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Assessing the accessibility impact of transport policy by a land-use and transport interaction model – The case of Madrid

Yang Wang *, Andres Monzon [1], Floridea Di Ciommo [2]

Transport Research Centre (TRANSyT), Universidad Politecnica de Madrid, Calle Profesor Aranguren s/n, 28040 Madrid, Spain

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ABSTRACT

Accessibility is an essential concept widely used to evaluate the impact of transport and land-use strategies in urban planning and policy making. Accessibility is typically evaluated by using separately a transport model or a land-use model. This paper embeds two accessibility indicators (i.e., potential and adaptive accessibility) in a land use and transport interaction (LUTI) model in order to assess transport policies implementation. The first aim is to define the adaptive accessibility, considering the competition factor at territorial level (e.g. workplaces and workers). The second aim is to identify the optimal implementation scenario of policy measures using potential and adaptive accessibility indicators. The analysis of the results in terms of social welfare and accessibility changes closes the paper.

Two transport policy measures are applied in Madrid region: a cordon toll and increase bus frequency. They have been simulated through the MARS model (Metropolitan Activity Relocation Simulator, i.e. LUTI model). An optimisation procedure is performed by MARS for maximizing the value of the objective function in order to find the optimal policy implementation (first best). Both policy measures are evaluated in terms of accessibility.

Results show that the introduction of the accessibility indicators (potential and adaptive) influence the optimal value of the toll price and bus frequency level, generating different results in terms of social welfare. Mapping the difference between potential and adaptive accessibility indicator shows that the main changes occur in areas where there is a strong competition among different land-use opportunities.

1. Introduction

The concept of accessibility is widely used to evaluate the impact of land-use and transport strategies, and is becoming increasingly popular with the transition from 'catering for mobility' towards 'catering for accessibility' in urban planning and policy making (Bertolini et al., 2005; Condeço et al., 2011; Omer, 2006). Typically, accessibility is assessed by using transport or land-use models independently or successively without a feedback loop, thus overlooking the interaction effects between both systems (Geurs & Van Wee, 2004; Geurs, Zondag, De Jong, & De Bok, 2010). This is more than a mere methodological curiosity, as failure to account for land-use/transport interactions leads to a substantial underestimation in policy effects. For example, converting a city centre into a pedestrian-friendly zone affects the accessibility and modal choice of road users (transport impacts), but may also have an effect on the attractiveness of the zone for new residents, workplaces and retail opportunities (land-use impact), which in turn increases transport demand in the area (i.e. a feedback loop).

The recent development of land-use and transport interaction (LUTI) models has led to a growing interest in their use for adequately evaluating accessibility (Badoe & Miller, 2000; Geurs & Van Wee, 2004; Geurs et al., 2010; Langford, Higgs, Radcliffe, & White, 2008; Thill & Kim, 2005). For example, Geurs et al. (2010) have estimated accessibility using a disaggregate log-sum method for trips at the individual level and calculated it in the utility function with a national LUTI model.

This paper follows this line of research in that it assesses accessibility using the LUTI model, but focuses on the aggregate level of accessibility changes by incorporating the competition effects of jobs due to the implementation of the transport policy. There are two aims associated with this objective. The first is to compute the Potential Accessibility (PA) by incorporating the effects of competition (Adapted Potential Accessibility, AA) using a LUTI model in order to estimate job opportunities – not only from the number of jobs within reach, but also from the competition for these jobs

* Corresponding author. Tel.: +34 91 336 67 08; fax: +34 91 336 53 62.
E-mail addresses: wyang@caminos.upm.es (Y. Wang), amonzon@upm.es (A. Monzon), fdiciommo@caminos.upm.es (F.D. Ciommo).
[1] Tel.: +34 91 336 53 73; fax: +34 91 336 53 62.
[2] Tel.: +34 91 336 52 33; fax: +34 91 336 53 62.

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(Geurs & Van Wee, 2004; Knox, 1978; Van Wee, Hagoort, & Annema, 2001; Weibull, 1976). LUTI models are particularly suitable for assessing AA because the competition factor is a function of the number of jobs, which is related to land-use attractiveness and number of employees – among other factors–, and to transport demand (Van Wee et al., 2001). The second aim is to identify the optimal policy implementation value on the basis of the PA and the AA, and analyse the results in terms of social welfare. To the best of our knowledge, this paper is the first attempt to incorporate this effect of competition on accessibility in the objective function in order to find the maximum social welfare. The Madrid Region is used as a case study to present the new approach and to highlight the policy recommendations for urban planners and policy makers.

The LUTI model used in this study is the MARS (Metropolitan Activity Relocation Simulator) developed by Pfaffenbichler, Emberger, and Shepherd (2010). The MARS model represents the cause and effect relations between transport and land-use systems and integrates an optimisation algorithm for long-term policy making. The competition factor is embedded in the accessibility equation through the calculation of the AA. The optimisation procedure involves maximising the value of the objective function defined on the basis of cost benefit analysis (CBA), and includes not only the costs/benefits to road users, transport operators and government authorities, but also transport externalities of the whole society such as safety, environmental quality and land depletion.

Two policy measures – cordon toll and increased bus frequency – are optimised and evaluated by the MARS model. Cordon toll is a restrictive policy aimed at reducing car use in the congested metropolitan centre, while the increase in bus frequency as a substitute transport mode for the car would provide travellers with a better public transport (PT) option for travel around the whole of the Madrid metropolitan area.

The paper is organised as follows. Section 2 describes the methodology of the paper, including the features of the MARS model, the definition of the accessibility indicators with competition, the objective function and the optimisation procedures. Section 3 presents the current situation in Madrid and defines the scenarios. Section 4 compares the accessibility changes using the PA and the AA, and analyses the results in terms of optimisation, derived social welfare, transport and land use impacts. The final section contains the conclusions.

2. Methodology

The proposed methodology consists of linking land-use and transport submodels by means of accessibility indicators. Fig. 1 shows the relations between the land-use/transport submodels and the accessibility indicators that are influenced by transport policies, and the optimisation procedure. The core of the relation between land-use and transport systems is the accessibility indicator, which is integrated in the model through the two submodels in the objective function affecting the optimisation procedure. The LUTI model estimates the accessibility changes to the scenarios conditioned by exogenous variables and policy measures; while the optimisation procedure –based on the CBA – maximises the objective function representing policy-makers' objectives.

2.1. The MARS model

The core concept of the MARS model is the adoption of the principles of System Dynamic (Sterman, 2000) and Synergetic (Haken, 1983). It is run in a SD (system dynamic) programming environment (VENSIM) based on causal loop diagrams (CLD), and represents the relation of cause and effect between the variables in the model (Shepherd et al., 2006). The MARS model was chosen for this study due to its ability to analyse the policy measures at the regional level, and because its structural flexibility allows the objective function to be modified.

MARS contains the transport submodel and the land-use submodel (Fig. 1). The transport submodel includes the first three stages of the common transport model (i.e. trip generation, trip distribution and modal split) and simplifies the road network into aggregate links for each origin-destination (OD) pair. It involves three travel modes: car, public transport (bus, metro, urban train) and walking. The congestion effect is recreated through speed-flow curves (Singh, 1999), in such a way that a higher number of trips results in a lower travel speed and vice versa (Pfaffenbichler et al., 2010).

The land-use submodel comprises a residential location submodel and a workplace location submodel. These two location submodels have a similar basic structure consisting of four further submodels: a development model, a willingness to move in model, a willingness to move out model and a supply/demand redistribution model. The willingness to move in/out submodels is influenced by the rent price, share of green land and accessibility level. Based on these two submodels (move in and move out), we can obtain the ratio of demanded/supplied housing utility for each zone. The demand would therefore be re-distributed if it is higher than the supply (Pfaffenbichler et al., 2010).

All the variables in MARS are interrelated through CLD relations. The exogenous variables such as demography (population, residents), economics (household income, household size) and land use (area, land-use type) etc., must be entered according to the case study. The interaction process is modelled using time-lagged feedback loops between the transport and land-use submodels over a long period (30 years for example) in one-year intervals. For this case study, the MARS model that comprise 90 zones based on administrative municipal has been calibrated by Guzmán (2011) using two household mobility surveys for the Madrid Region in 1996 and 2004 (CTRM, 1998, 2006).

2.2. Accessibility indicators with competition

Two accessibility indicators are applied in the MARS model: the traditional PA and the proposed AA that accounts for competition for jobs on the employment market. There are two reasons for incorporating competition effects with job accessibility: first, the policy measures considered here are aimed at encouraging modal shift during morning peak hours, when 65% of the trips are work-related. Secondly, work-related trips involve routine daily travel which is important when considering long-term regional economic growth, and therefore form the backbone of transport and land-use models. In this study, accessibility is defined only in terms of work trips.

The PA is widely used to measure the aggregate level of job accessibility, (Handy, 1994; Gutierrez, Monzón & Piñero, 1998), and is estimated on a rigorous methodological basis (Koenig, 1980). PA combines the effect of transport/land use and incorporates assumptions regarding personal perceptions of transport by using a function that decreases with distance or time (Geurs & Van Wee, 2004). Eq. (1) shows the typical form of PA (Hansen, 1959), which assumes a negative exponential cost function. The variable t represents the period of time. The i and j are origin and destination zones respectively and m represents the type of travel mode.

$$\text{Potential accessibility} : PA_i(t) = \sum_{jm} W_{jm}(t) * F(t_{ijm}, c_{ijm}) \tag{1}$$

where PA_i is the potential accessibility of opportunities between i and j by mode m in year t, $W_{jm}(t)$ is the opportunity to reach