reviewed paper

Geographic Information System and Genetic Algorithm Application for Multicriterial Land Valorization in Spatial Planning

Mirza PONJAVIC & Zikrija AVDAGIC & Almir KARABEGOVIC

(MSc EE Mirza Ponjavic, Gauss, Geoinformation Systems, Stupine B9/6, Tuzla, mirza@gauss.ba
PhD Zikrija Avdagic, Sarajevo University, Faculty of Electrical Engineering, Zmaja od Bosne b.b., Sarajevo, zikrija.avdagic@etf.unsa.ba
MSc EE Almir Karabegovic, Gauss, Geoinformation Systems, Stupine B9/6, Tuzla, almir@gauss.ba)

ABSTRACT

This paper is focused on the development of methodology for multicriterial land valorization in land use planning by application of genetic algorithm. One of the key tools for design of the decision support system based on this methodology is geographic information system which serve to quantify multicriterial data and represent resulting spatial data. The methodology and the algorithm are applied to a specific problem of spatial planning in Tuzla Canton, Bosnia and Herzegovina.

The crucial points of the research are the following: possibility of multicriterial valorization of the land from the GA use perspective, how to utilize the capacity of the GA optimization techniques in the frame of decision support system and with usage of the GIS tools and how to apply the GA in the field of genotype presentation in spatial modeling.

1 INTRODUCTION

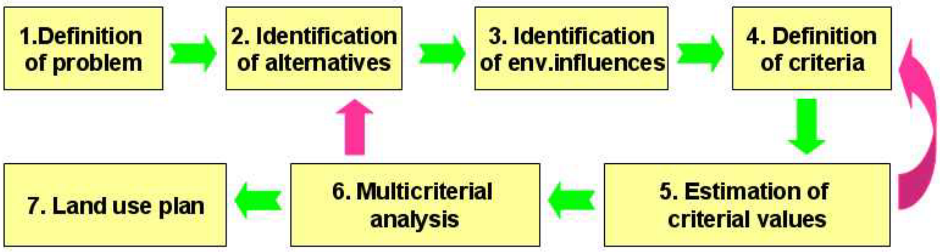
One of the key products in urban spatial planning is digital land use map, that with a system of settlements and traffic infrastructure plan, describes spatial organization [4]. Using the optimal model of multicriterial land use valorization with geographic information system (GIS), this map could be generated automatically [1]. The model requests a methodology built on existing principals of spatial planning and based on both GIS and multicriterial spatial analysis applications[10]. The methodology could be used for development of decision support system in spatial planning.

In this work it has being developed a methodology for finding the optimal model of multicriterial land valorization in land use planning by application of genetic algorithm (GA). One of the key tools for design of the decision support system based on this methodology is geographic information system which serve to quantify multicriterial data and represent resulting spatial data. The methodology and the algorithm are applied to a specific problem of spatial planning in Tuzla Canton, Bosnia and Herzegovina.

2 MULTICRITERIAL OPTIMIZATION PROBLEM IN SPATIAL PLANNING

The optimization problem always exists when there are more alternatives in space, among which the most acceptable should be selected. So, problem is related to multicriterial optimization [8].

Spatial planning methodology contents three phases: analysis, synthesis and planning. Graph 1 shows procedures during the multicriterial analysis in spatial planning.



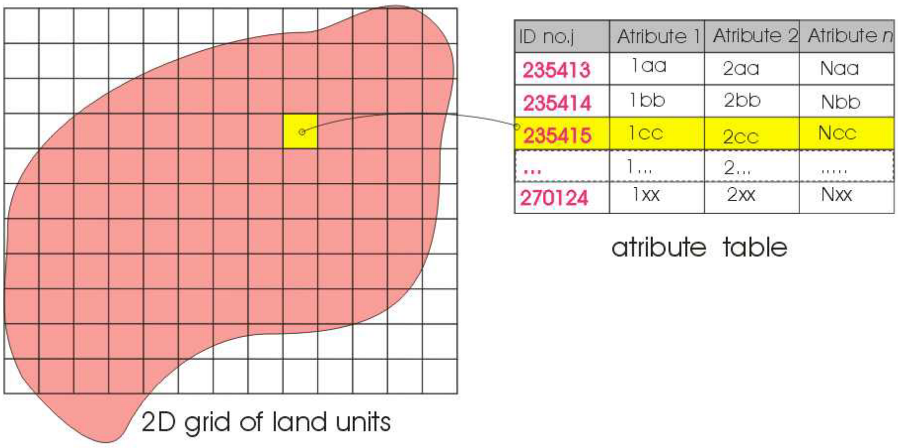
Graph 1: Multicriterial Analysis Process

In synthesis phase of planning, typically, opposed alternatives for spatial organization are presented by synthesis models. Due to environmental trend in urban spatial planning it is defined a, so called, environmental model based on protection of environment, and as such favors criteria which guarantee an environmental values continuity. Another one is functional, based on aspect of as more as possible land exploitation for settling, not seeing the environmental consequences.

Simulating these variants by adjusting the criterial weights it is possible to search for optimal model of spatial organization. This fact designates to possibility of genetic algorithm application in multicritrial optimization process.

3 SPATIAL REPRESENTATION

For an example is used region of Tuzla Canton enclosing 13 municipalities with total area of 2700 km2. For spatial representation of the region of interest is used 2-dimensional grid of cells (land units), arranged in rows and columns, and with resolution of 100mx100m (Graph 2). To each of land units, it is added a database record, i.e. a set of attributes related to the unit properties in sense of its accessibility. By these attributes, during the multicriterial analysis it is performed scoring and classification of the units. Optimal model of land valorization is result of processing of data related to specific criteria [12].



Graph 2: 2-dimensional Grid of Cells

For realization of 2-dimensional grid, its integration with criterial database and geographic thematic representation of results is used GIS [7].

Additionaly, this GIS approach makes planners enable to use various spatial information formats such as vector or raster data and convert it in spatial multicriterial data.

4 CRITERIAL FACTORS AND CATEGORIES USED FOR LAND USE VALORIZATION

For land use valorization, the following criterial factors are used:

land accessibility (related to the center of settlement),

slope of terrain,

relative height (above lowest point) of terrain,

aspect of terrain,

value of land usable for agriculture and forestry (according to adopted soil classification) and

environmental value of vegetation coverage (estimated according to basic topographic classification and CORINE methodology).

For synthesis models (functional and environmental) are introduced the following four categories of land use:

extraordinary suitable,

very suitable,

suitable and

unsuitable.

Extraordinary suitable category is related to area for reconstruction, and basic use is mixed: collective and individual dwellings with central functions (e.g. services, administration etc.).

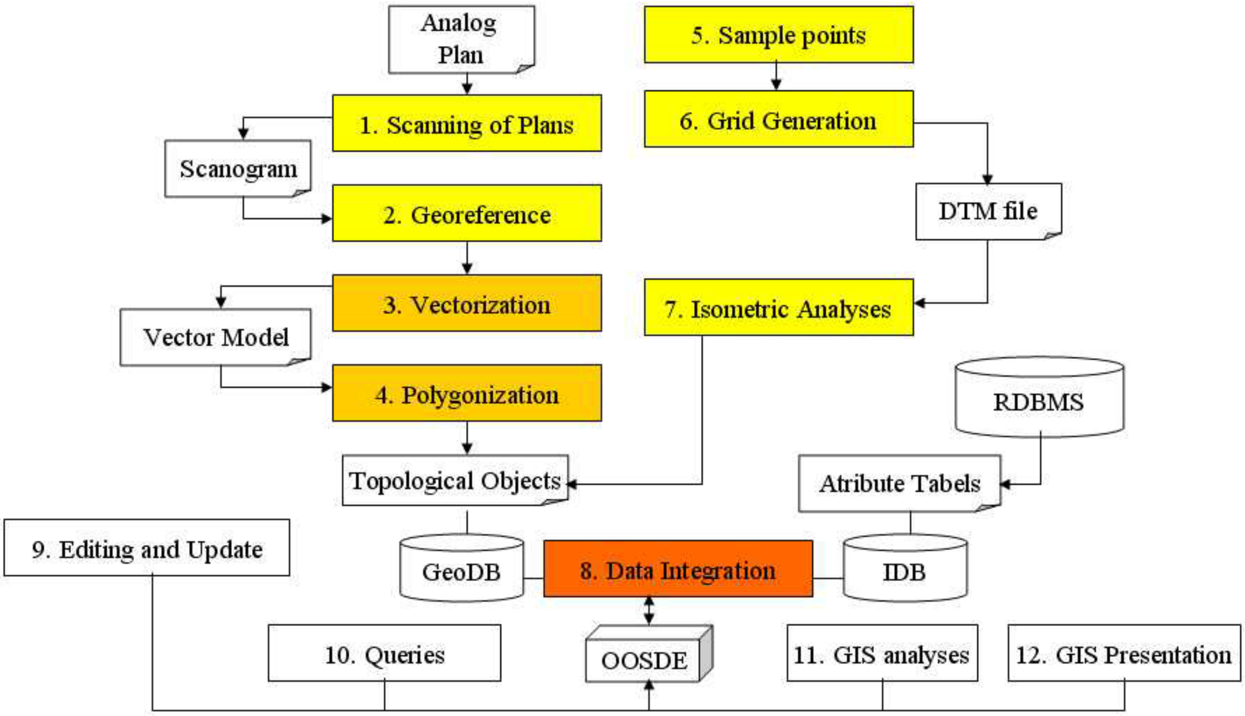
Very suitable category is related to area of intensive urbanization with collective and individual dwelling units, industrial and recreation zones.

Suitable one is related to area of extensive urbanization with mostly individual dwelling units, rural agricultural production and small business.

Unsuitable category includes two sub-categories. One is related to area mostly intended for agricultural production, and only exceptional for other uses. Another, which is related to area reserved only for forestry and agriculture, is not considered here.

5 APPLICATION OF GIS IN DATA PREPARING FOR MULTICRITERIAL ANALYSIS

Study of multicriterial land valorization of Tuzla Canton starts with application of geographic information system. Graph 3 shows procedures (analytical process model) of data production for multicriterial analysis e.g. scanning plans, georeference, vectorization, polygonization, data integration etc.



Graph 3: Analytical Process Model of Data Production in GIS

Graph 4 shows 3D model of Tuzla Canton that enables classification of heights, aspects and slopes of terrain. By defined parameters for every class of aspect and slope it is possible to create thematic map in GIS.

Graph 4: 3D Model of Tuzla Canton

Assignment of criterial values to classes is realized by selection of objects belonging to specific class and by attachment of common attribute values in database.

Five classes are defined for aspects: east, west, north, south and horizontal. Slopes are divided into five classes: flat, small inclination, inclined, steep and very steep. During the classification of relative heights, three zones are used for scoring: plain, hill and mountain land. To classify usability, here are used three categories of land bonity, and classification of land accessibility is based on chronometric analysis realized in GIS. By CORINE methodology is provided classification of environmental value of land [6]. All classes are scored in scope from 1 to 5 points (Table 1).

Slope of Terrain Classes	Slope of Terrain Description	Aspects of Terrain Classes	Aspects of Terrain Description	Relative Hights Classes	Relative Hights Description	Land Usable Value Classes	Land Usable Value Description	Environmental Land Value Classes	Environmental Land Value Description	Land Accessibility Classes	Land Accessibility Description	SCORES (1-5)
flat	0-2%	horiz.	0-360°	plain land	0-300m	1st agrozone	I-IVa category	very low value	2.3.1, 3.2.1	very near	0-5min	5
small inclinat.	2-4%	South	135-225°	-	-	-	-	low value	2.2.1	near	5-10min	4
inclined	4-10%	East/ West	45-135°/ 225-315°	hill land	300-700m	2nd agrozone	IVb-VI category	middle value	2.2.2, 2.4.3, 3.2.2	accesible far	10-15min	3
steep	10-20%	-	-	-	-	-	-	high value	2.4.1, 2.4.4, 3.2.3,	far	15-20min	2
very steep	20-30%	North	0-360°	mountain land	above 700m	3rd agrozone	VII-VIII category	very high value	3.1.1, 3.1.2, 3.1.3	very far	20-30min	1

Table 1: Scoring of Land Units

Land for reconstruction is determined by analysis of existing construction areas, as it is shown in Table 2.

Order Number (k)	Municipality	Area Used for Reconstruction (P_{ok}) in hectars
1	Banovici	165
2	Celic	341
3	Doboj Istok	383
4	Kalesija	124
5	Gracanica	422
6	Gradacac	770
7	Kladanj	578
8	Lukavac	1485
9	Srebrenik	155
10	Sapna	280
11	Teocak	402
12	Tuzla	508
13	Zivinice	127

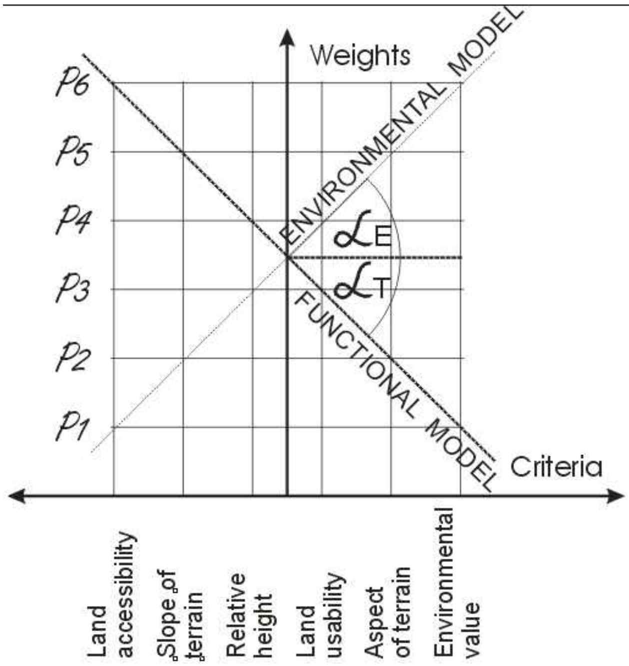
Table 2: Balance of Areas Used for Reconstruction

6 REPRESENTATION OF ALTERNATIVES BY SYNTHESIS MODELS

Weights of criteria are defined according to differences in their importance which are adopted as linear dependent values in a model. Table 3 shows normalized weights for two syntesis models according to their importance related to the specific model.

Normalized Weights for	Land Accessibility	Slope of Terrain	Relative Height	Environmental Value	Aspect of Terrain	Land Usable Value
Environmental Model	0.28	0.24	0.19	0.14	0.10	0.05
Functional Model	0.05	0.10	0.14	0.19	0.24	0.28

Table 3: Weights of Criterial Factors for Environmental and Functional Model



Graph 5: Synthesis Models and Values of Criterial Weights

According to Graph 5, behavior of the model, in functional and environmental sense, is possible to describe by the following set of linear equations:

p_1= -2,5 tg α + 3,5
p_2= -1,5 tg α + 3,5
p_3= -0,5 tg α + 3,5
p_4= 0,5 tg α + 3,5
p_5= 1,5 tg α + 3,5
p_6= 2,5 tg α + 3,5 (1)

where p_1 , p_2 ... p_6 denote weights of specific criteria, and α is angle of model gravitation that represents how much the model gravitates to some of the alternatives (synthesis models).

7 OPTIMIZATION OF MODEL

If coefficient of direction, tang α i, vary from -1 to 1, then angle of gravitation, α i , takes values from $-\pi/4$ to $\pi/4$. Optimum model is characterized by total suitable area P depending on the angle α .

If existing land for construction is adopted as extraordinary suitable category, then the condition for model optimization can be described by expression:

$$F = (P_r - P_O)^2 = \min. \quad (2)$$

where P_r is extraordinary suitable area for optimum model, and P_O is existing land for construction.
In order to make description of the problem easier, function $P_r(\alpha)$ is presented by appropriate polynomial ψ_r , and expression (2) can be transformed into:

$$\Phi = [\psi_r(\alpha) - P_O]^2 = \min. \quad (3)$$

which represents objective function for model optimization.
As a method for solving optimization problem it is used the genethic algorithm that is based on natural selection, the process that drives biological evolution. It can be applied to solve various optimization problems in which the objective function is discontinuous (or with discrete values), nondifferentible, stochastic or nonlinear.

The building blocks of the genetic algorithm are evaluation of fitness, selection, recombination and population of chromosomes.

The genetic algorithm repeatedly modifies a population of individual solutions (chromosomes). At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them produce the children for the next generation. Over successive generations, the population evolves toward an optimal solution [5].

8 FITNESS FUNCTION

According to expression (3) fitness function F_f can be described as:

$$F_f = \sum_{k=1}^{n} \Phi_k = \sum_{k=1}^{n} \left[\psi_{rk}(\alpha) - P_{Ok}\right]^2 \qquad (4)$$

where n is total number of enclosed municipalities.
The expression (4) is used for evaluation of fitness values needful for creation of each next generation of potential solutions (chromosomes).

Fitness function is defined in M-file (Matlab) by calculated polynomial coefficients and balance of areas from Table 2.

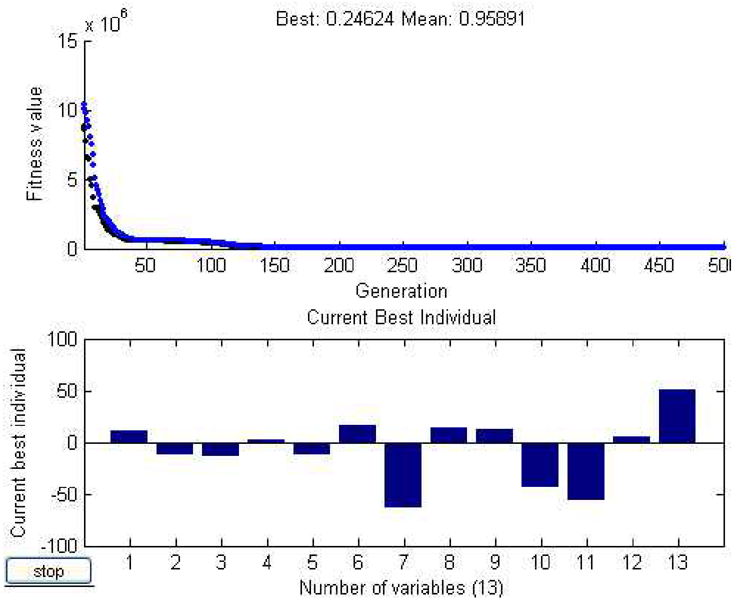
9 REPRESENTATION OF CHROMOSOME

For representation of chromosome it is used binary string λ [2]. Variable is encoded so that it presents real values of the angle of gravitation in radians. Domain of searching is defined with adopted precision of 0.01 radian. By this way, the solutions are presented by chromosomes (104 bits strings) consisting of 13 genes.

Each of the gene (8 bits string) represents model (by angle of gravitation) of specific municipality.

10 PARAMETERIZATION OF GA AND RESULTS

After the testing, the parameters which gave acceptable results of optimization are determined as: roulette wheel selection, 100 chromosomes in population, elite count 2, crossover fraction 0.25, mutation with gaussian distribution, single point crossover and stopping after 500 generation.



Graph 6: Current Best Individual and Fitness Value

Final value of fitness obtained in the last generation is 0,24 ha, while predefined value of tolerance is 2 ha (Graph 6).

Angles of model gravitation (MGA) obtained by GA optimization are given in Table 4.

Order Number (k)	Municipality	MGA (α_k) in *rad*
1	Banovici	0,103
2	Celic	-0,118
3	Doboj Istok	-0,131
4	Kalesija	0,026
5	Gracanica	-0,127
6	Gradacac	0,162

7	Kladanj	-0,639
8	Lukavac	0,133
9	Srebrenik	0,118
10	Sapna	-0,437
11	Teocak	-0,571
12	Tuzla	0,049
13	Zivinice	0,507

Table 4: Angles of Model Gravitation

11 LAND USE CLASSIFICATION AND THEMATIC PRESENTATION IN GIS

Applying the genetic algorithm for searching the optimum model for land use classification are determined values of the angles of gravitation enough close to optimum. In order to achieve final objective of multicriterial analysis, it is necessary to perform aggregation, i.e. summing the factorized criterial values and classifying the areas according to the land use (already described).

Total value of a land unit is calculated as:

$$\upsilon_{zk} = (w_{1k}f_1 + w_{2k}f_2 + w_{3k}f_3 - w_{4k}f_4 - w_{5k}f_5 - w_{6k}f_6 + \upsilon_{\max})/(\upsilon_{\max} - \upsilon_{\min}) \quad (5)$$

where:

w_{ik} are normalized weights from equations (1), for criteria $i=1...6$ and municipalities $k=1...13$,

f_i is assigned scores for specific criteria, and

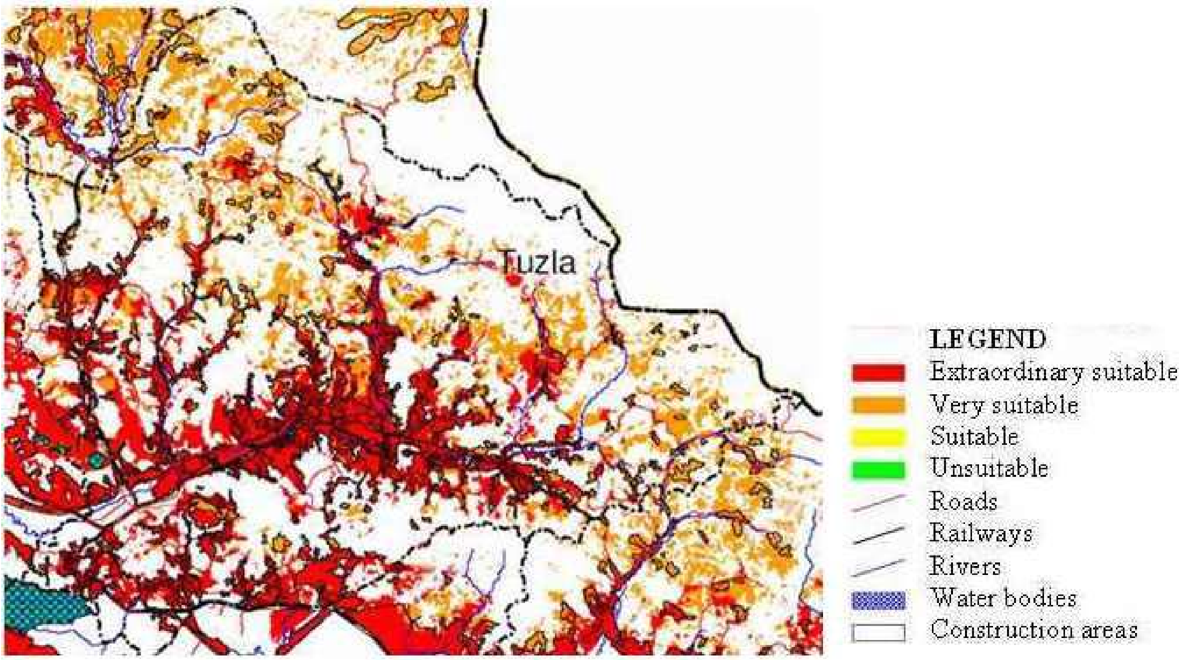
$\upsilon_{\max}$ i $\upsilon_{\min}$ are maximal and minimal value of land unit ($\upsilon_{\max}$ =3.276, $\upsilon_{\min}$ =-3.276).

Table 5 shows ranked values used for classification of land use.

Category of Area	Ranked Values (normalized)
extraordinary suitable	0.75 - 1.00
very suitable	0.50 - 0.75
suitable	0.25 - 0.50
unsuitable	0.00 - 0.25

Table 5: Ranked Values for Land Use Classification

Based on the ranked values, total land units values are presented by thematic visualization in GIS. To each of the ranks (classes) is assigned a corresponding color (Graph 7).



Graph 7: Thematic Map of Land Use Categories

12 CONCLUSION

This paper shown how to apply genetic algorithm (GA) in optimization of spatial valorization multicriterial model during the regional urban planning process.

The matter exposured in the work, described both the problem of multicriterial spatial valorization from land use aspect and finding the optimal model methodology and it was illustrated by actual examples taken from the spatial planning area and available existing studies in this field.

The crucial points of the research were the following:

possibility of multicriterial valorization of the land from the GA use perspective,

how to utilize the capacity of the GA optimization techniques in the frame of decision support system and with usage of the GIS tools and

how to apply the GA in the field of genotype presentation in spatial modeling.

As one of the approaches for finding a methodology for multicriterial land use valorization, application of genetic algorithm gave acceptable results. Weights used in initial equations of mathematical presentation, are indirectly optimized by modified objective function applied in GA during fitness values evaluation. Populations of binary vector strings which indirectly represent solutions for criterial weights, are maintained by unique mechanism of GA [3]. By the applied methodology is enabled searching the alternatives of spatial organization for given land use categories and finding the optimum alternative.

The optimum can be searched for various given parameters influencing the objective function.

Due to its general application, genetic algorithm could have key role for development of a decision support system for spatial multicriterial analysis.

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