A LUTI MODEL FOR STRATEGIC URBAN PLANNING: IMPACTS ESTIMATION OF A NEW TRANSIT SYSTEM

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ABSTRACT

The problem of simulating mutual interactions between spatial economic and transport systems has been tackled by the so-called Spatial Economic and Transport Interaction (SETI) models.
As literature is very large and involves economics and transportation planning, SETI models may be classified according to the spatial scale of analysis, defining as NETI (National Economy Transport Interaction) models the ones operating at national scale and as LUTI (Land Use Transport Interaction) models the ones operating at urban scale.
The paper proposes a LUTI model, which refers to a Multi-Regional-Input-Output (MRIO) framework. The model has two main components: a transport macro-model and a land use macro-model. The LUTI model is an urban specification of a general SETI model, which is designed to capture the dynamics of the processes represented and to integrate them into a multi-level framework.
The objective of the paper is to test the applicability of the general SETI model at the urban scale, in order to support land use and transport planning activities in the strategic urban dimensions. Strategic urban planning concerns interventions and policies that affect the use of physical urban structures and that require long times to be implemented.
The results of the application show that the defined general framework offers the potentialities to simulate the processes involved within the spatial economic and transport systems in urban areas and that it may represent the core of a decision support system for land use and transport planning activities in the strategic urban dimensions.

Keywords: spatial economic and transport interaction models, urban specification and application

1. INTRODUCTION

Spatial economic and transport systems are mutually interacting. The transport system plays an important role in the economy and in the spatial organization (geography) of an area (national, regional, urban), affecting activity location, production levels and trade patterns. Conversely, the spatial economic system affects travel demand characteristics.

As far as concerns the three planning dimensions of time, study-in-depth and space (Russo and Rindone, 2007; 2008), in the time dimension the Spatial Economic and Transport Interaction (SETI) process has a strategic scale; in the study-in-depth dimension, it has directional scale (in which objectives and strategies are defined); in the spatial dimension, it may be related to two different scales. At the national scale, attention is devoted to estimating the competitiveness of the different activities, defining production levels and location convenience. As the economic component is dominant over the land use component, we define a National Economy Transport Interaction (NETI) process. At the urban scale, the focus is on analysing the effects of transport mobility on the spatial organization of an area (e.g. location of residential, service and production activities) with subsequent land use. As the spatial component (land use) is dominant over the economic one, we define a Land Use Transport Interaction (LUTI) process (Russo and Musolino, 2008).

The paper proposes a LUTI model, which refers to a Multi-Regional-Input-Output (MRIO) framework. The model has two main components: a transport macro-model and a land use macro-model. The two macro-models are mutually interacting; the transport macro-model provides transport accessibilities to location model; the land use macro-model provides activity flows to travel demand model.

The LUTI model proposed is a specification of a general SETI model, which is designed according to a multi-level integrated framework. Theoretical aspects of the SETI model, even if recalled, are object of a specific line of research (Russo and Musolino, 2009).

The focus of this paper is to test the applicability of the specified LUTI model to support land use and transport planning activities in the strategic urban dimensions. Strategic urban planning concerns interventions and policies that affect the use of physical urban structures and that require long times to be implemented.

The LUTI model application concerns the estimation of long-term impacts determined by the introduction of a new transit system, called Sustainable Mobility System (SMS), in the town of Reggio Calabria (Italy). The main component of SMS is represented by a high-frequency light rail transport line in the central district of the town. The proposed transit system could offer an integrated and sustainable service to the different segments of travel demand, offering a direct connection among the existing attraction-generation travel demand urban poles and an indirect connection among the poles, the suburban districts of the town and the whole regional area.

The main conclusions of the paper are that the results confirm that the defined general multi-level framework offers the potentialities to simulate the processes involved within the spatial economic and transport systems and that it may be considered as the core of a decision support system for land use and transport planning activities in the strategic urban dimensions.

The paper is articulated in five sections. The first section recalls the main literature on SETI models, which refer to a Multi-Regional-Input-Output (MRIO) framework. The second section contains a formalization of a general SETI model. The third section reports a LUTI model, as a specification of the general SETI model. The application to the town of Reggio Calabria (Italy) is presented in the fourth section. In the last section the conclusions and the research perspectives are reported.
The work is part of a research project, which has the following general tasks: general formulation of a SETI model and analysis of its theoretical properties (Russo and Musolino, 2009), model specification and application in an urban area (Musolino, 2008), definition of land use and transport interventions and policies; simulation, assessment and comparison of their long terms effects through evaluation methods (Rindone and Musolino, 2009).

2. LITERATURE REVIEW ON SETI MODELS

The paper deals with the class of SETI models based on a Multi-Regional Input-Output (MRIO) framework. MRIO was originally developed to represent national economies, subdivided into sectors and zones (regions). In the national context, attention is focused on production location and on travel (freight and passenger) demand estimation, neglecting land use aspects. The basic concept lays in Keynes's theory (Keynes, 1936), who introduced the principle of effective demand, whereby production is determined by consumption. In the sphere of Keynes's theory, Leontief (1941) firstly proposed an IO model to simulate inter-dependencies between economic sectors through fixed technical coefficients. Further theoretical developments from the original IO framework, able to reproduce the spatial representation of the economy, were later proposed (Isard, 1951; Chenery, 1953; Moses, 1955). They introduced trade coefficients to calculate exogenously interregional trade patterns and locate production across zones, although they did not specify any model to estimate them. Several NETI models were proposed, which incorporates a location model into the IO framework in order to obtain an endogenous estimation of trade coefficients. Initially, trade coefficients were estimated through entropic-gravitational location models (Leontief and Strout, 1963; Wilson, 1970a, 1970b). However, after the proposition of random utility theory (Domencich and McFadden, 1975), they were estimated through discrete location models (de la Barra, 1989; Echenique and Hunt, 1993; Cascetta et al., 1996). The economy and freight travel demand have been extensively simulated at a national scale (Cascetta et al., 1996; Russo, 2001; Marzano and Papola, 2004; Kochelman et al., 2005).
In the urban context, a distinction must be made between models with exogenous transport costs and models with endogenous transport costs (LUTI models). A model belonging to the former category was proposed by Lowry (1964), which simulates location patterns of residential and service activities, given the level and location of basic (exogenous) employment. Several later attempts were made to overcome the original limitations of the Lowry model. Garin (1966) extended its applicability by casting the entire model in matrix notation. Macgill (1977) presented it as an input-output model; marking the first attempt to build a metropolitan Input-Output (IO) model that captures inter-sectorial linkages. Further developments were presented by Putnam (1973, 1983, 1991), who proposed two models to respectively locate residents (DRAM, Disaggregate Residential Allocation Model) and employment (EMPAL, Employment Allocation Model) across zones. Models belonging to the

latter category (LUTI models) incorporate a transport modelling framework, which generally has three main components: a supply model, a travel demand model and an assignment model. A large variety of models belonging to each component may be found in the literature. Detailed state-of-the-art of transport models are presented in Ben-Akiva and Lerman (1984), Ortuzar and Willumsen (2001), Cascetta (2006). Several LUTI models are proposed in de la Barra (1989), Echenique and Hunt (1993), Echenique (2004), Wegener (1998), Bifulco (2000), Simmonds (2000). A detailed classification is reported in Russo and Musolino (2007, 2008).

3. SETI GENERAL FORMULATION

The section reports the general formulation of a SETI model, which refers to a Multi-Regional-Input-Output (MRIO) framework. The SETI model has two interacting macro-models: the transport macro-model and the spatial economic macro-model, which are presented below.

3.1. Transport macro-model

The transport macro-model has three main components, namely the supply model, demand model and assignment model.
The supply model is represented by a network model, with a primary graph and aggregate link cost functions (time-flow relationship). The general formulation of the congested network model consists of a path costs vs link costs consistency equation (1.a) and of a path flows vs link flows consistency equation (1.b):

$$\mathbf{g} = \Delta^{T} \boldsymbol{c} (\mathbf{f}) \qquad (1.a)$$
$$\mathbf{f} = \Delta\, \mathbf{h} \qquad (1.b)$$

with
g, path costs vector;
Δ, link-path incidence matrix;
c, link cost functions vector;
f, link flows vector;
h, path flows vector.
The demand model is behavioural (random utility based) and elastic to transport costs on the trip generation and mode dimensions and to trade flows, with a stochastic path choice model

$$\mathbf{h} = \boldsymbol{P} (\Delta^{T} \boldsymbol{c} (\mathbf{f}))\, \boldsymbol{d} (\mathbf{n}, \mathbf{v}) \qquad (2)$$

with
P, probability path choice functions matrix;
d, demand functions vector;
n, trade flows vector (obtained rearranging the matrix **N** defined below);

$\mathbf{v}=\boldsymbol{v}(\mathbf{g})=\boldsymbol{v}(\Delta^{T}\,\boldsymbol{c}(\mathbf{f}))$, transport utilities vector (obtained rearranging the transport utilities matrix $\mathbf{V}$).
The assignment model is a user equilibrium model with stochastic path choice model and elastic travel demand:

$$\mathbf{f} = \Delta\,\boldsymbol{P}\,(\Delta^{T}\,\boldsymbol{c}\,(\mathbf{f}))\,\boldsymbol{d}\,(\mathbf{n},\,\boldsymbol{v}(\Delta^{T}\,\boldsymbol{c}\,(\mathbf{f})) \qquad (3)$$
$$\mathbf{f} \in S_{\mathbf{f}}$$

with
$\mathbf{f}$, link flows vector;
$S_{\mathbf{f}}$, set of feasible link flows.

3.2. Spatial economic macro-model

The spatial economic macro-model is composed by:
an activity generation model with technical coefficients depending on selling prices

$$\mathbf{y} = \boldsymbol{A}(\mathbf{p})\,\mathbf{y} + \mathbf{y}^{\mathbf{e}} \qquad (4)$$

with
$\mathbf{y}$, activity demand vector;
$\boldsymbol{A}(\mathbf{p})$, technical coefficients functions matrix;
$\mathbf{p}$, selling prices vector;
$\mathbf{y}^{\mathbf{e}}$, exogenous activity demand vector;
an activity location model for estimating trade coefficient matrix, $\mathbf{T}$, which depends on transport utilities, selling prices and production

$$\mathbf{T} = \boldsymbol{T}(\mathbf{V},\,\mathbf{p},\,\mathbf{x}) \qquad (5)$$

with
$\boldsymbol{T}$, trade coefficient functions matrix;
$\mathbf{x}$, production vector;
an activity generation-location interaction model:

$$\mathbf{N} = \boldsymbol{T}(\mathbf{V},\,\mathbf{p},\,\mathbf{x})\,\boldsymbol{A}(\mathbf{p})\,\boldsymbol{Dg}(\mathbf{y}) + \boldsymbol{T}(\mathbf{V},\,\mathbf{p},\,\mathbf{x})\,\boldsymbol{Dg}(\mathbf{y}^{\mathbf{e}}) \qquad (6)$$

with
$\boldsymbol{Dg}(\mathbf{y})$, matrix obtained by arranging the elements of vector $\mathbf{y}$ along the main diagonal.
Finally, production vector, $\mathbf{x}$, is obtained from:

$$\mathbf{x} = \mathbf{1}^{T}\,\mathbf{N} \qquad (7)$$

3.3. Interaction between spatial economic and transport macro-models

The spatial economic macro-model and the transport macro-model are mutually interacting. The transport macro-model provides transport utilities, **V**, for the spatial economic one

$$\mathbf{N}=\boldsymbol{N}(\mathbf{V}) \qquad (8)$$

and the spatial economic macro-model provides trade flows, **N**, for transport

$$\mathbf{V}=\boldsymbol{V}(\mathbf{N}) \qquad (9)$$

Combining eqs. (8) and (9), we obtain:

$$\mathbf{N}=\boldsymbol{N}(\boldsymbol{V}(\mathbf{N})) \qquad (10)$$

4. URBAN SPECIFICATON OF THE SETI MODEL

In this section the above SETI model is specified for the urban scale.

4.1. Land use model specification

The land use model is composed by an integrated activity generation-location model, obtained combing eqs. (6) and (7):

$$\mathbf{x} = \boldsymbol{T}\,(\mathbf{V},\mathbf{p},\mathbf{x})\,\boldsymbol{A}\,(\boldsymbol{p})\,\mathbf{y} + \boldsymbol{T}\,(\mathbf{V},\mathbf{p},\mathbf{x})\,\mathbf{y}^{\mathbf{e}} \qquad (11)$$

The emphasis is laid mainly on tertiary economic sectors (such as services and commerce), t, on residential, h, and on land, l, sectors. The urban spatial system is discretized and production (vector **x**) and intermediate consumption (vector **y**) of socio-economic activities are generated by their exogenous (final) consumption (vector $\mathbf{y}^{e}$). All socio-economic sectors demand for land, represented by the available floor-space.
In eq. (11), vectors **y** and **x** are specified as follows:

$$\mathbf{y}= [\, \mathbf{y}^{\mathbf{t}} + \mathbf{y}^{\mathbf{t,e}} \mid \mathbf{y}^{\mathbf{h}} + \mathbf{y}^{\mathbf{h,e}} \mid \mathbf{y}^{\mathbf{l}} + \mathbf{y}^{\mathbf{l,e}}]^{T}$$

$$\mathbf{x}= [\, \mathbf{x}^{\mathbf{t}} + \mathbf{x}^{\mathbf{t,e}} \mid \mathbf{x}^{\mathbf{h}} + \mathbf{x}^{\mathbf{h,e}} \mid \mathbf{x}^{\mathbf{l}} + \mathbf{x}^{\mathbf{l,e}}]^{T}$$

where
$\mathbf{y}^{\mathbf{t(h,l)}}$ is the sub-vector of tertiary (residential, available floor-space) endogenous sector consumption;
$\mathbf{y}^{\mathbf{t(h,l),e}}$ is the sub-vector of tertiary (residential, available floor-space) exogenous sector consumption;
$\mathbf{x}^{\mathbf{t(h,l)}}$ is the sub-vector of tertiary (residential, available floor-space) endogenous sector production;

$\mathbf{x}^{\mathbf{t(h,l),e}}$ is the sub-vector of tertiary (residential, available floor-space) exogenous sector production.
Sector production and consumption may be expressed in monetary value (e.g. euro) or specific quantity (e.g. households, employees). Technical coefficients of matrix, **A**, simulate the generation process of tertiary, residential and land sectors by exogenous consumption. Technical coefficients connected to tertiary and residential sectors are constant, while technical coefficients connected to available floor-space consumption are elastic (de la Barra, 1989) to prices:

$$a_j^{l,n} = \beta_1^{l,n} + \beta_2^{l,n} \exp(-\beta^n p_j^l) \qquad (12)$$

where
$a_j^{l,n}$ is the unit of available floor-space consumption (technical coefficient) by sector n(=t, h) in zone j;
p_j^l, the average price of a unit of available floor-space in zone j;
$\beta_1^{l,n}$, $\beta_2^{l,n}$, β^n, parameters to be calibrated.
Trade coefficients matrix, **T**, simulates the location process of tertiary and residential sectors among zones of an urban area. Each component of trade coefficients matrix, $t^m_{i/j}$, is estimated through a multinomial logit model (assuming that random residuals are i.i.d. according to a Gumbel distribution):

$$t^m_{i/j} = \exp(v^m_{i/j})/\Sigma_{k \in N} \exp(v^m_{k/j}) \qquad \text{for m=t, h} \qquad (13.a)$$

where
$v_{i/j}^m = \beta_p^m\ p_i^m + \beta_v^m\ v_{ij}^m$ is the systematic (dis)utility of locating sector m(=t, h) in zone i conditional upon it being consumed in zone j;
$p_i^m = k_i^m + e_i^m$, average price of sector m produced in zone i (as sum of a production cost, k_i^m, and a rent, e_i^m);
v_{ij}^m, the transport (dis)utility of sector m from zone i to zone j;
β_p^m, β_v^m, parameters to be calibrated.
Interzonal trade coefficients for available floor-space (land) sectors, l, are set to zero:

$$t^m_{i/j} = \begin{cases} 0 & \text{if } i \neq j \\ 1 & \text{otherwise} \end{cases} \qquad \text{for m=l} \qquad (13.b)$$

Limited production concerns restrictions in available floor-space in each zone, which could generate a rent if demand of floor-space exceeds available supply.

4.2. Transport model specification

The transport model consists of an assignment model with travel demand elastic to transport (dis)utility in trip generation, mode and path dimensions:

$\mathbf{f} = \Delta\, \boldsymbol{P}\, (\Delta^T \boldsymbol{c}\, (\mathbf{f}))\, \boldsymbol{d}\, (\mathbf{n}, \boldsymbol{v}(\Delta^T \boldsymbol{c}\, (\mathbf{f})))$ (14)
$\mathbf{f} \in S_{\mathbf{f}}$

The transport model comprises travel demand and supply models.

4.2.1. Travel demand models
Travel demand is estimated through a three-step system of demand models that simulate path, mode and making-a-trip choices. The distribution model is not present, since the spatial distribution of demand is derived from inter-zone activity flows supplied by the model of eq. (6).
The stochastic (logit) path choice model provides the percentage (probability) of trips, undertaken by users of category s, choosing path k between OD pair ij with mode q, p[k/ijsq]:

$p[k/ijsq] = \exp(v^s_{k/ijq}/\theta_k) \,/\, \Sigma_{k' \in K_{ijq}} \exp(v^s_{k'/ijq}/\theta_k)$ (15)

where
$v^s_{k/ijq} = -\beta^s g_k$, utility of path k for users of category s;
$g_k = \Sigma_l\, \delta_{lk} c_l(f_l)$, average generalized flow-dependent cost of path k (eq. 2.a);
β^s, weight connected to path cost for users of category s;
K_{ijq}, path choice set connecting OD pair ij with mode q;
θ_k, logit dispersion parameter.
The stochastic (logit) mode choice model simulates the percentage (probability) of trips, undertaken by users of category s, choosing mode q between OD pair ij, p[q/ijs]:

$p[q/ijs] = \exp(v^s_{q/ij}/\theta_q) \,/\, \Sigma_{q'} \exp(v^s_{q'/ij}/\theta_q)$ (16)

where
$v^s_{q/ij} = \theta_k \ln \Sigma_{k' \in K_{ijq}} \exp(v^s_{k'/ijq}/\theta_k)$, utility of users of category s associated to mode q for OD pair ij;
θ_q, logit dispersion parameter.
The trip generation model simulates the choice of making a trip from each origin for user category s. The probability of undertaking x trips between OD pair ij, p[x/ijs], is expressed as

$p[x/ijs] = \exp(v^s_{x/ij}/\theta_x) \,/\, (\exp(v^s_{x=0/ij}/\theta_x) + \exp(v^s_{x=1/ij}/\theta_x))$ (17)

with
$v^s_{x=1/ij} = \theta_x \ln \Sigma_{q'} \exp(v^s_{q'/ij})$, transport utility of making one trip for category s for OD pair ij;
x(=0, 1), number of trips between OD pair ij;
θ_x, logit dispersion parameter.

4.2.2. Supply models
The supply model for private mode is a congested network model, consisting of a synchronic graph and flow-dependent link cost functions. Transit services are represented through a line-based supply model, where the graph is made up by a service sub-graph and an access-egress sub-graph, with no flow-dependent link cost functions (non-congested network).

4.3. Input and output variables of the LUTI model

According to the above definitions, the variables that feed the proposed LUTI model (input variables) are:

- link-path incidence matrix, Δ, which represents the transport network topology;
- link cost functions vector, $\boldsymbol{c}(\mathbf{f})$;
- exogenous production of available floor-space (land) sectors, $\mathbf{x}^{\mathbf{l,e}}$;
- exogenous demand vector, $\mathbf{y}^{e}$.

Among the variables provided by the LUTI model (output variables), we recall the ones that are used in the application:

- travel demand vector, **d**;
- transport (dis)utilities matrix, **V**.
- production vector, **x**, which describes the spatial distribution of tertiary and residential sectors among the zones of the urban area;
- price vector, **p**, which also includes average values per zone of floor-space prices.

5. MODEL APPLICATION

The proposed LUTI model has been applied to the town of Reggio Calabria (Italy). The study area includes the municipality of Reggio Calabria, with about 180,000 inhabitants and an area of 236.02 km^2. It consists of a central district with residential and retail activities, educational and public services clustered into three poles (university, regional government and health, municipal government); and of three suburban districts (northern, southern, hill) with manufacturing activities and scattered residences.
The study area is divided into thirty-five zones with homogeneous socio-economic characteristics. The central district is divided into twenty-four zones, the northern district into six, the southern district into two and the hilly district into three zones. The activity system inside the study area is segmented into eight sectors to match available census residential and employment location data (ISTAT, 2001): manufacturing, service and office, retail, school education, university education, low-income population, high-income population, available floor-space.
The current transit supply is represented by bus services, segmented in urban (896 runs/day) and extra-urban (256 runs/day) services; regional and interregional rail services (34 runs/day), interacting with bus services through interchange terminals close to the two rail stations located in the central district, interregional maritime services (21 runs/day), interacting with bus services through an interchange terminal located in the harbour area. The analysis of supply and demand characteristics allows affirming that existing transit services are not attractive for many reasons: absence of direct connections among the three above poles, attracting and generating travel demand, and between the poles and interchange terminals; low regularity and commercial speed of bus services, low frequencies in the peak periods.
According to the above critical points, a new transit system, called Sustainable Mobility System (SMS), is proposed to offer an integrated and sustainable transport service to the different segments of travel demand. SMS is specifically designed to operate in small-medium urban areas, as it is the town of Reggio Calabria, where, on one side, traditional

heavy rail transport services offer an excess of transport capacity, so they are not economically convenient, and, on the other side, bus services are not able to offer enough transport capacity along corridors connecting different attraction-generation travel demand poles. The main component of SMS is represented by a high-frequency light rail transport line travelling in a reserved right-of-way, with stops every 400-500 metres and an automated vehicle guidance (Russo *et al*., 2008). Figure 4 shows the area inside the central district where the light rail transport (SMS) line operates, pole locations and a schematic representation of bus, rail and SMS itineraries.

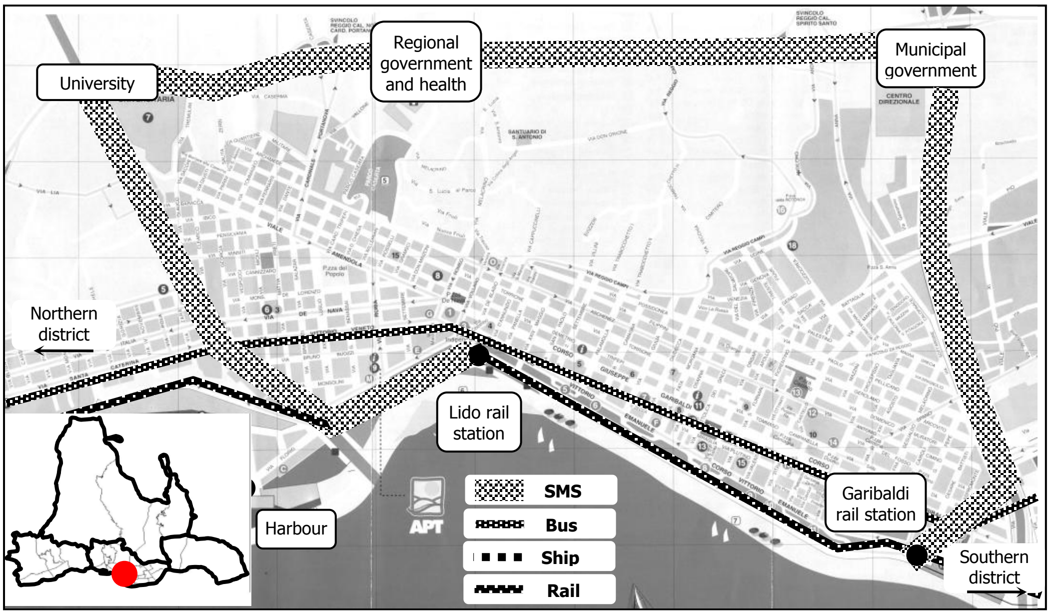


Figure 1. Bus, rail, SMS itineraries and poles location inside the central district

5.1. Model calibration and validation

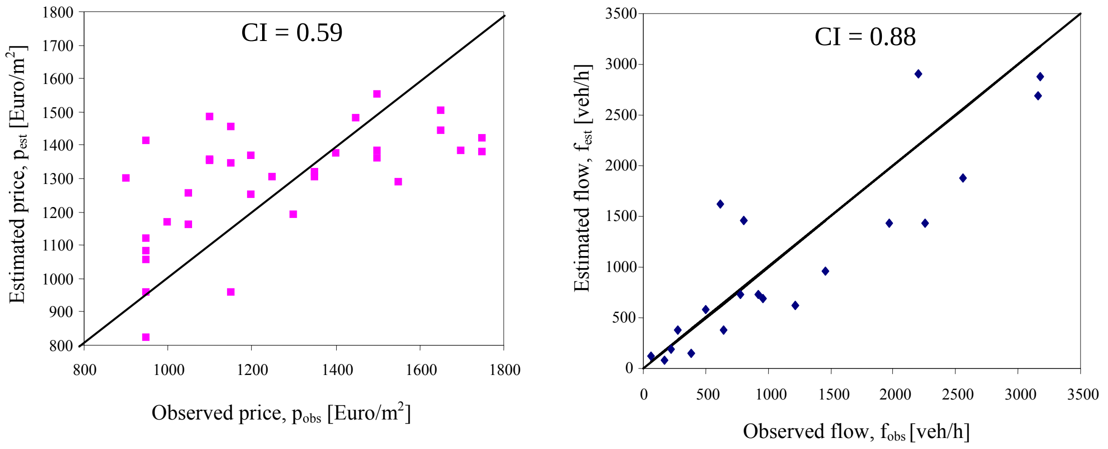
Before presenting simulation results, some comments concerning model calibration and validation are reported.

In the land use model, activity segmentation into sectors was performed in order to ensure consistency with available data at urban scale. Fixed technical coefficients were derived from available census data related to the town of Reggio Calabria provided by Italian National Statistics Institute (ISTAT, 2001) and municipal authorities, while parameters of model (12) were estimated through an aggregate calibration from observed data concerning average unit of land consumption per sector and land prices in each zone.

Validation has been performed concerning floor-space price per zone, which is estimated as the result of an interaction between a floor-space consumption (eq. 12), generated by each sector which production is located to each zone through the location model, and the floor-space supply present in each zone. Observed values of floor-space prices are provided by Real Estate Observatory of the municipality of Reggio Calabria (www.agenziadelterritorio.it). Figure 2 shows a comparison between observed and estimated prices for each zone (Correlation Index = 0.59).

In the transport model, parameters of link cost functions are derived from the literature, considering urban roads with similar characteristics. Four link categories have been identified, for each of them specific values of free speed and capacity are determined. An extensive sensitivity analysis is performed on parameters of models (15), (16) and (17) according to observed aggregate available data.

Validation has been performed comparing observed and simulated vehicular link flows on some selected urban links (Correlation Index = 0.88), as reported in Figure 2.



Correlation Index: $CI = (\Sigma_i (x_{i,obs}-x_{avg,obs}) (x_{i,est}-x_{avg,est}))/((\Sigma_i (x_{i,obs}-x_{avg,obs})^2 (x_{i,est}-x_{avg,est})^2)^{0,5}$ for x=p, f

Figure 2: Observed and estimated floor-space prices and link flows

5.2. Scenarios definition

This paragraph describes the scenarios considered in the application, which are defined as a combination of transport and land use interventions. Transport interventions entail the realisation of infrastructure and services connected to the proposed SMS transit system:

- realization of a light rail transport line (SMS line);
- frequency doubling of bus and rail lines (DF, Double Frequencies);
- frequency doubling of rail lines (DF_{rail}, Double Frequencies of rail lines).

Land use interventions concern the identification and location of increments of available land inside the study area for locating new residential and tertiary activities:

- increment of available land in central district (LCZ, Land Central Zone);
- increment in available land in southern district (LSZ, Land Southern Zone);
- increment in available land in suburban districts (LS, Land Suburbs).

A Do-Nothing (DN) scenario is also defined assuming the current transport and activity system. Combined land use and transport scenarios are presented in Table 1.

5.3 Scenarios simulation

The combined scenarios are simulated by means of the LUTI model, converting the defined land use and transport interventions into values of input variables, which feed the model for each scenario, and estimating the values of output variables, provided by the model, as defined in section 4.3.

Table 1. Combined land use and transport scenarios

Scenario	Code	Description	
		Land use	Transport
1	DN	Do-Nothing	
2	LCZ+SMS	Land increment in central district	SMS line
3	LSZ+SMS	Land increment in southern district	SMS line
4	LS+SMS	Land increment in all suburban districts	SMS line
5	LS+SMS+DF	Land increment in all suburban districts	SMS line and frequency doubling of bus and rail lines
6	LSZ+DF_{rail}	Land increment in southern district	Frequency doubling of rail lines

Concerning input variables, in order to provide a general overview of their modifications at study area level for each scenario, the following aggregate variables are defined. The total length of transit lines is the aggregate variable connected to the transport network topology (matrix Δ), as itineraries of existing transit lines are not modified; while the total frequency of each transit service (SMS, bus, rail), calculated as the sum of the frequencies of the existing lines, is the aggregate variable connected to link cost functions vector, $\boldsymbol{c}(\mathbf{f})$, as frequencies of transit lines affect the components of vector $\boldsymbol{c}(\mathbf{f})$ related to waiting time at stops. The aggregate variable representing the production of available floor-space (vector $\mathbf{x}^{l,e}$) is the total floor-space increment available in the study area and the district where it is located. No modifications are assumed in the defined scenarios for the exogenous demand vector, $\mathbf{y}^{e}$.
Table 2 reports the percentage variations of the above aggregate variables for each of the combined scenarios related to the DN one.

Table 2. Input variables of the LUTI model

Scenario	Code	Δ	$\boldsymbol{c}(\mathbf{f})$			$\mathbf{x}^{l,e}$ Available floor-space	
		Transit lines var (%)	Freq. SMS(*) var(run/h)	Freq. bus var (%)	Freq. rail var (%)	var (%)	District
2	LCZ+SMS	0,7	12	0	0	4,7	c
3	LSZ+SMS	0,7	12	0	0	4,7	s
4	LS+SMS	0,7	12	0	0	4,7	h/s/n
5	LS+SMS+DF	0,7	12	100	100	4,7	h/s/n
6	LSZ+ DF_{rail}	0,0	0	0	100	4,7	s

var%, percentage variation related to the DN scenario, c= central district, h= hilly district, n= northern district, s= southern district; (*) morning peak period 7:30 am - 9:30 am.

The percentage variation of total length of transit lines is +0,7%, due to the introduction of new SMS line with a frequency of 12 run/h, in all scenarios except the LSZ+ DF_{rail} one, where the transport intervention consists in doubling frequency of existing rail lines (+100%). The percentage variation of total available floor-space in the study area is +4,7% in all scenarios, but their differ according to the district where the increment is supposed to be located.

As far as concern output variables, three aggregated variables at study area level are estimated form the disaggregate output variables provided by the LUTI model (see section 4.3):

- travel demand per transport mode, related to vector, **d**;
- transport disutility index, related matrix, **V**;
- spatial distribution of residential and tertiary sectors per district, related to vector, **x**.

The estimated values of travel demand per available transport mode for each scenario are presented in Table 3.

Table 3. Output variables of the LUTI model: travel demand per transport mode.

Scenario	Code	Private demand $d_{private}$	Bus demand d_{bus}	Rail demand d_{rail}	SMS demand d_{SMS}
1	DN	66121 (users)	9613 (users)	1255 (users)	0
		var (%)	var (%)	var (%)	(users)
2	LCZ+SMS	-6,1	-44,7	66,3	5629
3	LSZ+SMS	-7,7	-34,8	217,5	5707
4	LS+SMS	-5,4	-35,2	124,4	5507
5	LS+SMS+DF	-8,8	-27,1	128,3	5540
6	LSZ+DF_{rail}	-7,2	-1,0	45,3	0

var%, percentage variation related to the DN scenario

The results show that the introduction of SMS line ensures a direct connection among the three poles located in the central district. SMS line, fed by rail services, also offers an indirect connection between the central district zones and those in the northern and southern districts. This consideration is enforced by the considerable SMS travel demand and the positive variations in rail travel demand (ranging from +66,3% to +217,5%). The introduction of SMS line and the increment of rail users determine a negative variation in bus travel demand (ranging from -27,1% to -44,7%) in the scenarios where SMS line is present and a general reduction of users in private modes in all scenarios (ranging from -5,4% to -8,8%). In conclusion, the increasing level of service determined by the introduction of SMS line makes transit more attractive for transport users, causing an appreciable shift from private to transit modes.

The aggregate transport disutility index is defined as:

$$v = 100\ \Sigma_s\,{}^{,}\Sigma_{ij}\ v_{x=1/ij}^{s,SC} \,/\, \Sigma_s\,{}^{,}\Sigma_{ij}\ v_{x=1/ij}^{s,DN} \qquad (18)$$

where

$v_{x=1/ij}^{s}$, transport utility of making one trip for category s for OD pair ij, as defined in eq. (17);

SC, generic combined scenario.

The estimated values of index expressed by eq. (18) for each scenario are reported in Table 4. The highest variations in relation to the DN scenario (for which a value of 100 is assumed) concern the LCZ+SMS (81,4) and LS+SMS+DF (78,8) scenarios.

Table 4. Output variables of the LUTI model: transport disutility index

Scenario	Code	Transport disutility (v)
		(v_{DN}=100)
2	LCZ+SMS	81,4
3	LSZ+SMS	85,3
4	LS+SMS	88,7
5	LS+SMS+DF	78,8
6	LSZ+ DF_{rail}	86,3

The spatial distribution of residential (sub-vector, $\mathbf{x}^h$) and tertiary (sub-vector, $\mathbf{x}^t$) sectors per district of the study area for each combined scenario are presented in Table 5. The aggregate spatial distribution of residential and tertiary sectors is reported in absolute values (individuals) for the DN scenario, where central district presents the higher concentration of both residents and employees. The results concerning the other scenarios are reported in terms of percentage variations related to the DN scenario. In general, it is worth to recall that the results show to be affected, as expected, by the input connected to the location of incremental exogenous production of available floor-space (land) sector, $\mathbf{x}^{l,e}$ (see table 3). Comparing the scenarios, it emerges that the increment in floor-space availability in a district represents the main element driving the variations of residential and tertiary sectors location. Central district attracts residents (+11,85%) and employees (+2,53%) from suburbs in LCZ+SMS scenario, while they are clearly attracted by southern district in LSZ+SMS (respectively +74,92% and +27,41%) and LSZ+DF_{rail} (respectively +64,99% and +29,61%) scenarios. Residents and employees spread over the three suburban districts (southern, northern and hilly) in the LS+SMS scenario and a similar pattern, but less evident, is present in the LS+SMS+DF one.

Table 5. Output variables of the LUTI model: spatial distribution of activities per district.

		Scenario					
	District	DN	LCZ+SMS	LSZ+SMS	LS+SMS	LS+SMS+DF	LSZ+ DF_{rail}
		(individuals)	var (%)	var (%)	var (%)	var (%)	var (%)
Residents (h)	c	110553	11,85	-2,15	-1,24	0,79	-0,94
	s	19215	-9,09	74,92	13,84	2,95	64,99
	n	31290	-6,30	-6,15	16,97	6,57	-5,16
	h	17904	-9,46	-8,91	12,65	2,15	-10,04
Tertiary (t)	c	41639	2,53	2,20	2,54	-0,94	0,06
	s	2400	13,49	27,41	17,44	8,82	29,61
	n	3344	6,30	6,38	10,01	4,52	4,50
	h	1420	15,71	17,08	21,10	9,99	13,23

var%, percentage variation related to the DN scenario; c= central district, h= hilly district, n= northern district, s= southern district.

6. CONCLUSIONS

The paper proposes a LUTI model for urban areas as a specification of a general SETI model, which is designed according to a multi-level integrated framework. The SETI model allows simulating the mutual interactions between the (transport) processes concerning the user dimensions of mobility and the (spatial-economic) processes involving the spatial location of employment and population and the economic and technological elements which affect the use of the physical infrastructures. Theoretical aspects of the SETI model are object of a specific line of research (Russo and Musolino, 2009).

The focus of this paper is to test the ability of the specified LUTI model to support land use and transport planning activities in the strategic urban dimensions, which concern interventions and policies that affect the use of physical urban structures.

From the experienced application, the following considerations may be drawn which show the potentialities of the model and the directions of future research.

The aggregated outputs presented in the paper show that the LUTI model is able to capture long-term impacts on some dimensions of mobility and on spatial location of residents and employment determined by exogenous land use and transport interventions. The combined scenarios have in common increments of supply of transit infrastructures and services (introduction of SMS line and/or doubling frequencies of bus and rail lines) and increments of supply of available floor-space in different districts of the study area. The scenarios are defined in laboratory and are far than a practical implementation in an urban area; but they are useful at this research stage, because they clearly show that they, generally, affect the mobility process in the dimension of mode choice and the location process of residential and tertiary sectors.

The calibration and validation of the LUTI model is still today object of research, due to the lack of disaggregated data at urban scale that did not allow segmentation of activity system nor to calibrate some models parameters.

Further research activities regard the investigation of the relationships among activities location process, land prices and transport accessibility, the analysis of the dynamics of the mobility and spatial interaction processes, and the assessment of land use and transport interventions and policies through indicators able to provide disaggregate measures related to the three dimensions of sustainability (environmental, social and economic).

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