Hospital Site Selection Analysis

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Abstract

Michigan Community hospitals are tasked with serving diverse populations and providing a full range of medical procedures. Many healthcare facilities were built to serve large local populations (e.g. Detroit); others were intended to provide regional coverage across less populated areas (e.g. Alpena). The precise settings of these hospitals were dictated by a diverse set of geographical and historical factors, including the distribution of population at the time each facility was constructed, the physical characteristics of available sites, and the human and political context of the moment. In Michigan, it seems quite likely that the factors leading to the development of today's spatial constellation of 139 community hospitals were largely local and unique to each individual hospital. A multi-organization committee headed by the State of Michigan's Department of Community Health approached the authors with questions about how spatial analyses might employed to develop a revised community hospital approval procedure. In particular, the State was concerned with identifying populations with lengthy drive times to existing community hospitals. The methods used in this research quantify access to existing hospitals statewide, taking into account factors such as distance to nearest hospital and road network density to estimate travel time. Areas falling outside of a particular time threshold are identified as limited access areas (LAA). This criterion is now state policy in the evaluation of new community hospital proposals. Results help policymakers understand some of the spatial complexities associated with the demand and the accessibility dimensions of health care access and equity.

1. Introduction to the Research Questions

The Department of Geography at Michigan State University was contacted in July of 2004 about possible participation in the research component of the hospital site selection process for the state of Michigan. As part of that process a specific research question were asked.

1. Given that time to emergency services at hospitals is the most important criterion for hospital placement and demand estimation, how much time is required for people in the state to travel to the nearest suitable hospital.

Discussion with Community Health personnel and other interested groups resulted in an objective that comprise the topic of this paper. First, policymakers and the committee required a relatively clear, defensible assessment methodology that could be executed relatively rapidly using existing technology. As with many modern geographical planning exercises, it was hope that geographic information system (GIS) based approaches might provide powerful perspective on the problem (Birken et al., 1999; Phillips, Jr., 2000; University of Sheffield, 2005). The method would quantify access to existing hospitals statewide, taking into account factors such as distance to nearest hospital and road network density to estimate travel time. Travel times based on average representative speeds due to varying road types would also be applied (Brabyn and Skelly, 2002). Areas falling below a particular time threshold would be identified as relatively inaccessible. The identified inaccessible areas could be employed as a criterion in the evaluation of new community hospital proposals. Third, the committee wished to contrast the spatial constellation of existing community hospitals with a theoretical configuration that best met statewide demand. In contrast to the second objective, this one employed patient days data to quantify the spatial pattern of recent demand, but did not consider access as a function of the road network. The results might identify the degree of sub-optimality of the existing pattern of hospitals. Perhaps more importantly, it could foster dialogue on the definition of an optimal hospital configuration, and of what spatial characteristics were most important for Michigan's hospital system.

2. Travel Time Methodology

The research question is concerned with the development of a travel time methodology to identify locations relatively remote from an existing community hospital. There have been many studies all around the world regarding travel times and accessibility to health services (Burt and Dyer, 1971; Mehrez, 1996; Brabyn and Skelly, 2002; Jordan et al., 2004). Some research has dealt with simple distance to nearest provider. Some has dealt with provider-to-population ratios (Guagliardo, 2004). Lauder et al., 2001 stated that previous research has been split into two types of analysis. First, modeling for traffic prediction often associated with the Origin-Destination (O-D) networks which is mathematically intensive. This type of analysis requires excessive amounts of data. Second, modeling travel time for secondary purposes such as hospital accessibility. This type of model does not require specific data analysis as other factors come into play, such as availability of transport. Therefore, the modeling employed, that is specific to the travel times, is usually limited. In addition, there have been number of methods that have used to analyze accessibility such as Euclidian distance and Thiessen polygons by

Fortney, 2000 and Gething et al., 2004. Wei Luo and Fahui Wang, 2003, examining spatial accessibility (SA) by using the Floating Catchment Area (FCA) method to define the service area of physician by a threshold travel time combining with gravity-based model. Recently, researchers are beginning to combine the concepts of distance and supply under the SA analysis (Guagliardo, 2004).

The method developed for this study is in fact unique to the study but relies on well-accepted theoretical and computational foundations for support. While all the assumptions and model iterations are not presented in this document, the experimental process was quite involved and emerged only after many meetings with the committee.

Basic Requirements:

1. 3 mile spatial resolution
2. All places in the state must be measured
3. 30 minute travel time maximum to suitable hospitals
4. Variations in road types must be considered

2.1 Computing Travel Times Over Space

A grid-based model was proposed. The grid model requires more computing infrastructure than the network model, but is a complete spatial representation of state hospital and health coverage. The 3 miles spatial resolution criterion was initially considered the largest area that could be aggregated into a cohesive single unit for hospital services and the smallest readily computable area. After significant experimentation, the models were recreated to run on 1-kilometer cells and results using the 1-kilometer cells are presented here.

2.2 Travel Time Maps

The cost grid, or travel time, is derived from the Michigan Department of Transportation "FUNCLASS" or functional class of road designations. This class system uses the United States Department of Transportation (USDOT) system classifying all roads by their transportation function. This system is called the National Functional Classification (NFC) system. There are three major types (Arterial, Collector, and Local) within this system and roads are further divided into urban and rural (Table 2.1).

1 - Rural Interstate (principal arterial) 2 - Rural Other Principal Arterial (non-freeway) 5 - Rural Other Freeway (principal arterial) 6 - Rural Minor Arterial 7 - Rural Major Collector 8 - Rural Minor Collector 9 - Rural Local	11 - Urban Interstate (principal arterial) 12 - Urban Other Freeway (principal arterial) 14 - Urban Other Principal Arterial (non-freeway) 16 - Urban Minor Arterial 17 - Urban Collector 19 - Urban Local 0 or uncoded - not a certified public road

Table 2.1. MDOT National Functional Classification (NFC) code road classes

Speed limits are defined by road type, and, in Michigan, range from 25 to 70 miles per hour. No central organization manages or records speed limit information statewide.

MDOT records speed limit information for M designated roads only. Thus, speed limits for representative road types were based on the speed limits of representative roads in the Mid-Michigan area. National guidelines for speed limit determination state that speed limits be based on the 85^{th} percentile speed of all travelers over any given road segment. Thus, roads will change speed limits over their entire length but should do so within a 10 mph range or be redefined into another functional class.

2.3 Computational Methods

To produce maps and other data products displaying specific times, ESRI Arc/Info GRID based spatial analysis tools were employed. There are two existing classes of functions that might be used. The simplest class is the basic Euclidean distance function class, of which similar versions were employed in previous hospital site selection processes. Simply, these functions create buffers or boundaries around a site, hospital, of some specified distance. These functions have a long history in applied geographic research; however, they fail to effectively capture the variations in landscape and, most importantly for this project, transportation networks. Thus, "weighted distance functions" were tested and, ultimately, "Pathdistance" selected for the travel time methodology. These classes of functions are similar to Euclidean distance functions, but instead of calculating the actual distance from one point to another, they determine the shortest weighted distance (or accumulated travel cost) from each cell to the nearest cell in the set of source cells. A second exception is that weighted distance functions apply distance not in simple distance measures but in cost units. The term "cost" is the precise and correct term, but may be viewed very specifically for this research as "time."

All weighted distance functions require a source grid and a cost grid. A source grid can contain single or multiple zones, which may or may not be connected. A cost grid assigns impedance in some uniform-unit measurement system that depicts the cost involved in moving through any particular cell. The value of each cell in the cost grid is assumed to represent the cost-per-unit distance of passing through the cell, where a unit distance corresponds to the cell dimensions. For this project, these costs are specifically travel time.

The PATHDISTANCE function then determines the minimum accumulative-travel cost from a source to each cell location on a grid. PATHDISTANCE not only calculates the accumulative cost over a cost surface, it does so while compensating for the actual surface distance that must be traveled and for the horizontal and vertical factors influencing the total cost of moving from one location to another. The accumulated-cost surface produced by PATHDISTANCE can be used in dispersion modeling, flow movement and, for this research, least-cost path analyses.

2.4 Calculation of Travel Times

First, the source cells, or more specifically, the predetermined hospitals, are identified. Then the cost to travel to each neighbor that adjoins a source cell is determined. Next, each of the neighbor cells is ordered from least costly to most costly in a list. The cell location with the least cost is then removed from the list. Finally, the least-accumulative cost to each of the neighbors of the cell that was just removed from the list is determined.

The process is repeated until all cells on the grid have been assigned an accumulative cost.

2.5 The Cost Grid

Each cell location is given a weight proportional to a relative cost which is incurred by the phenomena being modeled when passing through a cell. The weightings are usually based on inherent features in the location that are static prior to the movement of the feature or phenomena. The cost units are any relative scale that is established. The units can be dollar cost, energy units expended, preference or even unit less, in this case, the scale is time derived by speed limits. Very specifically, the cost surface is derived from the time required to traverse a cell based on the slowest speed limit of any road within the 1 km cell. This is the most conservative estimate of the time required to cross any cell.

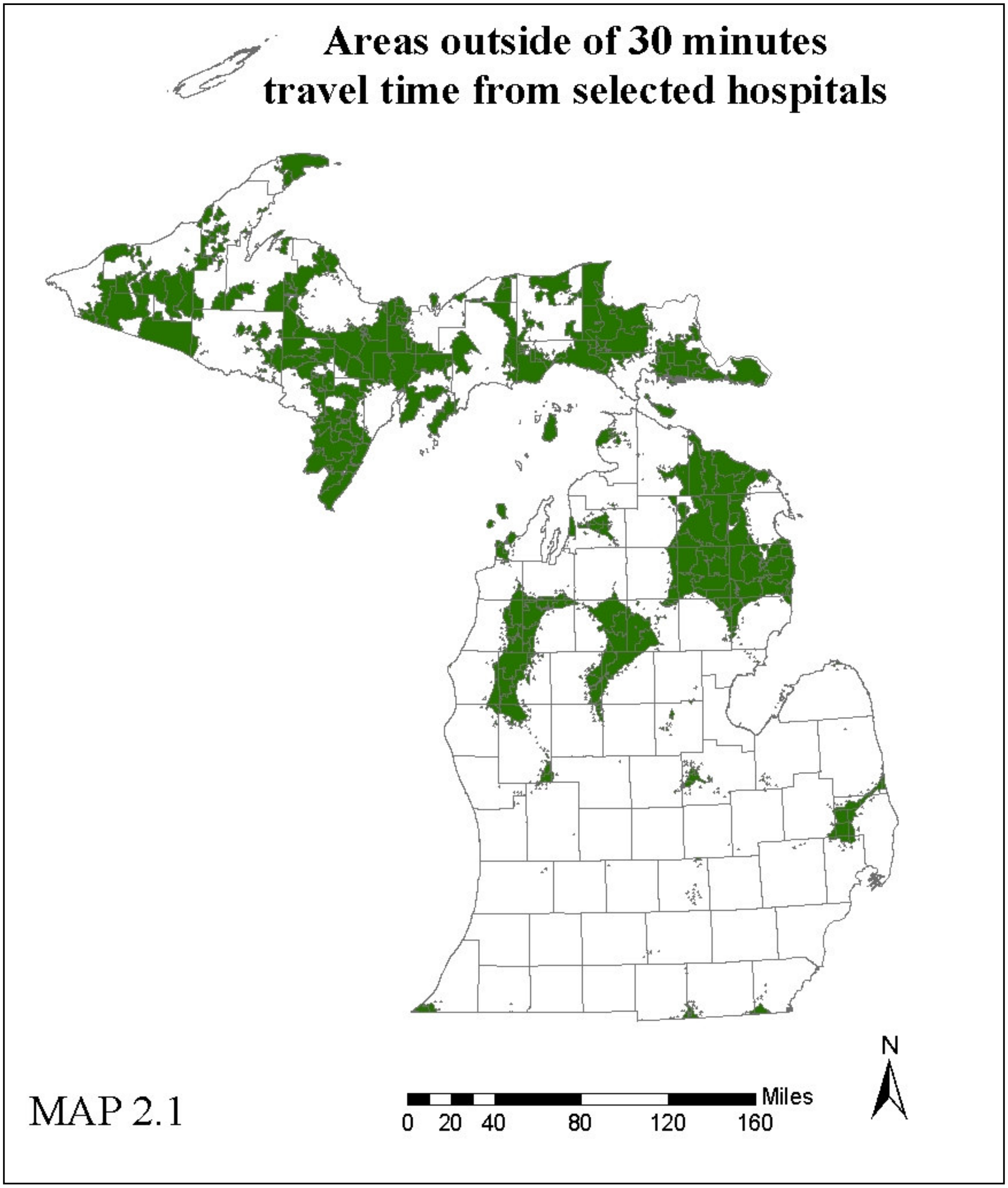
The cost values assigned to each cell are per-unit distance measures for the cell. That is, if the cell size is expressed in meters, the cost assigned to the cell is the cost necessary to travel one meter within the cell. If the resolution is 1000 meters, the total cost to travel either horizontally or vertically through the cell would be the cost assigned to the cell times the resolution (total cost = cost * 1000). To travel diagonally through the cell, the total cost would be 1.414214 times the cost of the cell times the cell resolution (total diagonal cost = 1.414214 [cost * 1000]). By interpreting the costs stored at each cell as the cost-per-unit distance of travel through the cell, the analysis becomes resolution independent. The PATHDISTANCE function creates an output grid in which each cell is assigned the accumulative cost from the lowest cost source cell.

2.6 Modeling ZIP-Codes and Travel Times

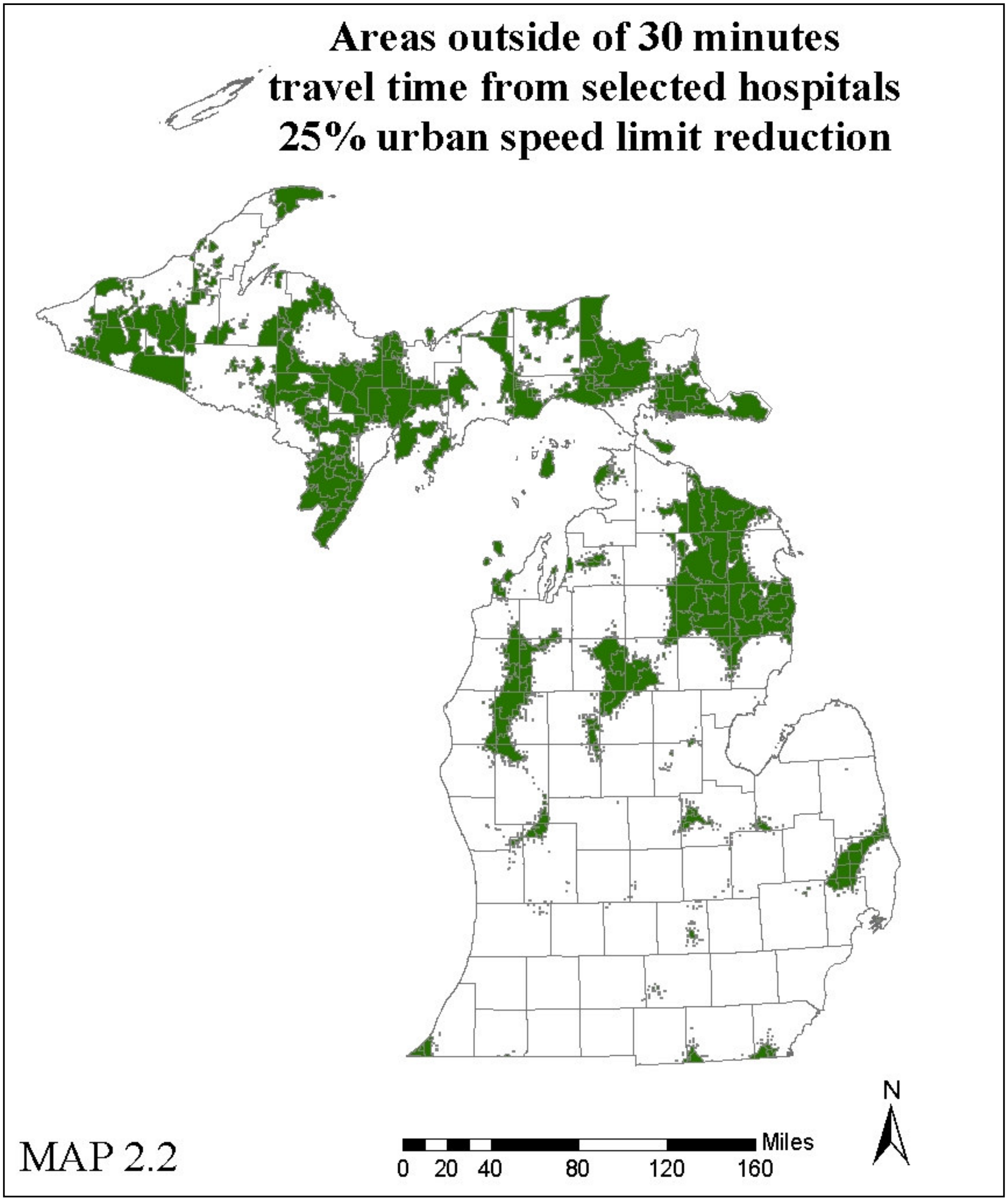
The specific output product is the total accumulative cost-distance grid. This grid stores for each cell the least-cost-accumulated distance that results from the least costly source cell. The least-cost-accumulated distance grid is transformed into a map product. The map product is used in a traditional map algebra process "overlay" with a zip-code map containing year 2000 census data. The final output products of this process are two-fold: a zip-code database that identifies unique zip codes and fractions of zip codes including multiple fractions of the same zip code, all outside the 30 minute travel time boundary. There are both map and database products. The final map is displayed here in Map 2.1. One concern raised by the technical committee was with respect to rush hour travel times, specifically assuming travel delays. To address that concern, travel times were redefined in urban areas, i.e. urban functional classes, to account for a 25% reduction in speed limits. All other modeling parameters were held constant. This model output is presented in Map 2.2. For research purposes, reductions in urban speed were modeled at 50% and 75% but are not presented here. The committee decided to use the "normal" or posted speed limits (Map 2.1) for service estimations. Two poorly serviced areas are identified in Map 2.3. The counties represented in these poorly served areas are identified on the map as well. The definition of poorly served as applied here is a contiguous area with a population of at least 50,000 in zip codes partially or wholly outside of the 30-minute travel time limit.

3. Results and discussions

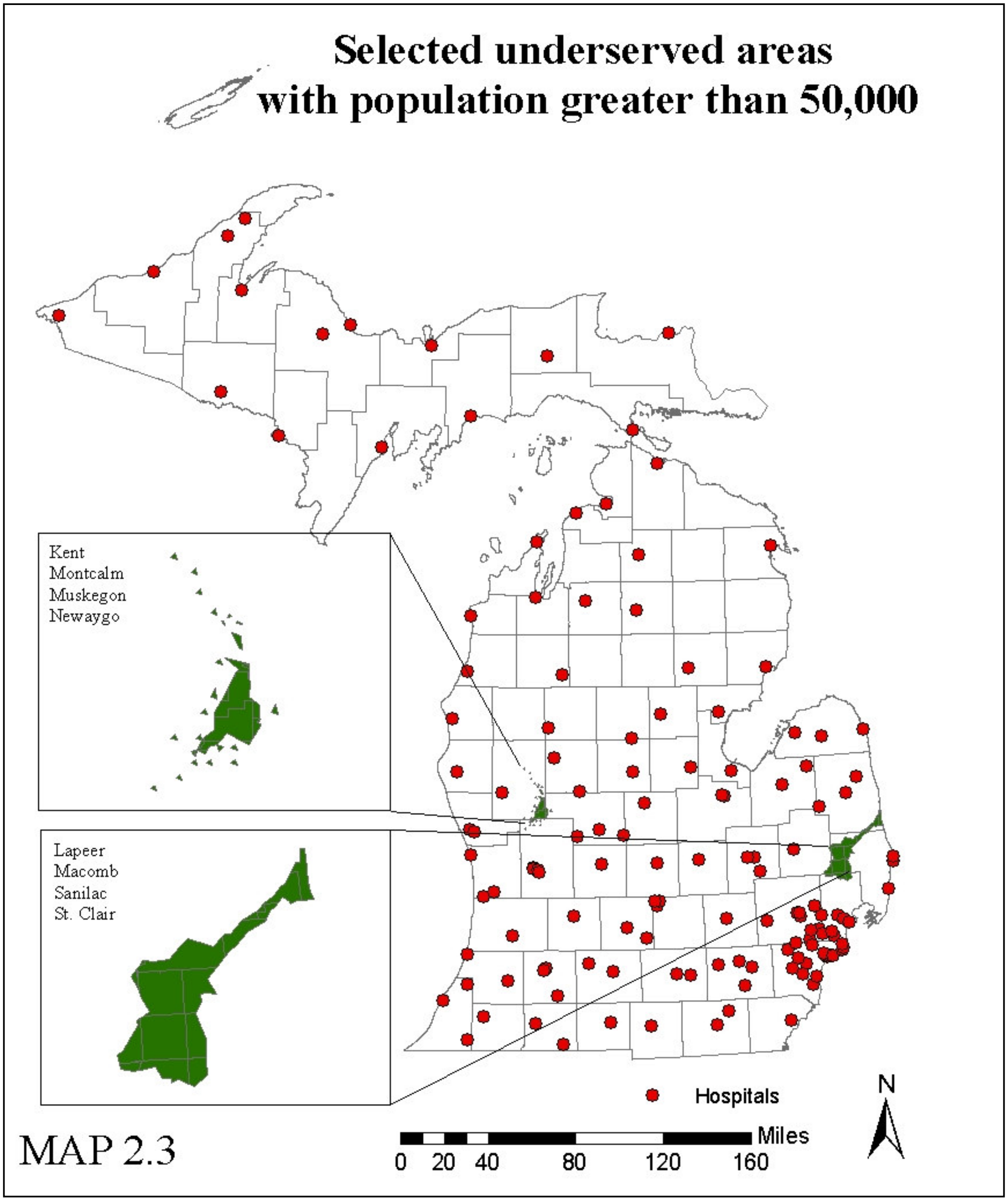
The limited access region in the thumb is the most significantly underserved. Using a conservative measure of contiguity, the underserved population total is 74,450 in year 2000. The region north of Grand Rapids also meets the definition of underserved but given the complex spatial pattern requires a more liberal delineation of contiguity. Using the more liberal definition, 61,046 people are underserved. Both regions contain both partial and complete zip codes. It is important to understand that the populations reported thus far are using zip code totals. Using only complete contiguity and proportionate zip codes, the area west of Alpena and the large block in the Upper Peninsular alone meet the > 50,000 population requirement with 57,791 and 111,781 respectively. The remaining limited access areas fell between 21,000 and 28,000. The zip code database files that present this information were disseminated separately.



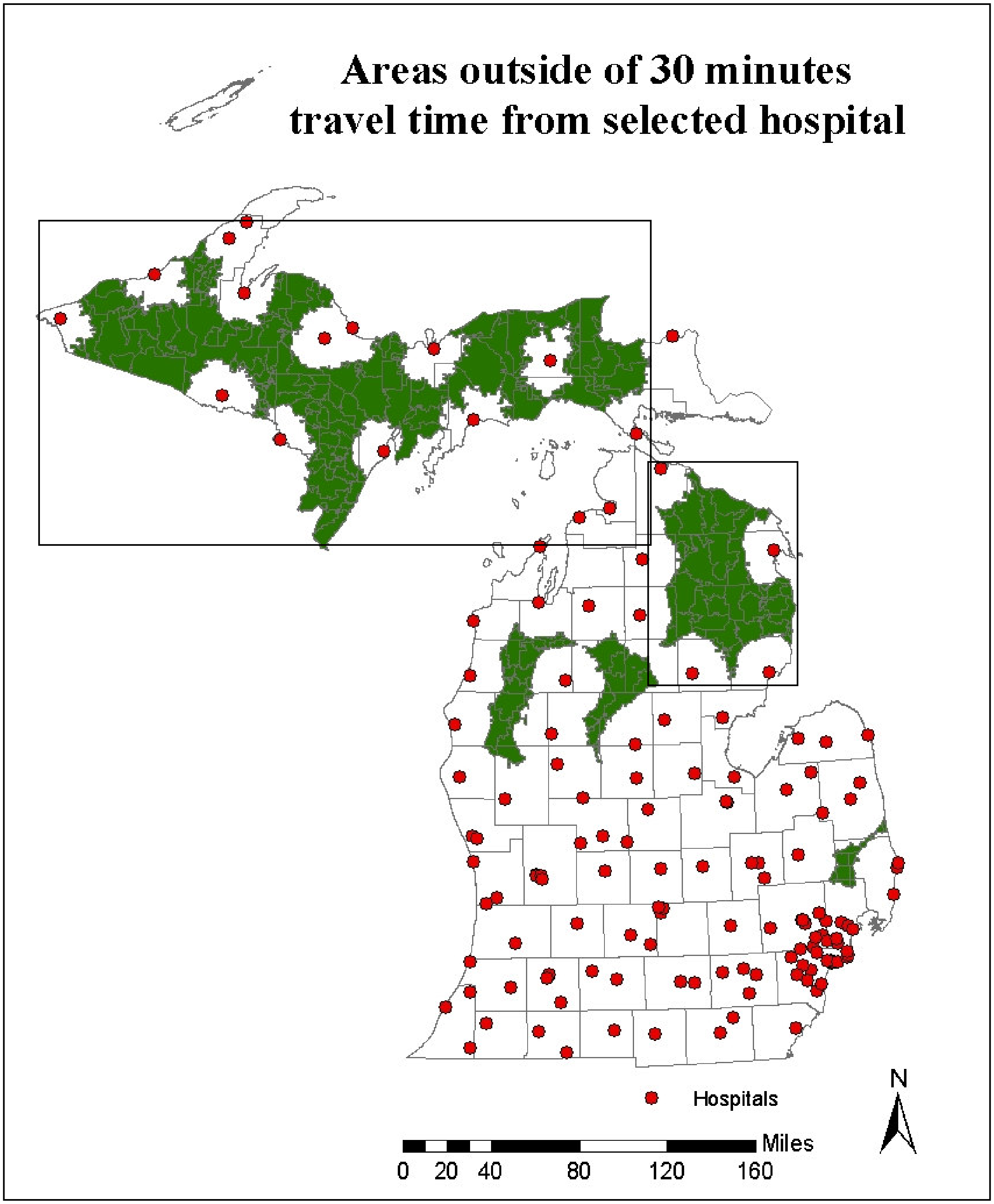
Map 2.1. Green = limited access. This map presents the results of the travel time methodology project. Not surprisingly, the Upper Peninsula contains the most area with poor medical access, but due to population totals and shifts, does not meet the criteria for an official underserved area. The northern Lower Peninsula also has a significant amount of area identified as poorly accessed, but also does not meet population criteria. There are three areas in the lower half of the Lower Peninsula that might meet the criteria: North East of Detroit, North of Lansing, North of Grand Rapids



Map 2.2. Green = limited access. Using a 25% urban road speed limit reduction, the areas underserved essentially remain with slightly more total area now included. Careful comparison of Map 2.1 with 2.2 permits the identification of new areas. However, this reduction in urban speed limits does not dramatically alter the configuration of the underserved areas.



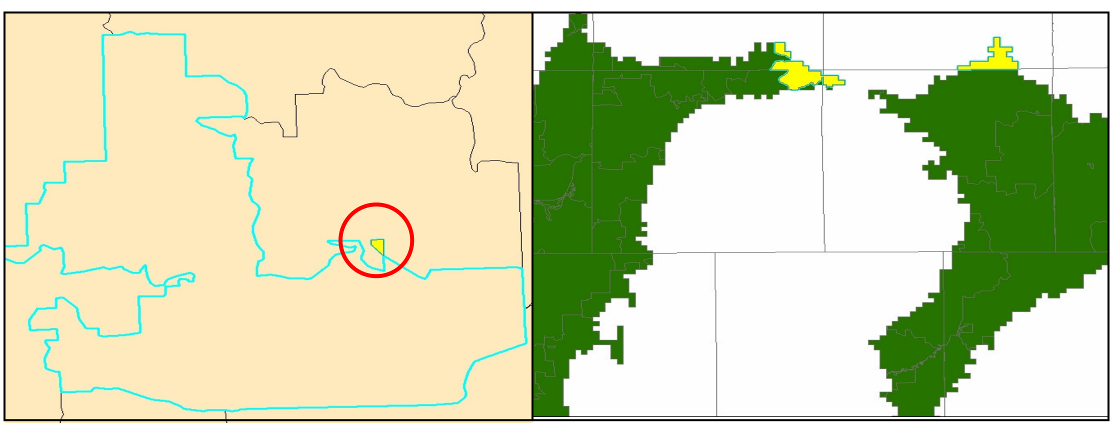
Map 2.3. Green = limited access; Red = selected hospitals. Using the results presented in Map 2.1 and contiguity and population criteria, two areas are identified as being "underserved." The top callout is centered north of Grand Rapids and contains four counties, though only a very small portion of Muskegon is actually part of the area. The lower callout is north/northeast of Detroit, contains the greater total land area and greater total population of the two regions.



Map 2.4. Green = limited access; Red = selected hospitals. Using the results presented in Map 2.1 plus the limited access zip code with no people, the strict contiguity and population requirements were modeled using the proportion of each zip code present within the limited access areas. Two of the areas were identified as being "underserved," the region west of Alpena and the large contiguous area in the Upper Peninsula.

Sources of Error

There were two primary sources of error associated with this research. The first error is a geographic data error associated with the use of zip codes as areas. Zip codes are postal routes and as such may have loops, as shown in Map 2.5 (L), built into the route. This is particularly the case in less densely populated areas. This looping condition, while not an error in the zip code, does introduce an error in population totals when modeled using any area based methodology. The error manifests as a counting error in the total population found within any given LAA. These errors were identified by hand and the final spreadsheet adjusted. The second type of error has two forms. The first occurs when a zip code is partitioned into multiple pieces as part of the processing. A more complicated type of this error occurs when a single zip code is split into multiple pieces and, further, is identified as being part of two or more LAAs. This type of error is presented in Map 2.5 (R). This error was less common but also produced an over counting, depending on the number of splits, of the impacted populations. Zip codes split in this fashion were identified by hand and spreadsheet adjusted.



Map 2.5. (L) Zip code looping example. (R) Zip code 49633 is a large zip code and is part of two distinct Limited Access Areas.

References

Birkin, M., Clarke, G. P., and Clarke, M. (1999) GIS for business and service planning. Chapter 51 in *Geographical Information Systems, 2nd Edition*. New York: Wiley. 709-722.

Mehrez, A. et al., 1996, On the Implementation of Quantitative Facility Location Models: The Case of a Hospital in a Rural Region. The Journal of the Operational Research Society, Vol. 47, No. 5, 612-625.

Davies, R., 1977, Location Problems in the Planning of In-Patient Facilities in the Health Service. Operational Research Quarterly (1970-1977), Vol. 28, No. 4, Part 2, 939-952.

Lauder, C. et al., 2001, Developing and Validating a road travel time network for cost path analysis. Presented SIRC 2001 –The 13th Annual Colloquium of the Spatial Information Research Centre.

Brabyn, L. and Skelly, C., 2002, Modeling population access to New Zealand public hospitals. International Journal of Health Geographics, 1:3, 1-9.

Burt Jr., J. and Dyer, J., 1971, Estimation of Travel Times in Multiple Mode Systems. Operational Research Quarterly (1970-1977), Vol. 22, No. 2, 155-163.

University of Sheffield, Public Health GIS Unit, 2005. An Introduction to Geographical Information Systems for use in Health Care and Health Services Research. Unit 5.

Phillips Jr., R. et al., 2000, Using Geographic Information Systems to Understand Health Care Access. Archives of Family Medicine, Vol. 9, No. 10, 971-978.

Fortney, J. et al., 2000, Comparing Alterative Methods of Measuring Geographic Access to Health Services. Health Service & Outcomes Research Methodology, 1:2, 173-184

Gething, P. et al., 2004, Empirical modeling of government health service use by children with fever in Kenya. Acta Tropica, Vol. 91, 227-237.

Jordan, H. et al., 2004, Distance, rurality and the need for care: access to health services in South West England. International Journal of Health Geographics, 3:21, 1-9.

Luo, W. and Wang, F. 2003, measures of spatial accessibility to health care in a GIS environment: synthesis and a case study in the Chicago region. Environment and Planning B: Planning and Design. Vol. 30, 865-884.

Guagliardo, M. 2004, Spatial accessibility of primary care: concepts, methods and challenges. International Journal of Health Geographics, 3:3, 1-13.