A MODEL TO EVALUATE THE ENVIRONMENTAL AND ENERGETIC EFFICIENCY OF THE TERRITORIAL FUNCTIONALITY (TRANSPORT AND ACTIVITY LOCATION)

Jorge **CERDA**, Carlos **MARMOLEJO**, Josep **ROCA**
Centre of Land Policy and Valuations, CA1, Polytechnic University of Catalonia
Av. Diagonal 649, 08034 Barcelona, Spain
jorge.francisco.cerda@upc.edu; carlos.marmolejo@upc.edu; josep.roca@upc.edu

Abstract

The main objective of the study is the development of a model for the evaluation of the environmental and energy efficiency of the interaction (mobility) and land use structure (called as "territorial functionality"), applied to the metropolitan area of Barcelona.

In particular there are four points that underpin the model: a) a basic land use-transportation model (LUTM), b) a model for the energy consumption and environmental emissions produced by the territorial functionality, c) a model for the consumption of land produced by the territorial functionality (developed land), and d) assessment of social equity in access to urban activities, and exposure to environmental effects.

The goodness of the proposed model is that is composed of empirical models (econometric), robust in their specific topic, but spatially disaggregated (municipality). With this structure is possible to evaluate the effects of functional changes (transport projects or urban planning) in the spatial structure of energy consumption, environmental emissions, and consumption of land, and also identifying the participation (responsibility) of different territories in these effects. It is a systemic and spatial view of the role that each territory plays in the functionality, and their responsibility in the environmental effects.

The model is currently under construction, joining the calibrated models of consumption and environmental emissions to an existing transport model in the metropolitan area of Barcelona. This paper presents the mathematical model, and the indicators defined for characterizing the state of the territorial system.

Keywords: efficiency, environment, energetic, activity/interaction

1.- Introduction

In recent decades, the metropolises of the Southwest Europe have undergone a process of territorial dispersion. The coastal and agricultural lands have been affected by urban expansion [7]. This context required the assessment, monitoring, and prediction of the externalities generated by urban expansion, under a comprehensive approach to the phenomenon. Only this approach can identify the elements that influence the efficiency of the territorial system, to predict the negative impacts of plans or programs, and preventive measures to mitigate them.

In relation to transport, the traditional view of sustainability focuses in technological factors, without giving a systemic dimension of the phenomenon of mobility in cities, understanding that the modal choice is the effect of a sequence of factors that have to do with the structure of activities in the city, and especially the behaviour of the population.

In practice, policies of transportation infrastructure (at the metropolitan level) have been evaluated essentially with the classic transport model (four stages), where the optimization has fallen mainly on aspects of private efficiency (of operators and users) in terms of generalized costs. In the last decade the methods has included other indicators, arising from the same model output, such as GEI emissions, accidents, etc [1][2].

Moreover, the transport model considers as exogenous the structure of urban activities for the base situation, and for different periods of evaluation. For these periods the model tended to perform city scenarios, mainly in response to extrapolations (based in more or less pro-active diagnostic) of the dynamics city growth [4]. The simple extrapolation of trends, however, has shown a clear ineffectively in order to anticipate the real location of urban activities, as well as the mobility they will generate.

In general, this methodology has been applied in the development of various transportation plans in Spain, specifically Barcelona (PDI 2001-2010) [1].

Environmental policies have influenced transport theme on several levels. At the tactical level (specific project) through the assessment of environmental impact, and the incorporation of good environmental practices in the different project stages [5]. On the metropolitan scale, with the strategic environmental assessment, to ensure environmental consideration in early stages of the plan design. Spite this, the simulation of environmental impacts of transport projects or land use plan, in a systemic approach over a metropolitan scale is not usual.

The propose in this work is to build a sustainability functional model for the metropolitan area of Barcelona (164 municipalities), based on an integrated transport and land use model, to assess the social efficiency, and especially the environmental efficiency of urban functionality in relation to flows and activities in the territories.

2.- The mathematical model

In particular there are four points that underpin the model: a) a basic land use-transportation model (LUTM), b) a model for the energy consumption and environmental emissions produced by the territorial functionality, c) a model for the consumption of land produced by the territorial functionality (developed land), and d) assessment of social equity in access to urban activities, and exposure to environmental effects.

The logical model designed to solve the problem has structured as follows:

- The **first step** is to determine the location of activities (economic and residential). In the process of locating these activities are considered demographic behaviour of the population (vital statistics, employment rates, household formation rates), space quotas for the various activities (generated by plans and planning requirements), and also the spatial behaviour of interaction (change of residence, daily mobility to work). The interactions phenomenons are modelled with gravitational models, considering cost matrices generated by the transport network (infrastructure and services). The result of this procedure is the total of population, housing, and jobs for each territorial unit of analysis, and for each period.
- The **second step** is to model the interactions (travels) produced by the location of residential and economic activities. For this, were applied traditional distribution and assignment transport models.
- The **third step** is the estimation of different type of consumption generated by the territorial system of activities and their interactions. The consumptions analyzed was; land (developed land), and energy (specifically electricity) by the different activities. Also are considered the transport consumption (specifically fuel) generated by the spatial interaction.

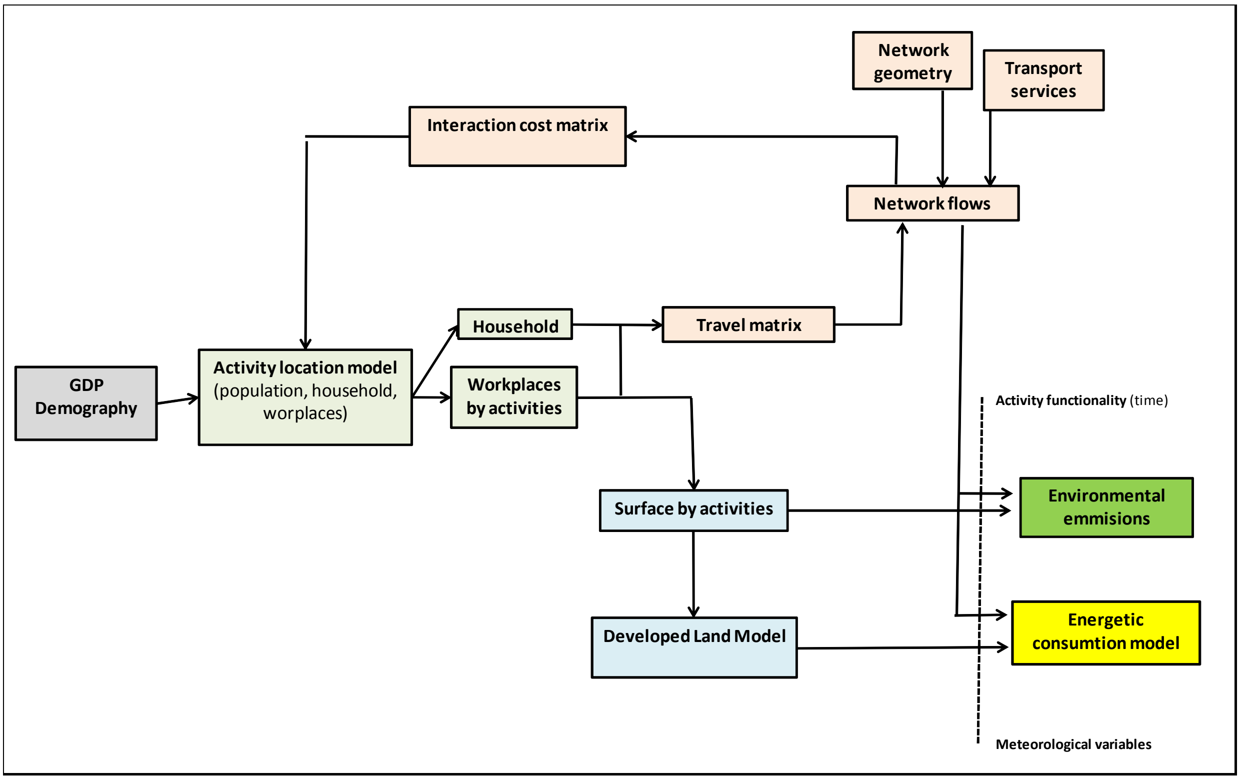
- The **fourth step** is the estimation of the environmental emissions generated by the activities and the spatial interaction.
- The **fifth** and final step is the assessment of environmental and energy efficiency of the territorial system of activities and their interactions.

The model evaluates the environmental and energy situation from a base scenario comparing with the proposed urban planning and/or transport projects.

The measurement of efficiency is not a simple issue [6]. The study proposed two strategies to evaluate efficiency. The first is that concerning the assessment of the situation with and without-project, and the differential effect that occurs. The second relates to an optimal situation (mathematics). So, the efficiency indicators are essentially spatial, concluding with the spatial efficiency of the system, or equity in the spatial distribution of environmental externalities.

The logic model provided the basis for the development of detailed mathematical model, which is presented in figure 1.

Figure 1.- Flow chart of the detailed model



Font: CPSV-UPC

The next section presented and described each of the used sub-models.

2.1.- Demographic and activity location model

This model considers the following sequential process:

2.1.1.- GDP and demographics projections: These procedures are exogenous. An average growth scenario of productivity was used for the GDP projections. The population is obtained from a cohort model for Catalonia.

2.1.2.- Location of population, housing, and employment: the model is based on the creation of households as a structural element of the housing demand. For that, the population are created by the natural movement and also by the migratory movement. The model of natural movement is part of the projection of the structure of ages and the households' formation patterns. The migratory model considers the Catalan labour market's ability to assimilate new occupied. The location of workplaces result from the application of two gravity models, one of this is the Krugman model for the spatial trends of labour markets, and the other is an origin constrained gravity model of daily home-work mobility. From these results was calculated the job balance, filled or not by immigrants.

2.1.3.- Employment by activity: This procedure distributed the total workplaces in various economic activities. For this were applied spatial specialization indices by activities, and its variation over time.

2.2.- Transport model

The transport model includes the following subtasks.

2.2.1.- Travel matrices: These procedures apply a growth factor model (average factor) to an initial matrix, with the variation of the households and workplaces in each zone. The platform used for this is SIMCAT, already existing and used for the evaluation of infrastructure plans in the metropolitan region of Barcelona.

2.2.2.- Flows in the network: The updated travel matrix was assigned to the transport network, based on a DUE model of traffic assignment. This procedure is also part of the SIMCAT platform.

2.2.3.- Network geometry and transport services: this is an exogenous information, which consider the development of the transport networks in space and time, and also of the various transport systems (public, private, etc), and their operational characteristics (rates, frequency, itineraries, etc.). The SIMCAT platform contains these different networks for different time.

2.2.4.- Cost of interaction matrices: this matrices were obtained by a multiple shortest path procedure, also included in SIMCAT. Finally this costs matrix feedback the population and activity location model.

2.3.- Model of developed land

The model of land consumption considers the following subtasks.

2.3.1.- Surface by activity: the activity location model calculates the number of households and workplaces (by activity) by zone. These workplaces (activities) eventually occupy a specific surface. To determine these built surface, specific rates was applied to the number of workplaces per activity, thus obtaining the activity surface by zone.

2.3.2.- Land consumption: this procedure incorporates the activity surfaces in an econometric model which explains the developed land, including streets or open space surfaces.

The phenomenon of land consumption can be seen, in reverse, as a production of developed land process. As a production model, the general structure of this type of model is the Cobb-Douglas function, which is perhaps the most widely used in economics (it is the neoclassical production function par excellence) [3].

By using the Cobb-Douglas function as a developed land model is necessary an understanding and interpretation of all the function factors, to achieve consistency with the analyzed phenomenon. So, the constant factor, which represents the rate of inputs outputs transformation in the original model, is replaced by a more complex term (no longer constant) that reflects the different structures of activities in each area. The exponential term should be interpreted as the rate of production of developed land (natural soil consumption) by a unit activity surface. Also the coefficients represent the effect of each activity in the developed land production.

2.4.- Energy consumption model

The model of energy consumption considers the following subtasks

2.4.1.- Energy consumption in transport: the transport model determines the consumption of fuel of the overall system. The SIMCAT platform already has incorporated these calculations.

2.4.2.- Energy consumption by localized activities: for this model we have information only for electricity consumption by different activities. Therefore were constructed and calibrated various econometric electric consumption models, by activities like housing, offices, shops, industries, hotels, etc. The dependent variable are always annual electrical consumption, and the explanatory variables are activity surfaces, and additional variables such as weather conditions in the territory, and the daily average duration of each activity (working time, shopping time, time of education, etc.).

The phenomenon of the electric consumption can be seen, also like a production of electric demand. Therefore the structure is a Cobb-Douglas function, in which the constant factor reflects the different structures of activities in each area, and the coefficients represent the effect of each activity in the annual electricity consumption.

2.5.- Environmental emissions

The environmental emissions considers the following subtasks

2.5.1.- Environmental emissions from transport: the procedure considered the various flows of vehicles in the transport network, and their rates of emission of gaseous pollutants. The SIMCAT platform already has incorporated these calculations.

2.5.2.- Environmental emissions by localized activities: in this case only was used the rate of gases emission by unit area of activity, and the surface by activity.

2.6.- Procedure of plans evaluation

All of the different models were integrated in a single procedure for assessing two types of plans, like as transport plans (or projects), and urban plans (or projects). The evaluation of a plan must define a basis situation against which to compare. Such a basis situation refers to the population and activity location, the network flows produced by this, the interaction costs, the spatial structure of energy consumption, the spatial structure of environmental emissions, and the developed land, for different periods.

The evaluation sequence of a plan is the following:

Step 1.- The implementation of the transport plan changes the structure of the interaction costs in the network, which produce the change in cost matrices.

The implementation of an urban plan (activities) modifies the potential distribution of workplaces and population in the territory, so alters the attractiveness of the territories, variable that are included in the gravity models.

Step 2.- The population and activity location models were applied with the new matrix cost, and/or with the new attractiveness of the territories. The result is a new amount of workplaces, population and household by zone. The comparison of this new situation with the base situation must be interpreted not in absolute value, but as a "trend" of residence and labour market relocation, produced by the implementation of the plan. This trend has the advantage that identifies the zones that increased (or decreased) its potential number of population/workplaces, so arise all of the differential effects of the plan in the territory.

The variation of the total workplaces produced the variation by activities, which produced the variation of the surface by activities. The outcome of the model may indicate that a given activity surface decreases (destroyed), but again is necessary to make clear that should not be interpreted literally, but rather as a tendency of pressure of the land market.

Step 3.-With the new values of population and workplaces, was applied the transport model to determine the new values of the network flows.

Step 4.- With the new values of surface by activity, was applied the developed land model, which results indicates the trend produced by the plan (again must be interpreted as a loss/increase of pressure).

Step 5.- With the new values of activity surfaces, and developed land, was applied the different electric consumption models, thus obtaining the new spatial structure of electric consumption, and total consumption values.
On the other hand, with the new values of network flows was calculated the fuel consumption.

Step 6.- With the new values of activity surfaces and network flows, was calculated the environmental emissions by activities and flows.

Step 7.-With all of the new values in the analyzed dimensions, was calculated synthetic indicators of total and spatial efficiency, concluding with the effects of the plan.

3.- Final remarks

Based on the current implementation state of the model, emerge the following comments:

- The functional design of the process has been adapted to the availability of information for the different sub-models and procedures.
- An important learning in the current stage of the model is that it is necessary to maintain consistency throughout the proceedings, in relation to the scale and complexity of the different models/analysis. This means that it must integrate appropriate techniques in each dimension, but not the more complex developments, because the global model requires consistent inputs and outputs between dimensions. In the future, for other applications, a specific model can be replaced by a more complex form of representation of each variable or externality.

- The current calibrated models shows good performance (adjust, significance, etc). Although the errors are significant, the use under a differential approach (difference of the situation with and without project), subtracts the absolute estimation error, giving validity to the measure of the effect of a project or plan.

Acknowledgment

The first author is supported by the “Comisionado para Universidades e Investigación del Departamento de Innovación, Universidades y Empresa de la Generalitat de Cataluña y del Fondo Social Europeo”. The study is supported by the Ministerio de Fomento del Gobierno de España.

Reference

[1] Autoritat del Transport Metropolità (2007) Pla Director de Mobilitat, Barcelona. Online. http://www.atm.cat/cat/apartado3/ap3_04.htm

[2] Banco Interamericano de Desarrollo (2006) Manual de Evaluación Económica de Proyectos de Transporte, Washington D.C., pp. 188. Online. http://idbdocs.iadb.org/wsdocs/getdocument.aspx?docnum=1037792

[3] Gujarati, D. (2003) *Econometría*. Fourth edition, Mc Graw-Hill Interamericana ed.

[4] Hunt, J.D. et all, (2005) Current Operacional Urban Land-use-transport Modelling Frameworks: a review. *Transport Reviews*, 25(3), pp. 329-376.

[5] Pozuea, J. (2000) *Movilidad y planeamiento sostenible: Hacia una consideración inteligente del transporte y la movilidad en el planeamiento y el diseño urbano*. Red de cuadernos de investigación urbanística: Instituto Juan Herrera ed. 97 p.

[6] Rueda, S. (2001) *Modelos de ordenación del territorio más sostenible*. Working paper, Zaragoza.

[7] Travisi, C., Camagni, R. Nijkamp, P. (2006) *Analysis of environmental costs of mobility due to Urban Sprawl – A Modelling Study on Italian Cities*. Tinberger Institute Discussion Paper http://dare.ubvu.vu.nl/bitstream/1871/9836/1/06042pdf