Urban Land-Use Transport Interaction modelling: state of the art and applications

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Abstract

This work focuses on urban Land-Use Transport Interaction (LUTI) modelling carried out to support the strategic planning process. A LUTI model is formalized and all modelling components and connections are described. The model is applied to forecast changes in transport and land use patterns at an urban strategic scale.
Keywords: Land-Use Transport Interaction, urban modelling.

1 Introduction

Transport systems affect economics and planning of an urban area, conditioning households and firms location choices, production levels, trade and land use patterns. Land-Use Transport Interaction (LUTI) modelling can support strategic planning, policy making, public and private investment decisions.

Many urban LUTI models refer to the Multi-Regional-Input-Output (MRIO) framework, estimating transport demand, generation and location of activities, land use, as a result of interaction between a transport system of models and an activity model. Schematically, the former provide transport supply performances which affect activity location in the latter; the latter provide the activity system generation and location which affect transport demand in the former.

The objectives of this work are: definition of a state of the art on LUTI models, in the part concerning the activity models; formalization of a LUTI model and description of all modelling components and connections; model application to forecast changes in transport and land use patterns at an urban strategic scale.

The paper is articulated in three sections, according to the above objectives.

WIT Transactions on The Built Environment, Vol 96, © 2007 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/UT070491

2 State of the art

Many LUTI models present in literature refer to the Multi-Regional-Input-Output (MRIO) framework. MRIO was originally developed to represent national economies, subdivided into sectors and zones (regions). At national scale, the attention is focused on production location and on transport (freight and passenger) demand estimation, neglecting the land use aspect.

The basic concept was in Keynes theory [1], who introduced the principle of effective demand, whereby production is determined by consumption. A key element was the idea of multiplier effect, where if investments (demand, y) increase, so will income (production, x), but in larger proportion:

$$x = (1 - a)^{-1} y \tag{1}$$

with a (< 1), marginal propensity to consume.

In the sphere of Keynes theory, Leontief [2] firstly proposed an IO model to simulate inter-dependencies between economic sectors through fixed technical coefficients, in order to capture more detailed multiplier effects at sector level:

$$X = (I - A)^{-1} Y \tag{2}$$

with X, production vector; I, identity matrix; A, technical coefficients matrix; Y, demand vector.

Further modelling developments able to reproduce a spatial representation of economy were later proposed in [3–6], introducing constant trade coefficients to locate production across zones:

$$X = (I – T A)^{-1} T Y \tag{3}$$

with T, trade coefficients matrix.

In [7] trade coefficients, elastic to production prices and transport costs, were estimated through a location model, based on random utility theory [8]. Several papers were presented finalized to simulate freight transport demand at national and international scales [7, 9, 10].

At the urban scale, land use has an important role in determining the process of activity generation and location. A pioneering work was the one of Lowry [11], who developed the earliest land-use model, from exogenous transport costs. Advancements were proposed in [12], using a simplified MRIO model to estimate activities generation and location. Several location models (spatial interaction models), based on Newton's gravity law [13], were also developed to simulate activities location and transport demand. Wilson [14, 15], derived location models from entropy maximization procedures, which were applied in [16]. But, after the proposition of random utility theory [8, 17], location models were firmly anchored into micro-economic theory. Urban location models of residential and economic activities, based on random utility theory, were proposed in [18, 19]. A class of urban LUTI models, which integrate the IO approach and discrete choice theory into a MRIO framework was proposed in literature [20–23]. According to this last class of models, transport and activity systems are simulated by means of market mechanisms, where demand and supply interact, providing simultaneously prices and quantities. In the transport model, users behaviour is simulated through demand models which estimate emission, mode, time-of-day, path choices. These choices are driven by utilities, which include transport costs provided by a congested network model. Demand-supply interaction is simulated through an assignment model, which estimates transport costs (prices) and flows on network (quantities). If the available supply (transport facilities and services) is limited, congestion costs arise which bring the transport system to an equilibrium condition. In the activity model, population and economic operators behaviour is simulated, through an activity generation model which estimates demand (consumption) levels of activities (population, employment, land) and an activity location model which simulate where activities supply (production) is located across zones. Location choices are driven by utilities, composed by a supply price plus transport cost. Demand-supply interaction leads to the estimation of supply prices and quantities in each zone. Due to supply constrains (ex. limited available land), a rent can be generated which brings the activity system to an equilibrium condition.

Figure 1 reports a classification of LUTI models, in the part concerning the activity models.

3 LUTI model

The proposed LUTI model has two interacting modelling components: the transport model and the activity model.
The transport model is composed by:

- a congested network model

$$g = \Delta^T c(f) \tag{4.a}$$
$$f = \Delta h \tag{4.b}$$

with g, path costs vector, Δ, link-path incidence matrix, c(), link cost functions vector, f, link flows vector, h, path flows vector,

- an elastic demand model (on the emission and modal dimensions), with a stochastic path choice model:

$$h = P(\Delta^T c(f))\, d(F, \Delta^T c(f)) \tag{5}$$

with P, probability path choice functions matrix, d(), demand functions vector, F, activity flows matrix,

- an assignment model

$$f = \Delta\, P\, (\Delta^T c(f))\, d\, (F, \Delta^T c(f)) \tag{6}$$
$$f \in S_f$$

with S_f, set of feasible link flows.

- Activity models
  - Activity generation models
    - Teorethical background
      - Keynes [1]
    - Input-Output (IO)
      - Leontief [2], …
  - Activity location models
    - Gravitational-entropic
      - Hansen [13], Wilson [14, 15], Putnam [16], …
    - Random utility based
      - Teorethical background
        - Domencich and Macfadden [8], Ben-Akiva and Lerman [17]
      - Discrete choice
        - Cascetta et al. [18], Cascetta et al. [19], …
  - Activity generation-location models
    - Multi-Regional-Input-Output (MRIO)
      - Fixed coefficients
        - Izard [3], Moses [4], Leontief and Strout [5], Lowry [11], Garin [12], Leontief and Costa [6], …
      - Elastic trade coefficients
        - Cascetta et al. [7], Marzano and Papola [9], Kochelman et al. [10],
      - Elastic coefficients and supply constraints
        - de la Barra [20], Echenique and Hunt [21], Simmonds and Still [22], Modelistica [23], ….

Figure 1: Classification of activity modelling component of LUTI models.

The activity model is composed by:

- an activity generation model with technical coefficients depending on prices

$$Y = A(p(X))\ Y + Y^e \tag{7}$$

with Y, activity demand vector, A(), technical coefficients functions matrix, p(), price functions vector, X, production vector, Y^e, exogenous activity demand vector,

- an activity location model for estimation of trade coefficients matrix, T, which depends on prices and path costs

$$T = T\ (p(X), g) \tag{8}$$

with T(), trade coefficients functions matrix,

- a model for activity flows matrix, F, estimation:

$$F = T\ Dg(Y) \tag{9}$$

with Dg(Y), matrix obained arranging the elements of vector Y along the main diagonal. Finally, production vector, X, is obtained from: $X = 1^T F$.

Figure 2 presents modelling components and connections of the LUTI model.

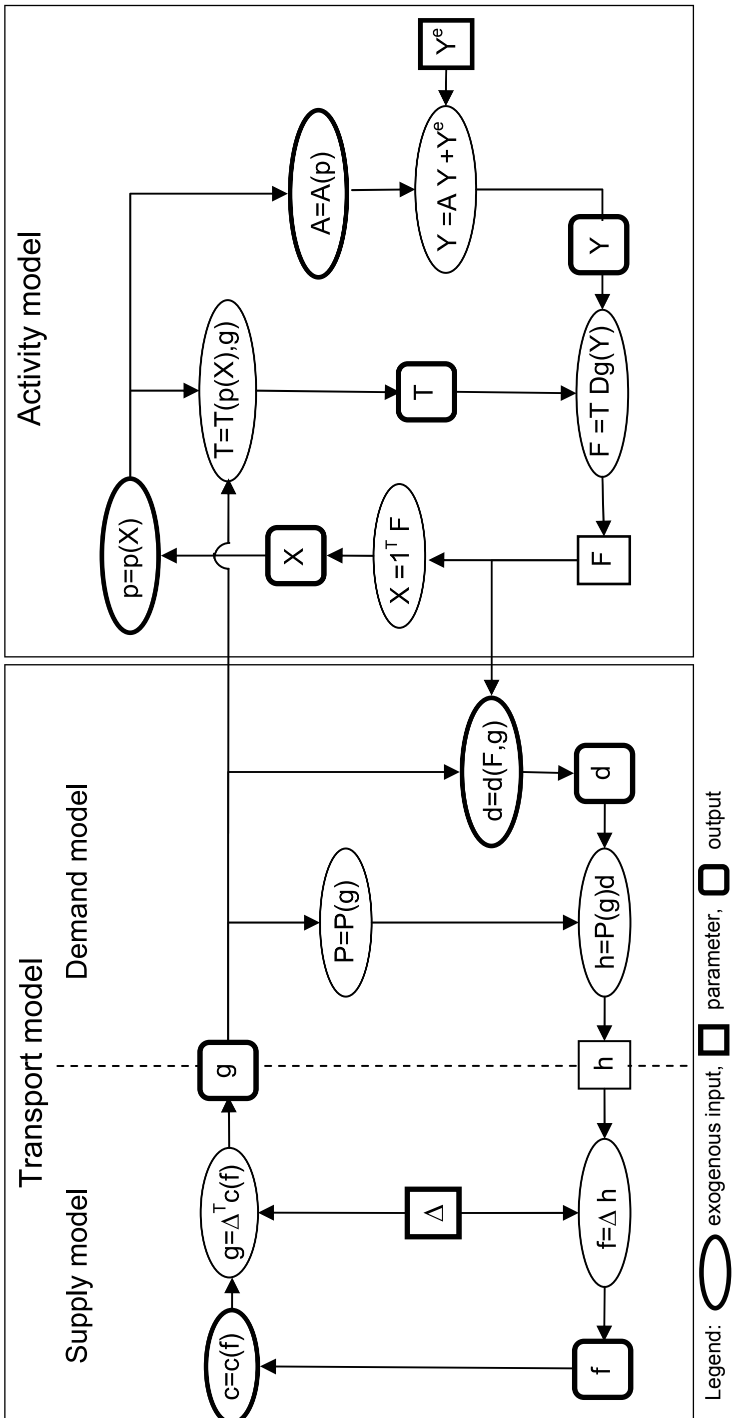

Figure 2: LUTI model components and connections.

The transport model has link cost functions vector, c(), demand functions vector, d(), as exogenous inputs; activity flows matrix, F, as endogenous input; link-path incidence matrix, Δ, as parameter. It provides as output path costs vector, g, from equation (4.a); modal demand, d; links flows vector, f, from equation (6). The activity model has price functions vector, p(), technical coefficients functions matrix, A(), as exogenous inputs; path costs vector, g, as endogenous input; exogenous activity demand vector, Y^e, as parameter. It provides as output total activity demand vector, Y, from equation (7); trade coefficients matrix, T, from equation (8); productions vector, X.

4 Urban application

The LUTI model is applied to the town of Reggio Calabria (Italy), to forecast changes in transport and land use patterns induced by an integrated transit-oriented transport system (SMS, Sustainable Mobility System).

Reggio Calabria is a coastal town of about 180.000 inhabitants, located in the south of Italy. The study area (figure 3) is composed by a central district, where diffuse residential and retail activities, educational and public services activities, clustered in three poles (university, regional public and health, municipal public), are located; and three peripheral districts (northern, southern, hilly) where are located manufacturing and dispersed residential activities.

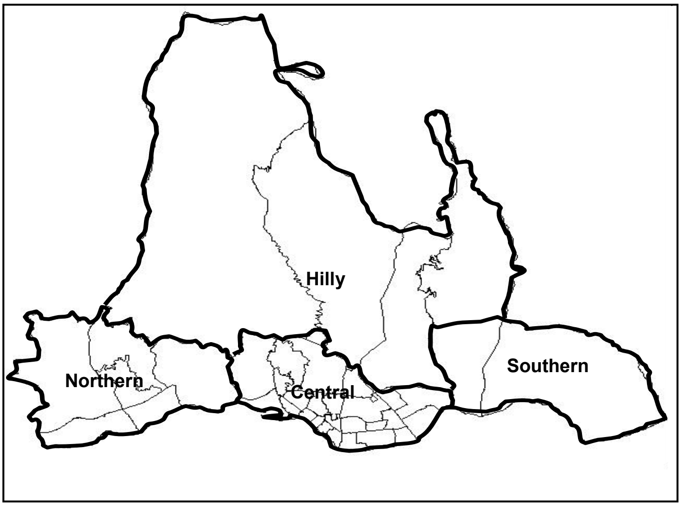

Figure 3: The study area.

Current transit system is composed by urban and regional bus services; regional rail services, connected with bus services through the bus terminal located beside the main rail station in the central district; inter-regional maritime services. Transit system has no direct connections among the three poles and between these ones and the rail stations, harbour, bus terminal. Trips are mainly executed by private mode (car), while transit services have a negligible role, generating high congestion, incidents and pollution levels.

The SMS system to be implemented is a funicular travelling in a reserved right-of-way, with stops every 400-500 meters. Vehicles guidance is fully automated and the control system is centralized. In figure 4 the three poles present inside the central district and a schematic representation of the bus, rail and SMS itineraries are depicted.

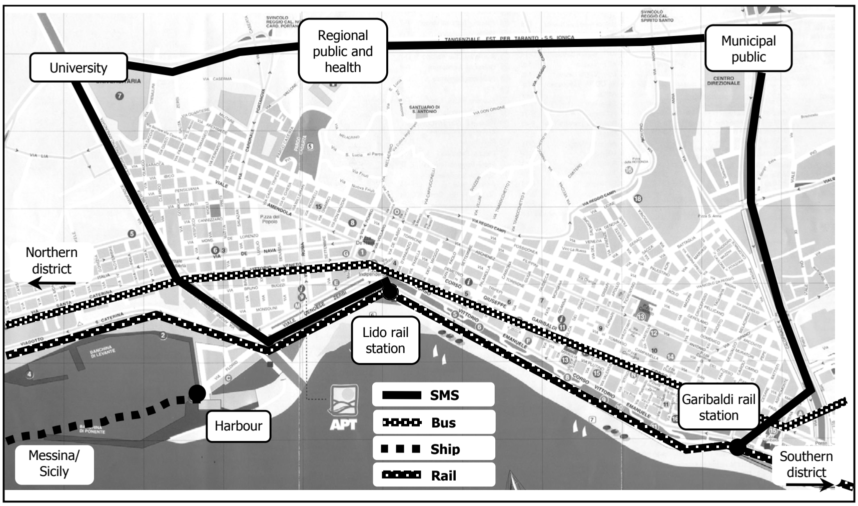

Figure 4: Central district: poles and scheme of SMS system.

4.1 Model implementation

The study area has been subdivided in 35 zones (11 peripheral zones and 24 central zones). The activity system is segmented in 8 sectors to match available census residential and employment location data. Inter-dependencies between activity sectors are defined in a semplified IO matrix, where each element describes the consumption needed to produce one unit of sector at a fixed or price elastic rate.

Transport demand, segmented into 6 transport categories (low-income work, high-income work, services, purchase, school, university), is associated to activity sectors which generate flows, according to a fixed corrispondence matrix.

Transport demand is estimated through a three-step system of demand models that simulate emission, mode and path choices.

Transport supply has two available transport modes (private, transit) and it is simulated through a congested network model, able to represent private transport facilities and transit services.

4.2 Simulation results

Three transport system configurations are considered and compared: current situation (Current); Sustainable Mobility System transport scenario (SMS), where the transit-oriented transport system is operating; combined transport scenario (F+SMS), obtained from the prevoius one doubling current frequencies (F) of bus and rail services. No land-use scenarios have been considered.
In the following sections some preliminary results concerning transport and activity systems are reported.

4.2.1 Transport system

Transport demand during morning peak hour is estimated and forecasted. Table 1 shows that forecasted transport demand with transit mode increases in the two scenarios (SMS: +12,66%; F+SMS: +37,82%), while transport demand with private mode presents a slight reduction (SMS: -2,96%; F+SMS: -6,86%).

Table 1: Transport demand. Comparison among scenarios.

Demand	Current (users)	SMS (%)	F+SMS (%)
Private	66303	-2,96	-6,86
Transit	10868	12,66	37,82

Individual trips for each transport service (car, bus, rail, SMS) are estimated and forecasted for the study area. Trips with bus services have a reduction in the two scenarios, while trips with rail services have a sensible increment. SMS attracts many users having the central district as origin or destination.

A relevant component of mobility involves the three poles present in the central district. Poles can be reached directly with bus services and SMS. The trend forecasted for the study area is confirmed for the three poles. Moreover, consistent reduction of trips by car to each pole is forecasted in relation to current situation, where bus service has a negligible role.

The above results are mainly caused by the direct connection, determined by the SMS system, among the three poles and between them and peripheral districts, served by railway.

4.2.2 Activity system and land use

Activities location and land use patterns are estimated and forecasted for each district. Central district is the one where are currently concentrated both residential (65% of population) and business (91% of service employment, 75% of retail employment) activities. In the two scenarios, central district attracts high-income population from southern and hilly districts, expelling aliquots of service and retail employment. Increments in retail and service employment location are forecasted in southern and hilly districts. Northern district presents no sensible changes in activities location.

Activities location patterns are in line with forecasted average floorspace prices in each district. They show an increment in the central district, because of its increasing attractiveness for residential location of high-income population, and a reduction in southern and hilly districts. They do not show sensible variations in the northern district.

5 Conclusions and future work

In this work a state of the art on LUTI modelling, in the part concerning the activity models is presented. A LUTI model is formalized and all modelling components and connections are described. The model is applied to forecast changes in transport and land use patterns at an urban strategic scale. Preliminary results are presented and some remarks concerning urban LUTI models can be drawn. The main advantage is related to the possibility to endogenously estimate changes in transport and land use patterns, due to the modification of transport supply, showing potentialities of LUTI models in supporting strategic planning process. Challenges concern data unavailability at the urban scale that does not allow high segmentation of activity system, calibration of some model parameters due to the difficulty to get appropriate observed data, general validation of the whole model.

Future work will concern the segmentation of population according to household composition, rather than census; the calibration of sector-specific floorspace consumption functions; the execution of a survey in order to identify attributes and estimate parameters of a behavioural location choice model.

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