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An enhanced approach for modeling spatial accessibility for in vitro fertilization services in the rural Midwestern United States

Pedram Gharani [a], Kathleen Stewart [b, *, 1], Ginny L. Ryan [c]

[a] School of Information Sciences, University of Pittsburgh, Pittsburgh, PA 15260, USA
[b] Department of Geographical and Sustainability Sciences, University of Iowa, Iowa City, IA 52242, USA
[c] Department of Obstetrics and Gynecology, Carver College of Medicine, University of Iowa, Iowa City, IA 52242, USA

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ABSTRACT

Highly technological in vitro fertilization (IVF) treatment is available at relatively few medical centers in rural United States. This research derives a spatial accessibility surface for IVF centers in a rural Midwestern state through the application of computational methods that consider spatial and non-spatial parameters to discover potentially underserved areas in the state. These methods include a modified gravity model and techniques from spatial interaction modeling. The approach develops an enhanced accessibility index that incorporates three key sociodemographic variables describing patients seeking infertility healthcare in Iowa that have been identified based on a survey of IVF care practitioners in the state. Self-organizing map techniques are used to reveal cluster locations based on the degree of match between census sociodemographic data and the expert-identified variables. The spatial accessibility surface is combined with the sociodemographic clusters to define an enhanced measure of spatial accessibility. The results suggest that while the state's IVF centers are located in tracts characterized by high spatial accessibility, at least 19% of patients travel from census tracts classed as moderate to low accessibility. This result reveals some opportunities for service improvements for these locations. Interestingly, for tracts that are characterized as having a lower patient sociodemographic match, high spatial accessibility does not appear to be a factor that improves the likelihood of patient care, at least for the variables investigated as part of this research.

1. Introduction

In the United States (US), approximately 10%–15.5% of reproductive-aged individuals are affected by infertility (Boyle, Vlahos, & Jarow, 2004; Chandra, Copen, & Stephen, 2014; Commenda, 2001; Thoma et al., 2013), and it is estimated that the demand for infertility care is being met for only 24% of patients (Centers for Disease Control and Prevention, American Society for Reproductive, & Society for Assisted Reproductive Technology, 2014; Chambers, Sullivan, Ishihara, Chapman, & Adamson, 2009; Chandra, Copen, & Stephen, 2014). Recent progress in medical technologies has significantly improved the chances for a successful pregnancy for many individuals (Centers for Disease Control and Prevention et al., 2014; Gunby, Bissonnette, Librach, & Cowan, 2009; Hammoud et al., 2009). One of the key modern treatments for infertility is in vitro fertilization (IVF). Due to the complexity and highly technological nature of IVF, and the fact that insurance coverage is usually limited and may be prohibitively expensive for patients; the availability of this care is limited to relatively few centers with the necessary equipment and expertise. As a result, the number of IVF treatment cycles performed per capita in the United States remains relatively low among nations in the developed world (Hammoud et al. 2009), and there is a particular concern for IVF treatment coverage in rural United States. IVF care can often be a time consuming procedure that requires patients to make many trips in order to complete the treatment. For this reason, accessibility plays an important role and patients with poor spatial accessibility may be at risk for not completing the cycles of treatment.

In this study, we investigate the topic of spatial accessibility to IVF care in Iowa, a prototypic Midwestern state in the US with a high proportion of rural counties, that is in the lowest quartile of

* Corresponding author.
E-mail addresses: pedram-gharani@pitt.edu (P. Gharani), stewartk@umd.edu, kathleen-stewart@uiowa.edu (K. Stewart), ginny-ryan@uiowa.edu (G.L. Ryan).
[1] Department of Geographical Sciences, University of Maryland, College Park, MD 20740, USA.

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states for percentage of reproductive-aged population covered by their own state's IVF centers (Nangia, Likosky, & Wang, 2010). The objective of this research is to develop a computational model for measuring spatial accessibility to IVF care in Iowa, i.e., define a quantitative index for spatial accessibility in order to reveal possible location-based disparities for this rural state. Considering the role of certain sociodemographic variables for accessibility enhances our approach (Summers et al., 2014). Others have also considered non-spatial factors with respect to accessibility, for example, Wang and Luo (2005) integrated spatial with non-spatial factors including ethnicity, income, and language ability using factor analysis in combination with 2SFCA methods in a study highlighting poor access to primary healthcare in Illinois. For this research, three variables including female age, median household income, and race and ethnicity were the focus, and we investigate how these variables influence the accessibility index and reveal locations that could be a good match with respect to patient populations. While undertaken for Iowa and for IVF treatments, the approaches developed for this research are generalizable to other geographic regions as well as other healthcare applications.

In Iowa, IVF care is offered by two centers: The Center for Advanced Reproductive Care at the University of Iowa Hospitals and Clinics (UIHC CARC) in Iowa City (http://www.uihealthcare.org/Infertilitycare) that includes an affiliated outreach clinic without laboratory facilities (the UI Women's-Quad Cities Clinic), and Mid-Iowa Fertility, P.C. in Des Moines, Iowa (http://www.midiowafertility.com). A number of factors relate to the likelihood of a patient seeking infertility treatment, including the age of the woman seeking care, household income, family size, race and ethnicity, availability of health insurance, religion, and level of education (Fujimoto et al., 2010; Greil, McQuillan, Shreffler, Johnson, & Slauson-Blevins, 2011; Henry et al., 2011; Jain, 2006; Jain & Hornstein, 2005; Missmer, Seifer, & Jain, 2011; Owen, Goldstein, Clayton, & Segars, 2013). Spatial accessibility refers to the relative ease by which services can be reached from a given location (Kwan, 1998) and highlights the possibility of barriers due to the spatial separation between supply (i.e., IVF care providers) and demand (i.e., individual residents) and how connected these two groups are in space. Previous research on spatial accessibility has shown that spatial accessibility is affected by numerous factors including the location of the patient population, the location of the centers that offer healthcare services, and the transportation network used by patients to travel to healthcare centers (Dewulf, Neutens, De Weerdt, & Van de Weghe, 2013; McLafferty, 2003; Morrissey, Ballas, Clarke, & Hynes, 2013; Schuurman, Bérubé, & Crooks, 2010; Shi, Alford-Teaster, Onega, & Wang, 2012; Wang, 2012). Key spatial variables include the distance and travel time linking potential patients' residential locations in a region with the locations of healthcare centers in their region (Joseph & Bantock, 1982).

The major contribution of this paper is an approach that considers both spatial and non-spatial parameters in a novel way in order to reveal underserved areas based on both spatial and non-spatial driving factors. In this research, a modified gravity model serves as the foundation for estimating spatial accessibility in Iowa at the granularity of census tracts. Street network data for Iowa from ESRI's StreetMap Premium is used for distance and travel time computations. Sociodemographic data from the 2010 US Census (http://factfinder2.census.gov) for female age, median household income, and race/ethnicity for Iowa is acquired to represent the variability of the state's population with respect to these factors, and to represent certain fundamental characteristics of patients seeking infertility care. A survey of IVF physicians and nurses at UIHC was undertaken to provide insights into the range and relative importance of these sociodemographic characteristics from the healthcare provider perspective based on their significant experience. To produce a map of the sociodemographic match of potential infertility patients per census tract, the multidimensional data collected via the survey is clustered using self-organizing map (SOM) techniques. The results of the sociodemographic analysis are integrated with the computed spatial accessibility index to derive an enhanced accessibility index for tracts in Iowa revealing where, for example, there is low spatial access but high match with respect to sociodemographic profile, or high spatial access but possibly low sociodemographic match. In this way, the variability in access to IVF centers across the state will be understood in light of the sociodemographic characteristics of the state's population, and potentially underserved areas may be revealed. The research investigates three different subtopics including:

- identifying the elements of an index for measuring spatial accessibility to IVF care;
- enhancing spatial accessibility results with the sociodemographic characteristics of typical IVF patients (i.e., how can the computed indices for spatial accessibility be combined with sociodemographic variables?); and
- locating census tracts that are low in access, but potentially a good match given the estimated sociodemographic characteristics of the locations.

The rest of this paper is structured as follows: In Section 2, we discuss related research on spatial accessibility and computational approaches to accessibility. We also present our approach that uses a modified gravity model for representing spatial accessibility, and describe the steps taken to calibrate the model. In the methods discussion of Section 3, the data used for this research are introduced, as are the computational framework for computing accessibility, the methods for integrating non-spatial (sociodemographic) parameters, and how clustering is utilized to produce an enhanced model of spatial accessibility. We show how the accessibility measures can be extended through the inclusion of sociodemographic variables. Section 4 presents the results including geovisualizations of spatial accessibility for IVF care in Iowa, and the final section presents conclusions and perspectives for future research including the implications for locations beyond Iowa.

2. Background

2.1. Spatial accessibility

GIS and related spatial analytic techniques comprise a set of computational tools for evaluating the spatial organization of health care, especially in regards to health outcomes and access. GIS plays a critical role in studies examining health care needs through facilitating the spatial linking of diverse health, social, and environmental data sets. The capabilities of GIS for mapping and visualizing spatial data as well as its strong analytic capabilities are well suited for generating meaningful spatial solutions for health care service accessibility. Spatial accessibility is measured using different approaches including counting the number of centers per a predefined area or zone, determining the distance from population centers to healthcare facilities, determining the travel time to reach healthcare service centers, and computing the opportunity cost and impedance as part of a formal model of access (Dewulf et al., 2013; Morrissey et al., 2013; Schuurman et al., 2010; Shi et al., 2012). Using GIS to compute spatial accessibility makes it possible to consider more variables as part of the analysis; for example, GIS contributes to more sophisticated approaches for measuring spatial access through the use of, for example, geographic aggregation and distance-based reasoning methods