Journal of Contemporary Issues in Business and Government Vol. 30, No. 01, 2024
https://cibgp.com/
P-ISSN: 2204-1990; E-ISSN: 1323-6903

TOWARDS A SPATIAL DECISION SUPPORT SYSTEM FOR TERRITORY PLANNING

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Received: 11/2023, Published: 01/2024

ABSTRACT:

In this paper, we introduce a multicriteria flexible decision-making system for regional planning. The proposed spatial decision support system integrates several variants which contribute simultaneously to obtain a better territorial context analysis. The suggested Multicriteria Spatial Decision Support System (MC-SDSS) mainly employs an improved version of Electre III as a methodological evaluation approach. Indeed, the classical Electre III method suffers from a few irregularities that can be considerably minimized by the use of optimization methods issued from Artificial Intelligence and Operational Research. The proposed approach has improved the decision quality for territory decision makers in the realisation of regional planning projects and particularly in identifying a surface area that more effectively meets certain criteria.

Keywords: Geographical Information System (GIS), Multicriteria Analysis (MCA), Multi Objective Genetic Algorithms (MOGA), Regional planning, Multicriteria Spatial Decision Support System (MSDSS).

I.INTRODUCTION

Spatial decision problems are complex and involve different dimensions by merging spatial (georeferenced data) and non-spatial data [1]. The geographical information system, with its capabilities in the storage, management, analysis, modelling and spatial data display, is considered as the most suitable instrument for understanding spatial decision-making issues [2]. Spatial Decision Support Systems (SDSS) are used in multiple domains such as the management of natural risks and the management of the environment planning. SDSS utilizes the functions of Geographic Information Systems (GIS), along with decision models. The objective is to identify the proprieties of problem solutions, ease the assessment of alternative solutions, and assess their trade-offs[1]. We categorize various types of spatial decision problems into network routing, resource allocation, location-allocation, service coverage, and site selection [3]. Such problems require reconciling an increasing number of always diverging objectives. Also, each criteria is defended by motivated actors using all administrative and legal avenues to achieve their end [4]. The integration of multicriteria MCA techniques to resolve spatial decision problems allows incorporating both objective/subjective actors' preferences and different criteria (qualitative or quantitative) in the spatial decision-making process [5]. The association between SDSS, GIS and MCA are known in the literature as Multi-Criteria Spatial Decision Support System (MC-SDSS).

MC-SDSS has been released and utilized in numerous scenarios including habitat site improvement, medical resource distribution, hydrologic resources management, soil suitability analysis, radioactive waste storage site location, and regional planning. There is intensive research in the field of MC-SDSS regarding its application in management of the environment and site selection [6,7,8,9]. As examples, we can cite [4] where the authors introduced MEDUSAT as a SDSS application for identifying the area designated for waste treatment plant in Tunisia. [10] is another work where the author recommended the MCDM model for determining the most appropriate allocation of a photovoltaic solar plant. Moreover, [11] introduced an MCDM approach to identify a solar power plant location across the entirety of Vietnam and [12] presented multi-criteria decisionmaking methods for minimising environmental emissions in construction projects.

Concerning research in multicriteria analysis, scholars aim to define new methods or to modify existing approaches of multicriteria aggregation. ELECTRE (ELimination Et Choix Traduisant la REalité - ELimination and Choice Expressing the REality) family of methods has been extensively employed to tackle multi-criteria decision problems since its introduction in 1960 [13,14]. In [15], the authors summarized the revisions and modifications made to the ELECTRE methods up to 2012. They suggested that coupling ELECTRE with Evolutionary approaches could be beneficial and reduce the complexity of certain computations within ELECTRE algorithms. In this paper, we will give a particular interest to ELECTRE III method which is used for ranking problematics and has been widely applied in different fields, such as education sector, production process, energy system planning, operation management, public transportation planning and territorial management [16].
Several approaches have been proposed for revising ELECTRE III method in order to enhance its performance and increase the quality of its results. One example is [17] where an enhanced ELECTRE III approach was suggested for the scientific assessment of PE teachers. Instead of the distillation algorithm of the ELECTRE III method, the authors proposed a simplified and reliable sorting algorithm by introducing three concepts: consistent reliability, inconsistent reliability, and net reliability. Also, the authors considered the proposed revised ELECTRE III as effective and feasible according to experimental results. [16] represents another study where the ELECTRE-III method was merged with the Kano two-dimensional quality model to streamline the smartphone selection process. In a separate research project [18], a modified ELECTRE was proposed to examine the influence of renewable energy policy selection on environmental development. Concerning the coupling of the ELECTRE III method with an evolutionary approach, we can refer to [19] where the authors introduced a novel ranking method by integrating ELECTRE III and the NSGA multi-objective algorithm to address the student selection problem. In [20], ELECTRE III was coupled to Multiobjective Evolutionary Algorithm (MOEA) and employed to tackle the credit ranking issue of a Parafinancial company. In the two last works the authors estimated that the ranking obtained by the coupling is more comprehensive to decision makers.
In this paper, we present a modified version of the ELECTRE III method, achieved by integrating it with the Multi Objective Genetic Algorithm (MOGA). Additionally, we propose an MC-SDSS tailored for environmental planning to address location issues in regional planning. This system merges GIS processing capabilities with the structured decision-making approach provided by multicriteria analysis techniques (MCA) for spatial decision-making. Our primary contribution is proposing methods and tools that significantly aid in executing urban projects. This is accomplished through a methodological step, assisting territorial decision-makers in executing various regional planning projects and enhancing decision rationale, all within a GIS platform. In the proposed decision model, multicriteria assessment can be performed using either the traditional ELECTRE III method or the modified version. This modified version, which constitutes the paper's second contribution, employs multi-objective genetic algorithms during its exploitation phase, aiming to enhance the spatial decision-making system's effectiveness and provide better support to decision makers.
This paper is structured as follows: The introduction outlines the context of our study, recent advancements in the ELECTRE family applications, and revisions to the ELECTRE III methods. It also addresses the fundamental motivations and objectives guiding this research. Section 2 is divided into two subsections: the first provides a theoretical background of the ELECTRE III method, while the second discusses its limitations. The conceptual design of the proposed MCSDSS (PRODUSMAGAT) is elaborated in detail in Section 3. The applicability of the suggested

methodology is illustrated through an experimental study described in Section 4. Finally, Section 5 concludes the paper, summarizing our work and offering future perspectives.

II. ELECTRE III

II.1 Principle

The ELECTRE III MCA method seeks to address issues classified as type gamma (type γ: ranking procedure) by arranging actions from best to worst, and then identifying the action(s) that seem(s) most suitable. To do so, Electre III combines partial preferences to form a fuzzy outranking relation. A table of performance structured in an incidence matrix (actions - criteria) is considered as the input data for ELECTRE III. The treatment of outranking provided on this matrix will allow to establish a final partial preorder. Typically, Electre III functions in two stages: aggregation and exploitation. [22]:

- The aggregation stage involves building outranking relations based on two principles: the concordance principle and the discordance principle. This phase also needs the introduction of multiple subjective parameters (Weight of actions, Preference threshold, Indifference threshold, Veto threshold) at the beginning of treatments.
- The exploitation phase utilizes the credibility matrix (produces during the aggregation phase) and aims to derive a final ranking of sites (actions) from the outranking relations. The algorithm used in by Electre III in the exploitation phase is known in literature as distillation algorithm.

Employing Electre III for ranking and classification issues offers the following benefits [23]:

- Both quantitative and qualitative information are considered.
- Incorporating the concept of non-comparability of choices throughout the entire classification or ranking process.
- Simplicity of comparisons, leading to a clearer comprehension of the results.
- Ease of method use, whether performed manually or on a personal computer.
- Utilizing subjective factors (such as weight, indifference, preference, and veto thresholds) to enhance the effectiveness of decision support.

II.2 Critics of ELECTRE III Method

Evaluating the relative performance of different MCDA has been tackled by different researchers. In this paper we have chosen to work with the following three criteria [25]:

Criteria1: "A proficient Multicriteria method should continue to highlight the best alternative (action) even when a non-optimal action is replaced by another worse one."

Criteria2: "The alternative ranking by a proficient Multicriteria method should satisfy the transitivity property."

Criteria3: "Assume a Multicriteria problem is partitioned into a collection of smaller problems. Each problem possesses two original decision alternatives and criteria. Let's assume later on that the categorization of the smaller problems adheres to the transitivity property. Based on this criterion, when the classifications of all the smaller problems are merged, the newly formed classification of alternatives should match the initial classification before partitioning the problem."

III. Description of the Proposed System

To test the modified ELECTRE III, we integrated it into the proposed MC-SDSS named PRODUSMAGAT. The latter is composed mainly of three components: Territory Model, Analysis Tools and Multicriteria analysis.

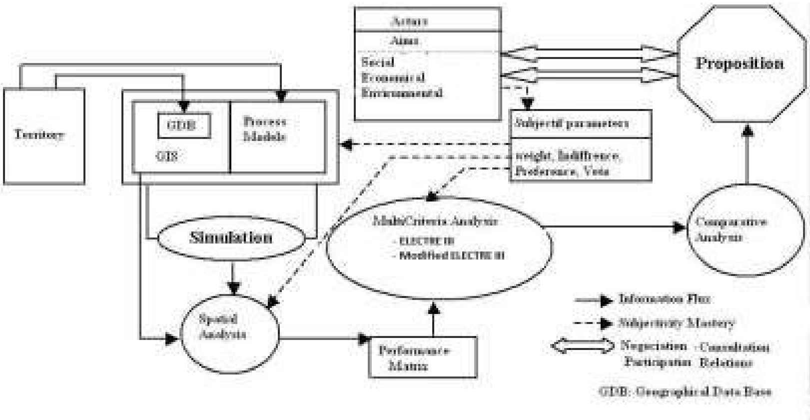

Figure 1. The proposed decisional model

III.1 Territory Model

The use of the territory model contributes considerably to the description of the context and the identification of planning variants. Constituted by the Geographical Information System (GIS) and simulation models, it constitutes the support of spatial analysis functions (5A) [4]: Abstraction, Acquisition, Archiving, Display and Analysis.

Hence, when decision makers successfully determine actions and criteria, spatial analysis procedures enable the assignment of values to various actions, assigning a value (or score) for each criterion. The collection of actions along with their scores for different criteria form the evaluation matrix (or performance table), which is managed by GIS. Actions are linked to locations, and consequently, the evaluation matrix can be represented in the form of chart. This distinct characteristic is an advantage because it allows locating, at any moment, the alternatives (actions) in their environment.

III.2 Analysis Tools

The comparison of the various actions was then conducted using analytical tools. The latter could generate one or more proposals. These tools are used also to synthesize geographic information to select the variants satisfying the decision maker (s) preferences. The criteria employed can be either quantitative, qualitative, or a combination of both.

III. 3 Multi Criteria Analysis

PRODUSMAGAT proposes two strategies for Multicriteria analysis: •
Exploiting ELECTRE III alone.
•Exploiting the modified ELECTRE III (ELECTRE III coupled with Multiobjective Genetic Algorithms).

Modified ELECTRE III

Irregularities detected in ELECTRE III are mainly due to the instability of the results provided by the distillation method used in the exploitation phase of ELECTRE III. To avoid these inconsistencies, we propose a modified ELECTRE III where we replace the distillation phase by the Genetic Algorithms GAs according to a multiobjective optimization [15,19,20]. The suggested solution is applicable to any domain. For this paper, we propose to work on the problems of regional planning.

Multiobjective genetic algorithms are designed to make a multiobjective optimization: simultaneous optimization of several criteria, which are usually contradictory. At the end, we obtain a set of solutions (individuals) reintroducing a good compromise known as, "pareto" [26,27].

In this work, we have used a multiobjective genetic algorithm. The different parameters and operators used are detailed below:

1) Coding

The individual is represented as strings of potential action in a decreasing order of preference. Every action represents a gene of the individual. Thus, the chromosome is represented by m actions, with m being the total number of actions in the decision problem (equivalent to the number of islets in the context of our problem). In the following an expression representing an individual p is given:

p= $a_{k_1}, a_{k_2}, \ldots\ldots\ldots\ldots, a_{k_m}$

with

$\{k_1, k_2, \ldots, k_m\}$ being a permutation of $\{1, 2, \ldots, m\}$

We use the following notation: a_{k_i} outranks a_{k_j} is denoted by: a_{k_i} S a_{k_j}

a_{k_j} does not outrank a_{k_i} is denoted by: a_{k_j} nS a_{k_i}

2) Objective Function

Each member of the population of solution is characterized by three functions: lambda, f, and u. In the following, the definition of each function is given for an individual p (defined upper).

Lambda: This function signifies the credibility level attributed to the individual, with a value range of 0 to 1. A lambda value nearing 1 indicates a more notable individual, with the algorithm targeting to approach a value close to 1.

Function f: This value denotes the count of actions that are incomparable within an individual p.

$f(p) = |\{(a_{k_i}, a_{k_j}); a_{k_i} \text{ nS } a_{k_j} \text{ et } a_{k_j} \text{ nS } a_{k_i}; i = 1,2 ...., m-1, j = 2,3, ..., m, i < j\}|$

The function u: This value represents the number of preferences among actions into the individual *p* which are not "well-ordered" $u(p) = |\{(a_{k_i}, a_{k_j}); a_{k_j} \text{ S } a_{k_i} \text{ et } a_{k_j} \text{ nS } a_{k_i}; i = 1,2 ...., m\ j = 1,2, ..., m\ i > j\}|$

3) Fitness Evaluation Procedure

In the field of multiobjective optimization, there are established algorithms for determining fitness, including VEGA, VOES, HLGA, MOGA, NSGA, NPGA, and SPEA. In this study, we employed the MOGA (Multiobjective Genetic Algorithm) [26].

The application of the MOGA algorithm aims to optimize the three objective functions: λ, f, and u, with the following objectives:

- Reduction in the value of u: Individuals with u = 0 are the most desirable.
- Reduction in the value of f: Individuals with f = 0 are the most desirable.
- Augmentation in the value of λ: Individuals with λ close to 1 are the most desirable.

IV. Case study

In this section, we present a selected case study for which the necessary data and information are available. This case study serves as a platform to develop and evaluate the proposed methodology.

IV.1 Delimitation of the Study Area

The study area encompasses a set of actions situated within El Yasmine, located in the eastern part of Oran, Algeria (Fig 2): action 49, action 25, action 51, action 50, action 22-3, action 22-1, and action 21. The selection of this region is primarily driven by its abundance of projects. Indeed, the urban development strategy for the city of Oran involves a linear extension along the eastern seaboard. Employing this case study enables a comparison of the results obtained by PRODUSMAGAT with the actual projections. The map of the study area is articulated using the GIS model (MapInfo), using all its features (Fig 3).

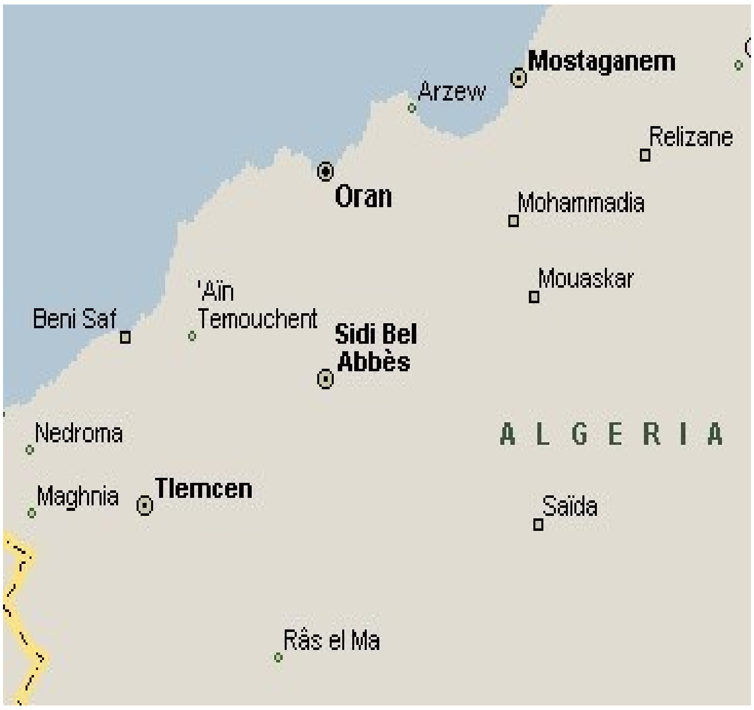

Figure 2. Geographical location of the study area

Figure 3. Visualization of the study area using GIS MapInfo

IV.2 Problem Definition

Within the framework of Oran expansion project to the east, a new bus station was planned as one future equipment. The issue addressed by PRODUSMAGAT relates to the localization of the most appropriate islands (among several alternatives) for the construction of this new bus station. We have opted for the environmental criteria represented in Table1 (depending on data availability and the particular characteristics of the study area).

Table 1. Identification and Assessment of the Criteria Employed in the Study

Criteria	Type	Factors associated subcriteria)	Evaluation Methods	Scale
Geotechnical	Natural	Ground surface, ground nature	Procedures of spatial analysis Experts consultation	Km
Equipment	Economical	Distance from equipments: gas, electricity, water, roads.	Calculation of weighted distances for connections to different networks	M
Accessibility 1	Social	Near the bus station to places of residence	Assigning a note from 1 to 4	
Noise	Social	Noise generated by the bus station on the nearby	Assigning a note from 1 to 4	

Accessibility 2	Economical	Near the centroid of the area served by the station	Assigning a note from 1 to3	

To achieve our study and in accordance with the specific characteristics of the study area, six actions (free islands) were identified. The evaluation matrix (performance) utilized by the ELECTRE III method (during the aggregation phase) is presented in the subsequent table (Table 2): Table 2. Performance Table

N °	Site	Area	C1	C2	C3	C4
1	907	48378,64	-50	4	-1	-1
2	1057	35744,03	-80	4	-1	-1
3	1109	38245,14	-1700	3	-4	-1
4	1067	47618,28	-1800	1	-4	-3
5	573	31727,25	-400	2	-3	-2
6	87	30739,75	-100	4	-2	-1

IV.3 Choice of Subjective Parameters

As we have mentioned in Section III, our decision model PRODUSMAGAT requires the values of four thresholds: the preference threshold (p), the indifference threshold (q), the veto threshold (υ), and the weight (p). These thresholds facilitate the incorporation of inherent uncertainties in the valuations into the decision-making process.

The determination of thresholds within the framework of environmental impact assessment often encompasses a notable degree of subjectivity. We propose the adoption of the Saaty Scale [28], a well-rounded method, for delineating realistic boundaries for the parameters p, q, and υ

The Saaty Scale operates on a mathematical model with the objective of evaluating and ranking various criteria based on their relative significance. It employs a sequential pairwise comparison approach, where each criterion is assessed against all others through a series of one-onone comparisons. Users are prompted to rate the relative importance of one criterion over another on a scale ranging from -9 to 9. Through this mathematical model, a relative weighting for each criterion is given.

IV.4. Treatment and Results

In this section, experimental results are presented along with discussions regarding performance findings. Three subsections are supplied; the first presents the pre-treatment phase of this work. The second subsection explains experimental results using Electre III only, or by coupling it with the multiobjective GAs. A brief debate about the results is given in the third subsection.

A. Pre-treatment Phase

This phase is needed before starting the treatment. The user is invited to visualize the free islands and choose those competing with the study (Fig 4).

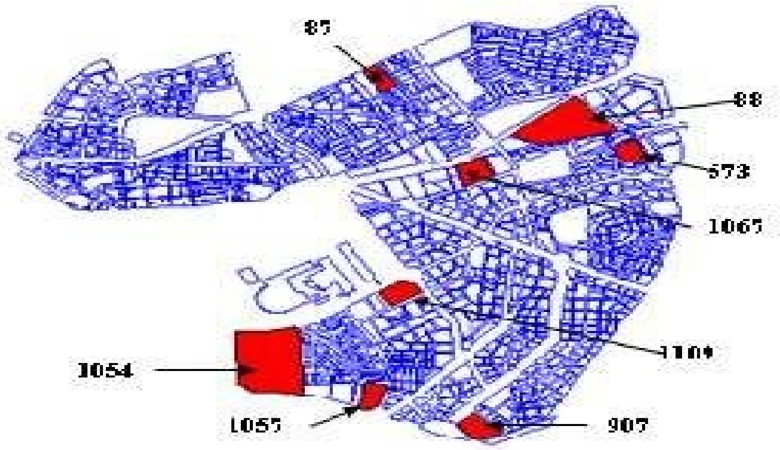

Figure.4 Display of the Map in PRODUSMAGAT Using GIS Components

The subjective aspect of PRODUSMAGAT is ensured by the introduction of subjective parameters: Threshold matrix and weight matrix. As a result of the aggregation phase, different matrix can be displayed to the user and illustrated in the Performance Table (Table 1).

B. Experimental Results

The goal of this study is to compare between the performance of ELECTRE III and the revised ELECTRE III, and to choose the method which gives the decision makers better assistance and guidance. Each of the two approaches uses the performance table as input data.
Initially, the performance of the ELECTRE III method was evaluated based on the first two criteria outlined in Section 4. In the first evaluation, ELECTRE III maintained the optimal alternative (action 907) even when a sub-optimal alternative was substituted with a less favourable one. However, the transitivity property was not verified for all the actions in the obtained results which means that the method has not checked the second test criteria. The storage obtained by the use of ELECTRE III (alone) is as follows (Table3):

Table 3. ELECTRE III Results

Class Number	Islet Number
1	907
2	1057
3	1109
3	1067
3	573
3	87

As a second step of this study, we have repeated the performance tests for the revised ELECTRE III. The same observations were found, the action number 907 was always the first one in spite of the change of the worse actions. However, transitivity propriety was not verified for all the actions. The storage achieved by the modified ELECTRE III is as follows (Table 4):

Table 4. Revised ELECTRE III Results

	Sol1	Sol2	Sol3	Sol4	Sol5
1	907	907	907	907	907
2	1067	1057	1109	1057	1057
3	1057	573	1067	1067	1067
4	1109	1109	1057	1109	1109
5	87	87	87	87	87
6	573	1067	573	573	573

C. Results Discussion

In this work, the obtained results have validated the location of the proposed bus station which corresponds to the choice established by decision makers in reality. Concerning the test criteria, both methods (ELECTRE III, Revised ELECTRE III) have not satisfied the second test criteria; future experiments are planned with more voluminous databases to re-evaluate all the criteria using both methods.

Regarding the results, multiobjective optimization has allowed proposing various solutions to decision makers with different values of λ while releasing the number of incomparable actions (f) and the number of actions poorly classified (u). However, ELECTRE III proposes a single classification without offering a diversity of choice. Thus, we can confirm through our study that the use of multiobjective GA in the conduct of territorial problems can better assist decision makers. The use of the modified ELECTRE III offers a variety of alternatives encouraging, subsequently, a more meaningful negotiation between them.

V. Conclusion

At the end of this article, we have proposed a modified version of the multicriteria method ELECTRE III. To test the proposed algorithm, we choose to resolve regional planning problem and a decision model that incorporates a territory model, Multicriteria analytical tools and genetic algorithms was proposed. The territory model consists of the Geographic Information System (GIS) which enables decision makers to identify actions and criteria involved in the study. It will also give a value (note) for the different actions related to each criterion as constituting the "matrix of evaluation" (or performance table). Comparison between the various actions is then performed by using the Multicriteria analysis method ELECTRE III and the modified ELECTRE III. The use of multiobjective GAs in the operating phase of ELECTRE III reduces the irregularities of the latter. Also, it provides the decision makers with a set of interesting solutions (Pareto).

The example used in our case study has permitted to validate the choice made by the management planning of Oran as for the location of the new bus station. For future exploration, we suggest employing more voluminous databases and extending the scope to other fields, such as the location selection for photovoltaic solar plants.

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