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# Spatial accessibility in suboptimally configured health care systems: A modified two-step floating catchment area (M2SFCA) metric

Paul L. Delamater*

*Department of Geography, Michigan State University, East Lansing, MI, USA*

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ABSTRACT

The floating catchment area (FCA) family of metrics employ principles from gravity-based models to incorporate supply, demand, and distance in their characterization of the spatial accessibility of health care resources. Unlike traditional gravity models, the FCA metrics provide an output in highly interpretable container-like units (e.g., physicians per person). This work explores two significant issues related to FCA metrics. First, the Three Step Floating Catchment Area is critically examined. Next, the research shows that *all* FCA metrics contain an underlying assumption that supply locations are optimally configured to meet the needs of the population within the system. Because truly optimal configurations are highly unlikely in real-world health care systems, a modified two-step floating catchment area (M2SFCA) metric is offered to address this issue. The M2SFCA is built upon previous FCA metrics, but allows for spatial accessibility to be discounted as a result of the suboptimal configuration of health care facilities within the system. The utility of the new metric is demonstrated through simulated data examples and a case study exploring acute care hospitals in Michigan.



## 1. Introduction

Characterizing the opportunities available to populations or groups of people has been a longstanding goal in health services and health geographic research. Populations are distributed nearly continuously throughout a region, yet are served by a facility or set of facilities located at discrete point locations (Joseph and Phillips, 1984). Inequalities in the availability and accessibility of resources are an inevitable outcome of this configuration. Regional availability measures attempt to characterize these differences, allowing researchers to explore relationships between population-based health outcomes or behaviors and the spatial organization of the health care delivery system.

Regional availability can be defined as the number of opportunities available to a population as moderated by distance. In this, the supply of resources and the potential demand (availability) and the separation between the population and supply (accessibility) must both be considered for a comprehensive characterization. Previous research has identified availability and accessibility as the spatial components of a population's overall access (Khan, 1992). The combination or fusion of accessibility and availability has more recently been referred to as "spatial accessibility" (Guagliardo, 2004).

The floating catchment area (FCA) family of metrics are based on gravity models, incorporating the interaction among supply, potential demand, and travel cost in their characterization of spatial accessibility. These metrics offer a substantial theoretical advantage over traditional container-based regional availability measures. Specifically, the shortcomings of container-based measures (e.g., travel across unit boundaries is not considered) are overcome by allowing the containers to "float" as travel buffers or catchments based on distance or travel time from the facility and population locations. Unlike general gravity models, the FCA metrics provide an output in a highly interpretable supply to population ratio. The most popular of the FCA metrics are the two-step floating catchment area (2SFCA, Radke and Mu, 2000; Luo and Wang, 2003) and the Enhanced 2SFCA (E2SFCA, Luo and Qi, 2009). The E2SFCA represents a significant advance in spatial accessibility characterization and has been implemented in a number of studies (e.g., see McGrail and Humphreys, 2009a; Dai, 2010; Wan et al., 2011).

Recently, Wan et al. (2012) and Bell et al. (2013) proposed modified versions of the E2SFCA, both called the three-step floating catchment area (3SFCA). Although these two metrics share a name, the content of the "3rd" step in each is dissimilar. In Bell et al. (2013), the 3rd step of the 3SFCA is an aggregation of E2SFCA values into larger population units. No modifications are made to

* Tel.: +1 213 448 7625.
*E-mail address:* delamate@msu.edu

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the underlying calculation of E2SFCA values for the smaller population units; therefore, this metric remains solidly grounded in the two-step framework. The 3SFCA provided by Wan et al. (2012) varies more dramatically from its predecessors. The 3rd step incorporates the potential for competition among facilities when more than a single facility falls within the catchment area of a population location. In this, the 3SFCA assumes that the potential population demand at a single facility will be discounted by the presence of other nearby facilities. The integration of competition into an FCA metric appears reasonable on a theoretical level and novel in the applied model; however, this work illustrates that the 3SFCA from Wan et al. (2012) overestimates the role of competition in an applied setting, leading to both over and underestimation of spatial accessibility for population units within the system.[1]

Luo and Wang (2003) and Luo and Qi (2009) point out that FCA metrics represent a special case of a supply to population ratio, integrating distance decay to overcome the limitations of treating regions as simple “containers”. The weighted average of FCA values for the individual population units has been shown to equal the supply to population ratio of the overall study area (Shen, 1998; Luo and Wang, 2003; Wang, 2012). This perceived strength of the FCA metrics also doubles as a major limitation – through this property, the overall study area is considered a single, large “container”. All supply opportunities are assumed available to the population, regardless of the configuration of people and supply locations within the study area. Thus, current FCA metrics carry the inherent assumption that the configuration of supply locations is *optimal* – (1) all supply is fully allocated to the population regardless of how the opportunities are arranged within the larger study area and (2) any reconfiguration of the supply locations will affect spatial accessibility of the individual population units, but will have no effect on the overall spatial accessibility of the study area. This is troubling given that no delivery system is truly optimal and any attempts to reconfigure existing supply locations will not be reflected in the spatial accessibility of the overall system as reported by the current FCA metrics.

As a result of this property, spatial accessibility calculated with current FCA metrics may accurately describe the availability of resources, but does not simultaneously integrate both accessibility and availability. The assumption of an optimal population/provider configuration will necessarily result in an overestimation of spatial accessibility throughout the system. The specific effects of this assumption are difficult to observe in large, complex systems of providers and populations, providing the likely explanation for why this problem has not been addressed in the previous literature.

This work presents the modified two-step floating catchment area (M2SFCA) metric. By accounting for suboptimal configuration of health care locations, the M2SFCA provides two major advances in characterizing spatial accessibility. First, accessibility and availability are integrated simultaneously and coherently into a single metric, allowing for the measured output to better resemble the underlying theory of spatial accessibility. Second, the M2SFCA can be used to describe the overall “efficiency” of spatial accessibility within the health care system. As a result, large-scale health care systems (e.g., states or regions) can be compared quantitatively. Additionally, the M2SFCA output offers the ability to evaluate the overall impacts of local changes in the health care system (e.g., opening, closing, or relocation of facilities) and provides a metric that can be employed in health care planning applications.

[1] For the remainder of this paper, any further mention of the 3SFCA refers to Wan et al. (2012).

The remainder of this paper is divided into five main sections. First, a short background on the evolution of the FCA family of metrics is provided and the limitations in the newly proposed 3SFCA are highlighted. The second section demonstrates the manner in which the current FCA metrics contain the assumption of an optimal population/provider configuration. Next, the M2SFCA is detailed, while also exploring the implications associated with assuming a suboptimal configuration. Fourth, to illustrate the applied differences in outputs among FCA metrics, the outputs of the M2SFCA, 3SFCA, and E2SFCA are compared in case study of the spatial accessibility of hospital beds in Michigan. The final section includes a discussion of the advantages provided by the M2SFCA and suggests directions for future research.

## 2. Background

Early research exploring the spatial components of population access to health care services often separated accessibility and availability characterization or only considered one or the other. The limitations of non-integrated measures can be highlighted simply by considering the differences in the available opportunities for two populations of equal size – one near a small, local hospital and the other near a major teaching or research hospital. Although the distance between each population and its respective hospital would be similar, the availability of resources would clearly be much different for the populations. As a result, only considering accessibility would inadequately capture the opportunities available to each population.

Another method often employed to characterize regional availability is to employ a container-based, availability metric. To calculate these metrics, the opportunities available within predetermined areal units (the containers) are summed, then divided by the population of the areal unit. Often, existing administrative boundaries (e.g., counties or Zip Codes) are chosen for this task. Container-based metrics are easy to implement and interpret; however, they are limited in their underlying assumption that facilities outside the predefined areal unit are inaccessible and that those within the unit are equally accessible to all people within the areal unit. This limitation is particularly significant for populations residing near the border of the areal unit or when the population units represent large geographic areas. Although both supply and potential demand is incorporated in container-based measures, the actual separation among people and facilities is not considered.

Gravity models allow supply, demand, and distance to be incorporated simultaneously to estimate spatial accessibility (Weibull, 1976). A gravity model takes the general form

$$A_i^G = \sum_{j=1}^{m} \frac{S_j f(d_{i,j})}{D_j} \tag{1}$$

where

$$D_j = \sum_{i=1}^{k} P_i f(d_{i,j}). \tag{2}$$

In the model, $A_i^G$ is the measure of “attraction”, $S_j$ is the supply of services at location $j$, $P_i$ is the population of $i$, $D_j$ is the potential demand at location $j$, $m$ is the set of all hospitals, $k$ is the set of all population units, and $f(d_{i,j})$ is a distance decay function based on the distance between $i$ and $j$. Unfortunately, the units of the output values ($A^G$) in gravity models are not intuitively comprehensible (Joseph and Phillips, 1984). Therefore, although gravity models offer a more complete theoretical model of spatial accessibility, their output units limit their general applicability towards health care resources evaluation and planning and/or health care policy concerns.