

Land Resource Sustainability for Urban Development: Spatial Decision Support System Prototype

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ABSTRACT / Land resource sustainability for urban development characterizes the problem of decision-making with multiplicity and uncertainty. A decision support system prototype aids in the assessment of incremental land development plan proposals put forth within the long-term community priority of a sustainable growth. Facilitating this assessment is the analytic hierarchy process (AHP), a multicriteria evaluation and decision support system. The deci-

sion support system incorporates multiple sustainability criteria, weighted strategically responsive to local public policy priorities and community-specific situations and values, while gauging and directing desirable future courses of development. Furthermore, the decision support system uses a GIS, which facilitates an assessment of urban form with multiple indicators of sustainability as spatial criteria thematically. The resultant land-use sustainability scores indicate, on the ratio-scale of AHP, whether or not a desirable urban form is likely in the long run, and if so, to what degree. The two alternative modes of synthesis in AHP—ideal and distributive—provide assessments of a land development plan incrementally (short-term) and city-wide pattern comprehensively (long-term), respectively. Thus, the spatial decision support system facilitates proactive and collective public policy determination of land resource for future sustainable urban development.

Dissatisfaction with the consequences of urban sprawl, characterized by “leapfrog” suburban development patterns, and by the pressures imposed upon local governments in the United States for public infrastructure, has provided an impetus for long-range growth management plans that provide a sustainable alternative. According to a recent report, “Since 1997, 22 states have enacted some type of land-use law designated to rein in sprawl. In 1999 alone, lawmakers introduced 1000 bills in state legislatures, and they passed more than 200. In 2000, there were 553 growth measures in 38 states.... Voters approved more than 70% of them. In fast-growing counties, people are electing ‘smart growth’ candidates to public office who advocate restricting sprawl” (El Nasser and Overberg 2001, p. 1A). Among recent state-level legislation are laws mandating that cities and counties delineate urban growth area boundaries. These boundaries are intended to

help government entities anticipate future urban growth and create an awareness of rural preservation, density, and livable quality, and sustainability of urban development. Although the terms “smart” or “sustainable” growth are used frequently and with apparent certainty, the future pattern of development is unknown and far from certain, given the long-term (20-year) time horizon of urban growth area plans. Although the urban growth boundary method manages the amount of land slated for future urban development strategically, conventional methods of local government control—zoning, infill development, subdivision or site-specific regulations or design guidelines—are still needed to manage the pattern, or structure of urban development, qualitatively and quantitatively. For a review and outcome assessment of various methods of growth management from referenda—California style!—moratoria on growth, state-mandated urban growth boundary, development impact fees, to local infrastructure financing, zoning and subdivision regulations, see Fulton and others (2002), Johnson (2001), and Juergensmeyer and Roberts (1998).

Urban spatial pattern is debated in the literature in deference to the new urban or smart growth sustainability principles that have received attention in local development control (see CNU 2004, SGN 2004). Mul-

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tiple sustainability principles address various dimensions of the built and natural environment—density, land-use mix, access, open space preservation, resource conservation, and the like. However, the principles have received partial implementation in local development plans (Berke and Conroy 2000). Little attention focuses on how the principles of sustainability that address multiple criteria are given relative importance, thus adapted to local conditions, and brought to bear upon the urban form with land resource allocation decisions in development plans.

The Rationale: Substance and Procedure, Macro and Micro, Long-Term and Short-Term Issues

This paper focuses on a spatial, micro-level approach to sustainable development. This approach contrasts with accounts given in the literature that focus on the non-spatial and macro indicators, such as social system reproduction or maintenance, the local and regional or global nexus, or intergenerational transfer of resources (e.g., Krizek and Power 1996, Beatley and Manning 1997, Berke and Conroy 2000). The focus on the urban level is significant not only because of the continual process of the urbanization of world population, but also because the proverbial devil-in-the-details has a manifestation at the urban scale. As Breheny (1993, p. 2) remarked, increasingly, sustainability is debated with an urban focus (see also Campbell 1996). Little wonder, then, that the term “sustainable urban development” is associated with smart growth or new urbanism, which are about urban spatial patterns (substance) as well as decision-making (procedure) in bringing about a desirable urban form (e.g., Katz 1994). Advocates of smart growth and new urbanism, for example, consider the variation in housing density or typology (to promote community diversity), or the land-use mix (residential, commercial, public) to permit the proximity of residential population to retail, employment, and public facilities in a central location that encourages pedestrian as well as vehicular accessibility, all with deference to the natural resources, as desirable urban forms (see also CNU 2004, SGN 2004). The physical form that human settlements must take qualitatively is integral to the debates about sustainability, with a view of ecology that poses the natural and the built-environment as one whole (see Lynch 1984, Calthorpe 1993, Calthorpe and Fulton 2001).

This paper contributes to planning decision-making methods that use multiple criteria to determine

sustainability of urban development. The methodology surmounts a limitation in the measurement of urban formal quality, with mixed tangible and intangible indicators, with priorities better determined strategically responsive to local site-specific conditions, instead of assumed fixed universally. The criteria are used to scale and measure formal quality, i.e., spatial structure of land development plans as well as urban pattern as a whole. Spatial, micro-level criteria are used here prototypically, although macro-level indicators of sustainability, the environment, the economy, as well as space may be systemically addressed in a unified framework. It should be noted, however, that “sustainability” is defined differently by different authors or stakeholders, and that its concepts and definitions are controversially held, owing to its complexity. Systems thinking is particularly plausible here when the logic of the links and the priority of the subsystem parts are essential toward an understanding of the whole. Alternatively, the systems-oriented framework of this paper can inclusively accommodate a concept of sustainability as a system with interrelated macro and micro, spatial and nonspatial subsystems that are given importance differently in different places and times by different authors or stakeholders. The spatial decision support system is intended to aid in proactive and collective public policy determination of sustainable urban development by means of assessment of land development plans introduced piecemeal (short-term) as well as the urban spatial pattern as a whole (long-term).

The system-oriented method (analytic hierarchy process; AHP) used in this paper highlights an approach that is holistic in treatment of the sustainability criteria (or principles) and of the urban form alternatives to attain them. This approach contrasts with adoptions of sustainability principles in urban development plans that are partial, and thereby compromise the integrity of the concept of sustainability (Berke and Conroy 2000). The variation in the actual, local piecemeal adoption of sustainability principles in plans, however, suggests a rationale for an approach that is holistic and strategic, responsive to local priorities, and site-specific constraints and potentials.

A two-pronged approach is taken for the problem of assessing sustainable urban development in the face of multiplicity and uncertainty. “Multiplicity” here connotes decision-making by different participants in different situations, and decision-making that is based upon multiple and diverse criteria with varying importance and trade-offs among the criteria. It connotes, also, a state of the world in which there exist multiple, sometimes controversial definitions, principles, con-

cepts, or worldviews of sustainability, emphasized differently by different authors or stakeholders, as noted above. First, a decision support system is illustrated prototypically to show how incrementally proposed land development plans can be assessed in the face of long-term community priority of a sustainable growth (see Land Development Concept Plan Evaluation section below). The procedure for assessment is facilitated by the AHP, a multicriteria evaluation and decision support system (Saaty 1996) (Multicriteria Evaluation of Urban Form with Analytic Hierarchy Process section below). The decision support system incorporates multicriteria factors that address various dimensions of sustainability. The criteria weights determine sustainability scores of land development (concept) plans that are proposed piecemeal for review and implementation (see Land Development Concept Plan Evaluation section below). Secondly, AHP is used with a geographic information system (GIS) to determine the likelihood of a sustainable urban development in the long run (see Estimation of Likely Sustainable Development section below). The spatial queries are refined for consistency with characteristic properties of urban form, in deference to the multiple sustainability criteria. The spatial decision support system thus provides a means to gauge long-term sustainability of urban development. A small, southeastern U.S. city (Piperton) is the case study for this research, with an urban growth area plan, a proposed land development concept plan, a long-term (2020) land-use plan, and parcel-level (GIS) data in the public domain. This city—with a population of 589 in the 2000 census and a population projection of 13,317 by 2020—is located in a state (Tennessee) that has recently required local (city and county) governments to delineate urban growth boundaries and to prepare comprehensive plans in anticipation of 20 years of growth.

A brief description of AHP given next is followed by applications in an evaluation of a land development plan and a GIS-aided estimation of urban form.

Multicriteria Evaluation of Urban Form with Analytic Hierarchy Process

Analysis of urban spatial pattern is increasingly aided by development of multi-criteria evaluation methods (MCE) and geographic information systems (GIS). GIS are interactive computer software designed to aid in the analysis and graphic representation of spatial and attribute data. Used in combination, or with seamless integration, MCE and GIS provide refreshing alternatives to earlier generations of urban simulation

methods and models that are limited in addressing, much less evaluating, physical features of the built environment as multi-attribute or multi-criteria spatial data analytically at a given development site (Wegener 1998, Landis and Zhang 1998).

From a variety of perspectives (including those of new urban or anti-sprawl proponents), urban sustainability is asserted as a multi-attribute concept. For example, with Beatley (1995; 1994, p. 44), sustainability is tantamount to public policies that encourage “efficient compact and contiguous development,” lessen automobile dependence, with a “greater use of mass transit and other alternative modes of transportation,” and promote “mixed-use development and infill growth.” The proponents of new urbanism also credit it as an alternative to sprawl with a sustainable or smart(er) growth (Katz 1994). In transit-oriented development (Calthorpe 1993), minimum density thresholds as well as land-use mix ensure sustainability. However, the political, economic, and spatial context variations call for the sustainability criteria (or indicators) to be weighted or valued differently in different contexts. For example, in a small city (case study) desirous of maintaining a low density, sustainability may be attained by preserving open space through clustered development pattern. Open space preservation (with a “rural ambience”) may be given a greater weight than “balanced” multi-modal access (auto versus transit). In contrast, a greater importance may be given to (higher) density and multi-modal access in a large city. MCE methods aid in the assessment of the relative importance of the sustainability criteria in context.

Standard applications of GIS include identification of the natural features (woodlands, wetlands, and the like) and thereby map constraints and potentials of a (large) development site (or region). Increasingly, methods of spatial analysis in GIS help determine the relative importance of natural- and built-environment features, rather than assume equal importance regardless of context. A MCE method coupled with a GIS aids in such an assessment (Malczewski 1996). Furthermore, a GIS helps with the spatial analysis of proximity and land-use mix (buffering techniques), which, as noted above, are also considered among the indicators of urban sustainability.

This paper uses the analytic hierarchy process as a decision support system (MCE) with a GIS. Analytic hierarchy process (AHP) is an inductive, multicriteria method, effective in the estimation of the likelihood of unique events, and in the face of multiplicity, uncertainty, and the limitation of information (Saaty 1996, 1998; Yoon Hwang 1995). When uniqueness of spatial phenomena matters, or historical observational

precedent does not exist, statistical (regression), and probability—particularly the relative-frequency—methods are of limited use in prediction. Furthermore, uncertainty arises in the face of both tangibles and intangibles as multiple criteria to be determined with relative importance.

Above all, among the criteria or indicators of urban sustainability noted in the literature are the intangibles: accessibility, proximity, land-use mix or “grain,” livability, sense of place, harmony or balance (of natural and built environments), self-containment (balance of housing and employment opportunity locally), equity, and the like. There are desirable thresholds, for example, housing in “close” proximity—defined by a 2000-foot radius of a transit station in a transit-oriented development (TOD), or the civic or commercial-retail center in a pedestrian-oriented, traditional neighborhood design (TND)—in two alternative paradigms of new urbanism; but how is a land-use mix or “grain” that is “fine”—defined with 5–15, 30–70, and 20–60% for public, core-employment, and housing uses, respectively, for an urban TOD (Calthorpe 1993, p. 63)—weighed in relation to another that is “coarse,” or considered in relation to yet another variable, proximity? They are intangibles, and thus have “no scale with a unit, by definition” (Saaty 1998, p. 14). There is no absolute scale with a standard unit to measure intangibles, the way money, temperature, weight, or distance are measured in dollars, degrees, pounds, or feet (Saaty 1990). Empirical methods use units of distance or time quantitatively in the measurement of accessibility. The subjective perception or sensation of distance or time eludes the objective methods. To paraphrase Howard (2004, p. 78) in a parallel, perfunctory distinction made between objective versus subjective probability, “You cannot get from data to [scale], however, without going through a person.” The author substituted scale for probability.

A plausible method to measure intangibles is by comparison with other intangibles by relative measurement, with the ratio scale of AHP (Saaty 1996). For example, how important is land-use mix compared to the variation in density for the goal of a sustainable urban development? Pairs of such variables—both intangibles and tangibles—are compared and their relative importance is indicated in a matrix of ratio estimates. A brief description of AHP architecture is given next with the approach to problem structure, measurement, and synthesis.

Problem Structure

AHP is a systems-oriented MCE. First, a decision problem is framed as a hierarchy (system) with multi-

ple levels whose elements represent the goal, criteria, and alternatives. Secondly, the elements (or factors) are compared pairwise. The second-level elements are compared with respect to the goal, the first level of the hierarchy. The third-level elements are similarly compared with respect to each of the second-level elements. The comparisons are similarly performed down to the final levels, which contain the alternatives. A consistency index gauges whether the comparisons are performed with a good logical consistency or are decided randomly. This AHP property is helpful in decision-making involving multiple criteria where errors in judging the relative importance (or weights) of the criteria can be both detected and corrected. AHP is the only multicriteria method with this property that is useful in practical decision-making.

A typical AHP problem is structured hierarchically. A hierarchy is a deductive system, but its common AHP application is inductive and “site-specific.” This is the problem framing part of AHP, which is both creative and challenging. The structure is linear. However, if nonlinearity, or feedback, is detected, then the problem is alternatively structured as a network of interacting elements. The hierarchical representation, though, is more common, a natural way for the mind to cope with complexity, by disaggregating or breaking it down into component parts so as to gain an understanding of a complex whole system. Furthermore, there is evidence that both natural and human-made systems exhibit hierarchical organization (Simon 1981).

Measurement

The paired comparison of elements is an approach to measurement at the kernel of AHP. The elements are compared pairwise in a matrix. A nine-point scale of absolute numbers—from equal (1) to extreme (9) importance—is used. The matrix of ratio estimates is reciprocal, all the diagonal elements are one, and it has unit rank. The robust method of the aggregation or synthesis of the relative weights of the elements in AHP is the eigenvector solution (characteristic root method; Saaty 1996). The resulting solution gives the relative weights of the elements on a ratio scale bounded from 0 to 100%. Thus, AHP is a versatile, robust ratio-scale MCE method, which may be regarded as a factor contributing to its wide-ranging applications. The other type of scales—nominal, ordinal, and interval—pale in comparison. The idea that when confronted with alternatives, people are subjectively instinctively inclined to compare them in order to assess relative merit reflects formally in AHP as a MCE with increasing popularity. In contrast to commonly used multicriteria

methods that similarly use a weighted-factor procedure, the AHP provides a calculus to gauge consistency. Consistency is violated naturally due to the intransitivity of preference in decision making, individually and collectively—a common occurrence in human affairs—in the face of limited information, uncertainty, and factor diversity (compare the theory of bounded rationality).

Synthesis

The comparison of the elements at each level with respect to all the elements in each previous level of the hierarchy determines the *local* weights of the elements, level by level. The principle of hierarchic composition determines the *global* weights of the elements at the lowest level of the hierarchy (alternatives). The weights of the elements, beginning from the goal to the alternatives, are propagated or synthesized in a multi-linear or nonlinear procedure. Sensitivity analysis is a natural extension of the application of this process, with “what if” scenarios that determine the impact on the global weights (of alternatives) from the perturbation of the weights of elements at any level, for instance, criteria, actors, actions, or policies. Planning and design implications are immediately suggested: insight that is gained once the elements of a system are taken apart (analysis) and, once again, after the elements are combined (synthesis).

Furthermore, two alternative modes of synthesis—ideal and distributive—represent recent embellishment of AHP (Saaty 1996). The ideal mode is used when there is a “benchmark”; for example, sustainability criteria with certain known or desirable thresholds are used to assess individual land units as alternatives. However, if there are other alternatives, for example, a land unit, such as housing, is considered at various distances from a nodal location, then it is desirable to account for the influence of each alternative on all other ones. This second approach uses the “distributive” mode of synthesis. The ideal mode is used in this article to assess a land development concept plan. The distributive mode is used in the estimation of the likelihood of sustainable development, whole city pattern. In combination, the two modes have received limited attention in the literature of environmental applications.

AHP has wide-ranging applications, including recently in conjunction with GIS (Anselin and others 1989, Malczewski 1996, Banai 1993, 2000, Saaty and Vargas 2001, Schmoldt and others 2001; for a critical discussion of AHP, see Forman 1993). Multi-criteria methods including AHP have been used in land suitability analysis either as a loose combination or seam-

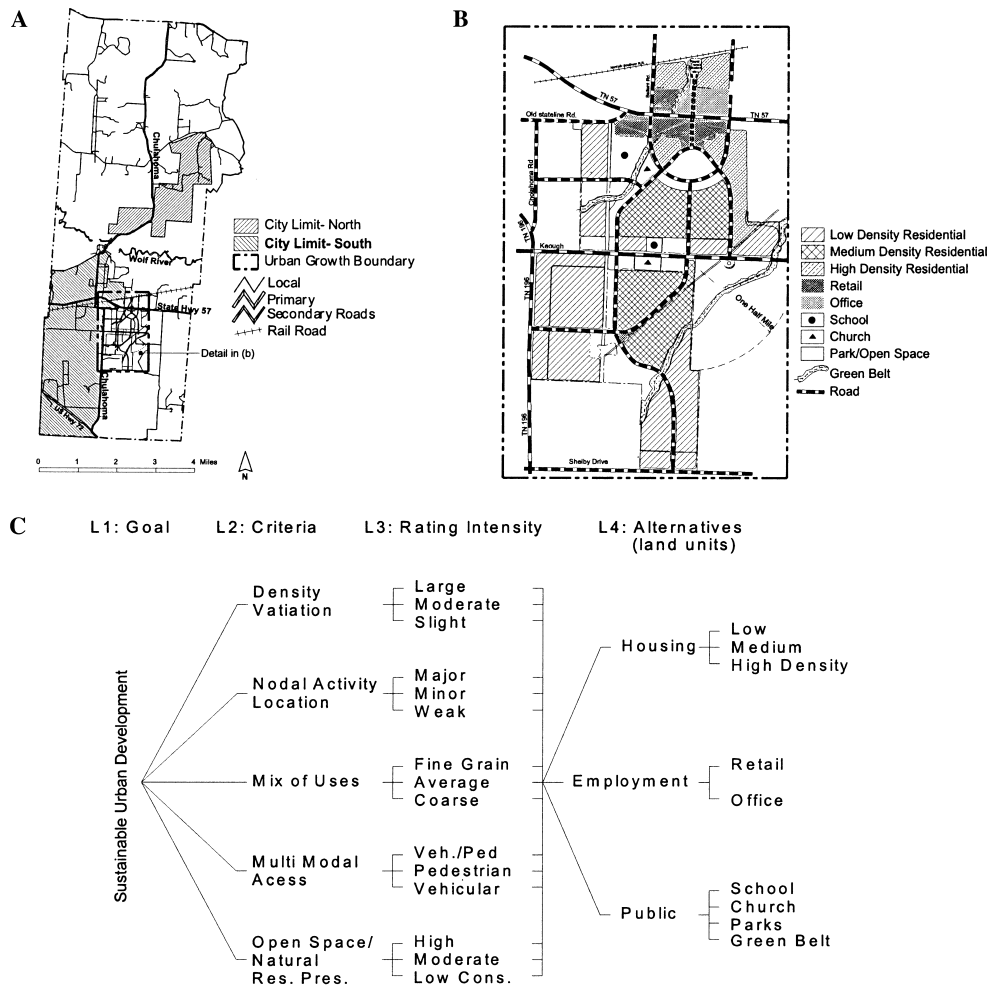
less integration with a GIS. The hierarchical structure provides an advantage of AHP when used to frame or define a multifaceted problem of environmental resource suitability, compared to evaluation methods that do not offer a structural (hierarchical) property. Environmental resource management is one plausible area of AHP application because concepts of sustainability are asserted multidimensionally, with variability in the political, economic, and spatial context (Schmoldt and others 2001; for a review of development of land-use suitability methods, see Collins and others 2001; see also Kaiser and others 1995). The variability requires attention to specificity of local context.

In the section that follows, the sustainability of a land development plan is assessed with AHP. Land development plans, subarea design plans, and the like are introduced piecemeal with the expectation of review, commonly on a case-by-case basis, and implementation in the interim and throughout the longer (20-year) time horizon of the comprehensive growth plans. The prototype spatial criteria draw upon the new urban and smart growth sustainability principles (see next section). The sustainability of land use in a development plan is assessed with the relative weights of the criteria determined by AHP.

Land Development Concept Plan Evaluation

Consider a recently proposed land development (concept) plan in the city (Figure 1b). This plan, with approximately 664 acres of land area, proposes housing with a variation in density. Office and retail land-use is located at nodal locations: primary roads intersections. The plan provides retail with varying intensity, while the property of a nodal location is maintained. Furthermore, land-use mix (see proportions in Figure 2) is respected, with office and retail as well as with civic uses, parks, and open space. The proximity of residential areas to various uses provides a flexibility of multi-modal access, pedestrian and vehicular. Is this plan a sustainable one?

The decision support system presented here assists decision-makers in determining a sustainable urban development pattern. This framework requires decision-makers' inputs in the selection and derivation of the priorities of the sustainability criteria, which reflect the context specific to a locality. The AHP method of paired comparisons of the criteria is particularly helpful in situations where the sustainability criteria are mixed tangibles and intangibles, and the relative importance of the criteria must be assessed strategically in response to unique local conditions: political, eco-



Steps in the rational method of the analytic hierarchy process (AHP):

- Frame decision problem hierarchy, from goal, criteria, to alternatives
- Paired comparisons of hierarchy elements, with consistency analysis
 - Ratings of alternatives
 - Composite scores of alternatives
 - Sensitivity analysis

Figure 1. (a) Urban growth boundary and city limits. (b) A land-use concept plan. (c) A multicriteria decision-making framework (AHP) for assessing sustainability.

conomic, environmental, and spatial. The priorities of the criteria thus derived are then weighted by means of various gradations of the criteria, called subcriteria: rating intensity scales developed to fine-tune the desirable thresholds used to assess local conditions in deference to the universal criteria. The scales are used to rate alternatives—land units—in a proposed development plan. A simple hierarchy to assess sustainability is shown in Figure 1c.

The prototype spatial criteria include the following factors: density variation, nodal activity location, land-

use mix, multimodal access, and open space/natural resource preservation. The relative weights of the criteria are first determined and then used in the assessment of the sustainability of land-use with rating scales. The definition of criteria, subcriteria, and rating scales used are as follows.

1. Density Variation: A measure of variation in the density of land uses, from housing to office, retail, and public space, distinguished by a rating scale (subcriteria) of high, moderate, and slight. Note

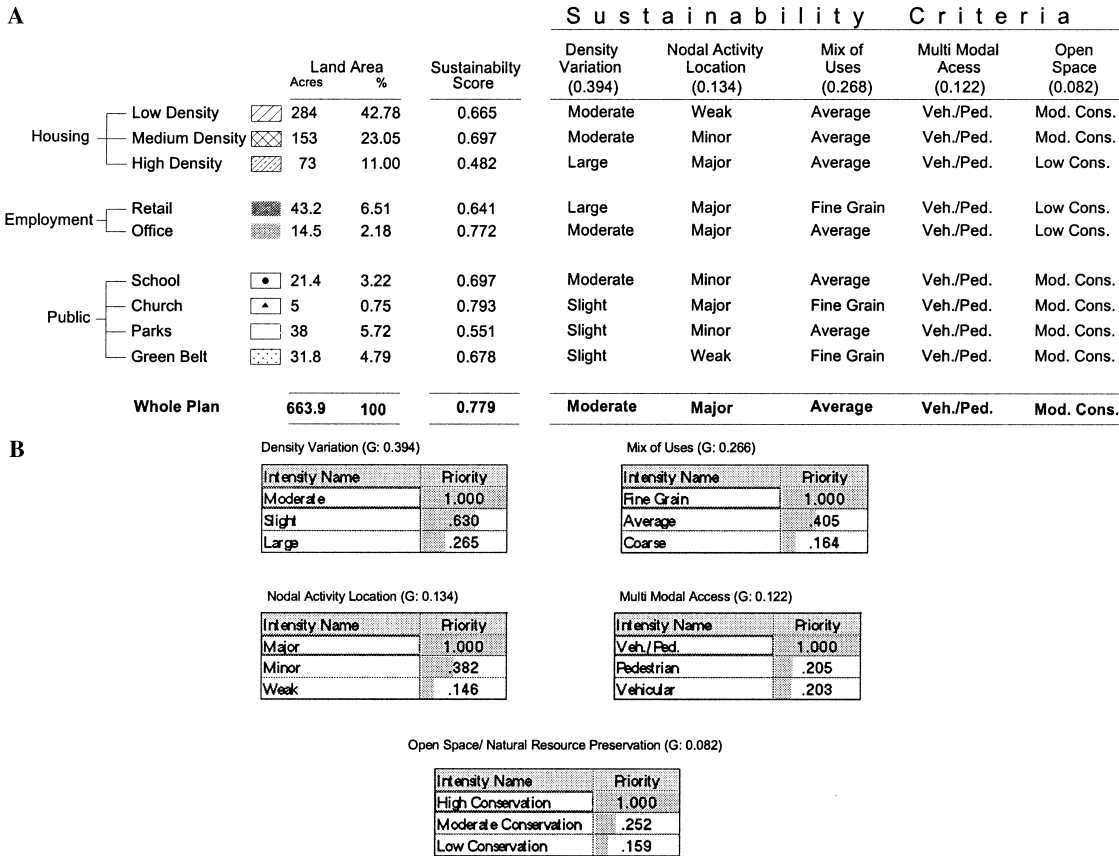


Figure 2. (a) Sustainability (total) scores of land-use in the concept plan derived from the ratings scales of the weighted criteria. (b) Rating intensity scales used in the assessment of concept plan as a sustainable urban growth pattern.

that various measure of density or intensity (dwelling unit/acre (housing), floor–area ratio (office and retail), or open space ratios (parks and open space) may be used to determine variation in land-use density.

2. Nodal Activity Location: Primary roads (atop the road hierarchy), and their intersections, provide a high “visibility” for office and retail locations, which are ringed by housing and other public land-uses in proximity. Three rating scales—major, minor, and weak—distinguish nodal locations in relation to primary (major), secondary (minor), and local (weak) roads.
3. Mix of Uses: Three rating scales from fine grain, average, to coarse, are used in deference to new urbanism and smart growth thresholds (above).
4. Multi-Modal Access: The subcriteria here are three types, from vehicular and pedestrian to pedestrian only, and vehicular only. Finally, three subcriteria assess open space/natural resource preservation. Just as the criteria are given weights that reflect the public policy priorities, exigencies, and conditions specific to a locality, the subcriteria rating intensity

scales are similarly determined in context. For example, land-use mix for a “fine-grain,” pedestrian-friendly TOD was noted above with a desirable proportion of the public, core-employment, and housing uses as a guideline. As Calthorpe (1993) remarked, a desirable threshold is seen not as a “universal model” but rather as a guideline to be adapted judiciously locally. Paired comparisons of the subcriteria determine their relative weights for assessing urban growth pattern with various rating scales (Figure 2b).

The indicators, determinants, or criteria for a sustainable development considered generally in the literature must now be assessed specifically to reflect public policy priorities, and preferences locally. Suppose decision-makers compare five criteria pairwise with respect to the long-term goal of a sustainable development. Decision-makers indicate the relative importance of these five criteria using a nine-point AHP scale: from equal (1) to extreme importance (9). To facilitate this task, the AHP-specific software (Expert Choice 2000) may be used as well, with a dialog box

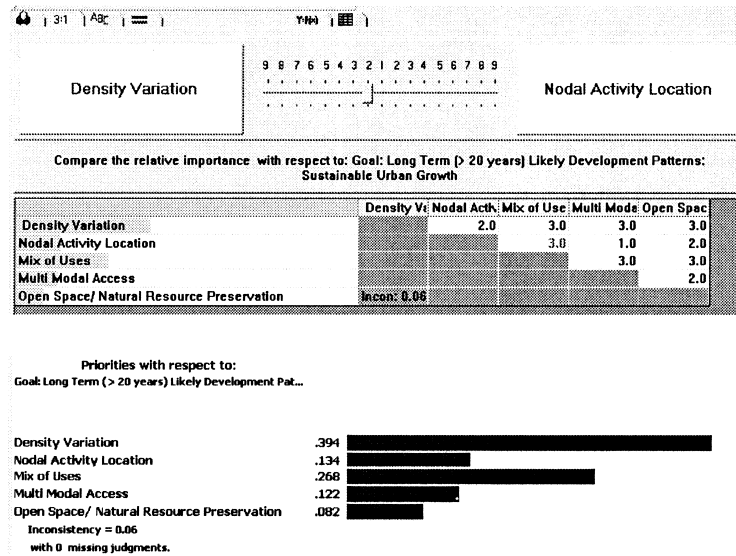


Figure 3. Deriving relative importance of the criteria through pairwise comparisons with Expert Choice dialog box in “numerical judgments” mode.

shown in Figure 3, with numerical mode of entering judgments.

In this example (Figure 3), the first row of the criteria matrix, density variation is given a near-moderate importance (2) in comparison to nodal activity location, and moderate importance (3) in comparison to mix of uses, multimodal access, and open space/natural resource preservation. All the diagonal elements are one, when comparing a factor with itself, and hence are not shown. Because the matrix is reciprocal, the entries below the diagonal ones are automatically determined. Density variation—from low, estate-residential, to high, traditional neighborhood design (TND)—is arguably a necessary land development feature in a small city, but not in itself a sufficient condition of urban sprawl prevention. Nodal activity location must also be a feature, if urban sustainability is a developmental goal. The nearly equal importance of density variation is thus justified in comparison with nodal activity location. The usefulness of a multicriteria logic of AHP with paired comparisons of urban development sustainability criteria is suggested. The remaining comparisons follow a similar logic of multicriteria evaluation of urban sustainability.

A consistency ratio of less than 10% (also shown in the dialog box) indicates judgments made with good consistency. Otherwise, the inconsistent results (greater than 10%) suggest revising judgments upon further consideration and discussion to maintain the AHP suggested threshold of consistency.

The relative weights of the criteria—eigenvector solution of the reciprocal matrix of paired comparison with unit rank—are displayed in the dialog box (Figure 3). In a descending order of importance, the criteria are density variation (0.394), mix of uses (0.268), nodal activity location (0.134), multi-modal access (0.122), and (open space/natural resource preservation (0.082). Next the relative weights of the subcriteria are determined (Figure 1c). The subcriteria provide a further refinement of the criteria by means of various scales of rating intensity. The subcriteria weights are determined with the same paired comparison procedure as in determination of the criteria weights. The rating scales of the sustainability subcriteria are shown in Figure 2, with dialog boxes corresponding to the criteria. Finally, the rating scales are used to assess the sustainability score of the alternatives: land-use units of the concept plan. The AHP software provides a “data grid” in which the various land units of the plan are assessed in deference to the criteria (Figure 2a). The sustainability scores of the concept plan as a whole as well as its various land units are shown.

This data grid uses the “ideal” mode of synthesis, which is a weighted, linear summation of the elements in the hierarchy (Figure 1c), from criteria to subcriteria to alternatives (land units). The ideal mode is used here because the sustainability criteria provide a “benchmark” against which a concept plan (with its component land units) is assessed (Saaty 1996). The distributive mode is used next in the estimation of the likelihood of sustainable development, whole city pat-

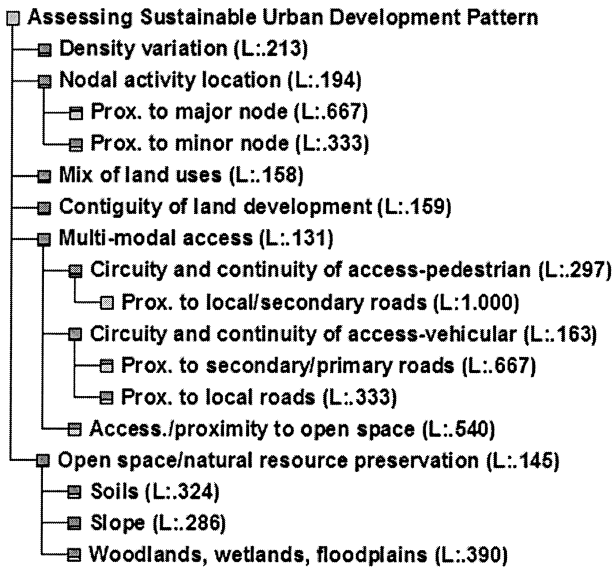


Figure 4. “TreeView” of a model for sustainable development whole-city pattern.

tern. This mode is also used with an example of assessing land-use “alternatives” in relation to a nodal location (see Appendix). The sustainability scores of various land units—housing, employment, and public—are given in detail. It turns out that the concept plan has a high overall sustainability score (0.779). Its (housing) density variation is moderate. It provides a major nodal activity location at the commercial core surrounded by residential uses with parks in intervals. The plan contains average mix of uses, accommodates both vehicular and pedestrian circulation with multi-modal access, and provides moderate conservation of open space/natural resources. Other criteria, for example, jobs/housing balance, or modal split, open space ratio, and the like may be added upon consideration of their relative importance locally.

This article now focuses on the question of whether the future development pattern within the urban growth boundary as a whole likely resembles the land development pattern of the proposed concept plan (above) or urban sprawl. Informed by the long-term (2020) land-use plan of the city, in the following section this question is addressed with a prototype spatial decision support system using AHP and a GIS.

Estimation of Likely Sustainable Development

Given the high sustainability score of the land development concept plan, is it likely for the whole city to be developed like this small area plan? The paper now uses a variation of the criteria for the assessment of the concept plan discussed above to assess land sustain-

ability for the whole city, an area defined by a 2020 growth limit shown in Figure 1a.

A model for sustainable urban development is first defined and depicted with a TreeView (Expert Choice) in which the relative weights of the criteria and sub-criteria are determined (Figure 4). The “local” weights of the criteria are indicated by L and shown parenthetically. This model is used to fine-tune the weights of the criteria in accordance with long-term development goals. Suppose, in deference to a public policy to preserve a “small-town ambience” in the city, decision-makers reduce the weight of density variation (0.213) in favor of open space/natural resource preservation (0.145). Furthermore, given a public policy of predominantly low-density residential development in the city, suppose vehicular access receives a higher priority than pedestrian access, even in the long run. The proponents of sustainability categorically may argue against this uneven pedestrian–vehicular priority of access. The 66.7/33.3 mode-split, however, may be regarded as “balanced” enough (!) upon consideration of context specific to the small city, namely, automobile dependency. The priorities of the criteria are shown in a model of whole-city pattern (Figure 4). Furthermore, an additional criterion, contiguity of land development, is distinguished from the mix of land-uses and included in the model as a measure of sprawl. Multi-modal access has a sub-criterion: circuitry and continuity of both vehicular and pedestrian access, with the intention of measuring how well the land-use/transportation network caters to the pedestrian and vehicular movement. The open space/natural resource preservation criterion includes soil types, slope ranges, woodlands, wetlands, and floodplains, which are considered as limitations as well as potentials in urban development suitability.

As a precursor to an assessment of the likelihood of a sustainable development pattern, the criteria and sub-criteria are mapped thematically in a GIS. Various themes are created in (ArcView 3.2) GIS, with the weights of the sustainability criteria or sub-criteria determined by AHP—contained in the Attribute Field of themes. The themes are developed with various buffers from one quarter, one half, to one mile mapping of the criteria and sub-criteria for land units or classes (residential, commercial, industrial, conservation, and undeveloped land). The thematic maps aid decision-makers’ assessment of likely potential urban development sustainability interactively. Although the quarter-mile distance is a desirable—pedestrian-friendly feature of urban form—indicator of sustainability, the mapping of proximity also includes distances beyond the quarter mile so that the development pattern within one-half to

Distributive mode	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	RATINGS	
	Density variation (L.:213)	Nodal activity location Prox. to major node (L.:667)	Nodal activity location Prox. to minor node (L.:333)	Mix of land uses (L.:158)	Contiguity of land development (L.:159)	Multi-modal access Circuity and continuity of acc Prox. to local/second roads (L.:1.000)	Multi-modal access Circuity and continuity of acc Prox. to secondary/primary roads (L.:667)	Multi-modal access Circuity and continuity of acc Prox. to local roads (L.:333)	Multi-modal access Proximity to open space (L.:174)	Open space/natural resource p Soils (L.:324)	Open space/natural resource p Slope (L.:286)	Open space/ natural resource p Woodlands, wetlands, floodplains (L.:390)	
Alternative	Total												
Residential-estate	.185	Moderate	Far	Far	Fine Grain	Adjacent	Near	Proximate	Near	Far	High	High: 0 - 8%	Low
Residential-cons.	.118	Low	Far	Far	Average	Adjacent	Near	Proximate	Near	Proximate	High	High: 0 - 8%	Low
TND	.149	Moderate	Far	Proximate	Average	Adjacent	Near	Proximate	Near	Proximate	High	High: 0 - 8%	Low
Commercial	.124		Near	Near	Average	Disjointed	Near	Near	Proximate	Proximate	High	High: 0 - 8%	Low
Employment ctr.	.090		Proximate	Proximate	Average	Adjacent	Proximate	Near	Proximate	Far	High	High: 0 - 8%	Low
Industrial	.071		Proximate	Far	Average	Disjointed	Proximate	Near	Proximate	Far	High	High: 0 - 8%	Low
Conservation	.084		Far	Far	Coarse	Adjacent	Far	Far	Far	Near	Low: Falaya	High: 0 - 8%	High
Undeveloped	.063		Far	Far	Coarse	Adjacent	Proximate	Far	Proximate	Proximate	Low: Falaya	High: 0 - 8%	Low
Whole City	.114	Moderate	Far	Far	Average	Adjacent	Near	Proximate	Proximate	Proximate	High	High: 0 - 8%	Low

Figure 5. Expert Choice dialogue box (“data grid”) showing sustainability (total) scores of land-use sectors.

1-mile limits is assessed also. The definition of density variation includes a 1-mile threshold and beyond. Open space/natural resource preservation is defined by soil types (Grenada, Falaya), slopes (0–5%, 5–10%, and >10%), and woodlands, wetlands, and floodplains.

Distance between residential parcels determines the variation in density of residential uses in proximity. All proximity is defined by a distance from a one-quarter to 1-mile distance. A major node is an intersection of primary and secondary roads with commercial or mixed land use from one quarter to 1-mile radius of the intersection. This definition includes nodal location of “strip” commercial and mixed use along primary or secondary roads. A minor node is defined by the commercial or mixed land use in a nodal location along or at the intersection of secondary or local roads. Finally, mix of uses in proximity is determined by proportions of various types of land use in proximity.

The potential sites (land units), with the spatial criteria-based desirable features displayed thematically, are now assessed by using the ratings scales interactively in a data grid, with the distributive mode of AHP (Figure 5). This data grid corresponds to a sustainable model of urban development (Figure 4). The buffered search for a development pattern generates separate themes (maps) for each individual criterion, from density variation, land-use mix, to open space/natural resource preservation, in which the likely sustainability ratings by land-use type are shown. The final composite map is shown in Figure 6.

Emerging GIS applications developed for land/site suitability problems increasingly incorporate software-specific language, e.g., script or simple macro language in ArcView or ArcInfo GIS systems, ESRI Inc. or extra-programming (e.g., C++, or Visual Basic), which allows for the weighting of the criteria factors thematically seamlessly (e.g., see Banai 2000, and Schock 2000 for a

review). Examples of GIS in which multi-criteria evaluation methods embedding parts of AHP include IDRISI (Eastman and others 1995, Siddiqui et al 1996, Eastman 1997), IDRISI Killimanjaro (2003), Arc/Info (Wu 1998), and ArcView (Jankowski and others 1997, Banai 2000). The seamlessly integrated spatial decision support systems noted above incorporate the paired comparison method of evaluating multiple criteria, or rating of alternatives with weighted linear combination methods of AHP.

However, there is an advantage in using a “stand alone” decision support system software (e.g. Expert Choice) that has some facility in modeling complex, multi-faceted decision making and evaluation problems, like the urban development sustainability problem in this paper. Characteristically “ill-defined” or unstructured problems pose the challenge of a definition or structure prior to evaluation of the component parts (see also Rittel and Webber 1973). As noted earlier, the parts are mixed tangibles and intangibles and thus require some facility in the decision support system software of the type of scale used in measurement of the diverse, interrelated parts. Furthermore, problems of this kind are better solved heuristically and inductively, rather than algorithmically and deductively (compare Simon 1981).

Expert Choice is a widely used decision support system software co-developed by the originator of AHP (Saaty 1996, Forman and others 2000). Furthermore, it interacts with a GIS with a common spreadsheet data transfer platform (e.g., Microsoft Excel). The “loose” coupling of a decision support system (Expert Choice) with a popular (ArcView) GIS offers the advantage of the full functionality of decision support system, particularly in the most creative or challenging part of the MCE: problem framing or structuring. The software supports individual as well as group multicriteria eva-

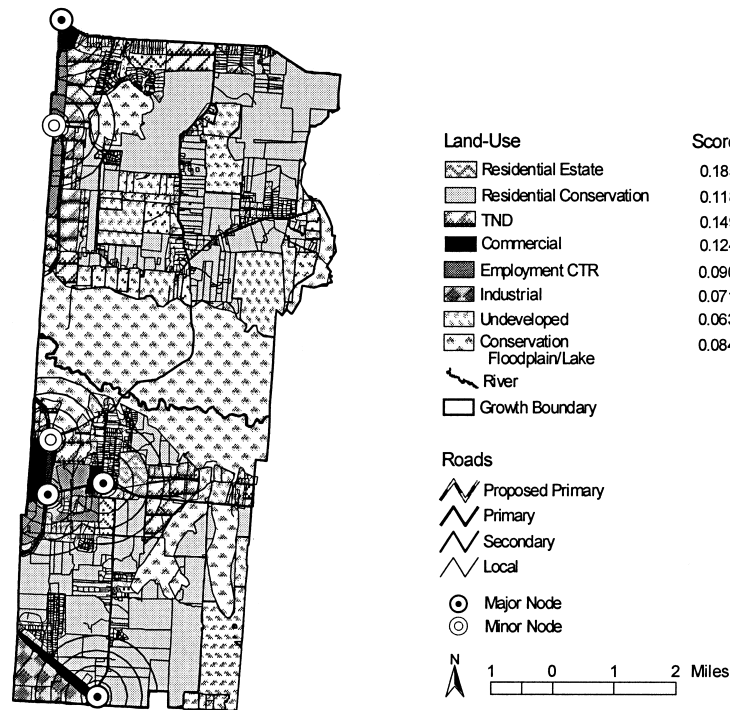


Figure 6. Land-use sustainability scores for whole-city pattern.

luation, with consistency and sensitivity analysis among the versatile features. However, there is some computational inefficiency of transfer of spatial and attribute data between systems, which is a disadvantage. For a detailed discussion of relative merits of different coupling strategies, see Malczewski (1999, chapter 9).

Expert Choice is used in combination with (ArcView 3.2) GIS to produce thematic mapping of the multiple criteria. Weighted (buffered) themes are overlaid to identify the universe (composite pattern) of land units as “alternatives.” The rating scores of alternatives are derived from a “data grid” in Expert Choice (Figure 5), with which a map is developed with ArcView GIS and displayed with the sustainability rating scores of land or parcel units (Figure 6).

It turns out that residential estate is the use with the most likely sustainability score (0.185). Interestingly, traditional neighborhood design, TND (0.149), and commercial land-use (0.124) have a greater score than residential conservation (0.118), owing to their nodal activity location advantage, and notwithstanding the land-conserving, design feature of residential conservation. Land allocated for employment center (0.090), conservation (0.084), and industrial (0.071) uses are the second best to the scores of residential land-use. Finally, and as expected, the undeveloped land has the least likely sustainability total score (0.063), confirming the city plan’s designation of undeveloped land.

The approach of this paper is similar to those that use a GIS and a rating scale to evaluate urban development pattern. For example, Talen (2002) uses a simple, categorical scale of “contributing” or “non-contributing” (to a desirable form) to evaluate existing urban development pattern. The suitability map is Boolean and therefore does not reveal the degrees of suitability. The sustainability map produced here is a product of a GIS-based decision support system that surmounts the rating scale limitation inherent to a Boolean logic, with indication of the degrees of sustainability and with a versatile ratio scale (0–100%). Also, the hierarchical structure facilitates logical grouping of factors and permits investigation of the changing relative importance of evaluation criteria and subcriteria and their impact on outcome with consideration of alternative scenarios. Furthermore, a decision support system (AHP) is used that offers the flexibility of application to the evaluation of a potential urban development pattern, when degrees of likelihood is all that can be opted for in the absence of precedent.

The “smart growth index” (SGI) is a “sketch” planning tool that uses a GIS and a number of environmental indicators of smart growth to assess alternative land-use and transportation scenarios (US Environmental Protection Agency 2003). This modeling and planning tool is applied in 20 pilot commu-

nities to aid their strategic planning by assessing future development alternatives.

SIG uses a large number of indicators (with various units), from land use (density, proximity, housing-jobs balance, and the like) to transportation (for example, mode-split, trip time, cost) and environmental (for example, vehicle pollutant emissions). A fundamental challenge as noted above, however, remains how to measure tangibles (land resources, alternative transportation modes, or environmental externalities) when mixed with intangibles (balance, proximity, livability, and so on). Like SIG, the prototype spatial decision support system in this article is intended to facilitate community decision making by evaluating urban spatial structure proactively. However, our prototype aids decision-makers in determining the relative importance (or unequal weights) of the criteria (or indicators in SIG) strategically, as well as in proactively responding to community-specific conditions, instead of assuming the equal importance of the indicators (in SIG) independently from the context in which they are applied.

Furthermore, our prototype is systems oriented, which helps decision-makers determine the organization of relationship—the logic of the links—among the variables (for example, land-use, transportation, and environment) in context creatively. AHP has a hierarchical organization, which is used to frame the relationship between the criteria and the alternatives (outcomes). AHP is particularly helpful when system variables include a mix of tangibles and intangibles, requiring measurements quantitatively and qualitatively. Alternative scenarios as outcomes may be assessed by varying importance of the criteria through sensitivity analysis. Finally, the software for AHP provides group decision-making, voting, and (Web-based) networking utilities (Expert Choice 2000). For examples of environmental applications of AHP, see Schmoltdt and others (2001).

Compared to seamlessly integrated (e.g., IDRISI, IDRISI Killimanjaro, ArcInfo) GIS software with embedded decision support including some MCE procedures of AHP noted above, the “loose” coupling of (ArcView) GIS and decision support (Expert Choice) has a disadvantage in the inefficiency of spatial and attribute data exchange between systems. The computational inefficiency, however, should be compared to the efficiency gained by using a decision support system that is particularly tailored to frame, as well as to solve, with MCE, “ill-defined,” complex, multifaceted problems such as urban development sustainability. The popularity of the two systems (GIS and AHP) may be regarded as another factor in their likely adoption in combination.

AHP has an intrinsic advantage of interface with a GIS with a ratio scale that aids in the analysis of the interrelation of criteria, criterion (map) weighting, graphical (or geographic) composite mapping, compared to MCE methods with interval, ordinal, or nominal scales with limited interface. However, Malczewski (1999, p. 186) raises a criticism of the procedure to determine the relative importance of evaluation criteria with the AHP scale independently of the underpinning scales of the criteria. The scaling method in paired comparisons of the criteria in AHP is regarded as a potential source of ambiguity and the possibility of error in decision-making. However, as noted above, the criteria that include intangibles have no scales with units. Paired comparisons are the only meaningful way to determine the relative importance of the criteria. Even when the criteria are tangibles that do have scales with units, the attribute data would still have to go “through a person” for the scale to be meaningful. Furthermore, the AHP procedure offers a gauge on consistency of judgment when violated in multi-criteria evaluation in the face of limited information, data imperfection, factor diversity, and uncertainty.

Conclusion

Urban development sustainability is characterized as a planning and decision-making problem under multiplicity and uncertainty. A two-pronged approach to the problem is developed. First, a decision support system—AHP—is illustrated prototypically to show how incrementally proposed land development plans can be assessed in the face of long-term community priority of a sustainable growth. Multiple sustainability principles, such as those asserted recently with new urban and smart growth models of urban development pattern, are incorporated in an AHP model of urban form. Secondly, AHP is used in combination with a GIS to gauge the problem of long-term sustainability of urban form. Evaluation of desirable urban form features is facilitated with spatial queries that are refined, with AHP-weighted, multiple sustainability criteria thematically in a GIS. Land-use mix with varied density, center(s) accessible by pedestrian and vehicular traffic, open space, and natural resource conservation in balance with development are among the features of better or smarter urban form. The spatial pattern queries, for example, residential buffers (areas) that surround the commercial buffers (centers) in close proximity, indicate whether or not a desirable property of a sustainable urban form—proximity—is likely and if so in what degree. Combined with assessments of

density, land-use mix, accessibility, and the site natural resources, the likely sustainability of urban land-use pattern is determined. Thus, the prototype spatial decision support system aids in proactive public policy determination of land resource sustainability of urban development.

Compared with other multicriteria evaluation methods used similarly with a GIS, the choice of AHP hinges upon its effectiveness (a) in estimation of the likelihood of unique events, as in unprecedented urban growth; (b) in decision making in the face of multiplicity and uncertainty; (c) in evaluation of mixed tangible and intangible criteria, as in multiple principles or indicators of urban sustainability; and (d) in measurement of relative importance of criteria in response to site- or location-specific conditions.

Effective application of the knowledge of the multiple sustainability criteria and their relative importance as public policy priorities streamlines, gauges, and directs the course of a desirable future development. Once determined, though subjected to periodic modification with feedback from the public, the public policy priorities guide decision-making comprehensively. The relative importance of the sustainability criteria thus reflects community-specific situations and values.

Knowledgeable agents, reflective of community-specific situations and values, determine the relative importance of the sustainability criteria locally. The definition of change “agents” is not limited narrowly to expert planners, politicians, or bureaucrats, however. Community-wide stakeholder or group participation is a decision-making procedural feature considered as desirable in models of smart growth, or new urbanism—design “charrette” or group workshop—noted in the discussions of urban sustainability. AHP facilitates group decision-making, with a robust method—geometric mean—for aggregating (ratio-scale) judgments of individuals to determine group choice (see also Aczel and Saaty 1983; for a discussion of individual and collective choice in AHP in relation to public choice theories, see Saaty 1996). As noted above, AHP software Expert Choice (2000) supports group decision applications.

The importance or priority participants give to multiple sustainability criteria motivates a negotiation process toward a consensus as well as identifies the source(s) of conflict. Unlike public choice theories that equate rational choice with transitivity of individual preferences—as in Arrow’s theorem—AHP allows for inconsistency (or intransitivity) of judgments in weighing multiple criteria, as means for learning and reflection with additional information (bounded-

rationality). AHP predication of outcomes that violate the principle of Pareto optimality, with disproportionate distributive impacts on different participants, can inform public discussions toward a collectively desirable outcome.

Finally, the prototype procedure offers a unified framework in which the embedded indicators of urban sustainability and development control—with local and state policy measures—become multicriteria factors with varying importance in varying contexts. The systems-oriented AHP method preserves the integrity of the concepts of sustainability, which are generally asserted multidimensionally. The inclusive framework of a hierarchy can be used to incorporate the macro- as well as microspatial indicators of sustainability, which is the focus in this article. Used inductively, the AHP method has implication with significance beyond the particular or the local to the general or the universal. Thus, our procedure offers the potential streamlining of decision-making, policy-making, and priority setting regarding urban development sustainability by facilitating comparisons across localities in a unified framework. The comparisons show how the indicators of urban sustainability become important in different contexts, and the multicriteria AHP method provides a means of assessing policy outcome in guiding future sustainable urban development.

Appendix: Estimation of Likely Development for a Nodal Location

In this appendix, a small area example with a somewhat different set of the criteria factors is presented. The AHP example predicts likely future land-use sustainability by using a number of assumptions: Intersection of major roads as the likely location of commercial and economic activity; residential and open space development are likely with increasing distance from the nodal location. The resulting map provides sustainability scores of land-use that are refined by three rings with various distances from a likely nodal location (Figure A.1). The scores (in distributive AHP mode) are interpreted in a similar way to those of the whole city given above.

A further inspection of the AHP predictions of likely future land-use is interesting for the purposes of comparison (compatibility/incompatibility) with the long-term (2020) land-use plan of the city. The plan includes the following land classification: estate residential, employment centers, conservation design, commercial, traditional neighborhood design, and industrial. It turns out that the focus area (buffered map above) has a high percentage of commercial and industrial parcels

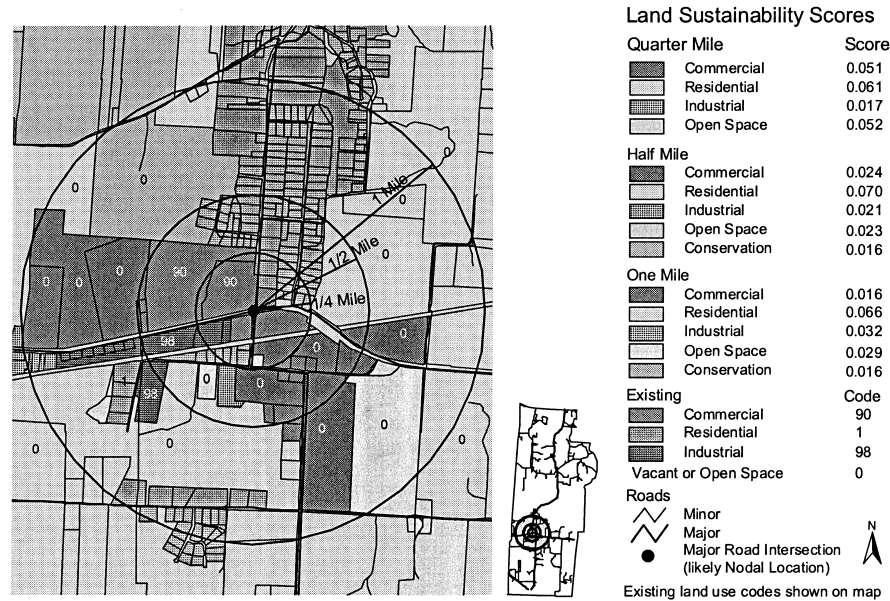


Figure A.1. Ratings scores of likely land use by distance from a nodal location; numbers on map are existing land use codes used in estimation of likely development (source: Assessor's GIS data).

just as in the long-term city plan (2020). The buffered map shows a lot of residential use which is classified as (residential) “conservation design” in the city plan. However, the buffered map shows more development than is called for in the land-use plan.

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