering objects of the excavation.
- Balance of water supplies.
- Prognoses concerning reservoir usage; research into ways of protecting water quality from unfavourable changes.

- Feasibility studies on integration of new objects, created in connection with the terrain revitalization, with those remaining post-mining.
- Local economic traditions and needs.
- Leisure and recreation needs.

The analysis of post-mining terrain restoration is expensive and time-consuming, because of the number of complex connections between the various factors. Therefore, the automation of the decision-making process is desirable. Computer methods have been used as a decision support system in a post-mining restoration possibilities analysis (Evans and Willgoose, 2000; Evans et al., 2000; Hancock et al., 2000; Hancock, 2004). However, it seems that artificial intelligence systems have not been used in this context apart from the expert system for prediction of vegetation succession in human-disturbed habitats created by Prach et al. (1999). The present paper is intended to address this. The proposed approach to decision making, concerning the direction of post-mining restoration based on hybrid rule-fuzzy system, appears to be new.

The applied fuzzy moduli were implemented as Mamdani-like systems, in which the defuzzification algorithm is a variant of those used in classical Mamdani systems (Jang et al., 1997, Section 4). The introduced inference system was applied to testing decision-making concerning the direction of revitalization after open-cast mining in Zator community, southern Poland. In conclusion, the
results from the system demonstrated that it was able to postulate the same solutions as those actually implemented in that area, and the solutions were positively verified in practice.

It should be stressed that the implemented system is introductory and therefore has some limitations. First of all, it was created for small open-cast mines located in central Europe. On the one hand, in the case of large mines, revitalisation of the whole local ecosystem should be taken into consideration as an essential possibility if the natural restoration direction is chosen. In such a case, the presented expert system could be completed by an expert system of the type described by Sklenička et al. (2004) in order to forecast the ecosystem behaviour. On the other hand, other factors, for instance various climatic conditions, should be taken into consideration if the system were to be adapted for more diversified climatic areas, for instance on the scale of the whole continent. The described approach can be also adapted for other types of mines, not only open-cast ones. It means that in this paper not only the implementation of the concrete expert system is described but the general design of the system aiding the decision process concerning post-mining restoration is presented as well. The general way consists of creating an inference tree in which all the possibilities are regarded in the context of vital factors. The tree can be completed by fuzzy moduli if some factors have a vague character.

References


