Multi-criteria Spatial Analysis for the localization of production structures. Analytic Hierarchy Process and Geographical Information Systems in the case of expanding an industrial area

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Abstract—Among the numerous economic evaluation techniques currently available, multi-criteria spatial analysis lends itself to solving localization problems of property complexes and, in particular, production plants. The methodology involves the use of *Geographical Information Systems* (GIS) and the *mapping overlay* technique, which overlaps the different information layers of a territory in order to obtain an overview of the parameters that characterize it. This first phase is used to detect possible settlement surfaces of a new agglomeration, subsequently selected through *Analytic Hierarchy Process* (AHP), so as to choose the best alternative.

The result ensures the synthesis of a multidimensional profile that expresses both the quantitative and qualitative effects. Each criterion can be given a different weight.

Keywords—Multi-criteria spatial analysis; Analytic Hierarchy Process; Geographical Information Systems; localization of industrial areas.

I. INTRODUCTION AND AIM OF THE STUDY

From a public perspective, any form of investment presents issues of complexity. This is generally due to the multiplicity of the objectives to be reached as well as their heterogeneous and conflicting nature. An evaluation model that supports any decisions made is both an essential tool for public Institutions as well as a valuable support for private investors due to its ability to rationalise the different aspects of the various project solutions.

This study aims to implement the multi-criteria Analytic Hierarchy Process technique [1]–[3] with a Geographical Information System [4], in order to define a decision-making model that can be used to solve the localization problems of industrial areas and, more generally, with easy adaptations, of new urban areas intended for service or production activities [5]–[8].

The model should be able to maximize the efficiency of investment projects [9]–[13], especially for works that affect large areas and play an important role in the effects they generate in various sectors.

The aim of this work is therefore to provide a support tool to investment decisions that meet the needs of the territory, from both the socio-economic and environmental aspect as well as the quality of life of the population involved. The evaluation process is applied to establishing the best location for the expansion of the industrial area of Tito (PZ, Italy).

This work has been written in equal parts by the three authors.

II. MULTI-CRITERIA SPATIAL ANALYSIS

The Multi Criteria Decision Aid (MCDA) is a procedure for comparing multiple criteria, with it being a support model to decision-making [14]–[18] . It makes it possible to evaluate the convenience of investment projects characterized by different types of impact, i.e., economic, social and environmental. In multi-criteria analysis, social welfare depends on many factors, which must be carefully considered and evaluated by the decision maker. In these cases, the evaluation is divided into two successive and complementary steps:

1) search for alternatives that have objective relevance;
2) an evaluation of the ranking of the alternatives.

The most recent multi-criteria evaluation methodologies "justify" the choices made. In particular, in participatory planning processes, the achievement of a "justified choice" is of significant importance. Consequently, *Geographic Information Systems* (GIS), which generate a large amount of data, have a key role in any decisions made.

GIS are a valuable tool for the management of spatial data as well as the construction of the necessary information base upon which decisions can be made. In fact, the decision-making problems that affect urban planners and evaluators typically involve a set of alternatives, along with a large number of conflicting evaluation criteria that are often not easily measurable. Thus, research carried out in the areas relating to GIS and multi-criteria analysis can benefit from each other.
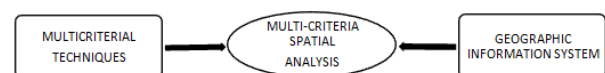

Fig. 1. GIS and multi-criteria analysis

Multi-criteria spatial analysis therefore represents a significant step forward compared to conventional multi-criteria techniques, due to the explicit spatial component, which requires both the knowledge and representation of the relative criteria data, and the geographical location of the alternatives. The territorial data are processed using the computing power of the GIS and the multi-criteria evaluation methods to obtain the information needed to support the decisions made. Multi-criteria spatial analysis can be considered a tool that combines

and transforms the geographical input data into an output decision.

Furthermore, the possibility of working with geo-referenced data makes it possible to have a complete scenario of the situation under study, providing a cognitive framework of easy reading and interpretation and, at the same time, with a high degree of detail.

III. STRUCTURE OF THE MULTI-CRITERIA SPATIAL ANALYSIS MODEL

With multi-criteria spatial analysis, it is possible to visualise and analyse spatial data with associated attributes, so as to resolve complex problems. Firstly, the evaluation process requires the correct analysis and characterization of the evaluation problem. Thus, all the necessary information relating to the system considered should be produced. Raw data should be collected, processed and examined in order to build a structured knowledge of the territory as well as the dynamics that influence it. It is at this stage that the ability of the GIS to store, manage and analyse the available data is a fundamental support.

Once the decision-making problem has been defined, the evaluation criteria should be chosen. Specifically, the objectives that highlight the relevant aspects of the problem of evaluation should be specified. Then, the criteria by which to achieve these goals and the corresponding measurement scale are established. The degree of achievement of the objectives, as measured by the attributes, constitutes the basis for comparing the alternatives. Since this is spatial analysis, the evaluation criteria and their attributes are represented through geographic maps, that can be assessment criteria maps as well as constraint maps. The construction of these geo-referenced thematic maps (data layers) makes it possible to evaluate the performance of each alternative against the criteria in question.

At this point, the alternatives are identified. This is done by creating either location constraints or placing constraints on the values of the attribute. In this phase, imposed by the weights, the preferences of the decision makers with respect to the evaluation criteria are incorporated into the decision model.

Finally, the measurements of the attributes of the criteria (geographic data layers) and judgements of the decision makers (preferences) are aggregated in order to evaluate the alternatives and indicate an order. In summary, the evaluation logic protocol that implements the GIS and AHP, requires to:

- formulate the localization problem;
- define the objectives, criteria and constraints;
- identify the location of alternatives through the construction of the information layers that match the criteria and constraints identified (GIS and overlay mapping);
- create a hierarchical structure. The problem of evaluation is structured by placing at the highest level the objectives, then the criteria and finally the alternatives;
- carry out a comparison. All the elements of each level are compared in pairs according to each element of the next highest level;

- summarise the results. The results of the comparison are summarized in order to establish a ranking of the alternatives;
- check the consistency of the responses and analyse the results.

It should be noted that, once the constraints and evaluation criteria have been established, three possible situations can occur:

1) localization depends solely on the constraints. Thus, the procedure allows for the identification of areas not subject to constraints. If no areas free from restrictions are identified, it is necessary to redefine the constraints until finally obtaining a result;
2) localization depends solely on the criteria. In this case, the procedure makes it possible to classify the areas according to a range of values between a minimum (not suitable for the location of the activity) and a maximum (highly suitable for localization);
3) localization depends both on the constraints as well as the criteria. In this case, step 1 is applied, and the provisions of item 2 on the areas identified.

IV. AN APPLICATION OF MULTI-CRITERIA SPATIAL ANALYSIS TO THE LOCATION CHOICES: THE EXPANSION OF THE INDUSTRIAL AREA OF TITO (PZ)

Multi-criteria spatial analysis is adopted to choose the best location for the expansion of the industrial area of Tito (PZ). The expansion is possible under Resolution no. 82/2006 of the Regional Administration of Basilicata, approving the new General Urban Plan of the industrial area. The study technique, which combines a *Geographical Information System* (GIS) and an *Analytic Hierarchy Process* (AHP), makes it possible to both interpret the spatial data that should be treated on the map as well as take into account various effects, not only financial, but also social and environmental. The contribution of GIS is essential in the design and interpretation of the information contained in the *shape file* provided by the Province of Potenza and Basin Authority of Basilicata. It includes data on: 1) altitude, 2) biotypes, 3) land use, 4) lithological and morphological homogeneity, 5) landslide risk, 6) types of landslides, 7) landscape constraints.

Along with the GIS, thematic maps are produced for each of the seven characteristics, with them being information *layers* that are graphically overlaid with an *overlay mapping* technique. The latter gives the surfaces that are free from constraints, which constitute the possible project solutions. Subsequently, the software *Superdecisions* implements the AHP, which schematises the localization problem. In fact, on the basis of a hierarchical model consisting of objectives, criteria, sub-criteria and alternatives, the latter are compared in pairs according to the established criteria, giving the reciprocal preferences among the different areas proposed for the intervention.

V. THE STUDY AREA

The industrial area of Tito, with an altitude between 600 and 800 m above sea level, is about 20 km from the city of Potenza

in Basilicata (Italy). It can be easily reached along the main road E847 that leads out of "Tito - Zona industriale Ovest", and to "Tito - Zona industriale Est", as well as to the "Stazione Tito Scalo S.P.95" railway station. The agglomeration includes built areas, with related infrastructures, as well as others to be built, where the only types of building allowed are those for production, trade and service purposes. The planimetry in Figure 2 highlights the activities currently present in the area. Figures 3 and Figure 4 show the territorial framework and a photograph of the area.

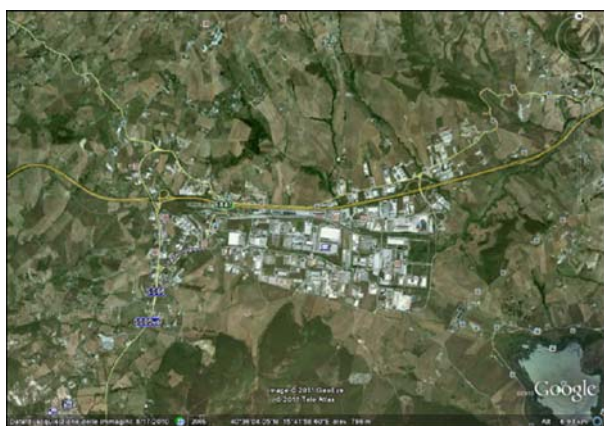Fig. 2.   Division of the area on the basis of the activities.

Fig. 3.   Territorial layout of the industrial area.

Fig. 4.   Industrial area of Tito.

The results of the studies carried out on the area are summarised below, which includes biotypes, land use, geology, lithological and morphological homogeneity, hydrogeological risk and landscape constraints.

Biotypes

The Preliminary Document of the urban plan of the province of Potenza[1] outlines areas of uniform vegetation cover, or biotypes:

- *Primary vegetation mainly shrubs* (oaks with a high degree of naturalness);
- *Heterogeneous areas*, i.e. areas connoted by agriculture, with areas of a medium level of naturalness;
- *Agricultural areas mainly herbaceous*, including non-irrigated crops, irrigated crops and arable wooded land with a very low level of naturalness;
- *Artificially modelled areas*, i.e. urban areas, green spaces and sports facilities (zero level of naturalness).

In addition to the production plants, the industrial area of Tito includes heterogeneous areas and a few residual fringes of natural vegetation. The corresponding level of naturalness is therefore low.

Land use

There are predominantly arable land (with crop rotation for the production of alternating cereals, vegetables, roots, food and fodder) and mixed crops or vines and trees (fruit, olive trees, but also poplars and maples) planted in rows.

Geology The extract of the ISPRA map 1:100.000 (Figure 5), gives a detailed geological representation of the area. Driving along the motorway in a west-east direction, on the right bank of the river Tora, there are chaotic terrains, made up of clay and silty clays mostly grey-lead, encapsulating seams of sandstone, limestone, loose scree and recent terraced stony, sandy alluvial deposits as well as recent lacustrine deposits. On the left bank, there is grey micaceous quartz sandstone alternating with layers of clay, shale or marl-shale and - slightly ahead - older, often terraced flood deposits. Further south, there is siliceous shale, jasper, grey clay marl, calcareous and grey and light green limestone marl, as well as calcarenites and sandstones. Finally, on the left bank, there are polygenic conglomerates in a sandy matrix on ancient formations[2].

Lithological and morphological homogeneity

From a physical-environmental perspective, the area constitutes a connecting zone where river valleys alternate with rocky slopes. There are minor river valleys and mountains. The slopes poorly shaped and predominantly clay, with the hills of medium height reaching higher altitudes with rounded hills and slopes of medium steepness.

Hydrogeological risk

The study of the maps highlight that the current industrial area as well as the adjacent expansion area are not affected by any possible landslide risks. The areas further north are

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[1]The data from the preliminary document, processed by the LISUT University of Basilicata, produced "The urban plan of the province of Potenza, studies and evaluations to complement the elaborations of the preliminary document" (2006).

[2]The authors would like to thank the geologist Dr. Fiorentino Calicchio for his valuable suggestions on the geological characterization of the area.

Fig. 5. Geological map - supplied by ISPRA.

classified at risk R1, R2, R3, R4, with possible phenomena represented by landslides from collapse, rotational sliding, translational sliding, slow sliding and creep phenomena. There is no risk of flooding in the area.

Landscape constraints

The geographical area that includes the industrial area of Tito, presents a scenic location with a brief description.

Site of Community Importance (SIC) code IT9210115. Located south-east of the study area, it consists of a limestone massif, with a morphology that goes from steep to very steep. The climate is continental, with heavy snowfall in winter and vast amounts of atmospheric moisture. There is the presence of the Apennine beech. The most important water sources are used for civilian purposes. There is excessive and unregulated pasturing.

Site SIC IT9210142. Semi-natural basin obtained by building a dam on the marsh. In terms of flora and vegetation, while not presenting particular or endemic species or varieties, it is a unique site due to its geographical position between the inland wetlands of the southern Apennines. Resting area and breeding ground for migratory birds. The lake has a high abundance of fauna.

Site SIC IT9210215. It occupies a mountainous area to the west of Potenza, dominated by the peaks of Monte Li Foi (1,354 m a.s.l) and Monte Li Foi di Picerno (1,350 m a.s.l), both in the countryside of Picerno. Between the two peaks, there are two broad plateaus as well as extensive forests.

The Sellata Volturino - Madonna of Viggiano. Located in the South, South-West of Potenza, it forms a complex mountain system, the central backbone of the Lucanian Apennines. The flora is mainly characterized by lush forests, to the north, overlooking the amphitheatre to the plateau of the Pantano di Pignola, with the homonymous lake, now a WWF oasis. The fauna is particularly rich.

National Park of Lucanian Appenines. Val D'Agri - Lagonegrese - Zone 2. Due to its physical-environmental characteristics, this area has a high naturalistic value, as highlighted by the presence of 13 Sites of Community Importance, three regional nature reserves (Lake Pantano di Pignola, Lake Laudemio, Abetina of Laurenzana) and three areas subject to the Landscape Plan (Sellata-Volturino-Mountain Viggiano, Massif Sirino and partially Maratea).

VI. DEFINITION OF THE THEMATIC MAPS AND OVERLAY MAPPING FOR THE OVERLAY OF THE CARTOGRAPHIC INFORMATION. HYPOTHESIS OF LOCALIZATION OF THE LOTS

Each of the characteristics described in the previous paragraph, is presented in a thematic map generated with the aid of GIS matrices. Further cartographic representations are inherent to the areas covered by roads[3] as well as the areas covered by the railway[4]. The overlaying of all the tables with *overlay mapping*[5], results in Figure 6.
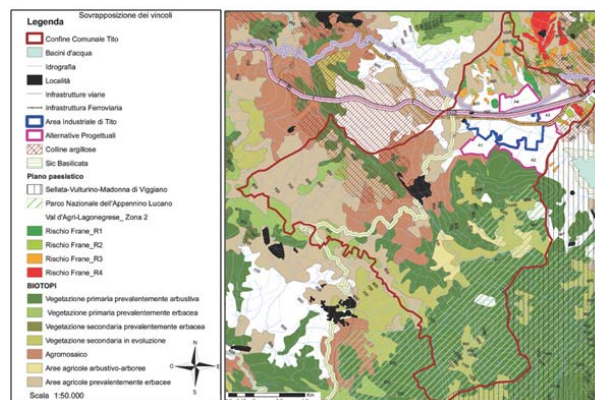

Fig. 6. Representation of the constraints and identification of the solutions (A1, A2, A3 and A4).

By overlaying the constraints, Fig. 5 distinguishes the areas that are not suitable for the location of new production activities from those that - in contrast - are suitable. The first are in colour or textured, where each colour or texture expresses conditioning in the legend. While, the others are in white. Among the areas adjacent to the existing industrial area, in white with a purple border, four possible solutions A1, A2, A3 and A4 are marked and best viewed with the magnification of Figure 7. The corresponding extensions are:

- A1: 659,553 m^2;
- A2: 1,396,438 m^2;
- A3: 284,241 m^2;
- A4: 773,328 m^2.

It should be noted that for technical-construction and economic reasons, based on the lithological and morphological homogeneity of the land, of all the possible areas of intervention, those with a predominance of clay were excluded. With reference to the biotypes and the intention of preserving plant species and ecosystems typical of the area, areas with primary vegetation mainly shrub or predominantly grassy have been discarded, along with those areas with secondary vegetation mainly herbaceous or evolving, agricultural and shrub land, as well as those that are primarily herbaceous, and open spaces without vegetation. According to the map of land use, the forest areas have also been left out.

[3]For areas covered by the road, see the New Highway Code. Specifically Article. 16, along with art. 26 of the Rules of Implementation of the Code.
[4]For more information on the railways, see the regulation, DPR 753/1980.
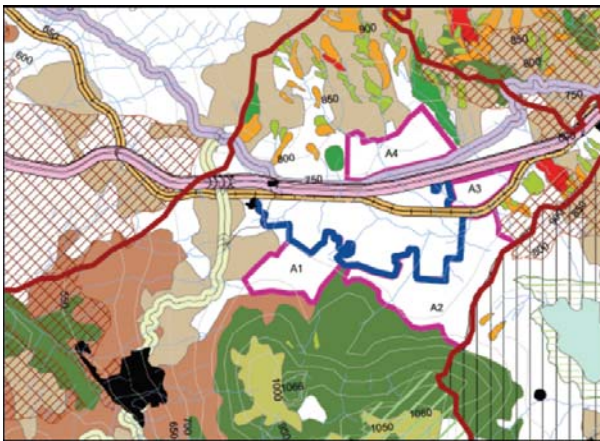[5]Operationally, by means of the function Spazial Analist - ArcGIS.

Fig. 7.   Conformation of the solutions A1, A2, A3 and A4.

VII. The Structure of the Analytic Hierarchy Process

Having described the areas A1, A2, A3 and A4, which are all potentially suitable for the new production facilities, the best solution should be chosen according to several objectives. The multi-criteria analysis model of the Analytic Hierarchy Process is used, with the following steps:

1) decomposition of the evaluation problem in a hierarchical order;
2) data collection for pairwise comparisons between elements (criteria and sub-criteria);
3) estimate the relative weights of each factor;
4) aggregation of the weights and evaluation of localization options.

1. The complex problem of evaluation is hierarchically broken down into elementary parts. Starting at the top, passing from the objective of the first level, to the criteria and sub-criteria at the lower levels, to the solutions at the lowest level:

- objective;
- criteria;
- sub-criteria;
- solutions.

The objective to satisfy is the identification of area A where to place new business activities, in the expansion of the industrial area. This satisfies the economic, social and environmental criteria. The economic criterion is represented by the sub-criteria:

- costs of infrastructures of the areas;
- distance of A from the railway station;
- distance of A from the motorway.

In turn, the cost of infrastructures of area A is related to the three sub-criteria:

- distance from the treatment plant;
- geology of the land;
- presence in A of a road network.

The social criterion is expressed by the market value of the land that, due to expansion must be expropriated and therefore removed from the agricultural production. In the light of the studies carried out on the local property market, there is a good correlation between land values and Agricultural Medium Values (VAM) established by the expropriation Commission of the Province of Potenza. Thus, the higher the VAM of the land that private owners must give, the higher the cost of the new structure for the community. The environmental requirements are considered in terms of distance from the town of the areas destined for industrial expansion, this has much less impact on the city centre when it is further away. The hierarchical scheme for the analysis is shown in Figure 8. As regards the economic
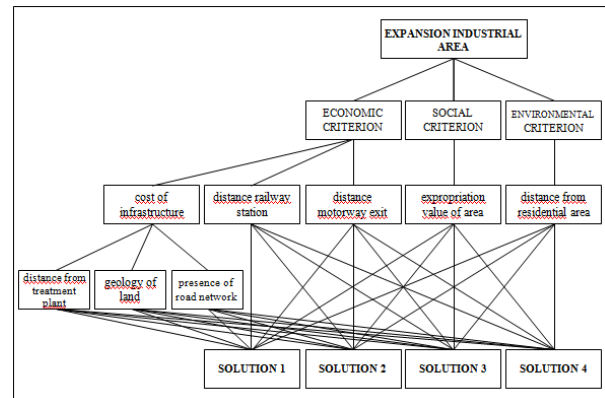

Fig. 8.   Hierarchy of the localization problem.

sub-criteria, the possibility to allocate the new buildings as close as possible to a railway station as well as a motorway exit, so as to reduce the transportation costs, is evident.

Furthermore, the choice between A1, A2, A3 and A4 should minimize the cost of the infrastructure that, in this case, depends on the distance from the treatment plant, the geology of the land as well as the presence of the road network. In fact, wastewater treatment plants have already been included in the area. Thus, minimising the length of the pipes leading to the treatment plants, reduces the cost.

It is also clear that land with worse geological and geotechnical characteristics determine higher costs for the construction of load-bearing structures. In this regard, from the study of the ISPRA geological map at a scale of 1:100,000, the area A1 is mainly composed of "loose scree" (dt^2). Area A2 is in part constituted by dt^2, in part by "clay marl, calcareous marl and marl limestones, calcarenites and sandstones" (Ol?) and marginally by "polygenic conglomerates with a sandy matrix" (P_1) and "siliceous shale" (G_s T_s). A3 is predominantly composed of "polygenic conglomerates" (P) and "old, often terraced, flood deposits" (a^1). A4 is almost all "clayey marl" (Ol?). This information, interpreted with the aid of a geologist, makes a list of priorities according to the sub-criterion under examination.

The assessment of the existing road network in the district allows for a further differentiation of the expansion areas. Thus, they are more appropriate due to requiring lower investment costs.

2. Having divided the hierarchical system, all the elements at every level are compared in pairs in relation to each parameter at a higher level. Thus, it is possible to first establish which element is more significant than the others and, at the end of

the process, to draw up a list of preferences. The fundamental scale of Saaty is used for the comparisons, with scores from 1 to 9, which express:

1, equal importance (the two terms contribute to the evaluation in the same measure); 3, moderate prevalence (judgement and experience slightly favour one over another); 5, strong prevalence (judgement and experience clearly support one of the two terms); 7, very strong prevalence (as demonstrated in practice); 9, extreme prevalence (proven with absolute certainty); 2, 4, 6, 8, intermediate values (or compromise).

The numerical values that fit into the matrices of the pairwise comparison of the elements have been obtained from the study of the collected data. The matrices are constructed for each hierarchical level, starting from the second onwards. It therefore follows that if n is the number of elements to evaluate to a certain level (e.g. solutions) and if m is the number of terms to the upper level (e.g. criteria), for that given level, there will be m matrices of the order $n \times n$[6].

Thus, the multiple pairwise comparisons must be mutually consistent. This translates into verifying that the matrices compared should be internally consistent.

3. Subsequently, the relative weights of each factor are estimated, with it being possible to use the knowledge and experience of the analyst, as well as "delta" logic and more specifically defined rational models.

4. The last phase of the evaluation process is related to the synthesis of priorities, through the matrix of pairwise comparisons and the identification of the principal normalized eigenvector. This results in the priority list of project alternatives.

VIII. Implementation of the evaluation model

Five *clusters* are created with the software Superdecisions, according to the hierarchy in Figure 8. The clusters are placed in reciprocal connections forming nodes.

Particular attention is given to the pairwise comparisons. In this case, the skills and experience of the analyst are used for some comparisons. While, for other comparisons, depending on the available data, specific patterns of rational evaluation are defined. It should be noted that Superdecisions recognises comparisons between non-coherent pairs, since it is able to verify the internal consistency of the matrices.

The calculations are carried out with respect to two different cases:

1) the economic, environmental and social criteria have different weights;
2) the economic, environmental and social criteria have the same weight.

A. Calculations and results: the first case study

In this first case study, the difference in weight of the three criteria (economic, environmental and social) arises from the preferences allocated as shown in Figure 9. Since this is an industrial area, therefore, with its primary goal being of

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[6]On the main diagonal, all the terms of the matrices of the pairwise comparisons are 1, because the solution or the criterion is compared with itself. The matrices are reciprocal, that is a mirror image of the main diagonal.

a productive and financial nature, the economic criterion is weakly preferred to both the ecological and social ones.

In turn, the economic criterion is a function of the cost of the infrastructure as well as distance from both the motorway and railway station. The comparison between these sub-criteria is shown in Figure 10.

In addition, the cost of the infrastructure is a function of the distance of A from the treatment plant, the geology of the land and the presence of an adequate road network, with the preferences being expressed in Figure 10. It should be noted

Fig. 9. First hypotheses: the different weights assigned to the three criteria.
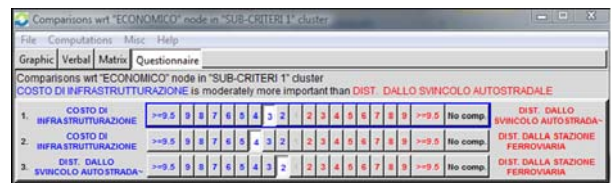

Fig. 10. Comparison between the sub-criteria: cost of the infrastructure; distance from the motorway exit; distance from the railway station.

Fig. 11. Comparison between the sub-criteria: distance of A from the treatment plant; geology of the land; presence of an adequate road network.

that the preferences expressed by figures 8, 9 and 10 depend in part on the technical and economic knowledge of the evaluator, and in part on political reasons declared by investors. They also derive from the quantitative analysis of the information collected, some of which is used in the construction of the simple mathematical patterns in the tables that follow.

The distance of A from the treatment plant is computed from the centre of the possible expansion area to the entrance of the treatment plant. For A1, A2, A3 and A4, table I shows these distances, expressed both in absolute terms and as a percentage compared to the sum of the same distances. A percentage difference of 15% with a score of "1" on the Saaty scale has been assumed.

The criterion "geology of the land" is related to the lithology of the possible expansion areas A. Specifically, a ranking on the basis of the mechanical and geotechnical soil characteristics of these areas is created. The geological map makes it possible to draw up table II, where the geological formations

TABLE I
DATA FOR THE COMPARISON OF THE ALTERNATIVES ON THE BASIS OF
THE DISTANCE OF A FROM THE TREATMENT PLANT.

	A1	A2	A3	A4
distance from the treatment plant	2.210 m	945 m	596 m	1.453 m
percentage difference	42,5%	18,2%	11,4%	27,9%

present in greater proportion are in bold. The best locations are those of solution A3, followed by A4, then A2 and finally A1. The scores are assigned in proportion to the ranking.

TABLE II
DATA ON THE LITOLOGICAL CHARACTERISTICS OF THE SOIL.

	Gs	dt^2	Gs Ts	fi	Ol?	P_1	a^1	a^2t	M_3ar	Tot
	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]	[%]
Area 1	0	69,41	9,05	21,54	0	0	0	0	0	100
Area 2	4,80	36,77	4,60	0	39,20	4,35	0	10,28	0	100
Area 3	0	0	0	0	0	42,11	49,55	8,34	0	100
Area 4	0	0	0	0	48,58	0	36,42	0	15,00	100

Legend	
Gs	galestrino flysch (grey and brown shales, often with a yellowish patina...)
dt^2	loose scree
Gs Ts	siliceous shale
fi	chaotic terrains consisting of clays and silty clays
Ol?	argillaceous marls, clacareous marls and marly limestones, calcarenite and sandstone
P_1	polygenic conglomerates with a sandy matrix
a^1	ancient, often terraced, flood deposits
a^2t	recent, terraced, flood deposits, stony and sandy. Lacustrine deposits
M_3ar	Quartz-mica grey sandstones, generally alternating, in banks and layers, with shales or marnoscists

The presence of a road network is calculated as the ratio between the area occupied by the roads and the total surface area of A. For the criterion "distance from the railway station", areas A closer to the station are preferred. Table III shows the various distances with the respective percentage differences of the total distances. A difference of 15% is calculated with a score of "2". The same applies to the distance from the motorway (Table IV). In this case, a percentage difference of 15% is computed with the score of "1". Saaty scale has been assumed.

With reference to the average agricultural value of the land, the pairwise comparison takes into account the higher value of the lands on the left bank of the river Tolve (olive groves, vineyards, orchards and crops) in relation to that of the right bank (all crops). For the first, there is a value of €8,907/ha, while for the latter €6,500/ha. The scores are assigned in inverse proportion to these values, so that the lands of lesser value are more attractive for the expansion of the industrial area.

TABLE III
COMPARISON OF THE ALTERNATIVES ON THE BASIS OF THE DISTANCE OF
A FROM THE RAILWAY STATION.

	A1	A2	A3	A4
distance from the rail station	1029 m	2401 m	2427 m	1494 m
percentage difference	14%	33%	33%	20%

TABLE IV
COMPARISON OF THE ALTERNATIVES ON THE BASIS OF THE DISTANCE OF
A FROM THE MOTORWAY EXIT.

	A1	A2	A3	A4
distance from motorway exit	1288 m	1683 m	447 m	837 m
percentage difference	30%	39%	10%	20%

In an effort to reduce air and noise pollution in the residential area, priority must be given to solutions that are further away from it, with it being reported in table V. The use of simple proportions that give a score "2" to the percentage difference of 15%, makes it possible to carry out the comparisons.

TABLE V
COMPARISON OF THE ALTERNATIVES ON THE BASIS OF THE DISTANCE OF
A FROM THE RESIDENTIAL AREA.

	A1	A2	A3	A4
distance from residential area	2.685 m	4.297 m	5.370 m	4.815 m
percentage difference	16%	25%	31%	28%

Figure 11 shows the results of the first case study. On the basis of the weights assigned and the comparison criteria adopted, solution A4 is preferred. Followed, in order, by solutions A3, A1 and A2.
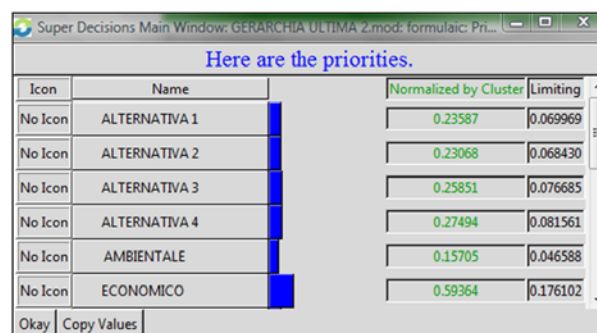

Fig. 12. Results of the first case study.

B. Calculations and results: second case study

In this case, the same weights are assigned to the economic social and environmental criteria. The weights used for the other pairwise comparisons coincide with those in Section 5.1.

Figure 12 shows the results of the evaluation. As with the first case study, solution A4 is still preferred, albeit to a lesser extent than solution A3. The order of preference between the expansion areas A1 and A2 is inverted, with the latter being in third place, ahead of A1.

Fig. 13.   Results of the second case study

IX. Conclusion

The present study shows that the multi-criteria spatial analysis is an extremely useful economic evaluation tool when solving the localization problems of industrial areas and, more generally, with easy adaptations, of new urban areas intended for services or production activities.

In particular, the combined use of GIS and AHP defines an evaluation protocol, that can be considered useful as a decision support system due to it creating associations of consequence between the criteria, constraints, and choices of location according to computerized mathematical procedures. It is an important support in the planning and implementation phases of urban planning, with the model making the location choices transparent, thus increasing the effectiveness of any interventions. In addition, the multi-criteria spatial model can be adapted to solve different case studies, by virtue of its ability to easily iterate the procedure as well as modify the criteria, constraints or any other parameters that may affect the results.

For the case study developed, the multi-criteria spatial analysis required, in a first phase, the use of GIS in order to arrange the necessary thematic mapping. The overlay mapping technique made the superimposition of the map information possible. Thus, on the basis of regulatory and functional constraints, an initial selection of possible localization areas was made.

In the second phase, the AHP compares the socio-economic and environmental variables. Each parameter has been studied, defined and calibrated for the individual project solutions. Thus, the results take into account the interactions between the expansion of the industrial site, the surrounding urban area, as well as the socio-economic and environmental aspects that relate to the population.

It should be noted that the evaluation carried out can be accompanied by a sensitivity analysis. Which, for each criterion, makes it possible to verify how the preference of a solution changes with respect to another as a function of the variation of the parameter that defines the weight of that same criterion.

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