GIS BASED DECISION SUPPORT SYSTEM FOR SEISMIC RISK IN BUCHAREST. CASE STUDY – THE HISTORICAL CENTRE

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Abstract: Because of the increasing volume of information, problem decisions tend to be more difficult to deal with. Achieving an objective and making a suitable decision may become a real challenge. In order to better deal with decision making, decision support systems (DSS) have been developed. The decision support systems (DSS) can be used in any kind of a decision-making process and are very suitable in situations that involve a lot of stakeholders and a large number of criteria. DSS offers support in the decision-making process (*how* a decision should be made), and it does not focus on the result (*what* decision that should be made). DSS can also involve a large number of stakeholders and criteria, in the same time. A limitation of this method is that, regardless of the mathematical results, the final decision has to be made by the decision maker. Depending on the nature of the decision problem, a decision maker can use decision support systems (DSS), if the decision problem is economic or technical, and spatial decision support systems (SDSS), if the decision maker is faced with a spatial decision problem. The main objective of the present study is to apply a spatial decision support system in order to find a suitable shelter in the historical centre of Bucharest City in the post-disaster phase, in case of an earthquake occurrence. The present work represents a first step in applying SDSS in the context of the seismic risk in Bucharest. For the present paper, the SMCE Module for ILWIS 3.4 was used. The method included the following steps: structuring the problem in a decision tree, applying standardization and weighting methods to the criteria, finding suitable alternatives and choosing one of the alternatives. The results show that several buildings can be used as a shelter and among these are 'Creditul Roman' Bank Palace, the National History Museum and the National Bank of Romania.

Keywords: DSS, SDSS, seismic risk, Bucharest, shelter

1. INTRODUCTION

Because of the increasing volume of information, problem decisions tend to be more difficult to deal with. Achieving an objective and making a suitable decision may become a real challenge. In order to better deal with decision making, decision support systems (DSS) have been developed. The decision support systems (DSS) can be used in any kind of a decision-making process and are very suitable in situations which involve a lot of stakeholders and a large number of criteria, in the same time. DSS offers support in the decision-making process (*how* a decision should be made) and it does not focus on the result (*what* decision that should be made) [1].

In DSS, the main challenge is problem structuring [2] and the understanding the characteristics of the problem, e.g. if we face an economic or a technical problem [3]. Meantime, there are two separate visions of DSS [4]. There

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is the *objective rationality* or *substantive rationality*, in which the decision process results for best solution/decision and emphasizes *how a decision should be made*, and there is the *procedural rationality* or the *bounded rationality*. In the last one, the decision maker searches for an optimal or satisficing solution and emphasizes *how decision is made* [5]. There are several frameworks for decision support systems [4, 6, 7]. For the present study, we have selected Sharifi's model (2004), which is an adaptation of the original Simon's model (1960). This model includes four main phases: (i) the intelligence phase, where the system is described and understood, then the problem is identified and the objectives are set; (ii) the design phase, in which feasible alternatives are generated after formulating and validating the model; (iii) the choice phase, in which the alternatives are being evaluated and one of them is selected and (iv) the implementation phase.

If DSS involves spatial problems, then it becomes a spatial decision support system (SDSS). Even though SDSS and GIS rely on GIS technology, they are not the same thing. SDSS is based on spatially referenced data, and GIS is based on spatial data [8]. SDSS is able to deal with complex spatial problems, proving a framework for integrating database management systems, graphical display, tabular reporting capabilities and the expert knowledge of decision makers (Table 1) [9].

Table. 1. Differences between SDSS and GIS [9].

SDSS	GIS
Flexible – support individual decision-making approaches.	Supports only cartographic display.
Chiefly designed for decision-making environment.	Limited geographical information analysis.
Designed to solve ill-structured problems.	Too rigid to model (specific data formats, resolution).
Flexible, combining analytical models and data.	Limited tabular or diagram reporting.
Provides feasible alternatives.	Shortage in analytical modelling techniques.
Iterative, integrative and participative.	Shortage in designing ill-structured problems.
Can also include non-spatial data in the analyses.	

There are many examples for the theory of SDSS [8-13] and the applications involved [5, 14-18]. Because of the complexity of the decision-making process, spatial multi-criteria decision analysis (SMCDA) have been developed. SMCDA is a process that combines and transforms geographical data (the input) into a decision (the output), constituting a series of procedures that include spatial data, the preferences of the decision maker, the data manipulation and the preferences regarding the specific decision rules [5].
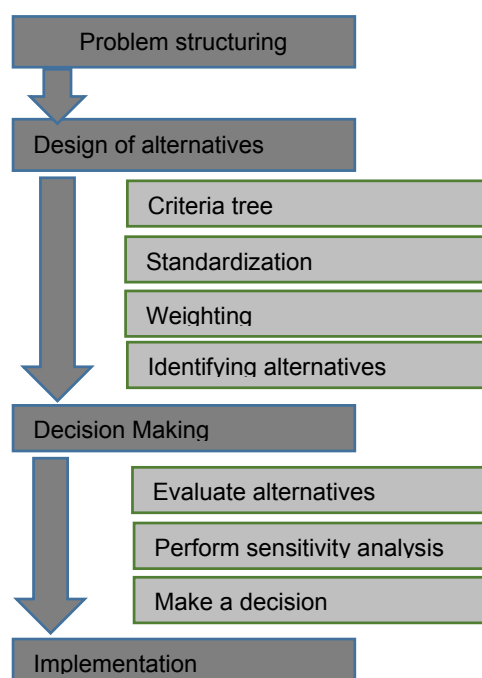

Fig. 1. Applied framework for SDSS.

For the present paper we used a more simplified Sharifi's model (2004), as seen in Figure 1. The structure of the paper follows the workflow of this model, presenting the problem structuring and the study area, the process of designing the alternatives, the process of decision making and the sensitivity analysis. Finally, some brief conclusions are offered.

2. PROBLEM STRUCTURING AND THE STUDY AREA

The main goal of this research is to find a suitable shelter in the historical centre to be used in the post-disaster phase if an earthquake occurred in Bucharest City (Figure 2).

Fig. 2. Study area.

The reason for choosing the historical centre for this goal is because it is highly populated. There are not only residents, but many visitors and employees. Almost all buildings have ground floor pubs, clubs, restaurants or stores, which attract many visitors and need many employees for sustaining the touristic services.

The main problem is that the buildings are very old and damaged. Many buildings were constructed in the 19th century and have experienced since then two world wars and several intense earthquakes, the last one in March 1977. Furthermore, most of these buildings have neither been consolidated nor properly maintained, making them extremely vulnerable to earthquakes [19].

3.   DESIGN OF ALTERNATIVES

The SMCE module from ILWIS 3.4 was used in this decision-making process, and the multicriteria approach was selected, because of the problem complexity. We have identified four groups of factors for designing the alternatives: 1) the building characteristics and 2) function; 3) the population; 4) the building damages in case of an earthquake. Besides these groups of factors, we have also used two constraints: the state and the area of the building. It was considered that damaged buildings or buildings with an area less than 1,000 square meters cannot be used for shelters, and they were eliminated from further analysis (Table 2).

Table 2. Data used for designing the alternatives [20].

Vector layer	Attribute	Description	Standardization	Weighting
Total Buildings	**New goal**	The main objective of the decision-making problem (finding a suitable shelter)		Rank Order - Rank Sum – the factors and the groups of factors are being ranked by the decision maker
	Cod_stare_clad	(constraint) The actual state of the building, regarding its structure (damaged buildings are eliminated from the start)	Constraint – pass on minimum. The buildings that are very damaged, damaged, under construction or ruins (code 0) can't be used as a shelter.	
	HECTARES	(constraint) Building's area (larger than 0.05 ha)	Constraint – pass on goal 0.05 ha. Buildings that have a smaller area cannot be used as a shelter.	
	Building functions	The functions of the buildings (encoded)	Benefit – maximum value	
	Buildings	Attributes of buildings		Rank Order – Expected Value – the factors and the groups of factors are being ranked by the decision maker, based by the expected value
		Number of storeys	Cost – maximum value	
		Number of exits	Benefit – maximum value	
		The existence of a direct access in the building		
		The state of the stairs (damaged or not)		
		The existence of an interior yard		
		Auto access (for ambulances, firefighters etc.)		
		Year built		
		The state of the building structure		
		Building vulnerability (codes)		
		People		
		Number of persons living in the building	Cost – maximum value	
Earthquakes damaging	**Building damages**	Building damages in case of an earthquake occurrence	Benefit – maximum value	Rank Order – Expected Value
		Probability for no damage	Cost – maximum value	
	MDR1	Economic losses		

All the above data were structured in a criteria tree. After problem structuring, every factor was standardized, resulting in values ranging from 0 to 1, depending on whether the factor represented a benefit (the more of it, the better for the goal) or a cost (the more of it, the worse for the goal) for the analysis.

The following equations were employed for value input standardization, depending on the nature of the criterion [21]:

$$\text{Benefit factor = value / maximum input value} \tag{1}$$

$$\text{Cost factor = 1 - (value / maximum input value) + (minimum input value / maximum input value)} \tag{2}$$

We analyzed all the buildings having damage codes greater than 0 (used for damaged buildings or under construction) and areas larger than 1,000 square meters. The next step was to weight the factors and the group of factors. The method selected was the ranking order, setting the factors and/or the group of factors by their importance.

Fig. 3. Suitability map for Lipscani historical centre and the buildings selected for decision-making phase.

In this method, based on the ranking established by the decision maker, a set of feasible weights [21] is being computed for each criterion. Depending on the method selected, the set of feasible weights are transformed into quantitative weights, according to the following formulas [21]:

a. Expected value method

$$w_k = \sum_{i=1}^{n+1-k} \frac{1}{n(n+1-i)} \tag{3}$$

where: Wk is weight for criterion k; n – number of criteria.

b. Rank sum method

$$w_k = \frac{n+1-k}{\sum_{i=1}^{n}(n+1-i)} \tag{4}$$

The result (Figure 3) shows that a large amount of buildings cannot be used as shelters in case of an earthquake. The values range from 0 to 0.9, with an average of 0.59 and a standard deviation of 0.19. The value 0 was obtained for the buildings that failed the constraint conditions. From all 357 buildings, only 23 buildings obtained values over 0.5, and only four over 0.75.

From these 23 buildings, only 6 were selected as alternatives for the decision-making phase (Figure 3), based on the values obtained.

4. DECISION MAKING

The third phase of the analysis consists in evaluating the alternatives. For this phase, we also used the SMCE module of ILWIS software, but selecting the decision-making mode. A criteria tree was designed, with a different column for each alternative. The alternatives were evaluated based on three non-spatial criteria: area, suitability and no. of inhabitants and/or employees (Figure 4).

Criteria Tree	clad1	clad2	clad3	clad4	clad5	clad6
shelter -- ExpVal	0.4810	0.8054	0.6477	0.9078	0.6302	0.6431
◊⁺ 0.11 suprafata -- Std:Maximum	0.415	0.129	0.146	0.198	0.105	1.163
◊⁺ 0.61 pretabilitate -- Std:Maximum	0.65	0.81	0.78	0.9	0.76	0.63
◊⊖ 0.28 persoane (locatari) -- Std:Max...	80	10	50	0	50	50

Fig. 4. Criteria tree for the decision-making phase.

Standardization was applied, considering the area and suitability as benefits and the number of persons living in each building as a cost. The ranking order with expected value was selected for weighting. We considered that the most important criterion for choosing one alternative is the suitability, secondly it is the persons living and/or working in the building and thirdly the area of the building.

The results show that the highest value was obtained by building 4, which also has the highest suitability value. The lowest value was obtained by building 1, which has the second lowest suitability value, but has the highest number of persons living and/or working there.

5. SENSITIVITY ANALYSIS

Sensitivity analysis is performed to test the robustness of the analysis [13]. In decision-making problems, the biggest fear of the decision maker is if the decision is wrong. What if not all the criteria has been taken into account, or what if the standardization or weighting applied was not the most suitable? For avoiding making bad decisions, sensitivity analyses can be very helpful. They consist of changing one or more elements of the performed analysis. It can be used by changing the standardization or by changing the weighting method, or both. If the results are very similar to the original ones that means the analysis is very robust, so the decision is satisficing, under the given conditions. However, if the results differ with every small change that means that the analysis is very sensitive and should be reassessed.

For the present analysis, a sensitivity analysis was also applied (Table 3). Because of the nature of the criteria, we can assume that the standardization is correct, so we can change only the weighting methods. Also, it was always assumed that suitability is the most important criterion.

In a first phase, it was considered that the number of inhabitants and/or employees is more important than the surface of the building. In this case, regardless the weighting method used, the results are very similar, showing the highest values for building 4.

Secondly, it was assumed that the area of the buildings is more important than the number of persons. In this case, for expected value and pairwise methods the results are similar, but for rank sum method, the highest value was obtained by building 6, with a small difference.

Table 3. Results of the performed sensitivity analysis.

	clad1	clad2	clad3	clad4	clad5	clad6
Persons more important than area						
Expected value	0.4810	0.8054	0.6477	0.9078	0.6302	0.6431
RankSum	0.4206	0.7602	0.5793	0.8617	0.5623	0.6417
Pairwise	0.5782	0.7380	0.6691	0.8322	0.6464	0.7291
Area more important than persons						
Expected Value	0.5405	0.6780	0.6062	0.7695	0.5828	0.7472
RankSum	0.4801	0.6328	0.5377	0.7234	0.5148	0.7458
Pairwise	0.5407	0.8183	0.6953	0.9194	0.6763	0.6634

As a conclusion, we can affirm that the analysis performed in this paper is a robust one, and the most suitable building that can be used in case of an earthquake occurrence is building 4 - 'Creditul Roman' Bank Palace.

Even though the suitability for one alternative has a lower value, depending on the other criteria and on the weighting method applied, it can still become the most satisficing solution. In the present analysis, the most satisficing solution had also the highest suitability value, but if we observe buildings 1 and 6, we will see that the ranking resulted from the suitability analysis does not maintain in the decision making phase. Because building 1 has the greatest number of persons, at a considerable difference from the others it obtained the lowest values in the sensitivity analysis, despite the fact that it did not have the lowest suitability value. Similar, building 6 had the lowest suitability values, but did not obtain the lowest scores in the sensitivity analysis.

4. CONCLUSIONS

Decision support systems can be very helpful, especially in spatial planning, when a lot of data and of stakeholders are involved. A great advantage of these systems is that they can take into account, simultaneously, a large number of opinions, translated into 'what I want from this'. The stakeholders involved can differ significantly, they can be public authorities, private companies or NGOs, all involved at the same time, in the same decision-making problem. Also, because they do not focus on the result, on obtaining the *'best'* solution, but on the decision-making *process*, they ensure transparency in decision-making. Using DSS we do not obtain *best* solutions, but *satisficing* solutions and are based on trade principle, from the stakeholder's point of view. By trading, one stakeholder can maintain one demand and give up another one, in perfect agreement with the other ones.

A limitation of these DSS is that they are semi-quantitative and they rely on human judgement. The decision maker has to be able to integrate all the demands of the stakeholders, to structure the problem, to find suitable criteria and data needed, to perform a suitable standardization and weighting of the factors or group of factors. Also, a sensitivity analysis is very useful for testing the robustness of the decision-making analysis.

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