Enviromental and land use Planning decision support system: An application example.

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Resumen

Ordenación Ambiental del Territorio sistema de apoyo a la decisión: Un ejemplo de aplicación.

Este artículo trata sobre el uso del suelo / problemas de planificación ambiental y se describe la aplicación de un enfoque de planificación innovador para desarrollar soluciones alternativas de uso del suelo. Se proporciona un ejemplo de implementación de un marco que se puede aplicar a una variedad de complejos problemas de la planificación ambiental y uso de la tierra.
El primer artículo presenta brevemente un proceso de análisis relacionados con el sistema espacial de soporte de decisiones (SDSS), que utiliza modelos de SIG y de optimización, los cuales se han desarrollado en trabajos anteriores. A continuación, se intenta demostrar que el proceso y el SDSS se pueden utilizar en situaciones del mundo real para ayudar en el análisis y la planificación de la distribución espacial de las actividades. Esto se logra mediante la aplicación del innovador uso de la tierra enfoque de planificación de una zona situada en el borde de una próspera área metropolitana, que incluye un lago de nuevo desarrollo y las principales carreteras.

Palabras clave: planificación ambiental, optimización, desarrollo, procesos.

Abstract

This paper deals with land use/environmental planning problems and describes the application of an innovative planning approach to develop alternative land use solutions. It provides an implementation example of a framework that can be applied to a variety of complex environmental and land use planning problems. The paper first briefly introduces an analysis process and a related Spatial Decision Support System (SDSS), which utilizes GIS and optimization models, both of which were developed in previous works.

Then it attempts to demonstrate how the process and the SDSS can be used in real world situations to help in analysis and planning of spatial distribution of activities.

This is accomplished by applying the innovative land-use planning approach to an area located in the fringe of a thriving metropolitan area, which encompasses a newly developed lake and major thoroughfares.

Keywords: enviromental planning, optimization, development, processes.

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Introduction

Today planners deal with many complicated issues, such as land use and environmental problems. Many of the problems arising from these issues are too complex to be solved by a purely speculative approach based on experience, intuition, and imagination. On the other hand, an inductive analytic approach based solely on a detailed study of the problem is also insufficient. A more effective approach involves including elements of the two approaches in a scientific process based on a combination of experimentation, observation, and explanation.

This paper provides an implementation framework of this more effective approach which can be applied to a variety of complex environmental and land use planning problems.

This example uses a Spatial Decision Support System (SDSS) which integrates optimization models, Geographic Information Systems (GIS), and the knowledge and expertise of the planner-analyst. The planner-analyst also incorporates the community's wants and values into the planning process. The framework integrates the existing and recently developed ideas and theories into the SDSS

The goal of this Spatial Decision Support System (SDSS) is a more sensitive approach to land use planning which considers environmental and other important issues. The SDSS also strives to make use of technological advances to overcome some of the traditional problems and important non quantifiable considerations in land use planning.

The potential of the Spatial Decision Support System will also be investigated by applying it to a real-world situation.

The land use study presented can be used as a prototype by professional planners involved in a variety of related spatial problems, such as regional planning, location analysis, environmental planning, and landscape design problems of macro and micro scale.

Background

Early in the 20th century the impact of human activity on the environment became an issue with physical scientists.

With U.S. cities expanding rapidly beyond traditional urban centers, concern surfaced about the urbanization of the rural landscape. In 1970, popular support for improving environmental quality and mitigating future land impacts led to the enactment of the National Environmental Protection Act (NEPA). In more recent years, local and regional efforts have begun to recognize the effect of land use on the quality of the environment, and improved land use has resulted in a reduction of environmental hazards and land use conflicts. Efforts in the United States and Europe started basing land use decisions on land resources. Ian McHarg (1969) based a comprehensive plan for the development of an entire region on environmental and land resource characteristics.

McHarg also used land suitability analysis by applying overlaying map techniques.

McHarg (1969) used the traditional suitability analysis both for analysis of a highway location and also for land use planning for Staten Island which popularized the technique. With the advent of the computer and ever abundant digital data the analysis technique has evolved and has been integrated as one of the major component of GIS (for overview of the land use suitability analysis technology and projects see Collins et al., 2001). However, according to Jiang et al. (2000), "it is widely recognized that GIS still needs integration of new analysis and modeling methods if it is to achieve its potential as a general-all-purpose tool for environmental and urban planning" (in this point see also Goodchiled, 2000).

Integrating GIS and suitability analysis with other land use related emerging fields such as agent based modeling and land-cover change is a newer development first discussed by Gimblett (2002) and Westervelt (2002). (Also see Brown et al., forthcoming.) Similarly, land use change and land use dynamics is a more recent interest and have captured attention of several researchers including Veldkemp and Verburg (2004) and Verburg and Veldkemp (2005).

Currently, the allocation of land resources for human uses is seen as critical to ecological stability and energy conservation.

The question today is:

Can spatial arrangements of land use be found that yield significant improvements in energy consumption, ecological stability, or agricultural production? This question can be answered only by comparing existing patterns to the best known patterns.

As a step toward determining optimal land use patterns, Anjomani (1984 and 1992) suggested applying optimization models in the suitability analysis stage of the land use planning process, instead of the traditional overlaying map technique or its new variants as one of the major functions of the GIS packages.

He argued that because traditional suitability analysis and related GIS applications do not consider demand, the results are not useful. To achieve results that consider demand, he suggested applying an optimization model as a relatively simple or more sophisticated optimization models. These models are special type of linear or quadratic programming models (Mirchandani and Francis, 1990).

Replacing the overlay technique in suitability analysis with these type of models is important for several reasons, some of which will be discussed in this paper. At this point, however, the significance of this replacement in relation to GIS should be discussed. GIS is becoming an indispensable part of any spatial analysis because of its important attributes and capabilities.

Given the technological advancements of the past two decades, especially in regards to information and computer technology, it is only natural that GIS will also become an indispensable part of planning activities.

GIS's spatial analysis functions, such as overlays, buffers, measures of contiguity, and the like, along with the facilitation of data manipulation, analysis, and display and was demonstrated by Albers (1991), Miller et al. (1998) and others make GIS a necessary tool for every land use/environmental analysis.

GIS has also been a very useful tool in applying suitability analysis.
The combination of this feature with the functions and facilities mentioned above makes GIS a unique tool for land use/environmental planning.

All the features offered by GIS are needed in different stages of the land use/environmental planning process such as the one used in the proto-type example in this paper, however, our discussions are concentrated more around the suitability analysis aspects of GIS.
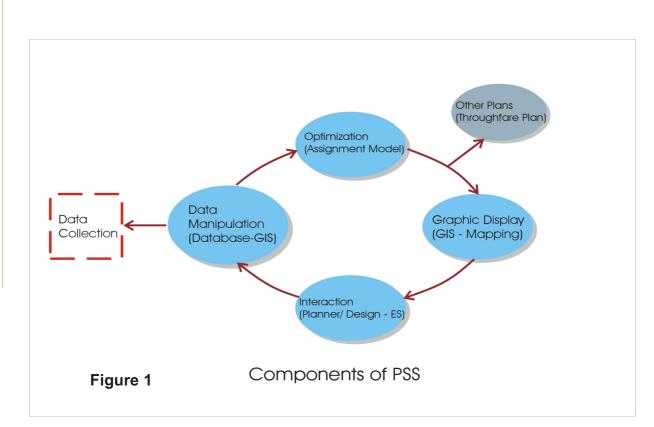
The suggestion to replace the overlay technique with the optimization model in suitability analysis is not intended to undermine the use of GIS for land use/environmental planning. What is needed, however, is a consensus on the best technique for suitability analysis. The technique can then be included in planning related GIS packages. Indeed, similar developments in facility location analysis have already resulted in the inclusion of similar optimization models in some of the GIS packages such as ARC/INFO, (Environmental Systems Research Institute [ESRI], Redlands, California, USA). This article will attempt to briefly demonstrate the superiority of the proposed optimization model.

This article will attempt to briefly demonstrate the superiority of the proposed optimization model. Recent advances in computer technology have greatly improved methods and models and their potential applications in planning. Two examples of this methodology are optimization models (Mirchandani and Francis, 1990) and (GIS) (Tomlin, 1990, Huxhold, 1991). Both approaches have characteristics that make them useful for a variety of applications. Harris (1988) encouraged the use of GIS in conjunction with analytic models, and Harris and Batty (1993) suggested linking GIS to models used in the planning process.

Anjomani and Saberi (1992) proposed a Spatial Decision Support System (SDSS, see Dansham, 1991 and Greenman and Stillwell, 2002).
As illustrated in Figure 1, aside from the data collection stage and assessment of land and

Figure 1   Components of PSS

environmental factors, this SDSS has four major components: 1) data manipulation, 2) an optimization phase to replace the overlaying technique of suitability analysis, 3) visualization, graphic analysis, and mapping (Ducrot et al., 2004), and 4) interaction with SDSS by the planner/analyst to manipulate and improve the results.

An optimization model was used in the optimization phase, and GIS was used for visualization, planning analysis, and data manipulation. This paper will examine and evaluate the applicability of this process and the SDSS in solving the problems of allocating land uses and preserving environmentally sensitive areas. The SDSS will be applied to a lakeside suburban area in the Dallas Fort Worth metropolitan and will provide details of how such a process can be applied in a real setting. Before describing the example, however, a summary review of the theoretical framework and the model will be discussed.

Theoretical Framework

Suitability Analysis is the traditional method for determining land use allocation, and is a major stage in the Chapin and Kaiser (1979) seven-stage and Kaiser et al. (1995) five-step land-use planning process.

Suitability Analysis is the traditional method for determining land use allocation, and is a major stage in the Chapin and Kaiser (1979) seven-stage and Kaiser et al. (1995) five-step land-use planning process. The main purpose of suitability analysis is to find the most suitable land area for each land use under consideration. The results of suitability analysis "are used as input to the land use design process and they help suggest more optimal spatial allocation of future urban activities and open space" (Chapin and Kaiser, 1979, p. 291).

The overlaying map technique has been the traditional method for suitability analysis. Hopkins (1977) provided a useful overview of suitability analysis, and some of the variants are provided by GIS software. Anjomani (1984) argued that the overlaying map technique only deals with the supply-side (i.e., which land is good for what use) without considering the demand-side (i.e., how much of each use is needed). As a result, the analysis normally shows oversupply of some uses and undersupply, or even lack of, other uses. This leads planners to select an area for a use in a less optimal location, or to not select a use in a more optimal location.

Our previous studies concluded that the results of conventional suitability analysis can be misleading[2].

Anjomani also argued that the overlaying map technique minimizes the negative effects for individual parcels, rather than for the whole area under study; and therefore, the results are not globally optimal.

To overcome this problem he suggested use of an optimization model. In particular, he suggested an optimization model that considers the demand for land uses and maximizes the total net effects (or minimizes the total negative effects)[3] , as opposed to maximizing or minimizing the effect of each individual parcel as was commonly done in deriving composite effects in traditional overlay techniques. Furthermore, the total cost figure of the optimization model provides a measure that can guide the planner in selecting alternatives or evaluating suggested changes at the later stages in the development process, based on observed cost increases or decreases.

Our previous studies discussed the need for a method of measuring the effect that proposed changes in zoning would have on the outcome for the areas as a whole and the need for a more precise land-use plan.

Also, it was asserted that land use planning "is a special *process* that a planner/analyst goes through using his/her tools, intuition, and knowledge;" and therefore, deriving one shot results from any particular tool or model for land-use/environmental planning is unrealistic.

Furthermore, since different tools require different ways of doing things, today's computerized methods necessitate modification of the process itself. As such, a main part of the SDSS is a planning process which employs the suggested optimization model as a tool in different planning stages which is used repeatedly and iteratively inside this process; therefore, the results from the optimization model are not final by themselves and gradually improve through the application of the process.

The process for use of the model in large-scale planning has been suggested in previous related studies as summarized below:[2]

Stage 1: Data manipulation and preparation of final ratings. Application of the optimization model to derive the first optimum solution.

Stage 2: Preparation of a general thoroughfare plan.

Stage 3: Overcoming the problems in the first optimal solution by considering the thoroughfare plan, design and community's input.

Stage 4: Checking the plan with respect to the problems discussed above.

Stage 5: Overcoming the problems by design inputs and by incorporating the intuition and expert knowledge of the planner.

Stage 6: Manipulating the data based on improvements (removal of the related data for cells that do not need improvements) and running the optimization model again.

Stage 7: Repeating Stages 3 through 6 until the results become satisfactory.

Stage 8: Further refining the results and applying the process to major sub-regions and different jurisdictions of the study area.

This process will fine-tune the plan to the needs of different localities so that it realistically reflects the situation. More details about this process will be presented in the application example.

If the suitability of an area for a particular use is assumed to be a linear function of several factors, such as soil condition, slope, accessibility, etc., then the development suitability of location *i* for land use *j*, S_{ij}, can be represented as:

$$S_{ij} = b1\, F1_{ij} + b2\, F2_{ij} + b3\, F3_{ij} + ... + bk\, Fk_{ij} \qquad \textbf{(1)}$$

or

$$S_{ij} = \square\ k\, bk\ \ Fk_{ij} \qquad\qquad \textbf{(2)}$$

where F 's are ratings of each factor according to the degree of its effects, positive or negative, on each of the selected land uses, j ; and b' s are coefficients, measuring importance (weight) of the k selected factors, F 's, in determining suitability of location i for land use j . Multi criteria evaluation techniques (Saaty 1980,

Voogd, 1983, Massam, 1988 and 1992 and Malczewski, 1999) can be used to determine the importance weights (b). Anjomani (1984) suggested use of the Delphi technique (Lindstrom and Turoff, 1977) to derive the coefficients. This technique is used in the application described in this paper.

When these coefficients are derived, data are collected for factors and encoded for each zone of the study area and each land use and their ratings are prepared accordingly. Suitability scores for each land use, *Sij's*, can then be calculated by multiplying coefficients and the related factor rating scores. They are then summed up as shown in equations 1 and 2.

Since the suitability scores for each land use, *Sij's*, are, in a sense, representing overal negative or positive effects of the factors on land uses. In deriving the composite suitability of all land uses, therefore, the goal of the overlaying map technique can be achieved by selecting the land use with the smallest cost score (or, the highest net benefit score) for each cell. Anjomani (1984) criticized this technique, and, suggested using an optimization model which uses S_{ij} to derive suitabilities with global optimization and demand consideration. (For further information on optimization models see Mirchandani and Francis, 1990, and on linear programming see Killen, 1983).

Optimization and the Model

Optimization models have been used in previous land use studies by several researchers (for review of these works see Van Ittersum et al. (1998) and Briassoulis (2002). Herbert and Stevens (1960) formulated a residential model which placed households in different socioeconomic groups based on their choice of housing type.
The location of each housing type was based on maximizing the difference between the housing budget and the cost of housing. This resulted in the allocation of households in an optimal configuration. In 1965, Schlager formulated one of the first applied mathematical programming models as a land-use plan-design model. His model minimized the cost of land development in the study area while meeting the development demands and other constraints.

Barber (1976) formulated a land-use plan-design model as a multi-criterion problem and used the same village that Schlager used as a case study to illustrate the application of the model in twenty four zones. Brotchie et. al (1973) proposed a model that determined least-cost allocation of activities to zones. Gordon and McReynolds (1974) formulated a model of optimal urban form which used an optimization model and applied it to the Los Angeles metropolitan area which was divided to 30 study zones. Churieco (1993) attempted to integrate linear programming and GIS for land use modeling purposes. Even though these studies were land-use related, none of them were used for suitability analysis, and only a few used similar models.

Furthermore, most used a much smaller number of zones (usually below 50), and the zones were much larger in size with a combination of different land uses.
The variants of optimization models which can be used for the purpose at hand normally selects land parcels with a minimum resource loss (or maximum net effects) for the proposed activities. In simplified terms, the cells with the least resource (or dollar) losses were selected first. Additional sites were selected sequentially with higher and higher losses until all the cells were filled with the specified activities. Similarly, the variant of the optimization model presented in this paper selects the cells with the least resource losses so that the proposed development area (33,027 cells) is filled with the seven land uses to a pre-specified limit based on the demand for particular land uses. Let X_{ij} stand for the allocation of land use j to cell i where $i = 1,....,$ 33,027, in our application example explained below, and j is the selected land use category according to the demand in the application example. If land use j, allocated to cell i, X_{ij} will take the value of 1; otherwise, X_{ij} will take the value of 0, which indicates land use i is not allocated to cell j. As such, X_{ij} is the solution matrix for the land use problem as formulated in the optimization model:

Maximize $\quad Z = \sum_i \sum_j S_{ij} X_{ij}$ (3)

Subjet to $\quad \sum_i X_{ij} = M_j \quad$ for all $j's$, j=1, 2,....,7 (4)

$\quad \sum_j X_{ij} = 1 \quad$ for all $i's$, i=1, 2,...., 33,027 (5)

$\quad X_{ij} = 0$ or 1 $\quad$ for all $j's$ (6)

Z is the total net benefit for the area as a whole. *M* represents the demand for each use, as explained in the next section, for the seven land uses of low, medium-low, and medium-high density residential; low and high intensity commercial; light industrial; and open space; respectively. The set of constraints (equations 4 to 6) is needed to constrain land use to only one land use allowed to be allocated to a cell. The objective function to be optimized is a function of suitability indices *Sij* whose values record the suitability of assigning use *i* to cell *j* as discussed before.

It is important to note that the net benefit (cost) indicator from the model output, *Z*, will determine the total benefits or net effects (cost or negative effects) of the final solution in relative terms. In addition, it also provides a helpful device for comparing alternatives, since an alternative with a "less cost" indicator is normally preferred to one with a "more cost" indicator.

Application Example

As previously mentioned, the process of land use allocation is determined by the interaction between the model and the planner analyst. The allocation model seeks to minimize the overall costs of development (or to maximize the net positive effects), whereas the planner-analyst seeks to improve the relationships between activities and bring intuitive considerations, community values and desires, and other important aspects into the plan. This interactive process leads to the creation of a discrete number of alternatives for land use allocation.

In one stage of the interaction process the planner traces the street network for each of the alternatives. Proposed roads are most commonly the subject of this combined land use thoroughfare analysis.

At this stage the planner selects the least-cost or least-environmentally-impacted corridors between points. Costly parcels are set aside, and favored areas are selected and entered into the computer to form the basis for progressive interactive searches.

The study area described in this paper surrounds the newly developed Joe Pool reservoir lake in the Dallas Fort Worth metropolitan area.

The study area encompasses six city jurisdictions and covers approximately 87,400 acres. For the purpose of this analysis, the study area is divided into 33,027 individual grid cells. This total number of cells is also reflected in equation 5 of the optimization model.

The first phase in applying the Spatial Decision Support System (SDSS) to the lakeside setting involves data collection and manipulation based on Anjomani (1984) and Turner II et al. (1995). Six environmental land features--soil strength, soil stability, flooding and drainage, visual resources, slope and tree coverage; and four man made land features--proximity to major sanitary sewer lines, access to major Six environmental land features--soil strength, soil stability, flooding and drainage, visual resources, slope and tree coverage; and four man made land features--proximity to major sanitary sewer lines, access to major highways, proximity to water lines, and compatibility of adjacent existing land use were selected as major factors affecting land development. These factors were then inventoried within each of the cells of the study area and encoded for each cell. When these were completed for all cells, it was necessary to rate each land feature according to its effects for each of the selected land uses.

The selected land uses were low density, medium low density, and medium high density residential, low intensity and high intensity commercial, light industrial, open space, and road location.4 However, road location was used only for preparing the thoroughfare plan and road locations. Land features (factors) and land uses used in the study are shown in Table 1.

Demand for each of these land uses was derived from an average land use mix of more than twenty cities in the metropolitan area. An adjustment was made to the average land use mix to take into account the large amount of recreational and open space necessary to accommodate a lake such as the one in this study. Table 1 also shows the land-use percentages that were determined. The land-use percentages multiplied by the total number of cells constitutes the demand figures for each land use, *M*, in equation 4 of the optimization model.

TABLE 1: LAND FEATURES (FACTORS) AND LAND USES USED IN THE STUDY		
Environmental	**Man-Made**	
Land Features	*Land Features*	*Land Uses*
1-Soil Strength	1-Proximity to Sewer Lines	1-Low Density Residential
2-Soil Stability Residential	2-Access to Major Highway	2-Medium-Low Density
3-Flooding and Drainage Residential	3-Proximity to Water Lines	3-Medium-High Density
4-Visual Resources	4-Compatibility with Adjacent Existing Land Use	4-Low Intensity Commercial
5-Slope		5-High Intensity
6-Tree Coverage		6-High Industrial
		7-Open Space

The importance weight for factors (the b coefficients in equations 1 and 2) are need to be determined at this stage. Banai (1993) and Wu (1998) use analytic hierarchy process. In this application, as mentioned earlier, the weights for factors were obtained using the Delphi technique. (Lindstone and Turoff, 1977). This technique was used to determine the importance weights of each factor for each land use. A group of knowledgeable persons not involved in the plan development were selected as experts and surveyed to determine the relative importance of the factors. The purpose of the repeated rounds of Delphi surveys was to reach a consensus among the experts in weighting the factors.

The purpose of the repeated rounds of Delphi surveys was to reach a consensus among the experts in weighting the factors. During the course of these surveys, the experts had the opportunity to compare their responses with those of other experts and to make changes accordingly or to offer a rationale for their choices.
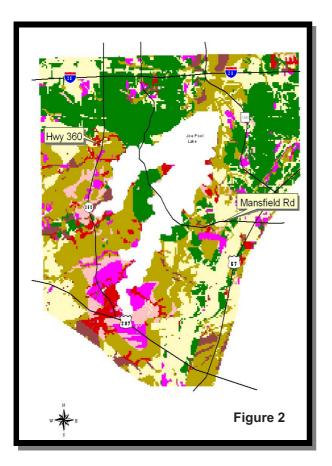Because in the Delphi technique the anonymity of the experts is maintained, the experts are able to make their responses without any undue pressure. The experts selected for this study represented a variety of backgrounds related to the planning and development fields (planners, developers, architects, landscape architects and engineers). This allowed for a variety of viewpoints and considerations beyond the technical aspects.

The survey instrument consisted of background information and a description of the project, the land uses to be considered, the factors to be weighted and the weighting system. Numeric weights consisted of discrete values ranging from 0 to 10 with 10 meaning very high importance and 0 no importance. In applying the process, three sounds of survey were conducted with each of the Delphi group members to reach the consensus.

The given weight of a land feature was then multiplied by the numerical ratings of the land features that provided the S_{ij} matrix. At this stage the optimization model was applied to this data set, S_{ij}, resulting in the first optimal solution for the area of study[4]. The results are depicted in map form in Figure 2[5].

As Figure 2 shows, the first round of results shows what the "final composite map" of the suitability analysis (overlaying map technique) should have provided: the most suitable location for each of the seven land use categories.

Evaluation of the First Optimal Solution

After the first application of the optimization model, the optimal solution is based solely on land and environmental resources, such as soil, slope, vegetation, etc., and the existing man made features in the area, such as street access and proximity to sewer lines and water pipes.

Figure 2

Five categories of problem with the plan at this stage of development have been identified in previous related studies.

First, the interactions between zones are not considered and secondly, they do not take the thoroughfare plan into consideration. These problems are inherent in the optimization procedure itself (or even in conventional suitability analysis).

For the first problem the adjacency and external effects have not been considered, and for the second problem, the trip type interaction effects related to the thoroughfare plan have not been considered [6].

The third problem with the optimization model was that the selected locations were either too dispersed or too concentrated for the specified activities. The fourth problem involved those planning and design considerations that require the planners' intuition and design knowledge. Lastly, as Harris (1989) asserted, most large planning problems cannot be solved optimally with computers alone. The last three problems are related to the degree of concentration or spread of activities in the domain of subjective planning design.

In order to overcome many of these problems, intervention by the planner analyst is necessary. This intervention becomes possible through application of the planning process laid out earlier in the Theoretical Framework section.

Applying the Process

It is important to point out that the conceptual planning and design process begins at the Stage 2 of the process and goes hand-in-hand with the subsequent stages. The conceptual planning and design process starts by identifying the most important planning elements and then deciding their approximate locations. Simultaneously, the thoroughfare plan and plan for other infrastructures are developed.

The process is then extended by stepping down gradually to less important elements.

Thoroughfare Plan and Important Land Use Elements

In Stage 2 the planner-analyst develops a rough thoroughfare plan for the whole region. The planner starts with a preliminary consideration of land use and transportation. This stage of the work began by considering the overall location of more important land use elements.

The elements are such things as major and minor activity centers including high intensity commercial activities, and in this particular example, location of open space around the lake for environmental considerations as well as accommodation of recreational activities. These also would be the best factors for providing guidelines for preparation of the thoroughfare plan.

The location of major land use elements, such as centers and open spaces, are identified using a 'bubble' diagram or a marked area map and a technique discussed below.

GIS features, like buffer zones and the analysis of scenarios, can be helpful in this step, however, the planners' intuition, design principles and community's wishes are the driving forces behind both selection of overall location of important land use elements and the thoroughfare plan.
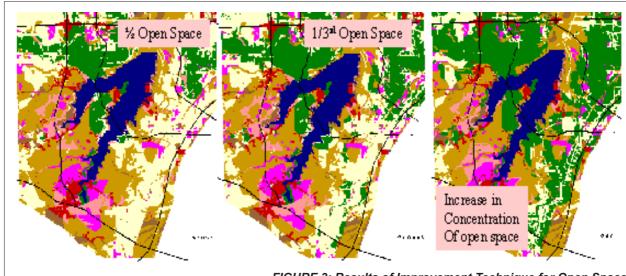
FIGURE 3: Results of Improvement Technique for Open Space

Technique to Help in the Selection Process

The selection process can be facilitated by informed decision making, based on the behavior of the model. Several runs can be performed in which demands for the land use type under consideration are changed, one at a time in small increments, to see how the model selects the incrementally selected preferred locations (second best, third best, etc.).

For example, knowing that the maximum demand for open space in this area is 7,752 cells (26.5%), the demand is increased incrementally from 20, to 30, to 40, to ... percent to discover the direction in which the incrementally added open space development would go.

By repeating this procedure several times, it readily becomes apparent how the model will behave in each circumstance. Figure 3 shows application of such a procedure for open space.

Figure 4 shows the result of this procedure for the peninsula, as a focus area of study. The best combination of commercials, and light industrial activity pattern and other related land uses for this area which was selected for this purpose in the previous stages also can be seen in Figure 4.

After completing the above procedure, the analyst has a better idea of how the model responds to changes and he/she can begin involving issues that have not been considered by the model (i.e., interactions between zones, socio economic factors, and political considerations).
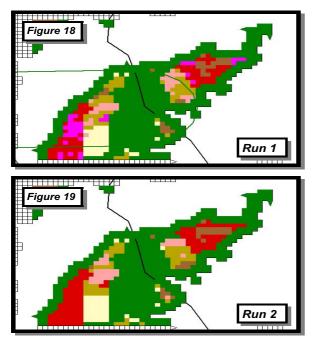
Those sites with the potential of becoming regional centers, preservation areas, open spaces, etc., will become apparent, and, after several runs and the consideration of the thoroughfare and infrastructure plans, the best arrangement for allocation of activities (land uses) can be selected. In the sample study area, the process helped to identify major nodes (Figure 4) as was discussed earlier.

The lower part of the peninsula was identified as the major business district.
The southeast part of the sector and the central part were identified as low and high commercial intensity centers.
The next step involves putting aside the scores assigned to the cells of those areas that were selected above for the specific development, deleting them from the input data set, and running the model to obtain the first generation alternative solutions (Figure 4). By doing this, the cells selected by the analyst are not included in the optimization procedure. Therefore, since their uses have already been assigned, the cost factors (or rates) should not be considered during the next round of applying the optimization process.

By fixing some locations and rerunning the model the resulting land use pattern for the rest of the area will also be affected. In the sample study area the results of the run were compared, and their outcomes indicated that

the policy restrictions caused a major difference in the settlement patterns (Figure 5). The result of the solution overall helps to satisfy more goals of the project.

The result of the solution overall helps to satisfy more goals of the project. Comparing these results, and the changes that process is allowing, with the static result from the traditional overlaying map technique, Figure 6, shows how much these two results differ and the potential that the new process and SDSS provides for improving the land use planning process. Putting all of the findings together, the planner is now able to use the GIS to overlay the proposed transportation map on this basic land use map. The planner can then begin to adjust the boundaries of the selected sites to generate a preliminary land use plan.

FIGURE 6: In the sample study area, it was decided to designate an area around the intersection of two state highways as a regional activity and retail area and also to centralize the scattered commercial activities at a peninsula near a state highway. This latter concept was supported with a bypass extension of a loop next to the site, as it was proposed in the regional transportation plans. This arrangement also improved access to the central part of the study region and ultimately affected the overall planning of the surrounding area.
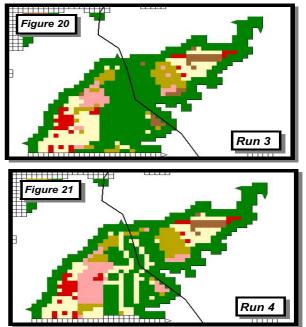
The planners also created a network of major arteries about a mile apart in accordance with the transportation network already developed or planned in the surrounding area.

This thoroughfare plan will play a major role in later stages of analysis when the preferred alternatives for activities inside the study region are selected.
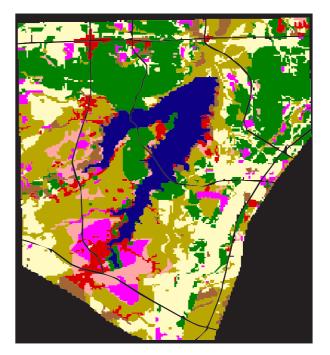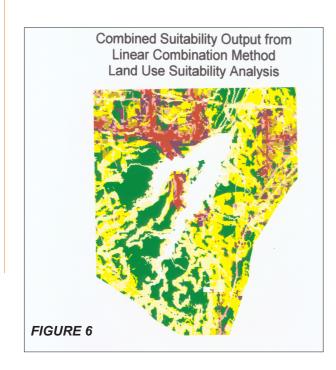

FIGURE 5: The Results of Third Round Application

Combined Suitability Output from
Linear Combination Method
Land Use Suitability Analysis

FIGURE 6

The selected location of the main commercial development can be seen in Figure 5.

After selecting the location of the high intensity commercial area the area is deleted from the database, the demand is adjusted accordingly, and the optimization model is run a second time. Figure 4 also shows the results of the second run of the optimization model because of the deletion of the designated amount of a high intensity commercial area from the data base with resultant adjustment of demand for the rest of the area. The second run of the model will produce a new selection pattern for the calls. This result constitutes the new best selection given the new demand specifications. These changes are observable in the new results in Figure 4.

Continuing Interaction and Locating Other Important Elements

As stated earlier, the main goal of the Interactive Model Planner approach is to introduce new information into a plan based on the planner's and the community's objectives. Planners and community objectives involve issues such as the preserving of certain resources, the locating of development on remaining lands based on least cost, the concentrating of certain land uses in certain areas, or the achievement of a meaningful overall distribution of land uses.

In the sample study area, important resource protection policies were considered, including the preservation of specific environmentally sensitive areas adjacent to the lake, the allocation of subcenters, the designation of critical intersections and lands adjacent to major highways and the preservation of sites for industrial development. In order to do this, these areas were deleted from the active data set, and after adjusting the demand factors, the model was run for the next set of optimum results.

This process emphasizes the interaction between the optimization model and the planner. Using this process along with GIS and its special features, a best solution to the land-use problem is sought. The interaction process breaks with the traditional static approach of urban spatial structure models which assume "all of the relevant information is initially known to the planner and there is no need for additional information to enter to the system throughout the procedure" (Berechman, 1974, p. 249). At the conclusion of the process a discrete number of alternatives are generated that are concerned with more sensitive issues such as aesthetics, socio economic political considerations, and transportation issues.

Putting all of the findings together, the planner-analyst can use GIS to overlay the proposed transportation map on this basic land-use map. The planner-analyst can then begin to adjust the boundaries of the selected sites to generate preliminary land-use plan. This is important to note that every time the model is run, aside from the results which were discussed; it also produces the total net benefit measure, Z in equation 3, which can be compared to previous measures to see the overall effects of the changes made. This measure, then, in a sense, provide an index which helps in deciding changes and understanding the tradeoffs involved.

The above procedure should be repeated several times, giving planners the opportunity to use their intuition about locational decisions in fixing the use, deleting the cost factors from the main data set, running the model, and evaluating the locations suggested by the model. This will ensure that the land use and thoroughfare plans will be considered simultaneously.

The chart below shows the summary of procedures:

Summary of the Procedures

The analyst in the regional base interaction with the preliminary land use solution:

 1. Determine model behavior by increasing or decreasing activities one at a time, and observing the results using GIS.
 2. Fix the preferred locations for major and minor CBD developments, based on the planner's professional judgment and intuition. The planner used basic planning principles and considered community and regional needs and preferences in making these decisions.
 3. Delete the cost factors related to the selected sites from the main data set.
 4. Run the model to find the optimal solution for the region based on the changes made in the previous steps. The first optimal solution was based on information collected by the study group and was determined without any interaction.
 5. Transfer the computer output in the form of a land use map using GIS and make further adjustments to the boundaries of the land use areas.

To further refine the derived plan, a similar process should be applied to important subregions and varying jurisdictions within the study area.

Discussion

By applying the SDSS to the study area, a plan was developed which avoids hazardous areas and loss of land resources, determines the most suitable sites for new development based on the considerations of the social, economic, and environmental values. This is made possible with the use of the optimization model. The model shows the optimum solution in every interaction and in every stage of the process. This allows deliberate intervention by the planner-analyst who also brings the community's values into the process. The process employs the optimization model as a tool for continuous use, as opposed to a conventional one-shot approach, and in this way overcomes some of the problems associated with these models (see for example Harris, 1989). This, along with the inclusion of the planner-analyst's intuition helps in deriving more meaningful results.

Different land use solutions can be examined for a given area and the best combination of uses can be selected.

The human factor is preserved by providing a way for the planner-analyst to interact in the process. He/she can control the demand and improve the results step by step. This is important since the common belief today is that science and technology based planning models cannot replace human value judgments.

 While a computer model can provide estimates on such things as resource and flood potential or ecological compatibility, trade off decisions should be subjectively evaluated by the planner analyst.

This can be given analytical support by alternative generating techniques (Brill et. al, 1982 and Chang et. al, 1982). The planner can base a decision on existing and future socio economic conditions and a community's objectives and desires, using compatibility, access, environmental, and other tangible and intangible factors.

 This type of land modeling allows analysts to test many alternative scenarios and examine the sensitivity of the SDSS process to small and large changes in different criteria (i.e., natural features of the land: slope, soil characteristics, etc.).

 Policy analysis can be greatly aided by the ability to choose the least objectionable areas for specific types of development.

This benefit to policy analysis has become possible partly through the total benefit (or total cost) figure being produced by the process in every step or for every alternative which, as a policy index, allows in a sense the planner or decision maker to ascertain the consequence of any policy or land use changes.

General land use patterns, new developments, transportation facilities, recreational facilities, and the overall potential of surrounding areas, as much as possible, are all taken into account in formulating an acceptable plan.

The plan is the result of simultaneous planning processes based on both physical environmental and socio economical aspects of the area. Using the SDSS process in the land use plan design is helpful to planning authorities who must deal with uncertainty and complexity, with ambiguity.

Conclusion

This paper provided a concrete implementation example of ideas and theories in land-use/environmental planning that has been presented in the literature for several decades, as well as more recent ideas and modifications.

The process discussed in this paper attempts to provide a comprehensive approach to environmental and land use planning on a large scale. This process aids decision makers in overcoming the negative effects, costs, and uncertainties in the planning process for relatively large areas. This is accomplished by providing pertinent information on specific locational decisions for a variety of applications partly through the overall measure provided by the model which guides planners and decision makers in evaluating changes and selecting alternatives.

The four major components of this approach are:

1) the assessment of land resources, 2) the optimization model that derives the land use plan, 3) visualization and plan manipulation using GIS, and 4) the interaction between the planner and the computer model.

In this last step the planner changes the solution suggested by the computer based on his or her understanding of reality. The spatial pattern of the most efficient sites which would generate the most environmentally beneficial and cost effective development can be determined, or, in broader terms, the development with the highest net benefit to the society can be created.

The computer aided Spatial Decision Support System presented in this study demonstrates savings in overall cost and negative effects which can be achieved by taking a more sensitive approach to the environment and resources through use of the optimization model.
The model's overall net benefit measure serves as an index in the planning process, that allowing planners or decision makers to know the relative savings cost magnitude as a result of planning decisions.

More importantly, this paper shows how this approach can be a tool for planners and decision makers in examining the multitude of land development or spatial planning options which exist.

The planner can objectively analyze the options and determine the ones which best resolve conflicts or make the most of available opportunities. The options which avoid heavy environmental costs can also be identified.

These approaches help decision makers, planners, and private citizens in the following ways:

1. Use environmental land use planning as a learning tool providing opportunity for monitoring cost and negative effects of land use change.

2. Rapidly generate alternative plans expressing a variety of community objectives and showing desirable and undesirable aspects.
3. Help make the planning process more logical by providing accurate and objective land use comments to the general public in a comprehensive fashion

This process helps in the understanding of environmental hazards and degradation, a region's land resources, and development opportunities.

This information can be combined with other relevant information to make informed and intelligent planning decisions which not only respect short term economic concerns, but also long term environmental conservation and community goals as well.
Further research needs to be directed toward a better understanding of related problems and in identifying and evaluating any possible problems in the steps of the application process. Also, further research is needed in the application of the SDSS in related areas, and it is important to further explore any other potential uses of the process. In addition, research into the implications of using SDSS in areas with multiple economic regions and multiple political jurisdictions is needed.

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FOOTNOTES

1. Harris and Batty, 1993, based on Harris, 1991, suggested that four interrelated approaches to the spatial world determine the Spatial Decision Support System: computation, social and functional planning, planning theory and spatial representation.

2. Some of the ideas discussed in this paper have been presented in more details in Anjomani (1992). This includes these steps and the overall process as well as problems with suitability analysis.

3. When the net effects are negative but treated as positive numbers (absolute values), the problem becomes a minimization problem.

4. For more information and details on data collection and manipulation see Anjomani (1984).

5. Anjomani (1984) provides explanation for all these steps along with numerical and graphical examples including the Sij matrix and the solution matrix and comparison of results to the results of the overlaying map technique.

6. Other variants of the optimization models, such as quadratic optimization or multi-objective programming, can handle the adjacency and transportation problem. However, other problems and limitations may be encountered, such as the number of land areas (zones) which can be handled.

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