CHAPTER 4

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Spatial problems can have single end objectives like landslide hazard zonation, site selection for check dams, or multiple ones like land use planning.

Real world problems are tractable if optimization is done sequentially rather than globally even though some price in global optimality has to be paid. The traditional goal of optimization is to maximize or minimize certain quantity, which depends on lumped parameters. For example, the maximization of yield from an area will not automatically indicate the crop type of each unit of land but will give bundled figures for each crop. Hence the unbundling of this number and arriving to multiple units need a spatial framework, which is best provided by GIS.

There are also problems which require prediction of complex processes in spatial and temporal domains like land degradation processes, land use change or settlement dynamics, which are other complex in nature. Such problems can be addressed with Cellular Automata, a spatial domain modeling tool.
4.1 Multi-Criteria Decision-Making

Multi criteria decision-making (MCDM) problems involve a set of alternatives that are evaluated on the basis of a set of evaluation criteria. The multi criteria decision analysis has recently received considerable attention in GIS. Alternate approaches to GIS-based multi criteria analysis have been suggested to overcome the problem of weighting and data integration. Analytical Hierarchy Process (AHP) was used as a weighting strategy and Compromise Programming (CP) technique was used for data integration.

4.1.1 Analytical Hierarchy Process (AHP)

Combining different factors, some exclusionary and some expedient, requires a weighting factor. AHP is an approach that can be used to determine the relative importance of a set of activities or criteria through pair wise comparison approach.
4.1.2. Compromise Programming

Another important problem in GIS is how to efficiently integrate data from various sources. Weighted linear additive model is the one that is widely used for data integration and is done with the help of algebraic functions available in any commercial GIS package. In this, a total compensation between criteria is assumed, meaning that a decrease of one unit on one criterion can be totally compensated by an equivalent gain on any other criteria. Compromise Programming technique, is a method to arrive at non-compensatory solution. It measures the deviations from the ideal point in each data layer and a min max rule is applied wherein minimum of the maximum weighted deviations are sought for getting a composite layer. The best compromise solution is defined as that which is at the minimum distance from the theoretical ideal. These methods have been used to solve problems like landslide hazard zonation and site selection for water harvesting structures.

4.2. Multi-Objective Multi-Criteria Decision-Making

Combination of Analytical Hierarchy Process and Compromise Programming techniques worked well in solving Single Objective Multi-
Criteria problems like Site Selection for Water Harvesting Structure, Landslide Hazard Zonation. But such a combination cannot be effectively used for solving Multi-Objective Multi-Criteria problems like land use planning. The goal of Land use Planning is to choose appropriate usages from a multiple set of options for each unit of land. These options could include individual crops or land use practice like agro forestry, silvipasture, etc. Hence this problem is characterized as a multiple objective one. Multiple criteria like land use, slope, soil, landform, groundwater prospects, etc, are involved in analyzing each objective.

Though the Multi-Objective Multi-Criteria Decision-Making problem can be broken into several single objective multi criteria decision making problems, solving them by applying combination of Analytical Hierarchy Process and Compromise Programming techniques is not going to be straight forward and effective. Moreover only absolute suitability within an objective can be addressed using MCDM techniques.

In Multi-Objective Multi-Criteria Decision-Making problems, what is needed is the relative suitability for different objectives. We propose a Fuzzy classification approach in GIS for solving Multi-Objective Multi-Criteria Decision-Making problem.
4.2.1. Fuzzy Classification in GIS

Fuzzy Classification in GIS approach not only solves a multi-objective multi-criteria decision-making problem, but also overcomes the information loss seen in classical set theory-based decision-making. The task of rating land suitability is to classify areas into land use classes according to their land characteristics. By representing areas as vectors in a feature space, one can use the distance between feature vector corresponding to an area and a land use class as a measure of their similarity. The similarity indicates the extent to which the area belongs to the land use class. This technique has been used to suggest alternate land use / crop. It is also possible to use the stored fuzzy membership grades for database queries like: Find the second most suitable crop for a particular area; List all the areas, which are suitable for both soya bean and sugarcane and find the suitability value etc.

4.3. Optimization technique

A big vacuum exists in the field of Spatial Modeling with regard to inclusion of socio-economic data. There are inherent problems in
incorporating socio-economic data, with the spatial land-related data. Until socio-economic data is involved in the model, we will not be able to model the problem close to real-world situation. An attempt has been made to use socio-economic data to generate optimum agriculture development plans, by integrating Linear Programming (LP) with GIS.

Identification of optimal crop that maximizes productivity or maximizes employment or minimizes water use, subject to constraints like, labor availability, finance, market price, water use, self requirement has been attempted to derive agriculture development plans. Integrating LP with GIS involves issues like spatialization of LP results, as it usually uses lumped parameters and also taking the constraints’ coefficients by performing preliminary analysis in GIS. Optimal proportion of area for land use transformation after satisfying the constraints is obtained from LP. LP does not provide a spatial representation for the suggested land use allocations. It would only say how much hectares of each land use should be changed, but would have no indications on which specific hectares should be altered. Spatial mapping of LP results was done by performing land suitability analysis in GIS.
4.4. Dynamic Spatial Modeling

Most current GIS techniques have limitations in modeling changes in the landscape over time. But the integration of Cellular Automata (CA) and GIS has demonstrated considerable potential. More sophisticated CA model has been built by improving the state-based cellular automata with suitability constraints, determined using the land degradation driver variables, for simulating land degradation scenarios.

Traditionally, CA simulation only uses a binary value to address the status of conversion based on the calculation of probability. The probability of conversion is calculated based on some kind of neighborhood function. Usually, the probability is further compared with a random value to decide whether a cell is converted or not (1 for converted and 0 for non-converted). In our model, the status of cell has a continuous suitability value between 0 and 1 to represent the stepwise selection or conversion process. A cell will not be suddenly selected or converted.

A stochastic disturbance term is added to represent unknown errors during the simulation. This can allow the generated patterns to be closer to
reality. Suitability values are converted into probability values by introducing a stochastic disturbance parameter. Thus this rule defines the probability of site selection in terms of land suitability.

The model developed for simulating the spatial dynamic process can be used as a planning tool to test the effects of different land use change scenarios. Cellular Automata are seen not only as a framework for dynamic spatial modeling, but also as a paradigm for thinking about complex spatial-temporal phenomena and an experimental laboratory for testing ideas.

4.5 Challenges

In spite of the proven abilities and increasingly widespread adoption of Decision Support Systems, there are number of areas where significant improvements can be made.

4.5.1 Fuzzy Logic methods in GIS

Fuzzy logic methods can be used as a representational and reasoning device in GIS. Geographical data has a number of properties, which present challenges to spatial modeling process. These include complex definitions
of locations, multidimensionality, and the inherent fuzziness in many features and their relationships. There are two issues that can be addressed.

(i) Representation issues: The database needs to hold information about features whose location and or extent are not known precisely.

(ii) Analysis issue: The expert performing spatial analysis may prefer to work with natural and expressive queries such as...

What are the areas, which are NEAR to the town,

SOUTH of the river and SUITABLE for agriculture?

4.5.2 Multi Agent Systems

Often, differential equations are used in dynamic modeling. The Cellular Automata / Multi Agent approach (CA/MA) can also be used for dynamic modeling and differs in many respect from sets of differential equation, both in the treatment of the data and in the working of the model. There is a conceptual shift from mathematical descriptions of a dynamic model to rule-based specifications of the behavior of individual agents. This is beneficial because rule-based specifications are often probably closer to the mental model people have of the systems, and because data from field studies may be more directly mapped into agents behavioral rules than into system level equations. Models of differential equation may include
hypotheses about the behavior of the elements at the micro level, but they
define rules that are applied at the macro/global level. On the contrary, the
information in a CA/MA model is treated at the local level from which
global pattern evolves. Comparing the MA approach to CA also helps to
illustrate its specificities. As in the case of CA, the evolution of a cell is
defined in a MA approach by a set of transition rules handling local criteria.
Within CA/MA framework each cell can be in one of the several states (land
use class), which can change over time. Change dynamics are determined by
the set of rules that define the state of each cell at the next time step based on
the state of a cell itself and the states of the neighboring cells. The difference
between CA and MA is mainly in the characterization of the cells. Whereas
each cell is defined by its state relatively to a single qualitative variable in a
CA application, it has a broader possibility of characterization in a MA
approach. The state of each cell is multi-dimensional and refers both to
qualitative variables (type of land use, for example) and quantitative ones
(population, for example). Therefore Multi Agents are the most appropriate
modeling technique to model multi-dimensional dynamic phenomenon.
Multi Agents are seen to be as an efficient technique to build Collaborative
Decision-Making systems as well and its potential in this field has to be
explored.
4.6 Conclusion

There is an ever-increasing demand to automatically derive information and make decisions out of the huge volumes of data available. This requires development and integration of efficient tools in GIS to enable it to progress to an Analytical GIS. The author has studied and worked on many of these analytical decision-making techniques for various land resource applications. It goes without saying that, further research in this direction is challenging and worth pursuing.