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ACCESSIBILITY MEASUREMENT AND USE IN LAND-USE PLANNING

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ABSTRACT

The use-capacity of any piece of land depends on its accessibility as well as its inherent physical characteristics. The measurement and use of accessibility has not been well documented. The Minnesota Land Management Information System (MLMIS) uses both accessibility and capability in estimating the suitability of lands across the state for a variety of uses. Three scales of accessibility are presented: accessibility to the road network, accessibility to local service and market centers, and accessibility to regional activities. This paper will discuss the measurement of accessibility at the various scales and the use of these measurements in determining land-use suitabilities.

Capability and accessibility are the two restricting factors limiting the use-capacity of a piece of land. Capability has to do with the physical resources available to the piece of land. Accessibility has to do with both the immediate approachability of the piece of land and the distance of that land to service and processing centers. Classically, these factors are called "site" and "situation." Clearly culture enters as an additional factor in how a particular piece of land will be used, but the highest-and-best use of the land is limited by its capability and its accessibility. The purpose of this paper is to explore the measurement and use of accessibility in land-use planning.

While most planners, economists and geographers admit that accessibility is an important factor, the measurement and use of

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accessibility in land-use planning has been poorly documented. Foresters know that getting timber to the mill is a major cost and, finally, an economic determinant of whether a stand will be harvested or not. Yet, forest management continues to concern itself strictly with tree growth rates. Schoolboys in New York City know that the Great Plains are drought prone and beyond the more stable agriculture production areas of the Midwest. Yet the Federal government spends millions of dollars to develop and protect farmlands on the Plains while ignoring the rich Midwestern lands where periodic weather inconsistencies also cause problems and where Federal investments would yield a better return.

The importance of accessibility in affecting land use stems from both economic and non-economic considerations. The main economic consideration is transportation cost [1]. The modes and distances of transport affect the economic viability of using land in a particular way. Any rational land-owner will use his land in such a way as to maximize his return (his rent). The rent will be equivalent to the value of the product less transportation costs and other production and marketing costs. Transportation costs include the costs of bringing production resources to the site and of getting the product to market. The closer a piece of land is to the production resources or market for a particular product, the more likely it is that the land-owner will find he can optimize his return by converting the land use to render that product. Where distances force transportation costs up high enough to reduce rent to zero, the spatial outer limits of production have been reached. For each product this distance (range) will vary.

Accessibility is also important in affecting the non-economic considerations affecting land use. The main non-economic accessibility consideration is related to communication and information flows. The closer one is to a given place or activity, the more likely he is to know about it and get caught up in it. In addition the size of the place or activity affects how much one knows about it and is likely to be caught up in it. If your neighbors are all growing corn, it is hard to use your land as a commercial forest because you are unlikely to know anything about growing trees. No one would be talking about trees. No experts would be locally available. You probably would grow corn. The disincentives to commercial forestry would include lack of both technical knowledge and social support.

With the importance of accessibility in determining land use, it is amazing that its measurement and use in land-related information systems is not more widely documented in the literature. The reports most advanced in this regard deal with simple distance functions like distance to the road network or distance to a particular facility. Clearly much more can be done.

The land information system used throughout this paper to demonstrate the measurement and use of accessibility in land-use planning is the Minnesota Land Management Information System (MLMIS).[1] This system collects, analyzes and displays data in a grid system based on the quarter-quarter section of the Public Land Survey. The methodologies described could be applied to any grid system with minimal effort. The conceptual framework could be transferred to any type of land-related information system.

MEASURING ACCESSIBILITY

Accessibility can be measured at a variety of scales. This paper will deal with three scales: accessibility to the road network, accessibility to local services and market centers, and accessibility to regional activities. One section will deal with the quantification of each of these accessibility indicators. It will explain the philosophy, the rationale, and the model for each indicator. It will give specific examples of how these measurements have been made by MLMIS. Another section will deal with the use of these measurements in determining the suitability of lands for specified uses.

The simplest accessibility measure is *highway accessibility*: distance to the road network. Land on roads has an economic advantage over land in the remote wilderness. Furthermore, the higher the quality of the road, the greater the economic advantages[2] since transportation costs can be reduced by larger trucks making faster hauls. Each land use has different highway accessibility needs so that distance-to-a-road would not be a useful measurement for general land-use planning. A better system would capture objective data on highway placement noting road type by surface, ownership and number of lanes. Additional measures such as tonnage, access restrictions and speed limits would be useful. Distance to a road of specified quality could then be computed by the information system for a particular land use. When studying a land use with different highway accessibility needs, it is not

[1] Research and development of MLMIS was done at the University of Minnesota. See Hicks and Hauger for details [2]. In July 1977, MLMIS became an operating service bureau of the Minnesota State Planning Agency.

[2] Points remote from intersections but adjacent to restricted access highways are an exception.

Table 1. Highway Classification

Code	*Highway type*
1	four lane controlled access or interstate
2	four lane other
3	two lane state and federal
4	two lane county paved
5	unpaved
6	residential street

necessary to code new data. The software would simply operate differently on the same data base. Distance to a highway is the recommended indicator of highway accessibility, but the measurement should be done by the computer for a distance specified at execution time. This distance would be keyed to the land-use issue being studied.

MLMIS measures highway accessibility in the following way. Highways are classified into the six categories shown in Table 1.[3] The coding and measurement of highway accessibility is illustrated in the four diagrams comprising Figure 1. The highway network is shown in Figure 1A. County highway maps are used as source documents. Here, for the sake of simplicity, all roads will be in the same class. Next a grid is laid over the map as in Figure 1B. The grid is township size with each cell one-quarter mile on a side. Township and section lines are used to orient the grid. Data codes are then transferred to a coding sheet for each cell which touches a road. These cells are shown in Figure 1C. This data is keypunched and fed into the computer to a data item termed "highway orientation."[4] Computer software is used to measure distance to road for any specified situation. In Figure 1D a search was made for those cells which lay within two cells of a highway oriented cell. Euclidean geometry is used to determine diagonal distances. By the nature of the grid data system, parcels two cells from a highway oriented cell may be from two to three cells from the highway itself, in a range of one-half to three-quarters of a mile.

The second accessibility measure—*market accessibility:* accessibility to local services and market centers—is easy to explain and understand in concept, but somewhat more complex in detail.[5]

[3] Additional codes exist for the intersections of these six road types.

[4] Notice that patterns depend on the relationship between the grid and the highway network.

[5] Much of the defining of this measurement and its rationale were done by Kirk V. Dahl of the MLMIS project staff.

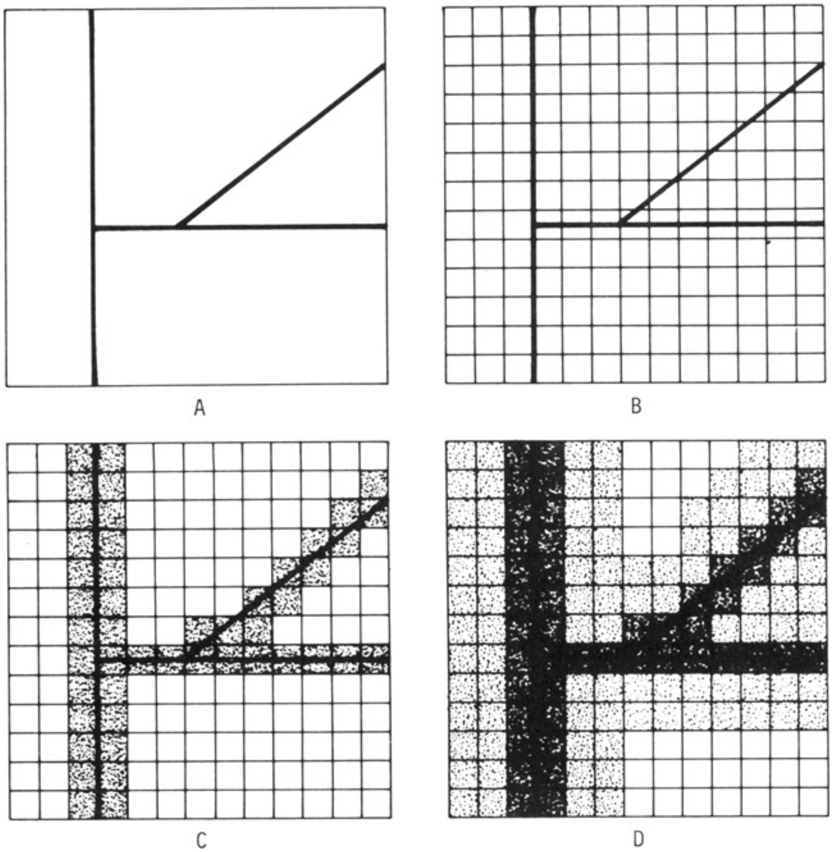

Figure 1. Coding highway orientation and measuring highway accessibility.

Service and market centers influence land-use decisions in two ways: as suppliers of goods and services to the land and as consumers of the products from the land. The influence of any center on a piece of land depends on both the distance between the center and the land, and on the size of the center. Accessibility to services and markets is best measured by a system which takes these two factors into account. Centers can be categorized by objective criteria. Then for each category of center, concentric rings can be drawn around the centers indicating a decline in interaction of increasing distance. These rings should reach to the useful outer range of transportation for the level of services offered by the center.

MLMIS measures accessibility to local services and market centers in two steps; categorizing cities, then measuring concentric

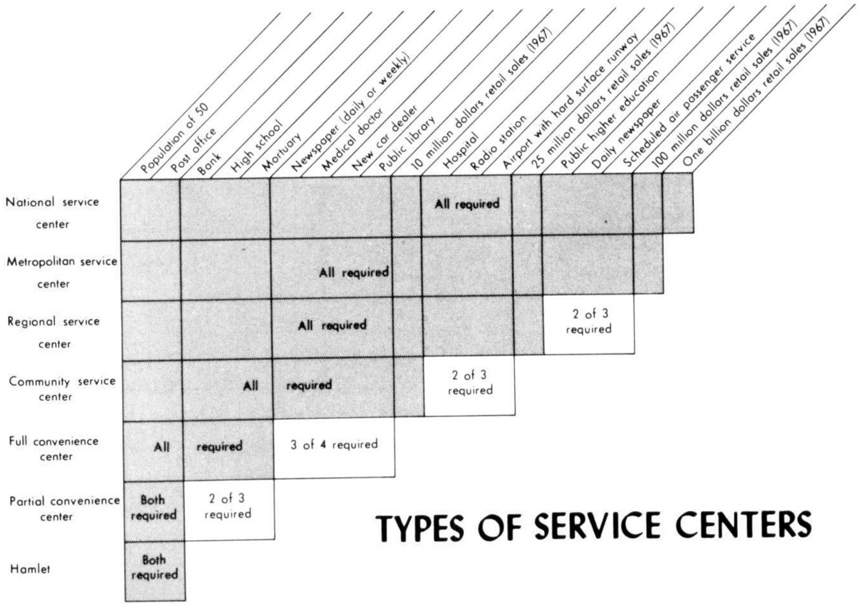

Figure 2. Criteria for categorizing cities.

rings. A classification system for centers had been designed by the Upper Midwest Council and is presented in Figure 2 [3]. The Council categorized each city and village within the ninth Federal Reserve District. MLMIS uses the six highest class centers only, excluding hamlets. As would be expected, city populations vary directly with center classification. Table 2 indicates that relationship.[6] These population thresholds were used to categorize Iowa cities since this had not been done by the Upper Midwest Council.

Table 2. Minimum Population Thresholds for Each Class

Service center class	*Minimum population threshold*
National Service Center	250,000
Metropolitan Service Center	50,000
Regional Service Center	10,000
Community Service Center	4,000
Full Convenience Center	1,000
Partial Convenience Center	300

[6] The National Service Center threshold is somewhat arbitrary; only the Twin Cities, with a 1970 urbanized area population of 1.7 million, falls into this class in the ninth Federal Reserve District. Other study areas, with more large cities, may wish to refine the higher service center classes.

Table 3. Code Scheme for Each Class of Service Center

	Shortest mileage to service center of this class					
Service Center Class	*0-5*	*5-10*	*10-15*	*15-20*	*20-25*	*25-30*
National Center	A	B	C	D	E	F
Metropolitan Center	A	B	C	D	E	
Regional Center	A	B	C	D		
Community Service Center	A	B	C			
Full Convenience Center	A	B				
Partial Convenience Center	A					

The second step in measuring accessibility to local services and market centers is the drawing of concentric circles and the quantification of the accessibility measure. Six measures are taken; one for each of the service center classes. The higher the order of the service center, the greater the number of rings drawn. The rationale is that bigger places with more unique services can attract people from greater distances. The coding scheme for each class of service center is given in Table 3. Since the codes are evenly stepped with distance, the accessibility measures are collected at a grosser scale. Where any part of a township falls within the concentric ring, the entire township is coded as being within the ring. Being within the range of two centers of the same order is both possible and important to recognize. A point within ten miles of two regional centers will experience more pressure for development than a point at the same distance from a single regional center. Additional codes have been devised to account for these possibilities. Figure 3 indicates the code scheme in operation for the twenty-four townships comprising Kandiyohi County. Figure 3A shows the service center classifications of cities in and around the county and their locations with respect to the townships. Figure 3B indicates the drawing of the two concentric circles for Full Convenience Centers and the codes assigned to the townships lying within those rings.[7]

Of the three accessibility measures the most difficult to understand is *regional accessibility*: accessibility to regional activities. The principle concept behind this measure is the determination of how distant a particular piece of land is from the center of action for a particular activity. Since all activities are dispersed the accessibility to the activities must be approximated by taking into account each

[7] In practice, higher order centers, since they provide Full Convenience services, would also be ringed by the two concentric circles.

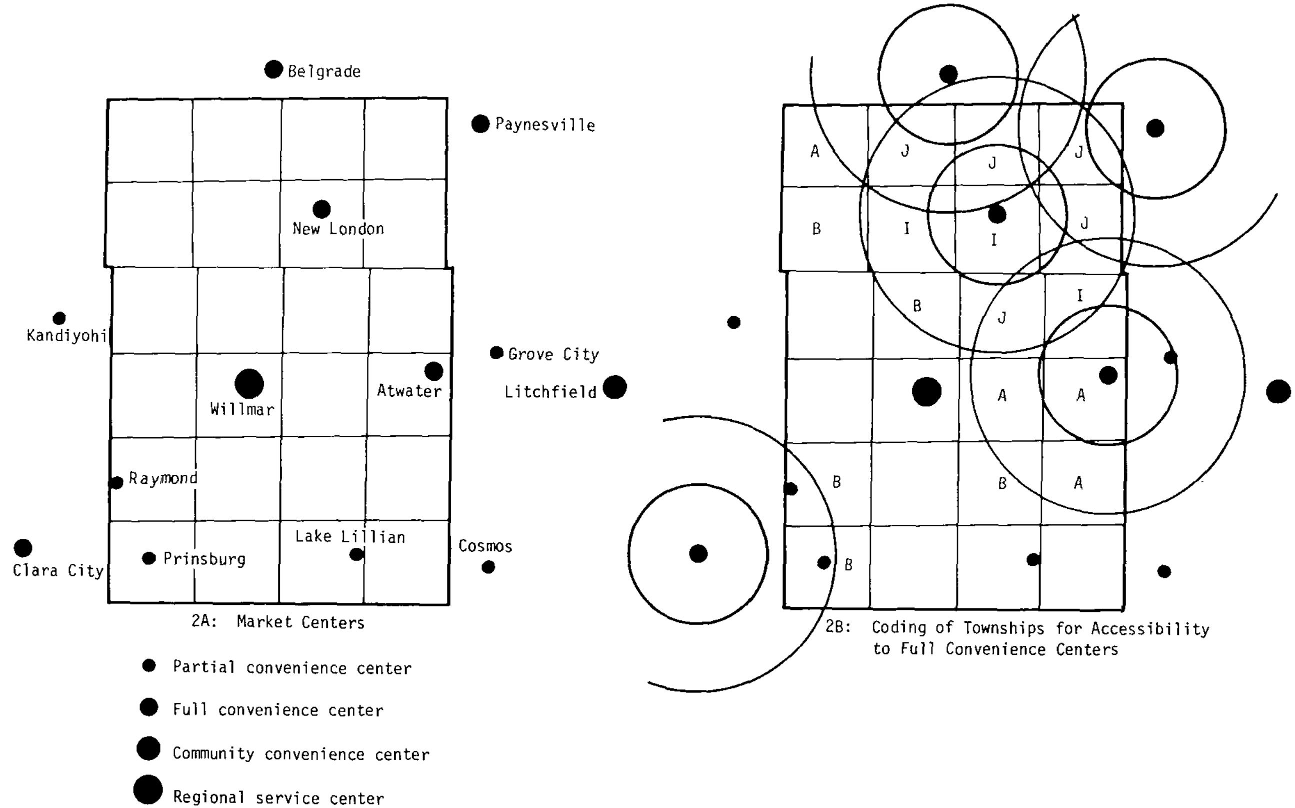

Figure 3. Market center accessibility for Kandiyohi County, Minnesota.

physically discrete measurable unit of the activity (e.g., county). The accessibility of a piece of land to an individual activity unit will be proportional to the size of the unit and inversely proportional to the distance to the unit. The accessibility of this land to the total activity is the sum of this ratio over all units. This is essentially the demographic potential model which has been widely used by transportation and marketing planners. Mathematically the model is stated as follows:

$$\text{Potential}_i = \sum_{j=1}^{N} \frac{\text{size}_j}{\text{distance}_{ij}} \text{ and}$$

where i is the point where potential is being measured N is the number of activity units. The model has been shown to be a good index of attraction, interaction and influence. Its development and use have been well documented by Carrothers [4] and Olsson [5]. When applied to all pieces of land the model will yield a smooth surface with a high point and surrounding lower points like a tent. The high point has the peak regional accessibility and all other points lesser values which should be scaled against that peak.

MLMIS measures accessibility to regional activities in the following way. First an area of influence is defined where activity units affecting Minnesota are found. Then a suitable measure of size must be determined for activity units where this data is available. The results of these steps are shown in Table 4 for the three regional activities currently being studied: agriculture, forestry and population. Accessibility is measured at each township centroid using the demographic potential model. An example of the application of the model is given in Figures 4 and 5. Figure 4 shows the size and location of pulp mills in Minnesota's area of influence [6]. Pulp mills consume 80 per cent of the state's forest

Table 4. Regional Activities

Activity	*Area of influence*	*Size measure*	*Unit*
Agriculture	Midwest including Minnesota, Wisconsin, Iowa, Dakotas, Illinois and Nebraska	Value of farm products sold	County
Forestry	Pulpmills-Minnesota, Wisconsin, upper Peninsula of Michigan.	Capacity for wood consumption	Pulp—individual mills
	Sawmills-Minnesota, western counties of Wisconsin		Saw—county
Population	Minnesota and several tiers of counties in surrounding states	Number of inhabitants	Minor Civil Division

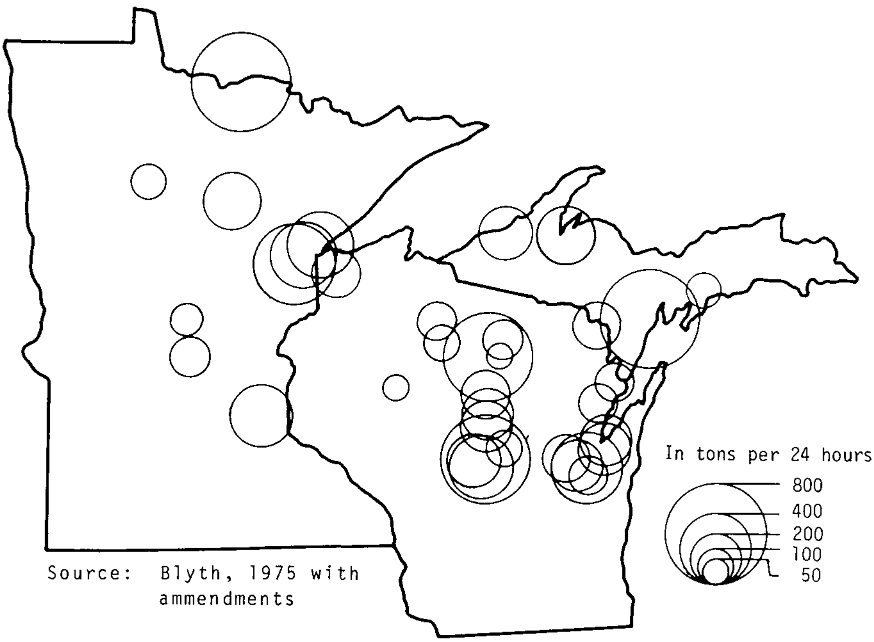

Figure 4. Pulp mill capacity, 1974.

production. Figure 5 shows the isolines of forest products processing potential for Minnesota. The peak of accessibility is at Cloquet with its three mills. Before this data would be used it would be scaled on a zero to one hundred basis to determine the accessibility of each township relative to this peak. The entire surface has an east to west downward slope indicating the influence of the Wisconsin mills. Data have indicated more intensive use of the forest lands in the higher scoring townships than the lower.

USING ACCESSIBILITY

The Minnesota Land Management Information System (MLMIS) project has been funded by the State Planning Agency to develop use suitability scores for each forty acre parcel of land in the state.[8] These suitability scores are to become the basis for a state land-use plan. They will be based on a priority ranking of all 1.36

[8] Many other state, federal and private agencies have contributed to MLMIS, but with other goals in mind [1].

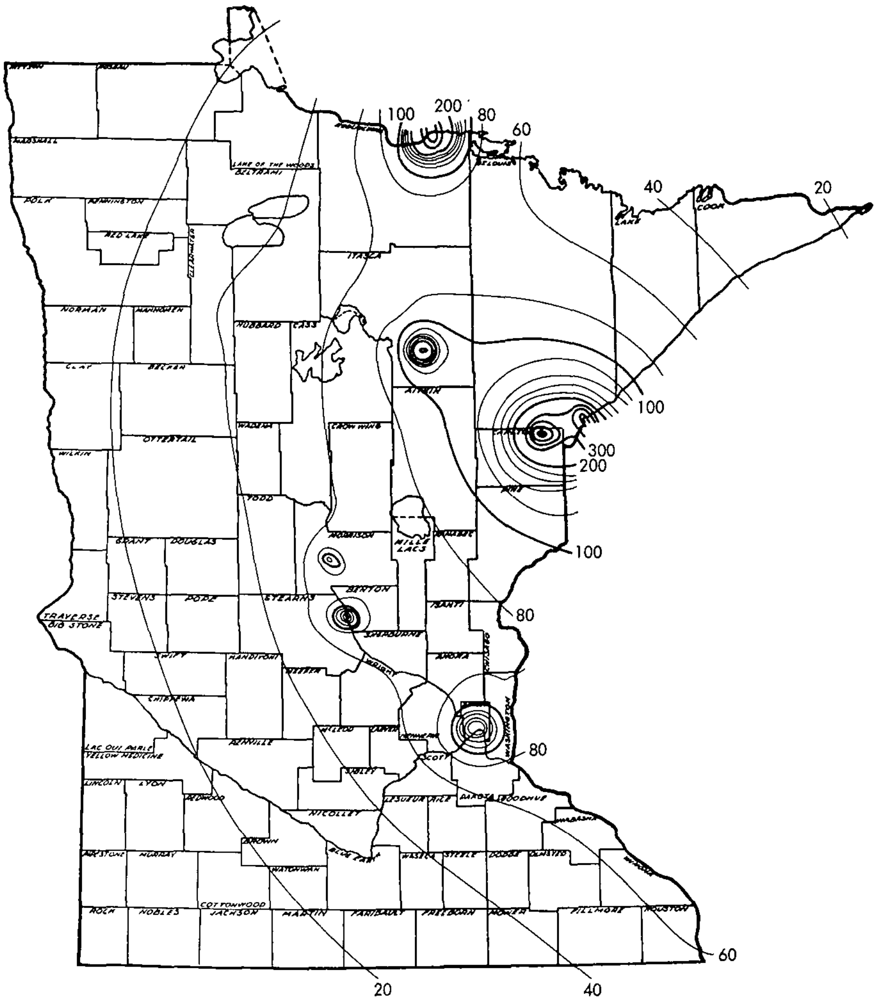

Figure 5. Forest products processing potential in thousand cubic feet per mile per year.

million parcels. Priorities, in turn, will be based on site capability (resource base), cultural limitations (e.g., amenity, zoning and public ownership policies), and accessibility. The suitability scores will be determined for the seven land uses: five development and two preservation uses indicated in Table 5. Specific data variables will be combined to yield priority rankings for each use. The variables to be used for each land use are indicated in Table 5; they have also been grouped by application type. Once all lands

Table 5. Variables Used in Priority Ranking

Variables / Land Uses	Site capability						Cultural limitations		Accessibility		
	Present Use	*Present Cover*	*Soil*	*Geology and Relief*	*Water Orienta-tion*	*Special Studies*	*Public Ownership Policies*	*Current Zoning*	*Highway Access-ibility*	*Market Access-ibility*	*Regional Access-ibility*
Development											
1. Cropland	X	X	X	X			X	X			X
2. Commercial Forest	X	X	X	X			X	X	X		X
3. Non-farm Residential	X	X	X	X	X		X	X	X	X	X
4. Commercial/ Light Industry	X						X	X	X	X	X
5. Heavy Industry	X						X	X	X		
Preservation											
6. Recreation Open Space	X	X	X	X	X	X	X	X	X		X
7. Preservation Open Space	X	X	X	X	X	X	X	X			

have been ranked for each of the seven land uses, the rankings across uses will be compared. Where a single use is given high priority, that use will be recommended for that site. Conflicting high, or low, priorities will be resolved by more complex applications of the system by people using other data sources, such as long run demand projections.

At this time, only preliminary analyses have been made in the northeastern part of the state [7]. The use of the accessibility measures in determining suitabilities for residential development and commercial forestry will be described below. The analytical procedures currently consist of overlaying nominally classed variables yielding a new variable. These new classes are easily ordered from best to worst with the best classes having the highest priority for development. The residential and forestry examples will illustrate the procedure.

Residential Suitability Example

Lands in Northeastern Minnesota were ranked according to their suitability for use as residential development. Figure 6 indicates the six variables that were combined to yield that ranking. These variables may be grouped into site capability, cultural limitations and accessibility.

Site capability was measured using five ratings of soils data: wetness, soils strength, susceptibility to flooding, septic tank limitations, and ground water contamination hazard. Each of these ratings was categorized into slight, moderate and severe problems. Where any rating was categorized moderate or severe, the builder would be faced with additional expenses. Also public policy should

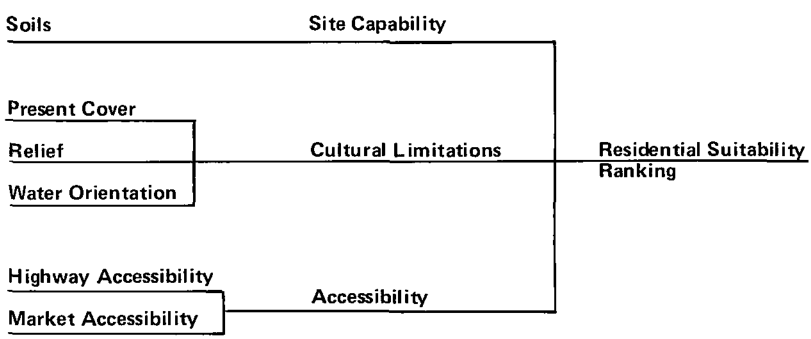

Figure 6. Residential land suitability ranking procedure.

call for additional monitoring to prevent degradation of the environment.

The cultural limitation for residential development is scenic attractiveness. The more attractive the landscape, the more likely it is that a buyer can be found who would wish to build and live on that spot. Attractiveness was measured using cover, relief and water orientation. Cover was categorized into three classes: conifer, hardwood (aspen-birch), and non-forested with desirability decreasing in that order. Relief was categorized into four classes in increasing order of ruggedness. Water orientation was categorized into three classes: 1) not on water and two equally desirable classes of 2) on a river and 3) on a lake.

Two accessibility measures were used in determining residential suitability of lands: highway accessibility and market accessibility. Highway accessibility was split into four classes to indicate increasing difficulty in connecting a proposed development to the highway network: on a road, within one cell of a road, within four cells of a road, and beyond. Assuming that people are required, and are willing, to travel further to larger market and service centers, a commuter zone was established using the market accessibility variable. This zone was fifteen miles in radius for the three highest orders of centers. The zone was ten miles for community service centers and five miles in radius for smaller centers.

Land suitable for residential development would ideally be those lands with no soil limitations, with high scenic attractiveness, near but not on a road, and within commuting distance of a city. Such lands are too few to be worthy of mention. Instead, the attractiveness factor was not used within the commuting zone where people are willing to give up beauty for accessibility in their permanent year-round housing. Outside the commuting zone, the scenic attractiveness of land was given a high weighting assuming that this land would be desirable for seasonal-residential development.

Commercial Forestry Suitability Example

Lands in Northeastern Minnesota were also ranked according to their suitability for use as commercial forest land. Figure 7 indicates the six variables that were combined to yield that ranking. These variables may be grouped into site capability, cultural limitations and accessibility.

Site capability was determined by combining present land use,

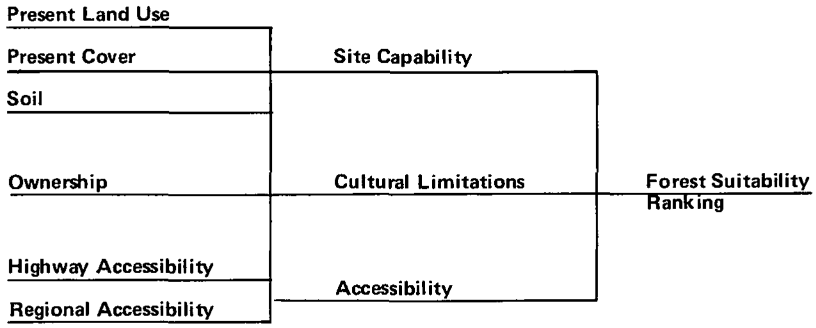

Figure 7. Commercial forest land suitability ranking procedure.

cover and soil variables. Present land use determined a dichotomy between forested and nonforested lands. Cover determined a dichotomy between conifer and hardwood forests. Soil productivity ratings for wood production provided a rating of lands within three productivity classes. Thus, productivity levels of conifer and hardwood forests is the resulting site capability map overlay.

Ownership data was used to separate all lands by management goals. Lands were separated by intent of the owner to operate his lands as a commercial forest. State and Federal parks restrict cutting while National Forests are managed for timber production. These cultural limitations on forest management were categorized into three management classes: tree harvesting, no harvesting and mixed.

Two accessibility limitations were used in determining commercial forest suitability of lands: highway accessibility and regional accessibility. Highway accessibility was dichotomized into two categories: within one mile (4 cells) of an existing road, and more than one mile from a road. The rationale used was that after one mile the removal of trees would require an extensive road building effort. The regional accessibility to forest products processing centers was used as a measure of demand. It was categorized into low, medium and high demand.

Land suitable for the production of timber products would ideally be those lands close to markets, with good access, productive, preferably producing conifer or high quality hardwood, and owned by individuals or agencies dedicated to timber production. About one-tenth of the land in Northeastern Minnesota falls into this category with other lands deficient in one or more respects, but still usable. These lands have been mapped and are being reviewed by the local regional development commission.

CONCLUSION

Accessibility has several aspects and therefore, can be measured and used in many different ways. This paper has presented three different measures of accessibility. It has shown how these measures are quantified, and how they have been used in land-use planning.

The accessibility of land is essential in determining its use-capacity. This is true in every day terms and in more rigorous economic terms. Any land-use planning or land-use information system which ignores the accessibility factor or one which does not adequately account for various aspects of accessibility, will yield an unsatisfactory product. The measurement and use of the accessibility factor is straightforward and the results are clearly worth the effort.

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