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Adding Robustness to Linear Planning Models Through Simulation

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ABSTRACT

The planning community concerned with subjective land evaluation criteria can benefit from an iterative simulation model based on a modification of the Kane Simulation language (KSIM). Within a linear planning model designed to protect prime agricultural lands, procedure implementation demonstrates promise for future applications. The interaction matrix is useful for refining factor selection and weighting and for incorporation of factor interactions within weights. Model temporality aids in determining proper planning strategies by allowing examination of future implications and permitting adjustments prior to policy implementation. To implement the model consistently and efficiently, further refinement is necessary. Some method of factor reduction prior to application of the cross-impact matrix is necessary to reduce model development time, to eliminate extensive explanations of the KSIM graphics, and to promote general model understanding.

Introduction

Techniques for quickly building inexpensive computer-based decision support models are considered a high priority by the planning community [1–7]. Many traditional models employ a checklist approach because of its simplicity [8]. These linear models lack robustness in part because they do not incorporate factor interaction; rather, they assume mutual exclusivity. Additionally, they lack the large volumes of quantifiable data and known mathematical relationships useful in modeling these interactions and processes because such data are seldom available to the planner in quantifiable terms. Moreover, the heuristics involved in the planning process are frequently applied to a given set of problems without the ability of the decision maker to reverse a decision once implemented.

The Kane simulation (KSIM) model is an alternative approach to both the linear model and the heuristic procedures most often used in the past [9]. Its procedures allow for insertion of nonmathematical factor weights and heuristic factor interaction. It is designed as an iterative learning procedure allowing the planner to redefine parameter weights or interaction weights in the advent of changing circumstances. These attributes are needed to improve existing land-use planning procedures and should be applicable to decision-making problems related to the loss of prime agricultural lands.

The U.S. Department of Agriculture Soil Conservation Service recently devised a system to enumerate the major planning factors and to rate each to ensure rational decision making. This Land Evaluation and Site Assessment (LESA) system is designed to " . . . determine the quality of land for agricultural uses and to assess sites or land areas

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for their agricultural economic viability" [10]. The LESA model is in two parts: the Land Evaluation subsystem determines the physical capability of the land for agriculture, while the Site Assessment subsystem incorporates social and economic planning factors [10].

In the land evaluation rating (LE_j) for a site (j), the soils are rated and placed in groups ranging from best to worst for agricultural potential. Soils in the region of interest are evaluated and placed in groups ranging from best to worst for agricultural use on a relative scale of 1 to 100 based on a selected indicator crop. This rating incorporates evaluative data from worksheets designed by the Soil Conservation Service for use with the National Cooperative Soil Survey. These worksheets systematically combine criteria from land capability class, important farmland category, and existing and potential indicator crop yields, and are modified to account for the amount of area for each category [10].

Land capability classes are based on soils limitations for production of crops and consist of explicit definitions of the limitation types present. Important farmland evaluation determines categories of land as "prime" when of national importance and "statewide" or "regional," indicating importance for these spatial subdivisions. Crop yields, both existing and potential, are calculated based on the indicator crop, so designated because it is the most common cultivated crop in the region.

Indicator crop yields are evaluated using one of two methods depending on data availability. Where land management costs are unknown, these crop indices are obtained through the soil productivity rating, which assumes high land management levels. These soil productivity ratings are easily accessed by state offices of the Soil Conservation Service through the archives at Iowa State University [11]. Alternatively, when costs of management for soil limitations are available, the soil potential index (SPI) is used. The SPI is a quantitative soil quality rating based on the following equation:

$$\mathrm{SPI} = P - (CM + CL), \tag{1}$$

where P is a local yield index, CM is an index of the costs of corrective measures, and CL measures the costs of long-term, continuing limitations [11].

These three factors are combined through the assistance of the district soil conservationist to produce eight or ten agricultural groups that indicate their rank order potential. Their relative values are based on the adjusted yields for each group, where the highest category is assigned a value of 100 and the remainder are prorated [10].

Site assessment identifies important factors other than soils that contribute to the quality of a site for agricultural use. Each selected factor (i) is given a weight (W_i) according to local needs and objectives. The site assessment rating (SA_j) for a site (j) is given by

$$\mathrm{SA}_j = \textstyle\sum_i W_i V_{ij}, \tag{2}$$

where V_{ij} is the value for factor i on site j. The values of W_i are adjusted so that the maximum possible SA rating for a site is 200.

These site assessment factors and their weights are achieved through discussion with local planners and interest groups in the planning area. Generally an informal procedure, because no formal strategies are prescribed by the Soil Conservation Service, the interested parties barter over which factors should be of paramount importance in the final model. As a principal component of the LESA model, these factors are meant to arithmetically incorporate locally important planning criteria more specifically allied to the socioeconomic constraints of local governments.

The LESA rating for a site is then defined by

$$LESA_j = LE_j + SA_j = LE_j + \sum_i W_i V_{ij}, \tag{3}$$

with a maximum possible LESA rating of 300 giving an SA : LE ratio of 2 : 1. These values are tabulated and checked against the following value standards: 300–250, very high protection efforts; 250–225, high protection efforts; 225–200, moderate protection efforts; and 200–0, low protection efforts.

This additive linear model exhibits major shortcomings relative to both the manner in which the knowledge base is acquired and the simplistic and erroneous results obtained through the manipulation of the data. First, the weight assigned to the land evaluation portion is arbitrary and is inordinately high for regions that may have high-quality soils throughout and low for regions with low-quality soils throughout. Second, there is no consistent, formalized approach for the selection of factor weights. Finally, the system assumes that each of the factors is separate and independent of the others.

Literature Review

The history of rural land-use planning methodology is difficult to trace because literature available on the subject is sparse [12]. Until recently, little definitive methodological work had been done, leaving the planner to use best judgment as the only approach. LESA is an attempt to assist the planner in the decision-making process where the loss of prime agricultural lands is the major concern.

One major difficulty with the LESA model, as with other checklist approaches, is in the initial selection of evaluative criteria. Public meetings and personal communication are the recommended methods for identifying appropriate evaluative LESA factors. These techniques often fall short of the required goal, exhibiting the same limitations as other checklist development techniques, but it is suggested that they may be used as one source of data, yet not as the exclusive source of such ideas [8]. They might be a first step to definition of LESA factors, as long as consensus opinion can be achieved within the group of decision makers.

A framework for processing these multiple views is necessary, both from the standpoint of factor selection and as a means of weighting site-assessment factors. The traditional approach takes the form of arbitration and debate among the decision makers. These discussions are often lengthy, and seldom accomplish compromise. Decisions from these discussions frequently are determined by the most experienced debater or the most ardent supporters or detractors of a particular idea, rather than consensus judgment. Furthermore, eliciting "expert" opinion from the decision makers assumes that each has an explicit knowledge of all aspects of the planning process. Because this is generally not the case, those decision makers who are most well versed in a particular aspect or variable will most likely weigh that aspect or variable most heavily. This produces the potential for individual bias influencing the decision to a great extent and requires a more formal approach to group decision processes.

The Delphi Technique, developed by the Rand Corporation, is a valuable tool "... for eliciting and processing the opinions of a group of experts knowledgeable in the various areas involved" [13]. This technique involves a pairwise comparison and subsequent ranking of attributes of the planners. The rankings are then weighed mathematically, and a group ranking for each factor can be obtained. This final checklist, however, affords little insight into the functional relationships, which are important in defining priorities.

Two basic approaches are commonly used for describing causation within lists of evaluative factors: networks and cross-impact matrices. These techniques redefine a problem by separating individual system elements or components and constructing network diagrams or cross-impact tables to show relationships and consequences of actions. This allows for disaggregation of a complex planning problem into its key constituents. In addition, networks direct attention to indirect impacts, and trace sequences of impacts, and can allow for the incorporation of feedback loops as long as their relationships are known in advance.

Several approaches have emerged to combine the best of the matrix and the network with the power of the computer. The "stepped-matrix" technique disaggregates each use of the land into various causative factors [14]. This technique is similar to the approach attempted by Lyle and Stutz [12], and shows some promise. Its major drawback is that it draws directly on the original network approaches and therefore contains all its weaknesses of oversimplification and lack of understanding of feedback and interrelatedness of factors.

Among the most promising techniques for indicating interrelatedness of events or factors is the KSIM model [9]. This technique is also capable of providing the individuals with an understanding of the dynamics of complex systems. KSIM starts with a group of participants identifying the factors that they consider to be important elements in the planning problem. This list is then entered in both rows and columns of a grid, forming a cross-impact matrix.

An important aspect of KSIM is that it allows for the incorporation of subjective data and eliminates the need for excessively numerical approaches, which require quantifiable attributes. Because subjective variables are often the controlling parameters in planning choices, this ability becomes extremely important in modeling efforts, including those related to land evaluation and site assessment. The matrix of data, then, may include both quantifiable data and subjective data [9].

The matrix comprises two separate sets of factors: those that impact others and are themselves impacted, and one column that is a compilation of those factors that impact others and are not themselves impacted (policy factors). Within the matrix, each column and row is compared. A $+10$ to -10 rating scale of impacts is used, where -10 indicates a maximum negative impact and $+10$ a maximum positive impact (this is a modification of the original scheme proposed by Kane and allows for ease of computation) [15]. The matrix entry contains the extent and direction that a positive change in the column factor will have on the row factor. This matrix can then be transformed into a network representing the interactions that have been estimated. A tracing of their relationships over time is generated, using a sigmoid growth curve to represent the assumed form of each relationship. This growth curve will plot the change in each factor against the time increment according to the following formula:

$$x_i(t + t) = x_i(t)^{pi}, \tag{4}$$

where

$$pi(t) = \frac{1 + t\,|\sum \text{negative impacts}|}{1 + t\,|\sum \text{positive impacts}|} \tag{5}$$

Rather than an end in itself, the KSIM model is merely a quick and inexpensive pedagogical method for indicating the relationships of the given set of initial judgments and assumptions. It can be used as a training tool to increase the expertise of the planners when interrelated events are encountered. Furthermore, the cross-impact values used for the KSIM model provide information that can be used to modify the existing LESA weights to exlicitly incorporate previously implicit factor interactions.

Learning Model

This research involves the concurrent development of a workable LESA model for Douglas County, Kansas, through the creation of an appropriate methodology for its development. The learning model includes approaches to enumeration of LESA factors, factor weights, and incorporation of factor interrelationships. Testing includes planner surveys and comparative techniques to evaluate the learning model.

The development of the learning model must be preceded by land evaluation. Douglas County, Kansas, has a soil survey that includes all of the necessary information for this determination [16]. Land evaluation is a combination of the interdependent soils, vegetation, and slope data, and is given a weight corresponding to the planners' needs. The procedure has been completed for Douglas County [17].

Presented with the completed land evaluation and a preliminary set of site assessment factors previously determined by the decision makers in Douglas County (Table 1), development of the learning model can begin. The approach is an iterative model, allowing several opportunities for the planners to change their minds in the face of new information (Figure 1). It provides a formal procedure for selection of factor weights as mutually exclusive entities where the factor relationships are structured using a cross-impact matrix. Further model operation occurs through the application of the KSIM model, which shows the effect of factor interaction over a period of time. Incorporation of these established dynamics and interactions results in the final LESA model.

TABLE 1
Preliminary LESA Model for Douglas County

1. % area in agriculture within 1 1/2 miles (weight 8) (PAAN) (adjusted weight 9.04)[a]

Value	Condition
10	95% of area in agriculture
—	50% of area in agriculture
0	10% of area in agriculture

2. Land in agriculture adjacent to site (weight 10) (LAAS) (adjusted weight 11.3)[a]

Value	Condition
10	All sides of site in agriculture
—	One side of site adjacent to nonagricultural land
—	Two sides of site adjacent to nonagricultural land
—	Three sides of site adjacent to nonagricultural land
0	The site surrounded by nonagricultural land

3. Size of site or farm (based on needed size unit to permit operation) (weight 7) (SOSF) (adjusted weight 7.91)[a]

Value	Condition
10	120 acres or more
—	80–120 acres
—	40–80 acres
—	20–40 acres
—	10–20 acres
0	Less than 10 acres

TABLE 1
Continued

4. Average size of land parcels within 1 mile of site (weight 9) (ASLP) (adjusted weight 10.17)[a]

Value	Condition
10	120 acres or more
—	80–120 acres
—	40–80 acres
—	20–40 acres
—	10–20 acres
0	Less than 10 acres

5. Agricultural support system/services (weight 1) (ASS) (adjusted weight 1.13)[a]

Value	Condition
10	Support system present
—	Some limitations to the support system
0	Severe limitations to the support system

6. Agrivestment in real property improvements within 2 miles (weight 10) (AV) (adjusted weight 11.3)[a]

Value	Condition
10	High level of investment in farm facilities (long term)
—	Moderate level of investment
0	Diminishing level of investment

7. Percent of land zoned agriculture within 1 1/2 miles of the site (weight 10) (PZAN) (adjusted weight 11.3)[a]

Value	Condition
10	90 or more
—	75–89
—	50–74
—	25–49
0	Less than 25

8. Zoning of the site and adjacent to it (weight 10) (ZOS) (adjusted weight 11.3)[a]

Value	Condition
10	Site and all surrounding sides zoned for agriculture
—	Site zoned agricultural and one side zone low-density residential
0	Site zoned agricultural and two sides zoned for residential, commercial, or industrial

9. Availability of land zoned for proposed use (weight 6) (AZPU) (adjusted weight 6.78)[a]

Value	Condition
10	Undeveloped land zoned for proposed use is beyond the primary and suburban growth areas of the incorporated city
0	No zoned land available for proposed use (this point value can only be assigned when parcel is within the primary or suburban growth areas)

10. Availability of nonfarmland or less-productive land as an alternative site within area of consideration (weight 8) (ALPU) (adjusted weight 9.04)[a]

Value	Condition
10	Large amount available
—	Moderate amount available
0	Not available

11. Need for additional urban land (weight 4) (NMUL) (adjusted weight 4.52)[a]

Value	Condition
10	Vacant, buildable land within city limits, capable of accommodating proposed use
0	Little or no vacant land remaining within city limits to accommodate the proposed use

12. Compatibility of proposed use with local area (weight 10) (CPUA) (adjusted weight 11.3)[a]

Value	Condition
10	Not compatible, high-intensity uses
—	Somewhat compatible but not totally
0	Compatible

TABLE 1
Continued

13. Does the property have unique topographic, historic, or groundcover features or unique scenic qualities (weight 9) (POUQ) (adjusted weight 10.17)[a]

Value	Condition
10	All of the site
—	Part of the site
0	None of the site

14. Is it the property adjacent to land that has unique topographic historic, or groundcover features or scenic qualities (weight 9) (ALUQ) (adjusted weight 10.17)[a]

Value	Condition
10	On all sides of the site
—	Three sides of the site
—	Two sides of the site
—	One side of the site
0	None of the site is adjacent to these unique features

15. Land subject to floods or in drainage course (weight 9) (LWFZ) (adjusted weight 10.17)[a]

Value	Condition
10	All of the site
—	50% of the site
0	None of the site

16. Suitability of soils for on-site waste disposal (weight 7) (adjusted weight 7.91)[a]

Value	Condition
10	Soil limitation that restricts the use of septic tank
—	Limitations to the soil can be overcome by special management design
0	Little or no limitations

17. Compatibility with an adopted comprehensive plan (weight 10) (CWCP) (adjusted weight 11.3)[a]

Value	Condition
10	Incompatible
—	Compatible with the intent of the plan but not with the plan map
0	Totally compatible with the intent of plan and the plan map

18. Within a designated growth area (weight 10) (WDGA) (adjusted weight 11.3)[a]

Value	Condition
10	Rural area
—	Clinton Reservoir Sanitation Zone
—	Suburban growth area
0	Primary growth area

19. Distance from city limits (weight 7) (DFCL) (adjusted weight 7.91)[a]

Value	Condition
10	More than 2 miles
—	2 miles or less
—	1 1/2 miles or less
—	1 mile or less
—	1/2 mile or less
0	Adjacent

20. Transportation accessibility (weight 7) (TRAN) (adjusted weight 7.91)[a]

Value	Condition
10	Limited transportation access dominated by rural township roads
—	Access to improved county roads or highway within suburban growth areas
—	Access to improved county roads or highway within primary growth areas
0	Access to full range of transportation services

21. Central water distribution system with available capacity (municipal system) (weight 8) (UWSA) (adjusted weight 9.04)[a]

Value	Condition
10	No water within 1 mile

TABLE 1
Continued

—	Water within 2,000 feet
0	Water at site

22. Central sanitary sewerage system with available capacity (municipal system or established sewer benefit district) (weight 8) (SSSA) (adjusted weight 9.04)[a]

Value	Condition
10	No sewer line within 1 1/2 miles
—	Sewer line within 1 mile
—	Sewer line within 1/2 mile
0	Sewer line adjacent to site

[a]Adjusted to total 200 points for comparison with new LESA factor weights.

Study Area

Douglas County, Kansas, is located in the northeastern part of the state (Figure 2). It has an area of 474 square miles and had a 1977 population of 62,907 [18]. Although located in a portion of the nation that is not expected to experience dramatic growth, its proximity to the metropolitan areas of Kansas City to the east and Topeka to the west increases growth pressures. This location affords the presence of transportation centers, cultural facilities, extensive markets, and the associated increase in nonfarmland development.

The farming of the county is based on cash crops and on livestock. Approximately 50% of farm income in 1972 was from cash crops [19]. An increase in cattle and hogs has been offset by a decrease in acres of pasture and hay [19–21]. It is expected that a decrease in farm acres for production and an increase in acreage for urban uses will typify the county's land use in the future [16].

In the past 15 years Douglas County has lost over 40,000 acres of productive farmland (13% of its total area) to the Clinton Lake and Park, rural and industrial development and expansion [22]. Lawrence is one of the most rapidly growing cities in the United States, and the rural townships have already passed their estimated population for the year 2000.

The county is served by the Union Pacific, Chicago, Rock Island, and Pacific railroads. Branch lines of the Atchison, Topeka and Santa Fe also serve the city of Lawrence. Roads include the Kansas Turnpike, a four-lane, limited-access highway that crosses the county in an east-west direction, as do U.S. Highways 40, 56, and 24. U.S. Highway 59 crosses the county in a north-south direction, with Highway 32 extending into the northeastern corner of the county and Highway 33 connecting with U.S. Highway 56 in the southeastern part of the county [16].

Several chemical industries in Douglas County produce phosphoric acid, phosphates, ammonium nitrate, urea, and ammonia. Also located in the county are compressed gas plants and electric power generation. The city of Lawrence has an organ manufacturing plant and a paper box company. Mobile home, greeting card, and food canning and processing industries are also located in the county. Farm machinery and other farm supplies are readily available through local businesses [16].

The most sensitive natural resource in the county is water, due to its variable supply. Other natural resources include sand and gravel, which are pumped from the Kansas River, and limestone, which is quarried and crushed for making concrete, road surfacing materials, and agricultural lime [16].

Douglas County lies partly in the Dissected Till Plains and partly in the Osage Plains, all part of the Central Lowlands physiographic province [23]. Major topographic features

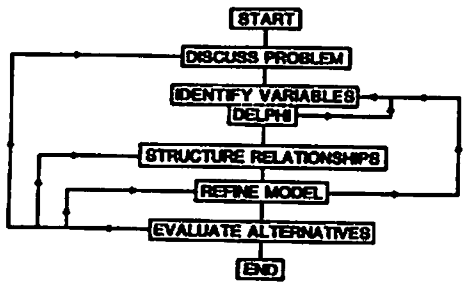

Fig. 1. Iterative learning model.

are the Kansas and Wakarusa river valleys and the upland limestone, shale, and sandstone cuestas. Plains developed in glaciofluvial deposits produce minor topographic features locally [24].

Recent interest by the Lawrence-Douglas County Planning Commission in the development of the LESA system for possible implementation provided the impetus for LESA research in this area. Two data bases have been developed by the University of Kansas Department of Geography for inclusion into an automated geographic information system. This work, outlined by Luckey [25], uses the two areas of study, each roughly five by six kilometers in size (Figures 3a and 3b).

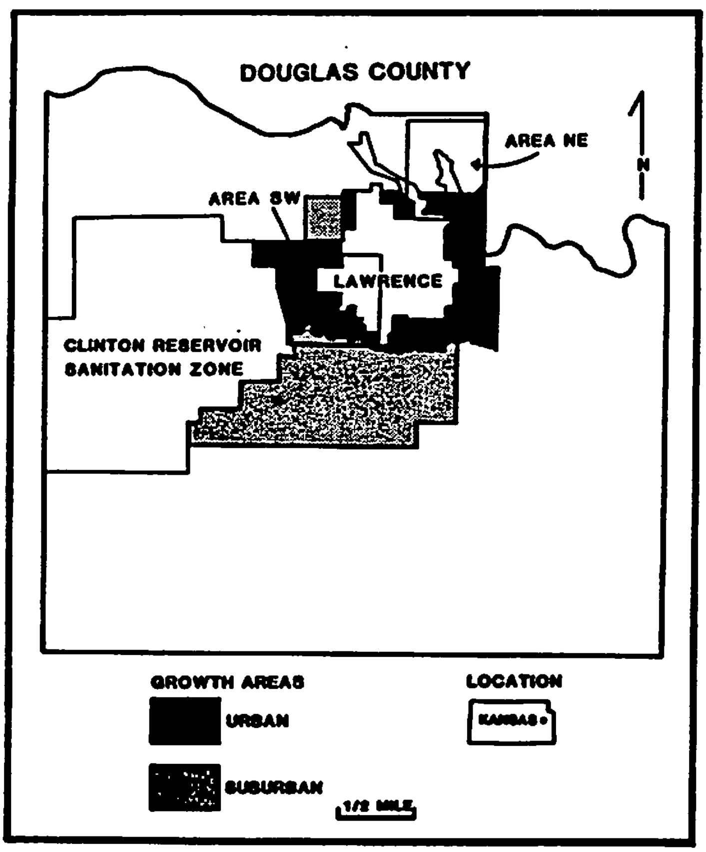

Fig. 2. Douglas County study area. From Luckey [25].

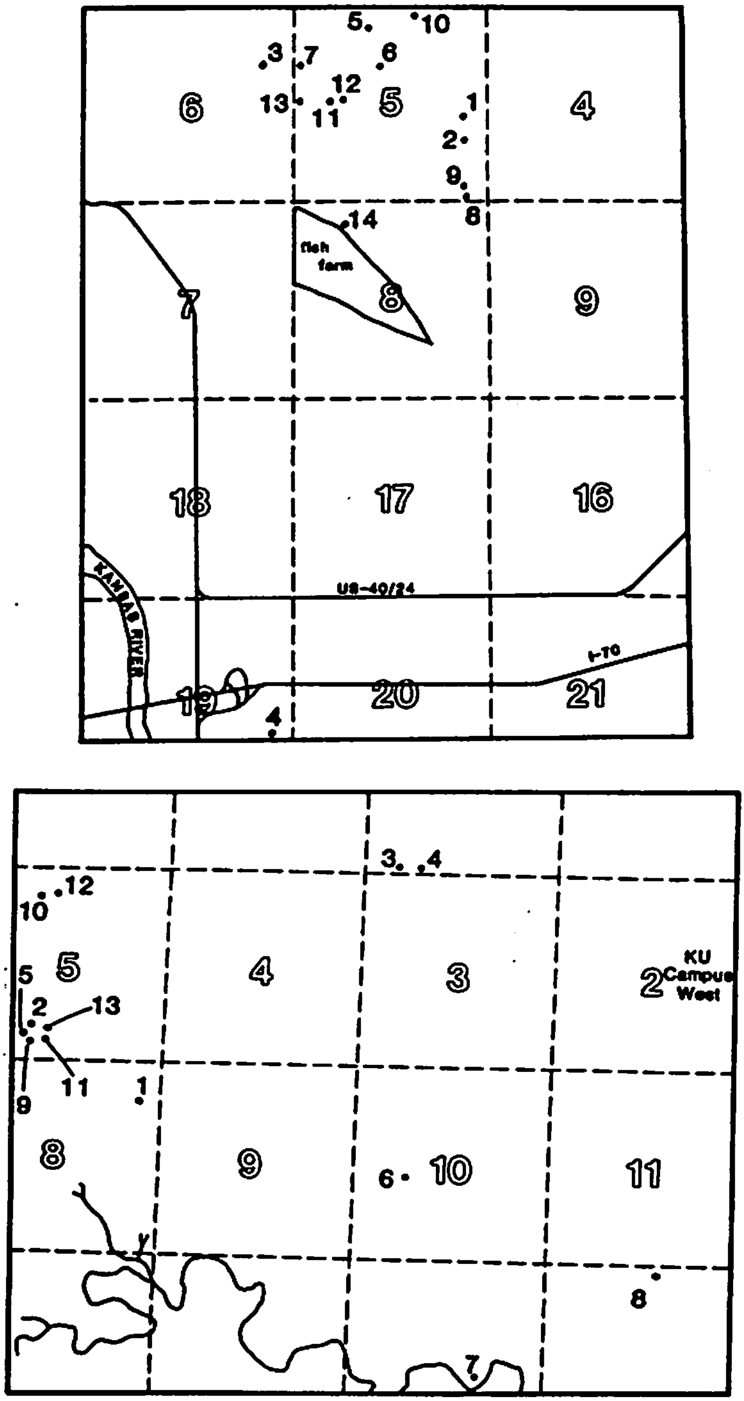

Fig. 3. Area study sites: (a) NE and (b) SW. Study site (•) and section boundary line (— — —).

These areas, one in the northwest portion of the county and one in the southwest, both have characteristics making them suitable for study. The northwest area is adjacent to the city of Lawrence, the Kansas River, and the Lawrence Municipal Airport, and is a proposed site for an industrial park. The southwest portion exhibits many of the physiographic types of the county, including the Wakarusa floodplain wooded areas, the cuesta complexes, and glacially drained plains. This portion is also located in an area that is experiencing increased development due to the completion of the Clinton Reservoir [25].

The combined factors of mixed land uses, adjacency to the city of Lawrence, abundant transportation facilities, and a variety of development pressures and physiographic provinces made both of these areas ideal for the previous studies. The very existence of these previous studies, as well as the continued interest in development of a LESA system, make Douglas County ideal for the present research.

Within these two areas individual sites have been selected previously for evaluation of past LESA scores [25] (Figures 3a and 3b). These sites were selected to correspond to a historical data base composed of zoning permits for nonagricultural uses. A sample of these sites, having a variety of different physical, cultural, and economic conditions, were selected from each area. The new LESA system was tested against these permits and against the existing LESA system values for Douglas County.

Methods

Because the primary thrust of this research was to develop a pedagogical model that would be useful to planners in the actual development of an information system, it was necessary that the model develop as a result of the planners' requirements. Each step of the learning procedure was adapted to the specific needs of the participants as they encountered them. Although guided by the original research design, the final model has been developed by the planners themselves.

Phase one of the model began with a discussion of the existing LESA system as originally proposed by the SCS with selected participants from the County Planning Office and the County Zoning Administration. They decided that the 100 point suggested value for land evaluation was arbitrary and not useful for the area under consideration. It should be noted here that previous research clearly shows that the relative ratio between land evaluation and site assessment has little effect on the final outcome of the LESA model [26]. Discussion continued with the presupposition that land evaluation would be weighted along with the site assessment factors and that it be given a weight appropriate for planning in Douglas County. This changed the formula for LESA (eq. 3) to the following:

$$\mathrm{LESA}_j = \mathrm{SA}_j = \textstyle\sum_i W_i V_{ij}, \tag{6}$$

with the total possible still equal to the 300 points. The planners then compiled a list of factors for decision making, and each participant was asked to privately rank each and assign a weight. They were also asked to define as completely as possible their reasoning for each factor rank and weight decision for later discussion.

Arbitration took place with graphed results of the original rankings presented to each planner during a subsequent meeting. Discussions were directed at the reasoning that might determine severe differences of opinion with each selected factor. This allowed the planners to rate each factor with the additional knowledge available from the other participants. This technique was continued until consensus opinion was reached in the

TABLE 2
Cross Impact Matrix

	AV	AAL	ALPU	ASNP	DFCL	LAAS	NMUL	PAAN	PZAN	SSSA	SOF	SOS	TRAN	UWSA	Policy
AV	2	−2	0	3	−4	2	−5	5	5	−8	2	−6	1	−8	−2
AAL	−2	1	−1	−2	0	−1	0	−1	−1	7	0	0	1	7	−5
ALPU	0	0	0	0	0	0	−2	0	−1	8	0	0	1	8	0
ASNP	1	−1	−3	4	−2	1	−3	1	4	−8	2	3	−2	−8	−9
DFCL	0	0	0	0	0	0	0	0	0	−8	−6	0	4	−8	−15
LAAS	4	−1	−2	3	4	2	−4	3	5	−9	3	−5	−1	−9	−10
NMUL	0	0	0	0	0	0	10	0	0	5	0	0	0	5	7
PAAN	3	−1	−2	3	5	5	−4	5	5	−6	5	−2	−1	−6	−6
PZAN	0	0	−4	0	5	5	−4	5	7	−6	5	−3	−1	−6	−10
SSSA	0	0	2	−3	−5	−3	3	−5	−5	7	−8	2	2	7	−3
SOF	3	−1	0	3	3	2	−2	3	3	−9	10	−4	1	−9	−16
SOS	−3	0	0	−2	0	−1	0	−1	−5	−8	−10	4	−7	−8	13
TRAN	0	0	2	−3	−5	−3	3	−5	−5	9	−8	2	2	4	28
UWSA	0	0	2	−3	−5	−3	3	−5	−5	9	−8	2	2	9	−4

form of "no movement" rather than collective agreement. The factor weights were then averaged as a simple means of incorporating disparate views.

Next the participants completed a cross-impact matrix of the factors, so as to conform to the KSIM model. Each factor was compared to each other factor by asking the planners the following question: "If factor X were to increase, what would the impact be on factor Y?" The impact would be either negative or positive and was weighted on a −10 to +10 scale to indicate the severity of impact. These numerical weightings were determined through discussion of each pair of attributes as they occurred. Policy factors, defined as those factors upon which other factors had no impact but that impacted the remainder of the factors, were added to provide one value so as to conform to the KSIM methodology. The values were then tabulated from the matrix (Table 2).

An individual study site was selected, with appropriate starting conditions assigned

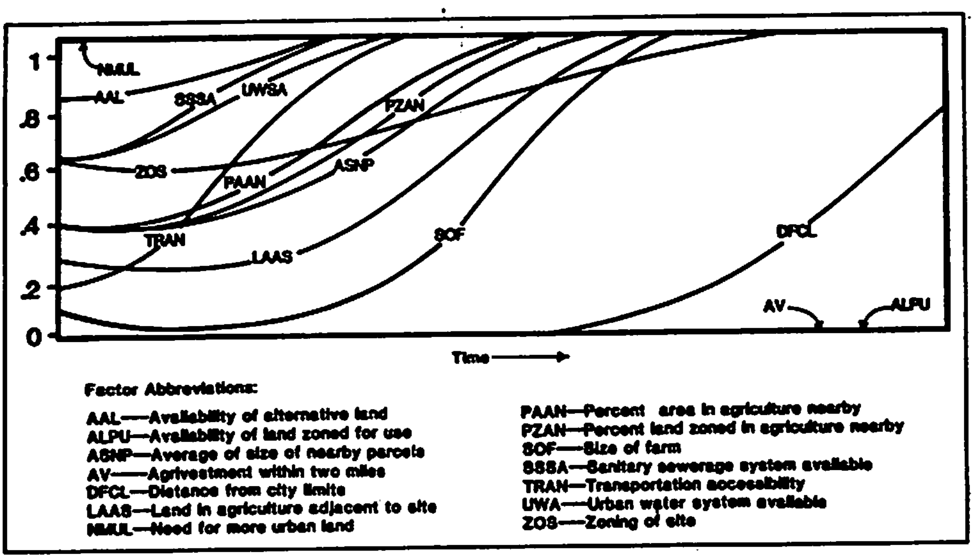

Fig. 4. Kane simulation model showing rates over time.

to the various factors. The site (W1/2, Sec. 27, T 12 S, R 19 E) was specifically selected because the planners were all familiar with its current conditions. These current conditions were translated into appropriate LESA factor weights as starting conditions to the KSIM model. The KSIM model was run to indicate the pairwise long-term impacts of these factors on each other in the selected site (Figure 4). The results were discussed with the planning staff to determine the validity of model performance based on their knowledge of the study area. Especially important was a discussion of the relative increase or decrease in importance value of each factor as it interacted through time.

Upon acceptance of the model, the LESA weights were adjusted by the values in the cross-impact matrix. By adding the cross-impact factors, converting them to percentages, and readjusting the scale by zeroing one weight, one produces a set of ranked multipliers that are then multiplied by the factor weights themselves. Because zeroing the factors subsequently eliminates the lowest factor, each factor weight is again added to the total to reintroduce this lost value. Formally, the combination of KSIM dynamic interaction weights with the static LESA model is performed according to the following formula:

$$FW = (30/\sum FW_i) * FW_i, \tag{7}$$

where FW_i is the interim factor weight defined by

$$[(\sum KR * -.01 * F_{wn}) + F_{wn}], \tag{8}$$

in which KR = cross-impact row values and F_{wn} = initial LESA factor weights.

This represents a new methodology for explicit incorporation of implicit interrelationships into the linear LESA model. The final LESA values, adjusted for factor interrelationships, were then used for evaluation of land in Douglas County (Table 3).

TABLE 3
Final LESA Model for Douglas County

1. % area in agriculture within 1/2 mile (weight 7.81) (PAAN)

Value	Condition
10	63–100% of area in agriculture
5	35–62% of area in agriculture
0	0–34% of area in agriculture

2. Land in agriculture adjacent to site (weight 13.67) (LAAS)

Value	Condition
10	All sides of site in agriculture
7.5	One side of site adjacent to nonagricultural land
5	Two sides of site adjacent to nonagricultural land
2.5	Three sides of site adjacent to nonagricultural land
0	The site surrounded by nonagricultural land

TABLE 3
Continued

3. Size of farm (based on needed size unit to permit operation) (weight 1.29) (SOF)

Value	Condition
10	12 acres or more
8	8–11.9 acres
6	4–7.9 acres
4	2–3.9 acres
2	1–1.9 acres
0	Less than 1 acres

4. Size of site (weight 1.60) (SOS)

Value	Condition
10	12 acres or more
8	8–11.9 acres
6	4–7.9 acres
4	2–3.9 acres
2	1–1.9 acres
0	Less than 1 acre

5. Average size of land parcels within 1 mile of site (weight 1.77) (ASNP)

Value	Condition
10	12 acres or more
8	8–11.9 acres
6	4–7.9 acres
4	2–3.9 acres
2	1–1.9 acres
0	Less than 1 acre

6. Agrivestment in real property improvements within 2 miles (weight 6.88) (AV)

Value	Condition
10	High level of investment in farm facilities (long term)
5	Moderate level of investment
0	Diminishing level of investment

7. Percent of land zoned agriculture within 1/2 mile of the site (weight 6.89) (PZAN)

Value	Condition
10	90 or more
7.5	75–89
5	50–74
2.5	25–49
0	Less than 25

8. Zoning of the site and adjacent to it (weight 6.89) (ZOS)

Value	Condition
10	Site zoned agriculture
6	1/4 of site zoned agriculture
3	1/2 of site zoned residential, commercial or industrial
0	Site zoned residential, commercial, or industrial

9. Zoning of land adjacent to site (weight 10.38) (ZLAS)

Value	Condition
10	All sides of site zoned agriculture
7.5	One side zoned low-density residential
5	Two sides zoned residential, commercial, or industrial
2.5	Three sides zoned residential, commercial, or industrial
0	Site surrounded by land zoned residential, commercial, or industrial

10. Availability of land zoned for proposed use (weight 8.27) (AZPU)

Value	Condition
10	Undeveloped land zoned for proposed use is beyond the primary growth areas of the incorporated city
5	Undeveloped land zoned for proposed use is beyond the suburban growth areas of the city

TABLE 3
Continued

0 No zoned land available for proposed use (this point value can only be assigned when parcel is within the primary or suburban growth areas)

11. Availability of nonfarmland or less-productive land as an alternative site within area of consideration (weight 7.18) (ALPU)

Value	Condition
10	Large amount available
5	Moderate amount available
0	Not available

12. Need for additional urban land (weight 7.14) (NMUL)

Value	Condition
10	Vacant, buildable land within city limits, capable of accommodating proposed use
0	Little or no vacant land remaining within city limits to accommodate the proposed use

13. Compatibility of proposed use with surrounding area (weight 25.75) (CPUA)

Value	Condition
10	Not compatible, high-intensity uses
5	Somewhat compatible but not totally
0	Compatible

14. Does the property have unique topographic, historic, or groundcover features or unique scenic qualities (weight 4.99) (POUQ)

Value	Condition
10	All of the site
5	Part of the site
0	None of the site

15. Is the property adjacent to land that has unique topographic, historic, or groundcover features or scenic qualities (weight 4.36) (ALUQ)

Value	Condition
10	On all sides of the site
7.5	Three sides of the site
5	Two sides of the site
2.5	One side of the site
0	None of the site is adjacent to these unique features

16. Land within 100 year flood zone (weight 1.84) (LWFZ)

Value	Condition
10	81–100%
7.5	61–80%
5	41–60%
2.5	21–40%
0	0–20%

17. Compatibility with an adopted comprehensive plan (weight 31.38) (CWCP)

Value	Condition
10	Incompatible
5	Compatible with the intent of the plan but not with the plan map
0	Totally compatible with the intent of plan and plan map

18. Within a designated growth area (weight 29.72) (WDGA)

Value	Condition
10	Rural area
6	Clinton Reservoir Sanitation Zone
3	Suburban growth area
0	Primary growth area

19. Distance from city limits (weight 40.55) (DFCL)

Value	Condition
10	More than 1 mile
7.5	1/2 to 1 mile

TABLE 3
Continued

5 1/4 to 1/2 mile
2.5 Less than 1/4 mile
0 Adjacent

20. Transportation accessibility (weight 5.08) (TRAN)

Value	Condition
10	Limited transportation access dominated by rural township roads
6	Access to improved county roads or highway within suburban growth areas
3	Access to improved county roads or highway within primary growth areas
0	Access to full range of transportation services

21. Urban water distribution system with available capacity (weight 26.62) (UWSA)

Value	Condition
10	No water within 1 mile
7.5	Water within 3/4 mile
5	Water within 1/2 mile
2.5	Water within 1/4 mile
0	Water at the site

22. Central sanitary sewerage system with available capacity (municipal system or established sewer benefit district) (weight 29.36) (SSSA)

Value	Condition
10	No sewer line within 1–2 miles
7.5	Sewer line within 3/4 mile
5	Sewer line within 1/2 mile
2.5	Sewer line within 1/4 mile
0	Sewer line adjacent to site

23. Land evaluation (weight 8.63)[a]

Value	Condition
10	Soils group I
8	Soils group II
7	Soils group III
5	Soils groups IV and V
1	Soils group VI
0	Soil groups VII and VIII

[a]Derived from original land evaluation scores.

Analysis

The learning model has as its final product the development of a useful LESA scheme. A more formal or even a simpler development scheme may be accepted readily by busy planners, yet the consequences of its development to decision making may not be considered in their acceptance of such a scheme. Evaluation of the functioning of the learning model is best accomplished by an evaluation of the validity of the results themselves. As a model LESA is meant to reflect the views of the planners. The validity of the model, then, is a comparison of its reslts with the wishes of the planners.

The 27 preselected study sites were divided into two separate groups, each representing either the northeast or the southwest study areas. This was necessary because these two areas are distinct in character. LESA scores from the system originally proposed were determined in a previous study [25] and have been reproduced here (Table 4). New LESA scores have also been determined using the newly developed system. Both sets of scores were developed from estimates of conditions existing during the year of building permit issuance for each site. Original and new scores were averaged for comparison.

All but one site within the northeast study border are within existing agricultural lands north of the city of Lawrence. It is the general feeling of the planners that these regions should be protected from further expansion whenever possible. A majority of the

TABLE 4
Site Comparison of LESA Scores

ID#	DG LESA	New LESA
NE 1	107.0	239.0
NE 2	104.0	247.3
NE 3	178.2	247.8
NE 4	178.8	116.6
NE 5	108.6	247.3
NE 6	112.9	245.5
NE 7	187.6	220.4
NE 8	171.8	228.4
NE 9	170.2	221.6
NE 10	108.6	245.7
NE 11	174.2	244.8
NE 12	181.3	243.9
NE 13	185.3	244.8
NE 14	176.5	235.2
Mean	153.3	230.6
SW 1	94.5	115.9
SW 2	157.6	132.6
SW 3	67.7	56.5
SW 4	51.4	49.4
SW 5	86.1	101.6
SW 6	144.1	133.9
SW 7	170.8	141.1
SW 8	128.6	105.4
SW 9	82.4	101.6
SW 10	97.7	120.3
SW 11	84.4	101.6
SW 12	165.6	118.3
SW 13	164.7	101.6
Mean	115.1	106.1

southwest study area is zoned as nonagricultural land and is an area of intense urban development. It is the view of the planning staff that this region, especially those areas not zoned as agricultural land, be given low protection efforts for agriculture. All permits issued in this study area were within the city's designated primary urban growth area, further mandating low protection efforts and ensuring high protection efforts elsewhere. Comparison of the newly developed LESA scores with the original scores, based on these planner views, indicate the model viability.

Results

The planners involved in this research found the new approach to LESA to be an improved method over that of the original LESA development structure. They found that the formal approach to selecting and weighting LESA factors gave them more chance to discuss the issues from different points of view. Discussions with the planners further indicated their interest in the use of a predictive type of framework (KSIM) in their decision making, yet they found the grahics confusing. This required a great deal of time for explanation of the model. All of the planners found the cross-impact matrix portion of the KSIM model to be of great value in evaluating the interrelationships among the factors for their community. They stated that they had never looked at these interactions before, and they found them to be helpful. This is reinforced by the subsequent selection of new factors, thus indicating the importance of the iterative approach to such a model development. It should be noted that the planners spent many hours developing the cross-impact matrix values, and it is unlikely that this amount of time would be given in all cases.

Results of the LESA model implementation indicate much-improved model performance over the original LESA model, especially in its protection of prime agricultural lands. The new model design yielded consistently higher LESA values for the northeast study region. An average of 206.22 indicates that at least moderate protection efforts should be applied to this predominately agricultural area, as opposed to an average of 153.3 for the original LESA model. More significantly, however, 11 of the 14 sites (NE sites 1, 2, 3, 5, 6, 8, 10, 11, 12, 13, and 14) fell within the high protection category (225–249) with the use of the new LESA, while the original model yielded none within this category. Additionally, the new LESA model placed two more sites (NE sites 7 and 9) within the moderate protection class, whereas the original model once again has none in this category. The new model also established only one of the sites within the low protection category; the original model placed all of the sites in this category, in diametric opposition to the wishes of the planners for this area.

In the southwest study area, little if any improvement can be seen with the use of the new LESA model. Because this is an area that is designated as an urban expanse area, one would expect to find low LESA scores. Both the original LESA and the new model yield results that are significantly below the 200 point cut off value to yield low protection efforts. In most instances, however (SW sites 2, 3, 4, 6, 7, 8, 12, and 13), the new LESA yielded slightly lower scores, while in the remainder of the sites it yielded higher scores.

As a new model for LESA development, the approach improves the score results when applied to areas of significant agricultural potential. In regions of lesser agricultural importance, the model performs as well as the original. Utility of the new approach is in its significantly higher LESA scores for agricultural regions needing protection. Because this is the intended purpose of LESA, it is suggested that similar modifications of the LESA system be considered.

Conclusions

The iterative learning model, developed as a combination of existing linear and simulation techniques, shows promise for applications to planning. Despite the inherent limitations of both systems, their marriage produces results similar to those desired by the planners. The model is more rebust than its original counterpart because it allows the planners to incorporate nonmathematical heuristics into their decision processes, to determine the selection of factors and factor weight assignments within a systematic framework, and to review the possible consequences of their decisions before they are implemented. All of this is done within a linear framework that is an easily understandable and generally acceptable methodology for planning purposes.

This approach is not suggested as a final solution to the problem of planning under circumstances of uncertainty or conflicting information, but rather a step toward developing such a model. Successful implementation of this model will require some method of factor reduction before the matrix is developed. The tree structure suggested by Luckey and DeMers [27] should prove very useful for this purpose. The incorporation of such a structure will reduce the time necessary for model implementation, thus improving its acceptability to the planning community. Further, factor reduction of this type will reduce the confusion of conflicting factors because they will have been categorized properly in the first place. And the graphics output of the KSIM portion of the model will be easier to explain and understand, thus improving model usefulness and enhancing subsequent factor weight validity.

Suggestions for future improvements of this model revolve around the nonlinear growth curve assumed by KSIM. Research needs to be done to determine how factors truly interact so that a more realistic predictive tool can be developed. It is suggested that research of this nature will greatly improve any modeling structure.

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