Modelling long-term impacts of the transport supply system on land use and travel demand in urban areas

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Abstract

It is commonly accepted that there is a two-way relationship between land use and transport in urban areas. Land use affects transport, conditioning travel demand. Conversely, transport affects land use, conditioning spatial distribution of activities and land market.

The problem of simulating mutual interactions between land use and transport has been tackled by so-called Land Use Transport Interaction (LUTI) models. Different modelling approaches are present in literature, which are generally grouped into three main categories: spatial micro-economic, spatial interaction and spatial accounting models.

The paper presents a spatial accounting LUTI model, which relies on Multi-Regional-Input-Output (MRIO) framework. The model has two main interacting components: an activity model and a transport model, which allow to endogenously estimate activities generation and location, land prices, travel demand and transport accessibility.

The proposed LUTI model has been specified and applied in an urban area, more particularly to the town of Reggio Calabria (Italy). The objective of the application is the estimation of long-term impacts on land use and passenger travel demand patterns when interventions on transport facilities and services are planned at a strategic scale. The results confirm that MRIO framework offers the potentialities to bring activity location, land use in line within travel demand modelling.

Keywords: Land use transport interaction; Activity location; Travel demand.

1. Introduction

In urban areas land use affects transport, conditioning travel demand. Conversely, transport affects land use, conditioning spatial distribution of activities and land market.

The two-way relationship between land use and transport may be simulated by so-called Land Use Transport Interaction (LUTI) models. Literature is very rich and involves urban economics and urban transportation planning. LUTI models are generally grouped into three main categories: spatial micro-economic, spatial interaction and spatial accounting models.

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Spatial micro-economic models treat space as a continuous variable, making it impossible to represent geography in all its variety. Modelling more than one market place or centre of employment is very complex, even if much effort has been, and is still, made in this direction. Furthermore, it is impossible to capture individual behaviour of consumers and producers. Spatial interaction models provide an aggregate perspective, since both space and activities are grouped into discrete categories. They are loosely structured from a theoretical point of view: the entropy-maximising method makes no assumptions about the behaviour of consumers and producers involved and no market equilibrium process is guaranteed.

The development of spatial accounting models pivots on the potential provided by the Multi-Regional-Input-Output (MRIO) framework, which considers the dimension of production in relation to the spatial structure. This potential has been translated into concrete application by the introduction of discrete choice modelling. The MRIO framework offers a set of relationships able to bring activity location, land use in line within travel demand modelling.

The paper presents an urban Land Use Transport Interaction (LUTI) model, belonging to the spatial accounting category. The model has two main components: a transport model and an activity model. The former solves the internal circular dependence among transport demand, link flows and link costs. The latter solves the internal circular dependence among activity demand, activity flows and land prices. Moreover, the two modelling components are mutually interacting: the transport model provides transport accessibilities to location model; the activity model provides activity flows to travel demand model.

The proposed urban LUTI models has been specified and applied to the town of Reggio Calabria (Italy), with the objective to simulate long-term impacts on land use and passenger travel demand patterns when interventions on transport facilities and services are planned at a strategic scale. The planned intervention concerns a high-frequency transit system, called Sustainable Mobility System (SMS), operating in the central district of the town.

Simulation results are related to activities location, land prices, travel demand and transport accessibility before and after the introduction of SMS. Regarding effects on location patterns, SMS increases transport accessibility. This makes the zones served by SMS more attractive to locate activities, leading to higher land prices. The process ends attracting activities with lower sensitivity to land prices in central district, pushing activities with higher sensitivity to land prices towards suburbs. Regarding effects on travel demand patterns, the increasing level of service due to SMS makes transit more attractive by transport users, causing a sensible shift from private to transit modes.

The rest of the paper is articulated in five sections. Section 2 presents a brief literature review on LUTI modelling. Section 3 describes the general framework of the proposed LUTI model. In the fourth section, each modelling component is specified. Section 5 illustrates the model application and presents some results concerning activities location, land prices, travel demand and transport accessibility. In the last section final remarks are reported.
2. Literature review

In literature LUTI models are generally grouped into three categories according to the background theory from which they could be derived: spatial micro-economic, spatial interaction and spatial accounting models.

Spatial micro-economic models focus their analysis on consumers (households and firms) and producers (landowners and employers). Their behaviour is driven by market mechanisms, in which consumers maximise their utilities subject to budget constrains and producers maximise their profits, generating an equilibrium pattern of land rent. The pioneering work of Von Thünen (1826) explained the effect of transport costs on activity locations and land prices. Wingo (1961) and Alonso (1964) adapted Von Thünen monocentric market proposition for the urban case by adding consumers budget constraints. Further developments were present in Muth (1968) and Mills (1969) models. After the proposition of random utility theory (Domencich and McFadden, 1975), Anas and Duann (1984) proposed an integrated model able to bring into agreement land rent with residential location and travel demand modelling. Recently, computable general equilibrium models able to clear land, labour and good markets and to simulate travel demand were presented (Anas and Kim, 1997, Anas and Liu, 2007). The large number of papers on these models may be included in the broad discipline called urban economics.

Spatial interaction models provide an aggregate perspective, since both space and activities are grouped into discrete categories. Lowry (1964) proposed a gravity-based urban land use model, which allows estimating the distribution of population, employment and land use. A general theoretical framework for gravity models is the entropy-maximizing method introduced by Wilson (1967, 1970a). Lowry model was further developed by Putman (1973, 1983).

Spatial accounting models rely on 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 travel (freight and passenger) demand estimation, neglecting land use aspects. The basic concept was in Keynes theory (Keynes, 1936), who introduced the principle of effective demand, whereby production is determined by consumption. In the sphere of Keynes 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 MRIO models were proposed, which incorporates a location model into the IO framework in order to obtain an endogenous estimation of trade coefficients. At a first stage, trade coefficients were estimated through entropic-gravitational location models (Leontief and Strout, 1963; Wilson, 1970b). But, 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). Several papers were presented in which the economy and freight travel demand at a national scale are simulated (Cascetta et al., 1996; Russo, 2001; Marzano and Papola, 2004; Kochelman et al., 2005).

At urban scale, several LUTI models, which integrate the IO framework and random utility theory, were proposed in literature (de la Barra, 1989; Echenique and Hunt, 1993;
The models simulate transport and activity systems 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, 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 (quantities) on network. If the available supply of transport facilities and services is limited, congestion costs arise bringing the transport system to an equilibrium condition. In the activity model, household and firms' behaviour is simulated, through an activity generation model which estimates demand (consumption) levels of activities (population, employment, land) and an activity location model which simulates where activities supply (production) are located across zones. Location choices are driven by utilities, composed by supply prices plus transport costs. Subsequently demand-supply interaction, supply prices and production quantities are estimated in each zone. Due to supply constrains (ex. restrictions in available land), a rent could be generated bringing the activity system to an equilibrium condition. A detailed state-of-the-art on MRIO framework is presented in Russo and Musolino (2007).

3. LUTI model formalization

In this paper a LUTI model, which belongs to the category of spatial accounting models, is proposed. The model has two interacting components: the transport model and the activity model.

3.1. Transport model

The transport model is composed by:
- a demand model, elastic to costs on the emission and mode dimensions, with a stochastic path choice model

\[ h = P (\Delta^T c (f)) d (F, V) \]  

(1)

with
- \( h \), path flows vector;
- \( P \), probability path choice functions matrix;
- \( \Delta \), link-path incidence matrix;
- \( c \), link cost functions vector;
- \( f \), link flows vector;
- \( d \), demand functions vector;
- \( F \), activity flows vector;
- \( V = V(g) \), transport utilities vector;

- a congested network model

\[ g = \Delta^T c (f) \]  

(2.a)

\[ f = \Delta h \]  

(2.b)
with
\( g \), path costs vector;

- an assignment model

\[
\mathbf{f}^* = \Delta P (\Delta^T e (\mathbf{f}^*)) d (\mathbf{F}, \mathbf{V})
\]

\( \mathbf{f}^* \in S_f \)

with
\( \mathbf{f}^* \), link flows vector at equilibrium;
\( S_f \), set of feasible link flows;

3.2. Activity model

The activity model is composed by:

- an activity generation model with technical coefficients depending on prices

\[
\mathbf{Y} = \mathbf{A}(\mathbf{p}) \mathbf{Y} + \mathbf{Y}^e
\]

with
\( \mathbf{Y} \), activity demand vector;
\( \mathbf{A}(\mathbf{p}) \), technical coefficients functions matrix;
\( \mathbf{p} = p(\mathbf{F}) \), sector prices vector, which depends on activity flows vector, \( \mathbf{F} \), through the production vector, \( \mathbf{X} \);
\( \mathbf{Y}^e \), exogenous activity demand vector;

- an activity location model for estimation of trade coefficient matrix, \( \mathbf{T} \), which depends on prices and transport utilities

\[
\mathbf{T} = T(\mathbf{p}, \mathbf{V})
\]

with
\( \mathbf{T} \), trade coefficient functions matrix;

- an activity generation-location interaction model:

\[
\mathbf{F}^* = T(p(\mathbf{F}^*), \mathbf{V}) \mathbf{A}(p(\mathbf{F}^*)) Dg(\mathbf{Y}) + T(p(\mathbf{F}^*), \mathbf{V}) Dg(\mathbf{Y}^e)
\]

with
\( \mathbf{F}^* \), activity flow vector at equilibrium;
\( Dg(\mathbf{Y}) \), matrix obtained by arranging the elements of vector \( \mathbf{Y} \) along the main diagonal.

Finally, production vector, \( \mathbf{X} \), is obtained from:

\[
\mathbf{X} = \mathbf{I}^T \mathbf{F}
\]
3.3. Model features

The general framework, depicted in Figure 1, shows each modelling component and mutual interactions of the proposed LUTI model. The transport model solves the internal circular dependence among transport demand (vector $d$), link flows (vector $f$) and link costs (vector $c$), which is represented in the assignment model (eq. 3). According to the transport model, path costs depend on link flows due to congestion (eq. 2.a). The activity model solves the internal circular dependence among activity demand (vector $Y$), activity flows (vector $F$) and prices (vector $p$), which is represented in the activity generation-location interaction model (eq. 6). According to the activity model, prices depend on activity flows due to limited production capacities.

Moreover, the transport model and the activity model are mutually interacting: the transport model provides transport utilities (vector $V$) to the location model (eq. 5); the activity model provides activity flows (vector $F$) to travel demand model.

The introduction of exogenous physical or regulatory constraints gives rise to rents, which reflect the congestion in the transport and activity systems and provide the mechanisms to bring the demand in line with the available supply (market clearing).

4. LUTI model components specification

This section presents the specification of the modelling components of the general model depicted in Figure 1.

4.1. Activity model specification

The activity model simulates the processes of generation and location of endogenous activity and land sectors, driven by exogenous ones. It derives from the MRIO framework and it is specified by combining equations (4), (5), (6) and (7):

$$X_i^m = \sum^m \sum a_{ij}^m X_j^n + \sum j t_{ij}^m Y_{j}^{m,e} \quad \forall \ m, i \quad (8)$$
where

- $i$ (j), origin (destination) zone;
- $m$ (n), production (consumption) activity sector;
- $X^m_i$, production of $m$ in $i$;
- $X^n_j$, intermediate demand of $n$ in $j$;
- $Y^{m,e}_j$, exogenous demand of $m$ in $j$;
- $a_{j,m,n}$, technical coefficient, defined as input $m$ necessary for one unit of output $n$ in $j$;
- $t_{i/j,m}$, trade coefficient, defined as the percentage (probability) of production of $m$ located in $i$ and consumed in $j$.

In the current specification, inter-activity technical coefficients are fixed. The only price-elastic technical coefficient is the one connected with land sector. The equation that describes land consumption in zone $j$ by activity sector $n$ is (de la Barra, 1989; Modelistica, 2000):

$$a_{j,\text{LAND},n} = a_{\text{min},j,\text{LAND},n} + (a_{\text{max},j,\text{LAND},n} - a_{\text{min},j,\text{LAND},n}) \exp (-\delta^n p_j \text{LAND})$$

where

- $a_{\text{min},j,\text{LAND},n}$, $a_{\text{max},j,\text{LAND},n}$, minimum and maximum values of land consumption by sector $n$ in zone $j$;
- $p_j \text{LAND}$, average price of land in $j$;
- $\delta^n$, elasticity of sector $n$ to land price.

Trade coefficients are estimated through an activity location model:

$$t_{ij,m} = \exp (V_{ij,m}) / \Sigma_{i' \in N} \exp (V_{i'/j,m})$$

where

- $N$, number of zones of the study area;
- $V_{ij,m}$, utility of locating production of $m$ in $i$ to satisfy consumption in $j$.

$$V_{ij,m} = \lambda^m p_i \text{LAND} + V_{ij}^m$$
with
\( p_{i, \text{LAND}} \), average price of land in i;
\( V_{ij}^m \), transport utility of m from i to j;
\( \lambda^m \), weight of land price against transport utility for m.

As eq. (11) shows, utility of locating production activity in each zone comes from a trade-off between transport utility and land price. Due to restrictions in available land in each zone, a rent could be generated. This has effects on land consumption by each activity sector (eq. 9) and on activity location patterns, provided by trade coefficients (eq. 10). The model provides land prices and activity location in each zone as a result of an equilibrium condition of land market.

4.2. Transport model specification

The transport model comprises travel demand models, supply models and demand-supply interaction models.

4.2.1. Travel demand models

Travel demand is estimated through a three-step system of demand models that simulate path, mode and emission choices. The distribution model is not present, since the spatial distribution of demand is derived from inter-zone activity flows supplied by the activity model (8).

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, \( p[k/ijsq] \):

\[
p[k/ijsq] = \frac{\exp \left( \frac{V^s_{k/ijq}}{\theta} \right)}{\sum_{k' \in K_{ijq}} \exp \left( \frac{V^s_{k'/ijq}}{\theta} \right)}
\]

(12)

where

\( V^s_{k/ijq} = -\beta^s g_k \), utility of path k for users of category s;

\( g_k = \sum_i \delta_{ik} c_i (f_i) \), average generalized flow-dependent cost of path k (eq. 2.a);

\( \beta^s \), weight connected to path cost for users of category s;

\( K_{ijq} \), path choice set connecting OD pair ij with mode q;

\( \theta \), 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, \( p[q/ijs] \):

\[
p[q/ijs] = \frac{\exp \left( \frac{V^s_{q/ij}}{\theta} \right)}{\sum_q \exp \left( \frac{V^s_{q/ij}}{\theta} \right)}
\]

(13)

where

\( V^s_{q/ij} = \theta \ln \sum_{k' \in K_{ijq}} \exp(V^s_{k'/ijq}/\theta) \), utility of users of category s associated to mode q for OD pair ij;

\( \theta \), logit dispersion parameter.

The emission model (Modelistica, 2000) provides the demand flow of category s for OD pair ij, \( d^s_{ij} \):

\[
d^s_{ij} = F^s_{ij} \left( b^s_{\text{min}} + (b^s_{\text{max}} - b^s_{\text{min}}) \exp \left( V^s_{ij} \right) \right)
\]

(14)
where
\[ F_{ij}^s \] is the activity flow related to category \( s \) for OD pair \( ij \);
\[ V_{ij}^s = \theta \ln \sum_q \exp(V_{q_{ij}}^s) \], transport utility for category \( s \) for OD pair \( ij \);
\( b_{\text{min}}, b_{\text{max}} \), are minimum and maximum emission rates for category \( s \).

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).

4.2.3. Assignment models

The private assignment model is a Stochastic User Equilibrium (SUE) assignment model (eq. 3). The transit assignment model is a Stochastic Network Loading (SNL) model (Cascetta, 2006).

4.3. Activity-transport interface model specification

The transport and activity models operate at two different reference periods: the transport model operates during the morning peak period of a working day, while the activity model is related to a one-month period. So, it is necessary to scale in times and volumes the input/output variables through an activity-transport interface model.

The activity-transport interface model (Modelistica, 2000) provides activity flow \( F_{ij}^s \) related to OD couple \( ij \) and category \( s \):

\[
F_{ij}^s = \sum_m \left( X_{ij}^m (v_{f_{s,m}}^s p_{c_{s,m}}^s / t_{f_{s,m}}^s) + X_{ji}^m (v_{f_{s,m}}^s c_{p_{s,m}}^s / t_{f_{s,m}}^s) \right)
\] (15)

where
\( X_{ij}^m \), production of \( m \) located in \( i \) and consumed in \( j \);
\( X_{ji}^m \), production of \( m \) located in \( j \) and consumed in \( i \);
\( v_{f_{s,m}}^s \), volume factor for activity flow \( m \) related to category \( s \);
\( t_{f_{s,m}}^s \), time factor for activity flow \( m \) related to category \( s \);
\( p_{c_{s,m}}^s \), proportion of activity flow \( m \) related to category \( s \) that travels from production to consumption;
\( c_{p_{s,m}}^s \), proportion of activity flow \( m \) related to category \( s \) that travels from consumption to production.

5. Urban application

The LUTI model formalized and specified above is applied to the town of Reggio Calabria (Italy) to forecast long-term changes in land use and travel demand patterns induced by a transit system called Sustainable Mobility System (SMS) (LAST, 2004). The emphasis is put on population and employment location choices (vector \( X \) in Figure 1), passenger modal trip patterns (vector \( d \) in Figure 1), transport utility (vector \( V \) in
5.1. Study area: current situation and transport scenarios

The study area includes the municipality of Reggio Calabria, which has about 180,000 inhabitants and an extension 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 35 zones with homogeneous socio-economic characteristics. The central district is divided into 24 zones, the northern district into 6, the southern district into 2 and the hill district into 3 zones. Figure 2 shows the study area, the districts and zones delimitation, the area where SMS will operate (SMS area).

The activity system inside the study area is segmented into 8 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 floorspace.

Inter-dependencies between the activity sectors are simulated through technical coefficients defined in a simplified Social Accounting Matrix (SAM). Coefficients connected to employment in each sectors are fixed, while those connected to floorspace consumption per sector are price elastic, according to eq. (9). The general structure of the SAM is reported in Figure 3.

![Figure 2: The study area: districts, zones and SMS area delimitations.](image)
Travel demand, segmented into 6 categories (low-income work, high-income work, services, purchase, school, university), is associated to activity sectors which generate activity flows, according to category vs. activity sector correspondence matrix in Figure 3.

The current transit system comprises urban and regional bus services; regional rail services, connected with bus services through the bus terminus beside the main railway station in the central district; and inter-regional maritime services. The transit system has no direct connections among the three poles or between the latter and the railway stations, harbour and bus terminal. Trips are mainly undertaken by private mode (car), while transit services have a negligible role.

SMS is a high-frequency transit system travelling in a reserved right-of-way, with stops every 400-500 metres. Vehicle guidance is fully automated and the control system is centralized. Figure 4 shows the SMS area inside the central district: pole locations and a schematic representation of bus, railway and SMS itineraries are depicted.
Figure 5 shows the transport graph for private mode inside the study area and the SMS service sub-graph (in the upper-right box) inside the central district.

Two transport scenarios are considered and compared. DN (Do-Nothing) is a scenario with the current transit system operating in the study area, SMS is a scenario including the Sustainable Mobility System. No exogenous changes in the activity system are considered.

5.2. Simulation results

Simulation results concern activities location, floorspace prices, travel demand and accessibility for the DN and SMS scenarios. Simulations are performed with the support of TRANUS (de la Barra, 1989; Modelistica, 2000).
5.2.1. Model calibration and validation

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

In the activity model, activity sectors segmentation (Figure 3) 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 (9) 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 floorspace price per zone, which is estimated as the result of an interaction between a floorspace consumption (eq. 9), generated by each sector which production is located to each zone through the location model, and a floorspace supply present in each zone. Figure 6 shows a comparison between observed and estimated prices in DN scenario for each zone. Observed values are provided by Real Estate Observatory of the municipality of Reggio Calabria (www.agenziadelterritorio.it).

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 one specific values of free speed and capacity are determined. An extensive sensitivity analysis is performed on parameters of models (12) and (13), according to observed aggregate available data.

Validation has been performed comparing observed and simulated vehicular link flows on some selected urban links (Figure 6).

Figure 6: Observed and estimated floorspace prices and link flows.

5.2.2. Activities location and floorspace prices

Central district presents in DN scenario the higher concentration of both population and employment (Table 1). In SMS scenario, central district attracts high-income population from suburbs (+9.8%), expelling small percentages of low-income population (-1.7%), service (-0.5%) and retail (-4.5%) employment towards suburbs. The above location pattern is amplified inside SMS area. Average floorspace prices (Table 2) rise in central district (+1.1%), because of its increasing attractiveness caused by the extension of transit services to places where they were not previously available,
and reduce in suburbs (-3.6%). More sensible increments are forecasted in all zones served directly by SMS (+3.2%).

Table 1: Location of population and employment.

<table>
<thead>
<tr>
<th>Sector</th>
<th>DN [individuals]</th>
<th>SMS [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service employment</td>
<td>20716</td>
<td>-0.5</td>
</tr>
<tr>
<td>Retail employment</td>
<td>6685</td>
<td>-4.5</td>
</tr>
<tr>
<td>LI population</td>
<td>77684</td>
<td>-1.7</td>
</tr>
<tr>
<td>HI population</td>
<td>33320</td>
<td>+9.8</td>
</tr>
<tr>
<td>Central district</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service employment</td>
<td>1212</td>
<td>+5.6</td>
</tr>
<tr>
<td>Retail employment</td>
<td>973</td>
<td>+9.1</td>
</tr>
<tr>
<td>LI population</td>
<td>21977</td>
<td>+2.8</td>
</tr>
<tr>
<td>HI population</td>
<td>9427</td>
<td>-12.3</td>
</tr>
<tr>
<td>Suburbs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service employment</td>
<td>11845</td>
<td>-1.3</td>
</tr>
<tr>
<td>Retail employment</td>
<td>3290</td>
<td>-8.1</td>
</tr>
<tr>
<td>LI population</td>
<td>32482</td>
<td>-3.2</td>
</tr>
<tr>
<td>HI population</td>
<td>13932</td>
<td>+20.1</td>
</tr>
<tr>
<td>SMS area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service employment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retail employment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LI population</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HI population</td>
<td></td>
<td></td>
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</tbody>
</table>

Table 2: Average floorspace prices.

<table>
<thead>
<tr>
<th></th>
<th>DN [Euro/m²]</th>
<th>SMS [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study area</td>
<td>1291</td>
<td>0.0</td>
</tr>
<tr>
<td>Central district</td>
<td>1406</td>
<td>+1.1</td>
</tr>
<tr>
<td>Suburbs</td>
<td>1041</td>
<td>-3.6</td>
</tr>
<tr>
<td>SMS area</td>
<td>1544</td>
<td>+3.2</td>
</tr>
</tbody>
</table>

The explanation of the forecasted location pattern is that the central district becomes more attractive in SMS scenario because of increasing accessibility and this ends with higher land prices. The result is that central district attracts high-income population, which is the sector with the lowest sensitivity to land prices ($\lambda$ in eq. 11), pushing low-income population and employment with higher sensitivity to land prices towards suburbs.

5.2.3. Travel demand

Table 3 shows forecasted travel demand share with private and transit modes inside the study area, central district and SMS area for DN and SMS scenarios.

Inside the study area, travel demand with transit modes increases in SMS scenario (+20.6%), while travel demand with private modes presents a slight reduction (-5.1%). Inside central district and SMS area, transit modes capacity to attract users is amplified than study area (+40.3% inside central district and +201.6% inside SMS area).
A relevant component of mobility involves the three poles present in the central district (Table 4). They can be reached directly by bus and SMS services, so rail service is not represented. The trend described for the study area is confirmed in the case of the single poles. The above results are mainly caused by the direct connection, determined by the introduction of SMS, among the three poles and between them and suburbs, served by railway.

Table 4: Trips towards poles.

<table>
<thead>
<tr>
<th>Pole</th>
<th>Service</th>
<th>DN [users]</th>
<th>SMS [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Car</td>
<td>1726</td>
<td>-5,2</td>
</tr>
<tr>
<td>University</td>
<td>Bus</td>
<td>51</td>
<td>-23,5</td>
</tr>
<tr>
<td></td>
<td>SMS</td>
<td>----</td>
<td>304</td>
</tr>
<tr>
<td>Regional government</td>
<td>Car</td>
<td>5594</td>
<td>-11,2</td>
</tr>
<tr>
<td>and health</td>
<td>Bus</td>
<td>664</td>
<td>-56,9</td>
</tr>
<tr>
<td></td>
<td>SMS</td>
<td>----</td>
<td>886</td>
</tr>
<tr>
<td>Municipal government</td>
<td>Car</td>
<td>3108</td>
<td>-6,4</td>
</tr>
<tr>
<td></td>
<td>Bus</td>
<td>162</td>
<td>-82,1</td>
</tr>
<tr>
<td></td>
<td>SMS</td>
<td>----</td>
<td>309</td>
</tr>
</tbody>
</table>

5.2.4. Transport accessibility

A transport accessibility indicator has been formalized in order to estimate relative values of active and passive accessibilities for each category s:

\[
\text{Acc}^{a,s}_{i} = \left( \frac{V^{a,s}_{\text{MAX}(i=K)} - V^{a,s}_{i}}{V^{a,s}_{\text{MAX}(i=K)}} \right) \quad \text{Acc}^{a,s}_{i} \in [0, 1] (16)
\]

\[
\text{Acc}^{p,s}_{j} = \left( \frac{V^{p,s}_{\text{MAX}(j=K)} - V^{p,s}_{j}}{V^{p,s}_{\text{MAX}(i=K)}} \right) \quad \text{Acc}^{p,s}_{j} \in [0, 1] (17)
\]

where

\[
V^{a,s}_{i} = \theta \ln \Sigma_j \exp(V^{a,s}_{ij}), \text{ active accessibility for category } s \text{ in zone } i \text{ to reach opportunities distributed in the study area;}
\]

\[
V^{p,s}_{j} = \theta \ln \Sigma_i \exp(V^{p,s}_{ij}), \text{ passive accessibility for category } s \text{ distributed in the study area to reach opportunities that are in zone } j;
\]

\[
V^{a(p),s}_{\text{MAX}(i=K)}, \text{ maximum value of active (passive) accessibility among all the zones of the study area for category } s;
\]

\[
K, \text{ set of zones of the study area.}
\]
Values of (active and passive) transport accessibility indicator related to zones of SMS area for users belonging to high-income work category are presented in Figure 7. Passive accessibility values are always lower than active accessibility ones both in DN and SMS scenarios, due to the fact that the simulation of transport system is related to the morning peak hours when trips are performed mainly inside the central district and from suburbs to central district for home-to-work purposes. Moreover, passive accessibility values in DN scenario ranges from 0.00 in the zones close to the university pole (this means that these zones present the lowest values of passive accessibility related to the study area) to 0.56 in the zone where the municipal government pole is present. In SMS scenario both values of active and passive accessibility increase in all zones respect to DN scenario, and the increment is more sensible in zones with the lowest values in DN scenario.

6. Conclusions - Final remarks

The paper presents a spatial accounting LUTI model, which relies on Multi-Regional-Input-Output framework. The model has two main interacting components: a transport model and an activity model. The former provides transport accessibilities to location model; the latter provides activity flows to travel demand model. Exogenous physical or regulatory constraints give rise to rents, which reflect the congestion in the transport and activity systems and provide the mechanisms to bring the demand in line with the available supply.

The model has been specified and applied to the town of Reggio Calabria (Italy), to forecast long-term impacts in land use and travel demand patterns due to interventions in the transport supply system at strategic scale. Severe challenges concerned data unavailability at urban scale that did not allow high segmentation of activity system, calibration of some model parameters, general validation of the whole model.

Simulation results are related to activities location, land prices, travel demand and transport accessibility before and after the introduction of SMS. Regarding effects on location patterns, the introduction of SMS into zones scarcely served by transit services increases transport accessibility. This makes these zones more attractive to locate activities, leading to higher land prices. The process ends attracting sectors with lower sensitivity to land prices in central district, pushing sectors with higher sensitivity to land prices towards suburbs. Regarding effects in travel demand patterns, SMS ensures a direct connection among the three poles and between them and suburbs. The increasing level of service makes transit more attractive by transport users, causing a sensible shift from private to transit modes.

The main conclusion of the work is that the proposed urban LUTI model is able to describe the two-way relationship between land use and transport, confirming that the MRIO framework offers the potentialities to bring activity location, land use in line within travel demand modelling.
Future work will concern model calibration, land use and transport policies impacts assessment through sustainability indicators, model development. Next step will regard the execution of a direct survey in order to identify attributes and calibrate parameters of the location model. A set of sustainable indicators will be defined and measured and policies will be assessed and compared in terms of social, economic and environmental impacts. Further developments will regard the activity model in order to overcome current theoretical limitations due to the presence of technical coefficients which are not consistent with utility and profit maximization.

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