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GIS AND HEALTH CARE

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■ **Abstract** GIS and related spatial analysis methods provide a set of tools for describing and understanding the changing spatial organization of health care, for examining its relationship to health outcomes and access, and for exploring how the delivery of health care can be improved. This review discusses recent literature on GIS and health care. It considers the use of GIS in analyzing health care need, access, and utilization; in planning and evaluating service locations; and in spatial decision support for health care delivery. The adoption of GIS by health care researchers and policy-makers will depend on access to integrated spatial data on health services utilization and outcomes and data that cut across human service systems. We also need to understand better the spatial behaviors of health care providers and consumers in the rapidly changing health care landscape and how geographic information affects these dynamic relationships.

INTRODUCTION

The geography of health care comprises the analysis of spatial organization (number sizes, types, and locations) of health services, how and why spatial organization changes over time, how people gain access to health services, and the impacts on health and well-being (16). Recent decades have seen dramatic changes in the health care landscape in the United States and other countries. Health care providers are opening and closing, new forms of health care delivery are emerging, and the persistently high costs of health care are raising concerns about quality, effectiveness, and access. GIS and related spatial analytic techniques provide a set of tools for describing and understanding the changing spatial organization of health care, for examining its relationship to health outcomes and access, and for exploring how health care delivery can be improved. Although GIS has been used for several decades to examine health care systems, the scope of GIS contributions has grown rapidly in recent years. Advances in computing power and graphics, as well as the development of GIS-based locational analysis models and methods have stimulated innovative health care applications.

This review emphasizes recent literature on GIS and health care. The review is organized according to major themes in GIS-based analysis of health care. The first section examines GIS research on analyzing need for health care. The second section looks at how GIS is being used to study geographical access to health services and to understand disparities in access among population groups. The third section focuses on utilization, emphasizing the use of GIS in analyzing geographic variations in health care use. The final section considers GIS applications in evaluating and planning health services. Location-allocation modeling, spatial decision support systems, and homeland security are discussed.

ANALYZING NEED FOR HEALTH CARE

Geographic variation in population, and population need for health care, provides the foundation for analysis and planning of health services. People are not spread evenly across the Earth's surface, and populations differ along many dimensions—including age, gender, culture, and economic status—that affect their need for health care, their ability to travel to obtain health care, and the types of services they are willing and able to utilize. Increasingly, GIS is being used to map and explore geographical variation in need for health services and to develop innovative indicators of health care need.

Need is a multidimensional concept that reflects characteristics of people, their behaviors, and the environments in which they live and work. GIS has been used for many years to link diverse layers of population and environmental information to characterize the many dimensions of health care need for small areas (23, 45). A recent example is the effort at creating "community environmental health profiles" that describe demographic, economic, and lifestyle characteristics of the population as well as exposure to potential environmental hazards (51). Efforts like these take advantage of the spatial database management and display capabilities of GIS. In general, they are restricted to predefined geographical areas such as counties or zip codes, but in the future such systems will likely incorporate GIS-based procedures that allow users to query data for user-defined areas.

An alternative approach is to incorporate data from household surveys in needs assessment. Such data can be geocoded to residential addresses to depict detailed geographic variation in health needs and household characteristics. In examining access to services at a primary health care center, data from a needs assessment survey were geocoded and mapped to better understand spatial variation in health-related behaviors, risk factors, and perceptions (52).

GIS-based needs assessment is relatively well developed in the United Kingdom, because Health Authority budgets and service levels are, at least in theory, tied to local health needs (5, 45). Lovett et al. (38) discuss methods for improving needs assessment by incorporating in a GIS data from patient registers—lists of all patients enrolled with general practitioners in an area. Because register data are continually updated, they can represent population characteristics and needs more accurately over time than data from the decennial census. To check the accuracy of the register information, GIS was used to allocate patients from postcode areas to census enumeration districts to allow comparison of register data for small areas with corresponding data from the census. In a second application, census data were weighted geographically, based on actual patient flows, to generate descriptive health indicators for practice locations.

This example raises the important issue of using GIS to create geographically compatible data sets for needs assessment. Often the data inputs for multidimensional indicators of health care needs are not available for common geographical areas. Spatial analysis procedures can be used to allocate data from one set of areas to another so that health care needs can be represented for consistent small areas (6, 13).

The increased availability of health service utilization data in digital form—for example, Medicare records and hospital discharge data sets—is stimulating interest in the development of needs indicators that incorporate health care utilization patterns. This is a complex task since there is not a direct correspondence between utilization and need. Utilization reflects need, but it also reflects contextual and service-related factors such as service availability and affordability and practice patterns (19, 68). Researchers have argued that certain conditions like asthma and diabetes are "ambulatory care sensitive"—that is, hospitalization is largely preventable by timely and appropriate primary and preventive health care. Thus, high rates of hospitalization for these conditions serve as indicators of need for primary care. Ricketts et al. present a GIS-based analysis of hospitalization rates for ACSC in North Carolina (56). They used cluster analysis to identify geographical service areas, consisting of neighboring zip codes with similar demographic characteristics and levels of access to primary health care. Mapping and statistical analysis revealed that high rates of ACSC were strongly tied to poverty and social deprivation. The availability and accessibility of health services had little impact on ACSC hospitalization rates.

In the United Kingdom, researchers are using spatially linked databases to determine whether prevalence rates for certain medical conditions can serve as accurate measures of need for services (19, 38). Statistical analysis reveals complex associations between morbidity, social deprivation, health service availability, and utilization. Clearly, further research is needed to sort out the connections between health care need and service utilization in both the United States and United Kingdom.

GIS has an important role in assessing health care needs for small areas by facilitating the spatial linking of diverse health, social, and environmental data sets. Although the layering capabilities of GIS have been used for many years, researchers are now making use of the analytic capabilities to relate data sets that rely on nonconsistent areal units and to generate meaningful service areas (38, 54). As digital information on morbidity, demographics, and utilization becomes more widely available, health needs data will be incorporated in GIS-based decision support tools that allow communities and decision-makers to examine questions of health care needs, access, and availability.

ANALYZING ACCESS TO HEALTH CARE

Access to health care is an important issue in the United States and other countries. Some populations face substantial barriers in obtaining care, and health care policies and imperatives are affecting the location, quality, and quantity of services available with concomitant effects on access. Access describes people's ability to use health services when and where they are needed (1). GIS research emphasizes the geographical dimensions of access. Health care decisions are strongly influenced by the type and quality of services available in the local area and the distance, time, cost, and ease of traveling to reach those services (20, 26, 31). For medical conditions that require regular contact with service providers, travel time and distance can create barriers to effective service use (16, 27).

GIS is being used to create better measures of geographical access and to analyze geographical inequalities in access as well as those patterned along social and economic lines. There is growing recognition that geographical barriers to health care intersect with those based on class, race, and ethnicity leading to complex patterns of disadvantage.

Measuring Access

Measures of geographical access to health care can be either area-based or distance-based. Area-based measures describe for areas like counties, towns, or states, the ratio of population need to services available. Measures like the physician to population ratio have long been used to describe geographical disparities in access to physicians across the United States. A recent analysis of the ratio of dentists to population by county and zip code revealed substantial differences in access to dental services in Ohio (62). Access was poorest in the rural and Appalachian areas of the state. GIS was used to geocode dentist locations, to link population and dental service data sets, and to map the results.

Area-based measures like these have well-known limitations: They work with predefined area units, often political units, and the choice of units strongly affects the results (6, 49). Most area measures do not take into account cross-area travel—an important factor when the area units are small; nor do they assess differences in access within areas—an important factor when the units are large. One way to address these problems is to aggregate small areas into larger regions that reflect actual travel patterns. This is the approach used in the Dartmouth Atlas of Health Care to create "hospital referral regions," which are used in exploring the relationships between access and utilization (67). With GIS, it is also possible to use spatial statistical procedures such as kernel density estimation to measure service availability, but such approaches have not been developed in the health care literature.

Distance-based measures, which focus on the distance or travel time or cost between the population and health service providers, avoid many of these problems. The most widely used measure is straight-line or Euclidean distance. Love & Lindquist (37) used GIS to compute Euclidean distances from the elderly population to hospital-based geriatric services. By examining the frequency distribution of distances, the authors identified elderly populations with poor access to geriatric services.

As a measure of geographical access, Euclidean distance is flawed because it fails to incorporate the ease, cost and time of travel, and access to transportation (41). One of the advantages of GIS is that it can combine spatial information on roads, transportation, and population to create more accurate measures of geographical separation. A study of access to primary health care in Bolivia incorporated topography to capture the difficulties of travel in a mountainous region (50). To assess travel along transportation networks, many studies have used GIS to calculate network distances (2, 16, 66) and travel times based on road type and quality (26, 55).

Transportation adds complexity to the measurement of geographical access. A given area typically contains a mix of people who rely on different transportation modes and thus have varying levels of geographical access (41). Lovett et al. analyzed access to general practitioner services in East Anglia (England), an area where travel by both bus and car is common (39). For car transport, travel times were estimated along the road network from each postcode area to the nearest GP. Car travel times were mapped as a continuous surface by generating a triangulated irregular network (TIN) of the nodal travel time values. To evaluate accessibility by bus, researchers focused on the frequency of bus service and whether or not residents could walk to a bus route that went to a particular GP's office. Spatial buffer functions in GIS were used to identify areas within walking distance of bus routes. Bus service was classified as "good," "moderate" or "limited" based on service frequency and the percentage of population within walking distance (Figure 1). Analyzing combinations of car and bus access, the authors found pockets of rural deprivation characterized by high health care need and low transportation mobility, and these areas were targeted for bus service improvements.

Health care providers differ greatly in the range, type, and quality of services offered. These differences affect people's health care decisions and thus are relevant in measuring access. Most people are willing to travel farther to obtain specialized or higher-quality care, so there is a trade-off between distance and facility size/quality. Spatial interaction models represent these trade-offs mathematically (6, 15, 25). In the late 1970s, these models were used to analyze access to general practitioner services (35) and later to explore the repercussions of hospital closings on access (40); however, neither application was performed in GIS. GIS offers not just a platform for spatial interaction analysis, but also a means for developing models that are sensitive to geographical context (18, 25). Both of these model enhancements are important for health care applications.

Incorporating information on activity patterns in space and time can enhance GIS-based access measures. People are more likely to use health services conveniently located in relation to their activity spaces that encompass travel for work, shopping, and child care (7, 48). Additionally, colocation of health services with other frequently used services can yield significant benefits (32). GIS models of

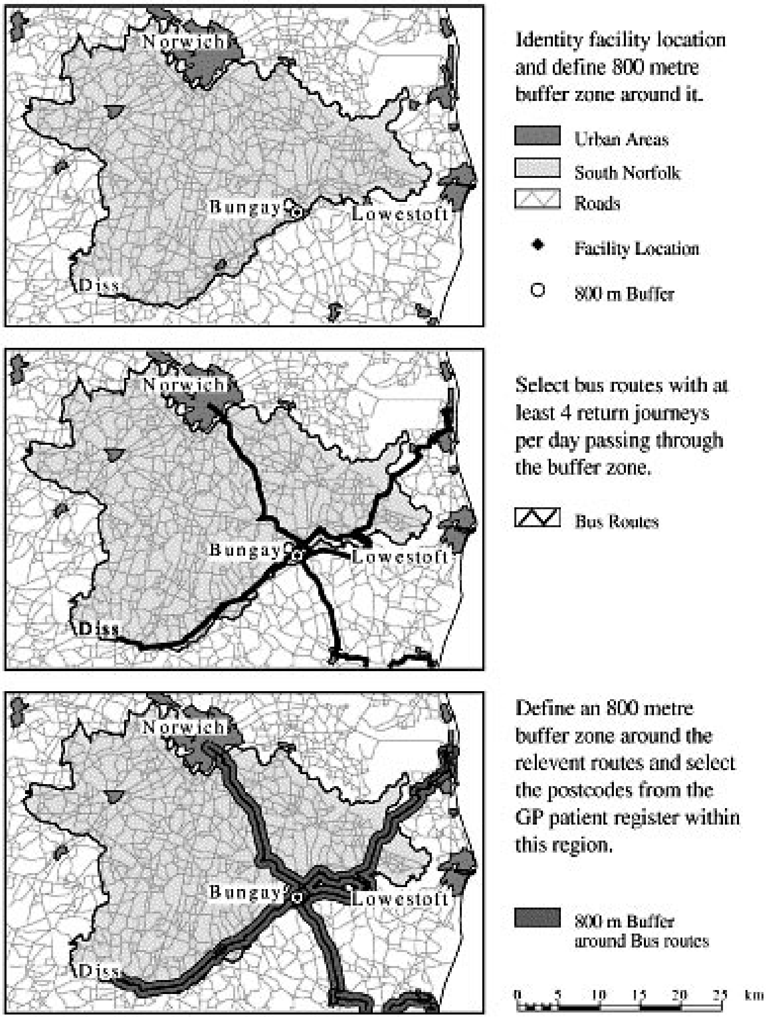

Figure 1 GIS procedures for evaluating accessibility for travel by bus to general practitioners' offices. Reprinted from *Social Science and Medicine*, 55, Lovett A, Haynes R, Sunnenberg G, Gale S, "Car travel time and accessibility by bus to general practitioner services," 97–111 (2002) with permission from Elsevier Science (39).

access that incorporate space-time activity patterns are under development and hold promise for health services research (44).

Evaluating Inequalities in Access

Evaluating differences in geographical access within the population and for population subgroups is a key task for health service analysts. Using the access measures discussed above, researchers and policy-makers have begun to explore inequalities in access to health care with the tools available in GIS (56). A study of the Canadian population's access to advanced medical treatments for stroke calculated typical transport times via ambulance and created one- and two-hour spatial buffers around the treatment facilities (59). By overlaying the buffers on a population map, the authors estimated that 15% of the Canadian population live outside the two-hour buffer, where excessive travel reduces treatment effectiveness. The study is flawed in its simple assumptions about ambulance travel, but it illustrates well GIS methods for combining population and transport data to examine inequalities in access.

Researchers have also looked at whether inequalities in access are patterned along social, geographical, or economic lines (34, 56). Combining GIS and statistical methods, a study in Perth, Australia, explored the relationships between social disadvantage and the quality and quantity of GP services available (28). The findings indicated that geographical access to services was relatively equal across socioeconomic groups. However, people residing in the most disadvantaged areas had difficulties in obtaining evening and same-day appointments. Thus, although services were geographically available, the times and quantity of services were inadequate for some disadvantaged populations.

In the United States, health care access problems for vulnerable populations such as children, racial and ethnic minorities, poor and immigrant groups are attracting increased attention. Although few GIS-based studies appear in the published literature [an exception is (56)], there is great potential for using GIS to identify vulnerable populations and examine geographical access to quality services and treatments. In exploring geographical access, we need to address the full range of barriers that vulnerable populations face in obtaining health care—transportation, time and economic constraints, and lack of social support and child care (70).

GEOGRAPHIC VARIATION IN UTILIZATION

Numerous studies have examined geographic variations in health care utilization in the United States. Among the most influential is the large body of research by Wennberg and colleagues (67). Their research involves computing utilization rates for specific diagnoses or procedures by hospital service area. After adjusting for age, gender, and race, rates are correlated with service-related and socioeconomic factors. The findings reveal huge disparities among areas in the utilization and cost of both elective and nonelective treatments and procedures (68). The causes of these variations are controversial, but most agree that both population need and service-related factors, such as the supply of health care providers, are important. Most geographic variations research does not use GIS explictly; however, GIS runs in the background, managing spatial data sets and displaying maps of utilization rates.

GIS can contribute in several ways to geographic variations research. Most research involves constructing geographical areas (i.e., Wennberg's "hospital service areas") and comparing rates across areas, and such area-based procedures have well-known limitations (49). GIS provides a tool for exploring the sensitivity of findings to changes in area definition. GIS also can be used to critically examine the geographical assumptions in utilization research, including assumptions about the allocation of services and patients across area boundaries and the measurement of health care supply and access variables. Avoiding the pitfalls of area-based ecological analysis (63) calls for innovative methods that work with data for small geographical areas and that recognize the complex forces that affect peoples' spatial interactions with health care providers. A study of mastectomy rates in Iowa employed GIS and spatial smoothing methods to describe variations at the subcounty level (58). Mastectomy rates clearly varied within hospital service areas and were higher in communities distant from hospital facilities.

An exciting new approach involves the use of individual-level data and multilevel modeling to understand variations in health care utilization. With multilevel modeling, one can estimate the effects of individual characteristics, as well as GIS-based measures of local health care supply and access (9). Increasingly, researchers are using these methods to examine the correlates of illness and health status (61), and some are using the methods to investigate the determinants of health care use. A multilevel analysis of immunization uptake in England found that the likelihood of uptake depended not only on characteristics of infants and their families, but also on characteristics of service providers. Some clinics achieved high rates of uptake despite serving a needy population (30).

GIS AND HEALTH CARE DELIVERY

Issues of need, access, and utilization come together in evaluating and planning health care services. How do health policies affect geographical access to health care? Does the geographical organization of services support high-quality, effective care? Where should services be located to best meet population needs? A growing number of studies are drawing on GIS tools and data sets to address these questions.

GIS-based research on service performance and effectiveness is in its infancy. This is a challenging area because it involves relating geographic data on health care need, access, utilization, and outcomes with the characteristics of service delivery systems. Most studies provide only a partial analysis of these relationships. An innovative project in Missouri examined the effectiveness of a community health center in improving access to care among needy, low-income residents (52). GIS was used to compare the actual areas served by the center with the areas targeted for service to determine if the intended target population was adequately served. The comparison showed significant gaps in service. By overlaying data from an assessment survey on health needs, the authors were able to identify areas of poor access and unmet need—areas with high priority for new clinic services and outreach.

For emergency medical services, effectiveness is measured in real time. Performance varies over time and space, with clear implications for health outcomes. A GIS developed for southern Ontario linked data on ambulance locations with a data set containing the location, time of day, response time, and type of call for each ambulance call (51). The system allowed analysts to display maps of response times by type of call and responding ambulance, and to identify calls and locations with unusually high response times. Maps and graphs provided a foundation for recommending improvements in ambulance deployment (Figure 2).

In the United States, the effectiveness of health care is also influenced by structural and technological changes in medical care, including, for example, the shift from fee-for-service to managed care and the growth of telemedicine and

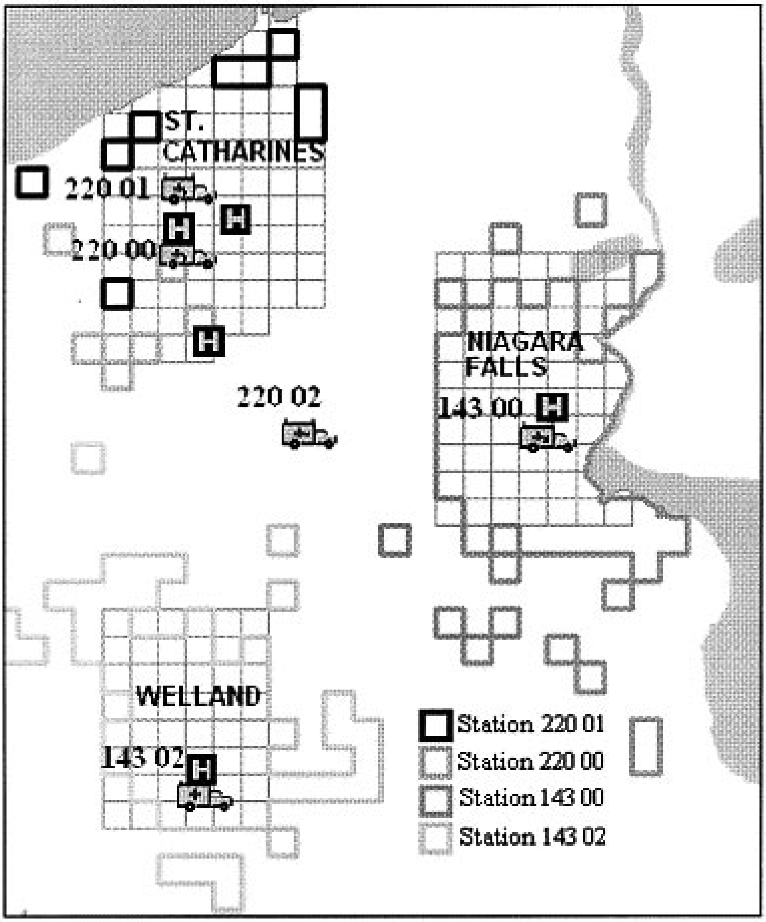

Figure 2 A map of ambulance catchment areas—areas in which a particular ambulance responds to 75% or more of all emergency calls. Reprinted from *Social Science and Medicine*, 49, Peters G, Hall GB, "Assessment of ambulance performance using a GIS," 1551–66 (1999) with permission from Elsevier Science (51).

evidence-based medicine. The effects of these changes vary from place to place. Geographical analysis of new organizational forms in health care is illustrated by Kronick et al.'s influential article (36), which appeared in the *New England Journal of Medicine*. Using geographic data and concepts, they showed that managed competition is only viable in metropolitan areas that have enough population to support competing managed care plans and enough independent health care organizations to provide the competition necessary to keep costs down. Outside these areas, in vast territories of the United States, managed competition was not seen as a workable policy for improving health care delivery.

In examining health care effectiveness from a geographical perspective, the effects on health outcomes are critically important (27). We know little about how the spatial organization of health services and treatments influences the outcomes of those treatments. Spatial organization refers to the numbers, locations, and place-based characteristics of service providers and the types of services offered at different locations. Utilization clearly varies with spatial organization, as does provider performance and decision-making (16, 43, 47). GIS can be used to integrate spatial databases and model spatial processes in order to untangle these relationships.

Locating Health Services

Health care analysts have long been involved with questions of location—deciding where to locate new service resources, which existing facilities to close, and how best to improve service locations. Location-allocation models, and related optimization methods, provide tools for addressing these types of questions (6). Relying on spatial data commonly available in GIS, location-allocation models are increasingly being implemented in a GIS environment.

The key component of a location-allocation model is the objective function, which specifies the goals to be achieved in choosing service locations. Most early health care applications worked with relatively simple objective functions, such as minimizing average distance or maximizing population coverage, and these considerations remain important, especially in developing countries where use of health services varies strongly with distance (33, 46, 64). More recently, optimization models have been used for vehicle routing problems—to identify shortest-path routes for Meals on Wheels programs—and in vehicle-based ambulance routing systems (69). These systems integrate the latest geographic information technologies. For example, an ambulance deployment system, currently being developed in Greece, includes ambulances equipped with GPS receivers for continuous monitoring of vehicle positions, automated geocoding of incident sites, and an efficient shortest path algorithm for ambulance routing that incorporates real-time road congestion data from traffic sensors (9). Extensive testing is needed before such systems can be widely implemented, and the role of human decision-making in automated deployment systems requires further attention.

Objective functions are becoming more complex to better represent locational goals for particular types of health services. Harewood developed a multiobjective model for ambulance deployment that considers the trade-off between population coverage and cost minimization (24). The model incorporates interdependencies among ambulances by estimating the probability that particular ambulances will be busy. For trauma care, a GIS-based model was developed that simultaneously locates both aeromedical depots and hospital-based trauma centers to optimize coverage by ground- and air-based ambulance services (3). Using Maryland as a test region, the model showed that substantial improvements in coverage of injured patients could be achieved by shifting existing trauma services to new locations.

Objective functions are also being extended to incorporate health outcome criteria. A model developed for coronary care units provided a solution for the number and locations of units to optimize estimated patient survival (43). Survival varied inversely with distance from the unit and directly with patient volume (the number of patients treated), reflecting the trade-off between facility size and geographical access. A more recent example attempted to optimize social costs, including the costs of maternal mortality, in locating obstetric care services in Bangladesh (33). These examples highlight the importance of linking the spatial organization of health services to health outcomes in selecting optimal locations.

GIS is being used to provide more accurate and detailed representations of "need" for services in location-allocation models. Because many health risks occur outside the home, it is often unrealistic to rely on surrogate indicators of need based solely on residential population. An analysis of EMS services in Connecticut incorporated data on the locations of motor vehicle crashes to evaluate ambulance sites and identify optimal locations (8). For services that address specific health problems, GIS can be used to geocode relevant data from surveillance systems or health surveys so that optimal locations are chosen based on the health problem of interest (3).

GIS also facilitates better measurement of geographical separation for location-allocation analysis. Today it is common to use GIS in calculating network travel times from demand areas to potential health facility sites (3, 8, 66). It is also straightforward to incorporate differences in mobility and transportation access among population groups, but few published location-allocation studies appear to have done this. Using tools readily available in GIS, analysts can better represent geographical context in identifying optimal health care locations, and they can visualize and explore model results (57, 69).

Spatial Decision Support Systems

Efforts are under way to develop spatial decision support systems (SDSS) that integrate GIS with an array of analytic methods to support health care planning and assessment. SDSS combine a geographic database, a system for database management and querying, a user interface, and a set of analytical tools like location-allocation and spatial interaction models (57). Designed for addressing "ill-structured" problems, the systems allow decision-makers to pose questions, explore alternatives, and identify potential solutions in an interactive, computer-based environment.

Most SDSS for health care planning have been customized applications developed for particular types of health services in particular contexts. Good recent examples include an SDSS for emergency response planning in the United States-Mexico border area (4), and a system to plan tuberculosis control in South Africa (65). Increasingly, SDSS include a suite of sophisticated spatial analytic models and tools that are tailored for a specific type of health service to explore geographic questions of interest. An SDSS for planning and evaluating home-delivered services includes algorithms for demographic forecasting, vehicle routing, and optimal location modeling with multiple objectives (22).

SDSS are often developed via a “top down” approach: Researchers and planners choose the tools and data to be included in the SDSS, and user input comes later in testing and fine-tuning the systems. An alternative approach is to involve decision-makers and stakeholders throughout the development process. Their input can guide all aspects of SDSS design including decisions about data, analytic methods, querying capabilities, and user interface. Foley took this approach in developing an SDSS for use in planning short-term care services to support informal carers—people who provide unpaid health care to relatives and friends (14). At many stages of the design process, input was sought from those who would use and potentially benefit from the system. Semistructured interviews were conducted with managers and planners of short-term care services to identify key geographic issues. Qualitative information from carers about their service needs was incorporated in the SDSS. The system grew out of a collaborative process, an approach that can facilitate participatory decision-making (60).

Another exciting development is the growth of Internet-based SDSS for health care planning and analysis. These systems generally have limited analytical capabilities, so they may not qualify as SDSS in the true sense of the word; however, they do provide spatial data and simple tools to support decision-making. A good example is the Primary Care Service Area Project (PCSA), recently released by the Health Resources and Services Administration (54). PCSA is a web-based system that provides a wealth of information about primary health care resources and demographic and health characteristics of the population for relatively small geographic areas. The areas reflect actual patterns of primary care use based on zip codes and are constructed by the same method as Wennberg’s hospital service areas. Although the PCSA areas suffer from the limitations discussed earlier, they provide comprehensive, small-area coverage of the entire United States for analyzing primary care. This is one of the first attempts at linking spatial data on health care resources, utilization and outcomes, and providing public access to such data—an effort with great potential benefits.

SDSS are evolving along two general frontiers: one that aims at incorporating expert knowledge and more complex and appropriate analytical tools, and another that emphasizes data dissemination, community concerns, and participatory decision-making (57, 60). These trends are apparent in health care applications, and they reflect a division between technical and human issues in SDSS. Closer ties between human and technical developments are needed for SDSS to be fully useful in examining major policy issues such as health care access, quality, and costs.

GIS and Homeland Security

The tragic events of 9/11 raised awareness of the critical roles of spatial data and GIS in homeland security. "Timely, accurate information, easily accessed and capable of being shared across federal, state and local political jurisdictions is fundamental to the decision-making capability of those tasked with the homeland security mission (12, p. 1)." In response to the terrorist attacks, GIS was used in high-resolution mapping of the World Trade Center site, in evaluating critical infrastructure systems, in coordinating emergency response, and in analyzing affected populations and businesses. Now homeland security is a national priority that calls for national preparedness and response capabilities.

Several recent reports highlight the spatial decision support requirements for confronting and addressing disasters, be they natural or human in origin (12). An essential component is a national spatial data infrastructure with detailed, integrated, and current geographic information including orthophotography, transportation, infrastructure, population, and emergency facilities. Information on the locations, capacities, and characteristics of health care resources, including hospitals and other health care facilities, health care providers, emergency services, medical laboratories, water and sanitary facilities, etc., is critically important. Spatial analysis tools are also needed for such tasks as impact assessment, emergency service deployment, spatial interaction modeling, and pattern detection. Developing a spatial decision support capacity at the national level, including both integrated spatial data and a common set of analytic methods, will be beneficial for many other policy arenas including health care.

FUTURE DIRECTIONS

Use of GIS in health care research has increased dramatically in the past decade. GIS has provided new ways to investigate health care needs for small geographical areas, better measures of geographical access to health services, and new approaches to analyzing and planning services locations. Nevertheless, adoption of GIS has been very uneven. Research areas that can benefit from GIS, such as research on geographic variations in health care utilization, have not made full use of GIS capabilities. Furthermore, some researchers continue to view GIS as primarily a mapping tool.

The uneven adoption of GIS in health services research is partly a result of structural barriers. Health services research requires spatial data on health resources, population, utilization, treatments, and outcomes, and data are often unavailable or provided at different temporal and spatial scales. Privacy and confidentiality restrictions limit access to data about health status and health outcomes, especially for individuals or for small areas. Data on health care utilization and treatments are often proprietary, controlled by health insurers and provider organizations. Even for public data, there may be problems with compatibility and sharing of information among agencies.

In the public sphere, efforts are under way to develop geographically linked health-related databases, such as the PCSA. However, data are provided only for predefined geographical areas. Flexible systems that allow users to define geographical areas of interest, and access data for those geographical areas, will greatly facilitate GIS-based health care research. Another challenge is to integrate health-related data across service systems. Many organizations—schools, social services, voluntary agencies—provide services that enhance and promote health. Some of these organizations provide formal medical care; others provide informal care that may reduce the need for formal health services. Linking such information by place/location can offer new insights into variations in health care costs, utilization, and outcomes.

Understanding health care needs and access also requires different types of geographical information. Indicators of health care need based on morbidity, mortality, and utilization have well-known limitations, as do many standard indicators of health care access. Researchers are turning to qualitative data from interviews, surveys, and oral histories in describing people's perceptions of health care (11). Such information can be incorporated in GIS based on place/location (42), but methods for analyzing qualitative data in GIS are not well developed.

Despite recent advances in spatial analysis methods and GIS, our understanding of the "human" dimension of geographic information remains limited. GIS and SDSS are appearing in a wide range of health care arenas—from health planning offices to homeland security agencies to managed care organizations. How do planners and decision-makers utilize these systems, and how do the systems affect decision-making processes? GIS is often used just for mapping, and maps can easily mislead (23). In addition, research suggests that health planners may have a poor grasp of the spatial concepts that underpin GIS and are confused by complex spatial analytic techniques (14). Research is sorely needed on how people acquire knowledge from GIS/SDSS and how they interpret GIS maps and analytic results.

At a broader scale, the wide dissemination of geographic information about health care quality, outcomes, and costs is reshaping consumers' interactions with the health care system. Through Internet and mass media, people can acquire information about the quality of health care at different locations and about the types of health problems that exist in their communities. How does such information affect health care decision-making, and how do the effects vary among population groups? At the same time, the rapid growth of managed care, ambulatory services, telemedicine, and provider networks is fundamentally altering health care delivery with concomitant effects on the spatial organization of health services. Traditional models that describe the spatial behaviors of health care consumers and providers are not likely to fit well in the new "digital" health care landscape. These new spatial behaviors, which can be studied and modeled in GIS, have high priority for future research attention.

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