Modeling Rurality using Spatial Indicators

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Abstract

The term rural is used to describe people, places, and traditions. It is often employed as a setting for study as well as an object of study. People's perceptions of rural differ considerably. For over a century researchers have attempted to define the term rural using social, economic, and ecological components. However, problems with definitions and measurements have created difficulties for policy making, planning and service delivery to rural populations. This paper presents the foundations of a new approach for defining and measuring rurality by using spatial characteristics as additional metrics to the currently used social or economic characteristics. This spatial rurality index (SRI) relies on the use of GIS for the computation. The index consists of two clusters, a connectivity cluster and an access-to-service cluster, which employ spatial relations of topology and proximity to create a novel measure of rurality.

1. Introduction

The term rural can describe people, places, things, and traditions. For almost a century now researchers have tried to define the term rural more precisely. Many authors (Christaller 1935, Pahl 1966, Willits and Bealer 1967, Gilg 1985) agree that rural refers to at least three different substantive aspects that involve the use of ecological, occupational, or cultural dimensions (Gilg 1985). However, no single aspect captures the meaning of the term precisely and problems of interpreting and using official definitions and measurements exist. Several researchers (Leduc 1997, Weinert and Boik 1995) have noted that the ability to differentiate rural areas has important implications for planning and policy making.

This paper presents an approach to measuring rurality by adding a more explicit spatial component. Previous definitions (Willits and Bealer 1967, Pahl 1966) were predominately aspatial. Reasons for this may be that researchers were mostly concerned with social and economic data, not explicitly spatial issues; to a large degree existing definitions (e.g. Census Bureau) were taken for granted; and appropriate technology (e.g. GIS) has only recently become generally available to handle spatial data effectively and efficiently. Hewitt (1992) and Weinert and Boik (1995) identify several limitations in commonly used definitions. These include the limitation of dichotomous definitions (US Census urban-rural or Office of Management and Budget (OMB) metropolitan – non-metropolitan categories). Dichotomous measures mask important rural-urban differences and do not capture the breadth of variation in rural areas. The Census based definition is one of the most widely accepted and used. However, Census data suffers from various reporting biases as well as non-reporting (Bureau of Census, 1999) and the Census definition of rural changes every five years depending on other statistical definitions. Many measures of rurality are county-based and hence too spatially coarse for situations in which there is a need to differentiate within as well as across counties. In 1993, rural-urban continuum codes were developed to make finer distinctions among non-metropolitan counties by degree of urbanization and proximity to metro areas; however one limitation of these non-metro categories is that they are not mutually exclusive.

Many definitions are intended for national scale application and these nationally normed measures such as the census definition assign a category based on how a participant compares to the national population on selected characteristics. Use of these nationally normed measures in sub-populations however may fail to indicate how rural or urban a participant is compared to others in the study. Overall definitions that have emerged in the last decade have tended to be either too coarse to discriminate rural differences or too agency specific for comparative purposes. Many researchers, most noticeably in the health care field, have called for a standard rural typology that captures rural diversity and improves the use and comparison of data (Hersh and Van Hook 1989).

Given some of these limitations in current definitions, there seems room for a new approach. Spatial aspects of rurality are identified and quantified using GIS technology and readily available geospatial data. This spatial definition is termed the Spatial Rurality Index (SRI). It distinguishes rural from urban but does not define prototypical rural. The underlying concept is that rural and urban are distinguished by degree of infrastructure and connectivity and proximity to services, both of which are captured through metrics based on spatial relations of connectivity and proximity. While consistent with previous definitions of rural, this approach was designed for application over varying spatial scales and for effective comparison of different regions.

In this paper we provide an extensive literature review for the reader to understand the multi-faceted solutions that currently exist. Building on that, we introduce our own Index as expressed through two different clusters, the connectivity and access-to-service ones. We conclude with remarks on our current methodology and we outline future directions of the approach.

2. Rurality approaches through time

The definition of rural has been an elusive one, involving concepts that have emerged from the fields of geography, economics, and sociology. As early as 1915 academics felt it necessary to define what was meant by rural. Charles Galpin's (1915) study of town and country, the first of a series of studies that took place in Walworth County, Wisconsin, USA questioned whether there is such a thing as a rural community and if so, what are its defining characteristics. Galpin concluded that rural areas are not separate communities and a fine line exists between town and country that cannot be exactly defined. Galpin's study initiated a large number of other descriptive studies throughout the 1920s and 1930s by social scientists. Kolb (1923) studied service relationships between farm and village residents. Brunner and Lorge (1930) plotted rural urban boundaries, and Loomis and Beegle (1957) tested other methods using empirical studies. A similar characteristic of these studies was the determination of geographic boundaries of rural-urban communities.

Christaller's (1935) work defined urban in terms of economic factors and remains an influential model for urban geographers. In economic terms, the urban place provides the market center for farmers (King 1984). A functional interdependence between a town and the surrounding rural area is the foundation of Christaller's central place theory. Although, this idea was not original, Christaller proposed a completely new framework for the study of settlement geography. His major task was to define a central place with its central goods and services and explain its mutual dependence on the countryside. The theoretical concept of central place as outlined by Christaller is not plausible in the real world. Forces may distort the hexagonal patterning of central places, and it does not incorporate a sociological or ecological theory of urban versus rural. His theory is purely an economic perspective.

In the 1960's a sociological perspective on ruralness emerged with the publication of the Urban-Rural Continuum (Pahl's 1966). Pahl outlined a rural urban continuum with no distinct boundaries: a reaction against the polar type dichotomies of urban and rural ("Gemeinschaft" (rural) and "Gesellschaft" (urban). However, as Pahl mentions (1966, p 302), there "are equal dangers in over-readily accepting false continuity". Sharp discontinuities may appear at different scales. The point at which a community is more properly described as urban rather than rural is, therefore, not easily determined.

Operationally, definitions are discontinuous over space as countries around the world use different population sizes to describe what is urban and what is not.

For policy purposes federally based definitions began to appear. The U.S. Census definition uses a demographic count of people to define urban, and the "leftovers" are rural. Essentially, what is not metropolitan in America is rural (Fitchen 1991), a definition of exclusion rather than inclusion. The Census Bureau defined "urban" for the 1990 census as comprising all territory, population, and housing units in urbanized areas and in places of 2,500 or more persons outside urbanized areas. Territory, population, and housing units not classified as urban constitute "rural".

Recently, space began to play a more prominent role in definitions of rural. The “new rural sociology” or “rural restructuring” is the most current stage showing broadening concern with spatial issues. In 1983 the U.S. Department of Agriculture subdivided the Census metro and non-metro categories to form the Rural-Urban Continuum Codes. This classification method distinguishes metropolitan counties by size, and non-metropolitan counties by the size of their urban population and proximity or adjacency to metro areas. Altogether it includes 714 metro counties and 2,383 non-metro counties. The Department of Agriculture (Economic Research Service, USDA, 1995) evaluates non-metropolitan counties using the concept of spatial adjacency. Adjacency is defined by shared boundaries (i.e. touching a metropolitan statistical area (MSA) at more than a single point) and commuting patterns (at least 1 percent of the county’s labor force commutes to the central county or counties of the MSA). Even with this extended classification, this measure still masks rural variations. This measure and other similar measures encounter the problem that counties with either several sparse or a few large concentrations cannot be discriminated (e.g. a county with one town of 20,000 versus a county with eight towns of 2500).

Cleland and Mushlitz (1991) define a Connectedness Index but their measure does not incorporate explicit spatial connections beyond adjacency. Their Connectedness Index includes 10 variables including proximity to a metropolitan area, population growth rate, level of education, type of employment, family income, level of retirement and number of locally published newspapers.

Health researchers are also quite interested in the definition of rural mainly for policy initiatives. One organization in the United Kingdom, the South West Public Health Observatory put together a review of the literature and an assessment of indicators for rural service planning (http://www.swpho.org.uk/ruraldep/). There, they discuss what is meant by the term ‘rural’, how to measure deprivation in the rural context, and how to empirically measure deprivation in different contexts. They are able to identify six broad approaches to the measurement of rurality, as first discussed in Chapman et al., 1998; and Higgs, 1999. These include measures of settlement size, population density/sparsity, accessibility to services, peripherality, land use, multivariate classifications. But as Martin et al. (2000) have examined, the representation of deprivation and low health status changes markedly using alternative measures of rurality. For instance, the profound problems faced by many peripheral communities are not always reflected when rural areas are defined on the basis of population density (Asthana et al, 2002). Furthermore, because their report focused on deprivation they found that indicators capturing deprivation in an urban context should not be expected to perform similarly in rural areas. The measure set forth in this paper however, does not focus on deprivation but on spatial dimensions of rurality.

Finally by the new millennium, researchers began focusing on a disparate type of data, one that is digital, from satellites or remotely sensed data. Jainquan and Masser (2001) proposed a spatial analysis framework for modeling urban development patterns by seeking determinants affecting land cover/land use change on various scales based on this type of data. Their paper looks at change to only an urban area instead of characteristics that might define an area and be able to compare it to another or many other areas. They use exclusively remotely sensed data for their analysis.

3. Incorporation of Spatial Indicators

To date the primary spatial characteristic considered in defining rural has been adjacency to metropolitan areas. The limitation in this approach is that a consideration of only shared boundaries overlooks other spatial effects. Shared boundaries assume a close association but do not consider the impact of geographic barriers or the absence of roads. Given the different perspectives and approaches, researchers have several methods for measuring and defining rural but none that work effectively across divergent spatial scales or none that are effective for comparative studies of sub-national regions. The three conceptual bases –ecological, occupational and socio cultural - have proven to be insufficient when considered independently. They are also problematic if one's aim is to study socio-economic issues and yet these aspects form the very basis of the definition.

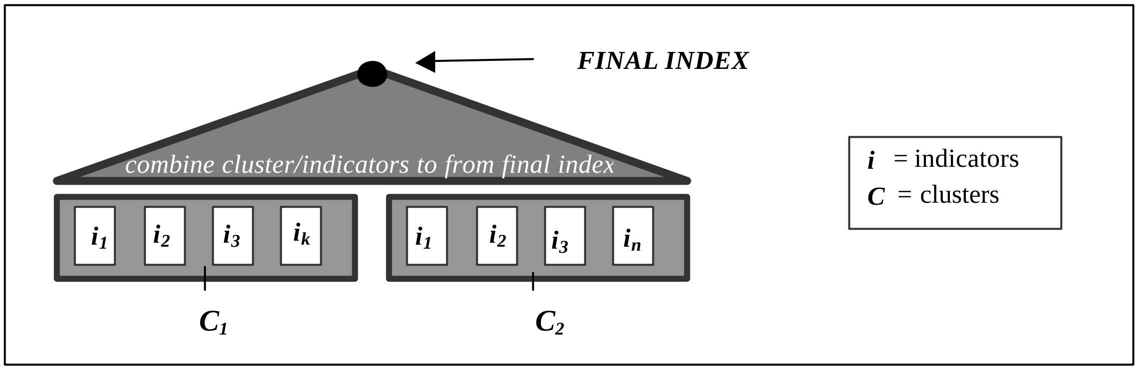
To address some of the above concerns we developed a Spatial Rurality Index (SRI), which can be used exclusively or be incorporated to other (non-spatial) approaches as an additional component. In the remaining of this paper we analyze the components of the SRI and the rationale behind them.

3.1 The Spatial Rurality Index (SRI)

The spatial model of rurality is presented in the context of building an index and its components. An index provides an empirical and numerical basis for categorizing, evaluating performance, calculating the impact of activities on the environment and society, or connecting past and present activities to attain future goals (http://iisd.ca/measure/default.htm). The measures that constitute an index are generally referred to as indicators. Indicators jointly summarize a system or indicate its status. Characteristics of good indicators are that they be simple, sensitive, reliable, consistent and easily estimated using available/affordable good quality data. The collection of rural indicators described below combine to an overall index and this index represents a specific region's measure of rurality. Clusters are groups of indicators. The use of clusters broadens the focus of an index to include a balance of different signals.

The SRI is composed of two clusters referred to as spatial clusters that incorporate different groups of indicators. The contribution of the indicators to the two clusters and the clusters to the final index is shown in Figure 1.

Figure 1: The Separate and Combined Components Making up the Index of Rurality.



One cluster, called the **Connectivity Cluster**, measures both degree of infrastructure and isolation based on a network of connections. A network is a representation of a connected infrastructure that may transport people, distribute or collect resources, or act as communication links. Urban areas have been characterized by high degrees of infrastructure (i.e. more varied and extensive networks). Mitchell (1999) sees the incipient networked city visible in the ruins of Pompeii, with its network of lead water-supply pipes running down through the town. He describes cities elaborating their networks by "improving streets to handle greater traffic volumes, adding streetcar and rail transportation systems to meet the demands of larger and more widely distributed populations, constructing municipal water supply and sewage systems to improve sanitation, creating gas and electric utilities to distribute energy, and eventually adding a local telephone network". Using the converse of Mitchell's argument, the SRI assumes that fewer networks and fewer network connections characterize more rural areas. The SRI captures the concept of rural as having less infrastructure by measuring the presence of networks and/or degree of network connectivity.

Access to Services is the second cluster in the index. While the Connectivity Cluster focuses on connections described by networks, this cluster is concerned with access to services either as a measure of presence or absence in a locale or as a measure of distance from a locale. The primary services considered are public services such as police, fire, schools, and health care facilities, since these are expected to be present unlike some retail or commercial services. However, the metric of this indicator, presence/absence or distance can apply to any type of service. Rural areas are expected to have less access to services and we use government or publicly subsidized services as representative indicators. Table 1 summarizes characteristics of the two clusters.

Table 1. Differences between Connectivity and Access to Service Cluster.

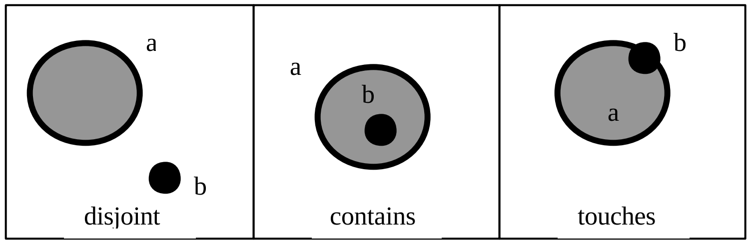
CONNECTIVITY CLUSTER	ACCESS TO SERVICE CLUSTER
Used as a measure of degree of isolation and infrastructure	Used as a measure of degree of accessibility
Measures nodes and node degree	Measures presence/absence and/or distance to a particular service
Hierarchical ranking based on quality and quantity of nodes and node degree	Hierarchical ranking based on function of distance and characteristics of the services
Spatial representations include networks (links, nodes), and polygons	Spatial representations include points and polygons

3.2 Spatial Components of the Model

The SRI does not rely on demographic or economic components. It relies on a set of spatial units and spatial relations among these units. The spatial data are represented by the geometric location of geographic features, along with attribute information describing these features, thus enabling GIS based analysis. The unit of analysis is a geographic area for which a rural measure is to be established. The SRI differs from other indices employing spatial units in that any arbitrary spatial units can be analyzed. Most other indices employ population and are thus generally restricted to census enumeration units. The MSU Rurality Index (Weinert and Boik 1995) is a resident-based index allowing spatial flexibility however it is dependent on individuals self-reporting. While theoretically the SRI can be applied to any spatial partition, it will most likely be applied to predefined areas such as municipalities or counties. As with other spatial unit based statistics, the SRI is subject to the modifiable area unit problem (Openshaw and Taylor 1981). Different SRI values will result from different spatial partitions but for any partition the ruralness of units is comparable.

Both clusters use topological and distance relations. The connectivity cluster considers a set of areas (to be tested for rurality) and their relations to one or more networks or network components representing infrastructure. The access to service cluster considers the set of areas to be tested and their relationship to a set of points representing services. The topological relationships are based on Egenhofer et al. (1994) 9-intersection model, which distinguishes topological relationships between spatial primitives embedded in R^2. The index requires the establishment of the relations between simple regions and points for which the possible 9 intersection model relations are *disjoint*, *contains*, and *touches* (Figure 2). Most commercial GIS support determination of these relations. The SRI simplifies these 3 relations to a Boolean *disjoint* or *contains+* relationship. The *contains+* relationship combines Egenhofer's *contains* and *touches* relationships. The following sections describe each cluster and how indicators combine within the cluster.

Figure 2: The Model Identifying the Relations between Simple Regions and Points.



3.2.1 Connectivity Cluster

The word connectivity can be interpreted in various ways, meaning to join, fasten together, link, or unite. In a community context, connectivity implies an emphasis on utility, transportation, and communication infrastructure. In one context it is the meeting of various means of transportation for the transfer of passengers. In another, it is the line of communication between two points in a telephone or similarly wired system. The common thread for all of the above definitions is that connectivity is a relationship between one area and another and measures an area's level of participation within a larger community or infrastructure. The connectivity within and between areas is typically materialized as infrastructure. Johansson describes infrastructure as a kind of capital that changes slowly, with respect to both its capacity and spatial distribution in comparison with social and economic activities thus providing more temporal stability to the index.

Table 2 summarizes several types of network infrastructure (transportation, utility, and communication networks) that can be included in the connectivity cluster and examples of the characteristics measured. Indicators in this set either singly or in combination have good comparative power and the data required to generate the metric are generally available. Several other types of infrastructure could fit the model and might be good discriminators but the relevant data may be more difficult to acquire at large scales. With the growing availability of spatial data (often accessible on-line) this cluster is practical to compute with inexpensive GIS software. A road network which is a primary dataset for the index is available nationwide from several sources.

Table 2. Connectivity Cluster Indicators.

Infrastructure Type	Indicator	Node Measurement		Link Attribute Measurement
		Node Count	*Max Node Degree*	
Utility	Water	Existence of water network or # of service connections	# of connecting pipes	Size of Pipe
	Sewer	Existence of sewer network or # of service connections	# of connecting pipes	Size of Pipe
Transportation	Roads	# of interstate exits, # of intersections (by class of road)	# of connecting roads	Class of Road
	Railroads	# of stations	# of transfer lines	Type of line
	Airports	# of airports (by type of airport)	# of carriers, # of connecting flights	Class of carrier
Communication	Internet	# of connections	# of connecting cables	Type of connection, speed of connection

Connectivity is measured for a set of geographic units and a particular infrastructure network. The formulation of the measures varies to some degree with the type of infrastructure but generally the measures take the form of node count *contains*+ in a geographic unit and/or the maximum node degree of contained nodes. These measures are based on the assumption that rural areas may have little or no infrastructure (e.g. no public sewer and water) and fewer or lower-level connections to other areas than more urban areas. The presence of a network node within a geographic unit is the relation of interest. The presence of a link in a geographic unit indicates the presence of infrastructure but does not signify a connection. To illustrate, consider an interstate passing through an area. If there is no exit ramp (node), then the area is not considered connected to the interstate. Node degree measures the number of links incident at a node and thus its degree of connectivity. A higher node degree reflects a higher degree of connectivity. Consider an airport as a node. Node degree could represent the number of immediately (first order) connected destinations, the number of different carriers serving the airport, or, taking connectivity to the temporal dimension, the number of flights per day. A measure of node degree is most relevant to transportation infrastructures as shown in Table 2.

A limitation of previous indices is that they typically do not scale well spatially. An index that might work well at the national level may not work well at a local or regional scale. The SRI is designed to work across scales without substantial change to the index structure. To do this we assume a hierarchical representation of infrastructure. At a detailed level individual components of an infrastructure are considered such as pipes and valves in a water or sewer system. At the coarsest level, an entire infrastructure system can be represented as a single node. For example, the entire water or sewer system for a town may be represented as a node. At intermediate levels, nodes are ranked on degree of importance. For the connectivity cluster the node degree is used to rank nodes on connectivity.

The connectivity cluster uses various levels of the network hierarchy to adjust the measure to the size and geographic extent of the area to be evaluated or to change the comparative power of the index as described later. To compute the connectivity cluster, we first identify the topological relationship between a geographic unit (*GU*) and the nodes (*n*) of a network indicator (*Ij)* where j is the number of indicators employed in the cluster. The number of *contained+* nodes is determined and summed for each indicator included in the cluster. These values are normalized to values between 0 and 1 by dividing by the maximum value. Where node degree is employed, the degree for each relevant *contained+* node is determined and where more than one node is *contained+* in a geographic unit, the max node degree is reported for the unit. The connectivity cluster can be computed for different levels of the network hierarchy to change the comparative power of the index. For the coarsest level, we assume the top level of the network hierarchy in which a network is represented by a single node. More detailed levels can employ subsets of nodes within an infrastructure down to the most detailed level that includes all of the represented nodes within a network.

Figure 3 shows an example set of geographic units and the nodes for three types of infrastructure: public water systems, airports, and bus depots. Public water is represented at the coarsest network level where a single node represents the presence of a public water system. Table 3 shows the *contained+* node counts and the combined connectivity cluster measures. For this set of geographic units A is the least connected and thus most rural and D is the most connected and least rural.

Figure 3: Example set of geographic areas with superimposed network nodes.

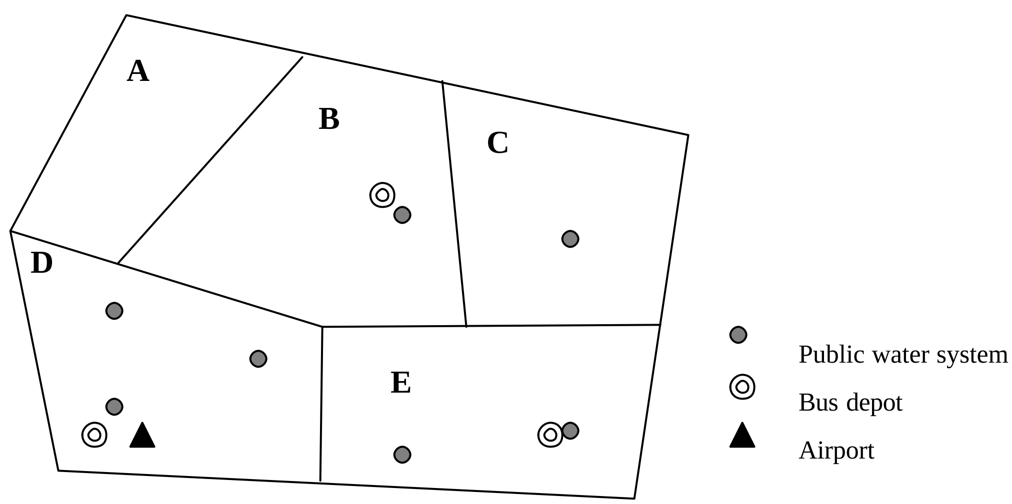


Table 3. Example set of geographic areas with superimposed network of links and nodes.

TOWN	NODE COUNT	MAX NODE DEGREE
A	0	0
B	2	2
C	1	1
D	5	3
E	3	2

The connectivity cluster measure can be quite parsimonious in that a few indicators can discriminate variation in the rural character of a set of geographic areas. More discriminating power can be achieved by using node degree measures, adding indicators, or using a more detailed level of the network representation. To increase the discriminating power, node degree for bus depots can be added in the form of the number of destinations and a new node degree indicator for primary roads can be added.

3.2.2 Access to Service Cluster

The access to service cluster measures access to a set of services where access is measured by containment of a service within a geographic unit and/or distance of the service from a geographic area. Many communities in rural areas do not have access to basic services, such as hospital facilities or police departments. By examining these factors, through topological and distance relations, another dimension of ruralness can be captured. Table 4 summarizes some of the indicators used for this cluster.

Table 4. Access to Service Cluster Indicators.

Service Type	Indicator	Access Measurement
Health Care	Hospital Facilities	Containment, distance, # and rank of medical services
Education	Schools	Containment, distance, Level of education
Safety	Fire Departments	Containment, distance, # of fire trucks, type of service (eg. Volunteer)
	Police Departments	Containment, distance, # of police cars
	Sheriff Departments	Containment, distance, # of sheriff cars
Wireless Telephone Service	Wireless Towers with broadcasting signal radius	Containment

Again, we first identify the topological relationships between a set of services and a set of geographic units. Either the geographic unit *contains+* a service type or is *disjoint* from a service type. If the relationship is disjoint, distances are computed between the geographic unit and the service. The distance calculation uses the centroid of each geographic unit and computes either the Euclidean distance from service to the centroid or distance along a road network.

We also use a network distance function for the access to service indicators, specifically for the hospital indicator. This identifies the closest services and displays the best way to get to or from a service from the geographic unit being evaluated. To generate these results, a location on a line, representing the geographic unit (in most cases the centroid) and the point representing the service are specified. The length of each link is summed allowing the final result to be the distance from the geographic unit (centroid) to the closest service.

3.2.3 Final Index

Segregating the two clusters allows examination of both degree of connectivity and degree of service accessibility. Including hierarchies of both topological relationships and distance metrics for analysis we can study a degree of rurality, instead of a Boolean dichotomous relationship. The user has the ability to choose the indicators, the level of granularity for an indicator, and how they are going to be employed in the model. There are several ways (e.g. weighting schemes) that can be used to combine the individual indicators to a final index. This is the next logical extension to our research work.

4. Conclusion and Future Work

Research has consistently demonstrated that there is not a single rural America but rather a complex mosaic of varying social and environmental settings. A model based on spatial relations, a hierarchy of network connections and indicator granularity that accommodates different spatial scales has been identified and formalized. As areas become more or less rural over time the importance of being able to capture the change in rurality without changing the definition of rural increases. The index proposed here is an initial step towards this goal. Allowing spatial dimensions of rurality to define the index, instead of relying on social factors, decreases the chances of changing definitions.

Currently our method does not account for the interdependence between indicators. For example, we expect good access to schools to be a function of a good road network. Our future investigation involves identification and support of correlations between indicators as we build our mathematical method for aggregating the individual indicator metrics into a final rurality index.

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