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A behavioral model of accessibility based on the number of available opportunities

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ABSTRACT

The paper proposes a new behavioral definition of accessibility as the expected number of opportunities "available" for a subject to perform an activity, where "available" means that the opportunity *i*) is perceived as a potential alternative to satisfy one's needs, and *ii*) it can be reached given the spatiotemporal constraints of the individual's schedule. A new class of accessibility models is derived in accordance with the above definition, exploiting the strengths of both utility-based and opportunity-based models, and explicitly incorporating spatiotemporal constraints which may limit the availability of perceived opportunities. The proposed model is formulated for both active and passive accessibility, does not suffer from reflexivity issues, supports both trip-based and activity-based formulations, and scales up from individual to spatially aggregated opportunities, taking into account effectively the different ways of perceiving opportunities. Moreover, the resulting accessibility measure has a straightforward interpretation, being expressed in physical units, and is comparable across different locations. Performances of the proposed model in reproducing the active accessibility to cinemas in the Naples metropolitan area (Italy) are compared to those of a traditional isochrone-based measure and a distance–decay model. For this aim, measurements of individuals' perceived cinemas were gathered through a survey, and adopted for the calibration of both the accessibility models. Calibration results show that the proposed model outperforms both the traditional isochrone-based measure and a distance–decay model calibrated against the same dataset, better reproducing both the quantity and spatial distribution of perceived opportunities.

1. Introduction

The concept of accessibility has long been introduced in the transportation planning literature as a way to "measure" the extent and quality of the interaction between land development patterns of a given area and the transportation systems serving it (Cascetta, 2009). Although originally introduced in the transportation planning literature, the concept of accessibility is inherently interdisciplinary, and over the years has been adopted in many other scientific fields including urban geography, network and spatial economics, regional science and geographical analysis. From a conceptual standpoint, accessibility reflects either the ease of a traveler to reach places in the study area where s/he can carry out a particular activity – in the literature referred to as person or active accessibility – or the ease with which an activity can be reached by potential users in the study area – in the literature referred to as place or passive accessibility. For a discussion on these dual concepts and the methodological problems involved, see Ben-Akiva and Lerman (1979), Pirie (1979), Hanson (1995), Geurs and van Wee (2004), Miller (2007) and Cascetta (2009).

Accessibility measures have been used in a broad variety of applications as a Decision Support System (*DSS*) for planning interventions involving transportation and land-use systems. These measures contribute in *i*) understanding and modeling transportation/land-use interactions (e.g. Wang et al., 2015), *ii*) understanding and modeling travel demand (e.g. activity participation and travel levels; Bifulco et al., 2010), *iii*) assessing the effectiveness of transportation plans and projects (e.g. Cascetta et al., 2015) with respect to planning objectives (e.g. equity and territorial development), and *iv*) solving optimal location problems for public/private utilities and/or services (e.g. Cartenì, 2014).

In particular, active accessibility has often been advocated as a cost-of-living index in relation to the quality of the interaction between land-use and transportation systems. Conversely, passive accessibility has received very limited attention in the literature, while its application fields are increasingly spreading (e.g. the problems of optimal location of public utilities and services or commercial activities such as shopping malls).

Despite its application in several scientific fields, accessibility is an abstract concept, and many possible definitions have been formulated

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over the years. In the seminal paper by Hansen (1959), the concept accessibility was defined as "the opportunity which an individual or type of person a given location possesses to take part in a particular activity or set of activities". Thereafter, accessibility was seen both as a measure seeking to capture the net utility received by a subject in a given location, i.e. "the consumer surplus, or net benefit, that people achieve from using the transport and land-use system" (Leonardi, 1978), or as the measure of "the average number of opportunities which the residents of the area possess to take part in a particular activity or set of activities" (Wachs and Kumagai, 1973), within a given travel time, distance, or generalized cost (see, for example, Hack, 1976; de Lannoy and van Oudheusden, 1978). A review of alternative definitions of accessibility can be found in Curtis and Scheurer (2010).

Cascetta et al. (2013) proposed a classification of accessibility indicators based on three levels. The first level reflects the two modeling approaches mentioned above, thus distinguishing utility-based from opportunity-based measures. At the second level, accessibility measures are classified as behavioral, i.e. based on explicit assumptions on user attributes and choice mechanisms, or non-behavioral, i.e. based on descriptive, non-causal relationships. Ultimately, at a third classification level, accessibility measures are classified with regard to the level of aggregation, i.e. individually disaggregate models vs. aggregated ones.

Other possible classification approaches can be found in Baradaran and Ramjerdi (2001), who classify accessibility measures into five categories (travel cost approach, gravity or opportunities approach, constraint-based approach, utility-based surplus approach, composite approach), or in the work by Curtis and Scheurer (2010), who presented a sevenfold classification (spatial separation measures, contour measures, gravity measures, competition measures, time-space measures, utility measures and network measures). An excellent review of the formulations and related applications of the main measures can be found in Bhat et al. (2000).

From a methodological point of view, in the last decade the development of accessibility models has undergone significant transformations: more detailed information on individual activity patterns has become available, knowledge of neighbor/reachable opportunities has improved thanks to smart technologies, and the accuracy of Geographic Information Systems has increased. In response to such augmented information, traditional measures of accessibility were extended in the spatial domain to better mimic the interaction between spatially distributed opportunities and the transportation system. For recent advances on this topic, see, for instance, Farber et al. (2013) and references therein.

However, greater awareness of the spatial relationship between land-use, activities and transportation systems has not translated into measures that can properly explain the behavioral differences in the level of perception of spatial distributed opportunities. In particular, existing measures are unable to describe more sophisticated behavioral phenomena in the perception of opportunities, such as the dominance of strong attractors versus competing alternatives, as well as the increasing attractiveness of agglomerated opportunities (Cascetta and Papola, 2001; Cascetta and Papola, 2009; Baradaran and Ramjerdi, 2001).

De facto, long-standing formulations of accessibility measures such as those of gravity, random utility and cumulative opportunities are still widely adopted in the field literature (e.g. Odoki et al., 2001; Recker et al., 2001; Halden, 2002; Bertolini et al., 2005; Straatemeier, 2008; Geurs et al., 2010; Chen et al., 2011; Condeço-Melhorado et al., 2011; Ferrari et al., 2011; Delmelle and Casas, 2012). Notwithstanding the acknowledged merits of these approaches, in this paper we claim that such indicators suffer from shortcomings that will be discussed in the following and motivate the proposed approach.

1.1. Limits of existing accessibility measures

Leaving out of the discussion network and spatial separation measures derived from graph theory (e.g. Savigear, 1967; Ingram, 1971; Leake and Huzayyin, 1979; Guy, 1983; Allen et al., 1993) as they are not rooted in a framework combining information from both the land-use and transportation systems, major shortcomings of traditional accessibility measures are reviewed below. It is worth noting that accessibility measures based on either gravity (e.g. Hansen, 1959; Knox, 1978; Guy, 1983; Giannopoulos and Boulougaris, 1989; Handy, 1992; Levinson and Kumar, 1994; Agyemang-Duah and Hall, 1997; Kockelman, 1997; Bhat et al., 1998; Bhat et al., 1999; Cervero et al., 1999) or random utility models (e.g. Ben-Akiva and Lerman, 1979; Richardson and Young, 1982; Martinez, 1995; Niemeier, 1997; Sweet, 1997) are seen here as utility-based measures, while cumulative opportunities (e.g. Wachs and Kumagai, 1973; Weibull, 1976; Black and Conroy, 1977; Breheny, 1978; Black et al., 1982; Guy, 1983; Handy, 1992; Ikhrata and Michell, 1997) are categorized as opportunity-based measures.

A common criticism to aggregate accessibility measures proposed in the literature is their tight dependency on the spatial zoning level (number and size of zones involved), and the fact that they assign the same level of accessibility to all individuals in a single zone (e.g. Ben-Akiva and Lerman, 1979). This limitation is particularly troublesome for gravity models which were shown to be very sensitive to the delimitation and zoning of the study area (Baradaran and Ramjerdi, 2001). Moreover, gravity measures suffer from a lack of behavioral justification, thus neglecting the possibility for possible attribute variations across individuals (Baradaran and Ramjerdi, 2001; Handy and Niemeir, 1997). Another shortcoming is related to the tailored calibration techniques of such measures and to the limited transferability of calibrated models to different study areas (Agyemang-Duah and Hall, 1997).

Accessibility measures derived from the random-utility modeling framework have also faced major criticism in the literature. Bhat et al. (2000) highlighted the inevitable bias in defining a set of choices for opportunities to be included in this approach. Indeed, when measuring accessibility, not all options may be available to all individuals, and there are no physical constraints for the choice set (Martinez, 1995). In other words, in this framework the choice set is assumed given, and no variability across individuals is modeled. Moreover, most of the measures presented in the literature, being based on multinomial logit specifications, suffer from the property of binary independency, also known as independence of irrelevant alternatives, which leads to a decreasing probability of viable choices (Martinez, 1995). To overcome some of the previous limitations, net utility indicators have been extended to reflect the outcome of travel and activity scheduling, hence the relative attractiveness of various alternatives for activity participation, trip combination, travel model and timing (e.g. Ben-Akiva et al., 2006).

At a more general level, the main criticism leveled at utility-based measures relates to the ambiguity in what the magnitude of the indicators expresses. In particular, Handy and Niemeir (1997) pointed out the lack of physical interpretation of the results, and stated that such measures are not suited to comparisons among different territorial areas.

To overcome this major limitation, opportunity-based measures have been proposed. The cumulative-opportunities index, based on the definition of isochrones, is by far the most popular of its kind. In this framework, active (passive) accessibility is defined as the total number of potential activities (users) available to an individual (destination) located in a given area. Despite the ease in the computation and interpretation of the above measure, several studies pointed at its main drawbacks: the lack of a behavioral dimension and the incapability to model the differences in the perception of near and far opportunities, i.e. opportunities are equal regardless of their cost and desirability for users (Vickerman, 1974; Ben-Akiva and Lerman, 1979; Baradaran and Ramjerdi, 2001; Geurs and van Wee, 2004). Weibull (1976) addresses the former issue by including a parameter related to car ownership, while Handy (1992) addresses both issues with a distance–decay weighted function calibrated against observed travel choices. Such enhancements, however, are still unable to describe more sophisticated behavioral phenomena conditioning the perception of available