Gravity-Based Accessibility Measures for Integrated Transport-Land Use Planning (GraBAM)

Enrica Papa, Pierluigi Coppola

To cite this report: Enrica Papa and Pierluigi Coppola (2012) Gravity-Based Accessibility measures for Integrated Transport-land Use Planning (GraBAM), in Angela Hull, Cecília Silva and Luca Bertolini (Eds.) Accessibility Instruments for Planning Practice. COST Office, pp. 117-124.

Gravity-Based Accessibility measures for Integrated Transport-land Use Planning (GraBAM)

Author of report: Enrica Papa*, Pierluigi Coppola**

* Organisation: Dipartimento di Pianificazione e Scienza del Territorio DiPiST, Università degli Studi di Napoli "Federico II"

Address: Piazzale Tecchio, 80, 80125 Napoli

E-mail: enpapa@unina.it

** Organisation: Dipartimento d'Ingegneria dell'Impresa, Università degli Studi di Roma "Tor Vergata"

Address: Via del Politecnico 1, 00133 Roma

E-mail: coppola@ing.uniroma2.it

Background

In transportation planning a paradigm shift is occurring: from mobility-oriented analysis (which evaluates transport system performance based on quantity and quality of physical travel) to accessibility-based analysis (which considers a broader range of impacts and options) (Litman, 2010). The instrument described in this paper, is an example of this shift which gives to accessibility measures a central role in transport and urban planning.

Such accessibility instruments have been developed both for scientific and planning motivations. In the academic field the important role of transport infrastructures for spatial development is well recognized: areas with better access to the locations of input materials and markets will be more productive, more competitive and hence more attractive than remote and isolated areas (Linneker, 1997). However, the impact of transport infrastructures on spatial development has been difficult to be verified empirically; in fact, modeling analysis, such as those based on accessibility measures, is necessary to investigate these impacts and to analyse the effects of transport infrastructure and service improvements on the spatial distribution patterns. In other words, the scientific question the accessibility instrument here presented, wants to answer is "what are the impacts on the land use induced by changes in the transportation system?"

The scientific question has direct implications for planning, related to the distributive issues of transport interventions: the goal of the accessibility instrument is to assess and to value the benefits of changes in either the land-use or the transportation systems, as a performance indicator of integrated land-use and transport planning. In other words, the question the instrument wants to address is "who reaps the accessibility benefits from investments in the transport system and where are these located?"

Conceptual framework and theoretical underpinnings

The accessibility typically measures "the ease and convenience of access to spatially distributed opportunities with a choice of travel" (U.S. Department of Environment, 1996). Several definitions, and related measures, can be found in the literature. Here we propose a "gravity-based" measure of accessibility, so called "gravity-based" since it can be derived from "gravity-type" trip distribution model (see Hansen, 1959); this has been used in various analyses (Geertman and Ritsema van Eck, 1995).

Starting from the general definition of "gravity-based" measures, two types of accessibility have been considered, referred to as "active" and "passive" accessibility (Cascetta, 2009). The active accessibility of a given zone *i* is a proxy of the ease of reaching the activities/opportunities located in different zones *j* of the study area for a given purpose (e.g. workplace, shopping) moving from *i*:

$$A_{act,i} = \sum_j g(W_j) f(c_{ij}) \qquad (1)$$

where W_j is the activity/opportunity to reach in zone *j*, and c_{ij} is the generalized cost of reaching zone *j* from zone *i*.

On the other hand, the passive accessibility is a proxy of the opportunity of an activity located in a given zone *i* to be reached from the potential "consumers" coming from all the other zones *j* of the study area for a given purpose (e.g. the clients of a shop):

$$A_{pas,i} = \sum_j g(W_j) f(c_{ji}) \qquad (2)$$

where W_j are the potential "consumers" of the activity/opportunity to be reached in the zone *i*, and c_{ji} is the generalized cost of reaching zone *i* from zone *j*.

Such definitions do consider the accessibility of a given zone as a sum of the generalized travel costs between zones itself and the other zones of the study area, weighted by an attraction term representing either the opportunities to be reached in the other zones (in the case of the active accessibility) or the potential "consumers" of the opportunity located in the given zone (in the case of the passive accessibility). The weights are typically powered by an exponent greater than one to take into account the agglomeration effects (if any), whereas the impendence function, $f(c_{ij})$, typically includes the travel time in a negative exponential form, based on the assumptions that: the attraction of a destination increases with size and declines with distance or travel time or cost (i.e. the gravity-based assumption).

In doing so, the accessibility measure can include both the effects of changes in the transportation systems, captured by means of the function $f(c_{ij})$, and in the land use patterns (captured by the weights W*j*).In that, gravity-based accessibility indicators are more powerful than travel time accessibility indicators[1] and daily accessibility indicators[2]; moreover, they are founded on sound and consolidated behavioral principles of the Random Utility Maximization (Ben-Akiva and Lerman, 1985).

Operational aspects

The accessibility indicators we have tested are:

- the active accessibility of the residents towards the workplaces of a study area;
- the passive accessibility of the economic activities with respect to the residents of a study area.

The active accessibility measures have been calculated as:

$$A_{act,i} = \sum_j E(j)^{\alpha_1} . exp\ (\alpha_2 . C(i,j)) \qquad (3)$$

where: *E*(*j*) is the number of workplaces in the zone *j*; *C*(*i,j*) is the generalized travel cost (i.e. weighed sum of the travel time and travel costs) between zone *i* and zone *j*; α_1 and α_2 are parameters to be calibrated (see Coppola and Nuzzolo, 2011).

The passive accessibility measures have been calculated as:

$$A_{pas,i} = \sum_j Res(j)^{\gamma_1} . exp\ (\gamma_2 . C(j,i)) \qquad (4)$$

where: *Res*(j) is the number of people residing in zone *j* (i.e. the potential clients of the economic activities in *i*); *C*(*j,i*) is the generalized travel cost between zone *j* and zone *i*; γ_1 and γ_2 are parameters to be calibrated.

The above definition of the accessibility measures requires the subdivision of the study area (and portions of the external area) into a number of discrete geographic units called *traffic analysis zones* (TAZ's) and the definition of the relevant infrastructures and services (Figure 1). All trips that start or end within a zone are represented as if their terminal points were in a single fictitious node called *zone centroid.*

To physically delimit the zones, the criterions generally adopted can be summarized in respect of (Cascetta, 2009):

- the physical geographic separators placed on territory as railways, rivers, etc.;
- the official administrative limits as census sections, municipal borders, etc.;
- homogeneity: the land use, socioeconomic characteristics, and their accessibility to transportation facilities and services.

In general the number of the zones inside the study area is closely connected to the end-users' level to be achieved. In our case study, the Regione Campania has been subdivided into 383 "homogeneous" traffic zones with respect both to their land-use characteristics (e.g. level of population and economic activities) and to their

---

[1] measures the accumulated generalised travel costs to the set of destinations: all destinations in the set get equal weight irrespective of their size and all other destinations are weighted zero (the activity function is rectangular).

[2] Based on the notion of a fixed budget for travel, generally in terms of a maximum time interval in which a destination has to be reached to be of interest.

accessibility to transportation networks. A traffic zone represents either one municipality, or a group of municipalities (typically the small ones) or part of a municipality (this is the case of the large cities).

Zoning is related to the subsequent phase of selection of the relevant supply elements and the definition of the transport supply graphs. By means of these graphs the OD travel costs and travel times needed for the computation of the generalized travel cost can be estimated.

The datasets used in the accessibility instrument here presented include:

- Origin-Destination (OD) tables for inter-zonal travel time and travel costs;
- Demographic and socioeconomic data (e.g. the employment distribution) by each zone;
- Zone geographic boundary files.

Socioeconomic data (workplaces and resident per zone) are typically available and acquirable from the National Institute of Statistics (e.g. the ISTAT in Italy). The implementation of the transport supply model is more complex, in that it requires the collection of the characteristics of transportation infrastructures and services in the study area, and the implementation of such elements into a simulation software package. In our case, the data have been processed using the "TransCAD Transportation GIS Software", that require a medium-high degree of technical expertise to perform the calculations and for the interpretation of results.

The calibration of the parameters, which might represent the mayor difficulty of the accessibility instrument, requires the estimation of a gravity-based trip distribution model using a survey carried on in the specific case study, or, alternatively, adapted to the case study from similar ones.

Relevance for planning practice

The above accessibility instruments can be used to measure the distribution of wider economic benefits of alternative transportation projects. Furthermore, by working with data in a GIS environment, the spatial distribution of current accessibility levels as well as future changes in accessibility can be displayed (Figure 3). Accessibility levels and changes can be associated with socioeconomic data available at the zone level to estimate how current accessibility and benefits may vary by socioeconomic group.

Furthermore the accessibility indicators can be also calculated for a specific transport mode (road, rail, multimodal transport), for a precise trip purpose, for a particular economic activity category and/or for a specific social group of residents.

These accessibility measures can be used in a variety of operational planning and public involvement activities of transportation agencies where it is necessary to evaluate how the impacts of new infrastructures and transportation services are distributed. Moreover, they could be integrated in a more complex Land-Use Transport Interaction (LUTI) modeling structure (see for instance Figure 2), to simulate the impacts of changing accessibility on the residential and economic activity spatial distribution, as well as on dwelling prices (see for instance Coppola and Nuzzolo, 2011). In this respect, they are useful in the Land-Use/Transport decision making process to identify an interrelation between the accessibility and the changes in the population and economic activities spatial distribution pattern, as well as on the dynamics of the real estate market.

In this respect, they have been already used in several applications in transport planning processes, in different feasibility studies for transport infrastructures assessment, and in Transport Masterplans at different scales (urban, provincial and regional). One of the latest applications regards the Regional Metro System Plan (RMS) of the Campania Region (South-Italy), which is an integrated land-use, infrastructure and operational plan, including Naples and the whole Campania Region (see Cascetta and Coppola, 2004; Cascetta and Pagliara, 2008).

It's important to stress that these measures in the Italian context are not the common practice used in city and urban planning tools; they are mainly used in transport planning decision process.

Strengths and limitations

From a scientific point of view, the described instrument has a strong theoretical base, which is well accepted in transport planning field. Furthermore the modeling framework takes into account the spatial interaction between the distribution of the demand and the accessibility level of opportunities (competition effects). Moreover this accessibility measure, in principle, can take consideration of the variations across individuals; in other words the measure could be specified differently according to the characteristics of individuals for whom the accessibility is being estimated.

From a practice point of view the complexity of the model framework might require high hardware and software requirements and a certain degree of technical expertise to perform the calculation. Accessibility calculation is immediate once the Level of Services - LOS values have been defined, but LOS calculation for large networks can take excessive time in execution. For example in the described application, where the Campania Region road graph consisted of 1.900 nodes and 650 links, the LOS values calculation time can vary from 15 to 60 minutes (in large part to write the OD tables on the hard disk) according to whether a congested or not congested network assignment model is used. In terms of memory usage the proposed instrument uses minimum space during computation.

The proposed instrument can be easily integrated with GIS in order to create and customize maps, build and maintain geographic data sets, and perform many different types of spatial analysis. According to this further improvements of the instrument can provide a more clear visualization module that could facilitate feedbacks in the consultation process with local authorities and economic stakeholders. It is necessary, in fact, to better disseminate and visually represent accessibility measures that could significantly enhance understanding, and engage a wide range of stakeholders and thus help to bring this important challenge further into the public arena. On the other hand, the possibility of a multimodal transport analysis can provide insights into the equity of alternative transportation investments.

References

Ben-Akiva M. and Lerman S. (1985), *Discrete Choice Analysis*. MIT Press.

Cascetta E. and Coppola P. (2004), *The Regional Metro System of Campania Region: from planning to operations*. Proceedings of the European Transport Conference 2004, © Association for European Transport, Strasbourg, France.

Cascetta E. and Pagliara F. (2008), Integrated railways-based policies: The Regional Metro System (RMS) project of Naples and Campania, *Transport Policy*, Vol.15 (2): 81-93.

Cascetta E. (2009), Transportation System Analysis Models and Applications. Springer.

Nuzzolo A. and Coppola P. (2007), Regional accessibility and socioeconomic activities location: from empirical evidences towards a modeling framework. In: Proceedings of World Conference on Transportation Research, Berkeley CA.

Coppola P. and Nuzzolo A. (2011), Changing accessibility, dwelling price and the spatial distribution of socio-economic activities, *Research in Transportation Economics*, Vol. 31: 63-71.

Engwicht D. (1993), *Reclaiming Our Cities and Towns: Better Living with Less Traffic*. New Society Publishers, available at: www.newsociety.com.

Geertman, S.C.M., van Eck, R., Jan, R., (1995), GIS and models of accessibility potential: an application in planning, *International Journal of Geographical Information Systems*, Vol. 9 (1): 67–80.

Hanson W. G. (1959), How Accessibility Shapes Land Use, *Journal of the American Institute of Planners*, Vol. 35 (2): 73-76.

Linneker B. (1997), Transport Infrastructure and Regional Economic Development in Europe: A Review of Theoretical and Methodological Approaches. Report to SASI Project. TRP 133. Sheffield: Department of Town and Regional Planning.

Litman T. (2010), Evaluating Accessibility for Transportation Planning Measuring People's Ability To Reach Desired Goods and Activities. Victoria Transport Policy Institute, available at: http://www.vtpi.org/access.pdf

Nuzzolo A. and Coppola P. (2007), *Regional accessibility and socioeconomic activities location: from empirical evidences towards a modeling framework*. In: Proceedings of World Conference on Transportation Research WCTR 2007, Berkeley CA.

U.S. Department of Environment (1996), *Policy and Procedure Guidelines*, PPG 6.

Figures

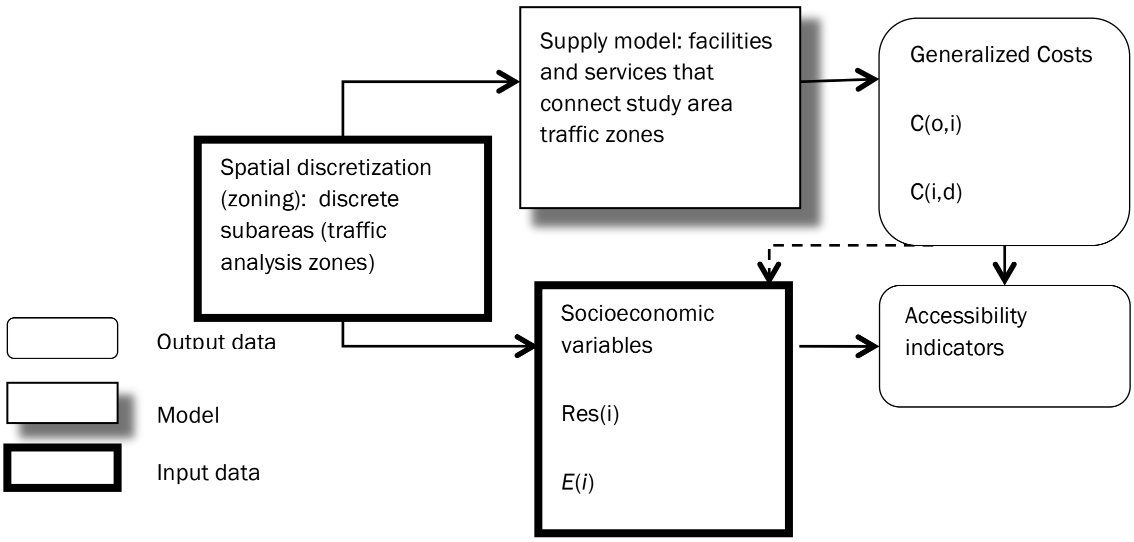

Figure 1 The calculation of generalized travel cost zone accessibility indicators in the present scenario

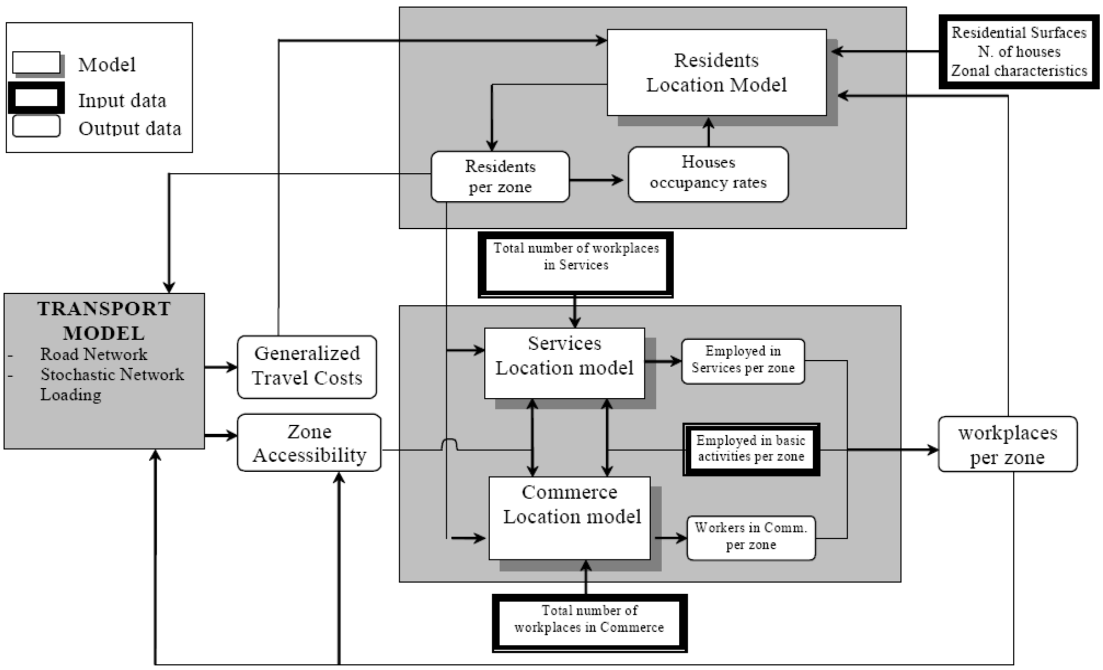

Figure 2 The accessibility measure as input data in LUTI model structure

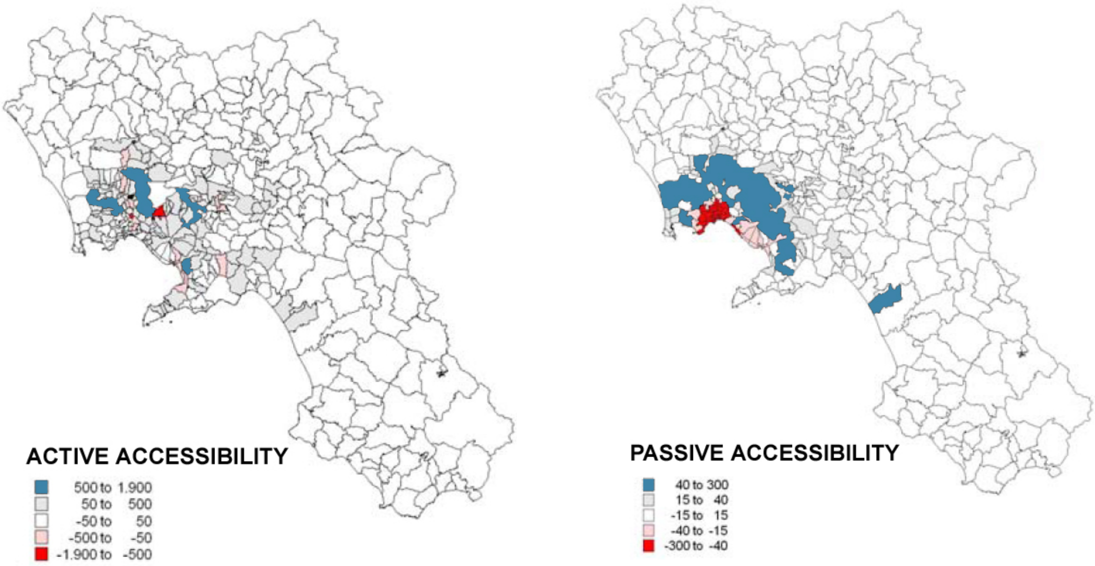

Figure 3 An example of representation of active and passive accessibility in Campania Region (Nuzzolo and Coppola, 2007)