Development of an integrated transport-land use model for the activities relocation in urban areas

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Abstract

The study presents a new Land Use – Transport Interaction (LUTI) planning model to provide an effective decision support system tool for the Urban Planning Administrations and to promote the use of the public transport system in urban areas. The idea is to relocate a subset of activities from urban zones with strong attraction, but poorly connected by the existing mass transit system, to urban zones close to the existing mass transit links with available residual capacity. This residual capacity is the main variable that indicates location and intensity of activities to be moved. The model has been applied for the real case study of the city of Rome in Italy. Results demonstrated the capability of the model to be a useful support system to suggest activities relocation pursuing the goal of sustainability for a short-term horizon.

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Keywords: activity location; land use model; location problem; LUTI;

1. Introduction

The structure of the city clearly influences mobility behaviors and the activity location is one of the main factor determining population trips. On the other hand, the transport system plays a very important role in accessing to these activities: transport supply affects the activities location choices, moving the economy of the city, its settlement structure and, consequently, the social environment. Therefore, it is clear that land use and the transport

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system are strictly connected and there is an increasing need to integrate them in order to achieve a sustainable environment.

In single land use models the future transportation system is assumed fixed, while in the usual four steps transportation models is the land use to have a fixed spatial pattern (Oryani and Harris, 1996). Consequently, different models trying to integrate transport planning and land use have been formulated since 1960. They are usually known as Land Use – Transport Interaction (LUTI) planning models and, according to Timmermans (2003), they can be divided into three generations:

1. first generation or aggregate spatial interaction-based models: based on aggregate data and on the principles of gravitation and entropy maximization (Lowry, 1963, Garin, 1966, Mackett, 1983);
2. second generation: multinomial logit models based on the principle of utility-maximization (Echenique, 1994, de La Barra, 1989);

At the beginning, the major limitations of the LUTI planning models were in the simplification of the behavior of the decision-maker and in the simplifications of the simulation models. In the last decade, several LUTI planning models with different level of comprehensiveness and detail have been developed and applied in integrated and sustainable transport policy studies (Geurs and Van Wee, 2004). Also as an example: the Environment Explorer (EE) model (Engelen et al., 2003); the TIGRIS model (Eradus et al., 2002); the LOIS Strategic Policy Model (WSP, 2002); the DELTA/START package (Simmonds and Still, 1999); PROPOLIS (Wegener, 2004).

Nevertheless, real integrated LUTI planning processes are often absent in planning practice. The reason is that the most sophisticated models require a tremendous amount of data to be calibrated and validated especially in the early stages of planning (Banister, 2005; Stead et al., 2004). Instead the investment, mainly for that models designed to give short-term forecasts, are usually quite poor. Thus, it seems that the utility of integrated land use - transport models is only in supporting long term, strategic planning decisions (Timmermans, 2003).

Nowadays, it happens that land use and transport develop their own separate visions, scenarios, plans and projects focusing on their specific issues (Brommelstroet and Bertolini, 2008). As a result, measures derived from these visions are not optimal and sometimes in conflict. The city of the XXI century is even more an “automobile” city, with activity centers and trip generators poorly connected, without concentration of trip ends and little concern for sustainable modes as the public transport (Gori et al., 2012, 2013).

This study proposes a new LUTI planning model that can be adopted as an effective decision support system tool by Urban Planning Administrations and able to promote the use of the public transport in urban areas. The idea is to relocate a subset of activities from urban zones with strong attraction, but poorly connected by the existing mass transit system of the city, to urban zones close to the existing mass transit links with available residual capacity. The aim is to shift with the relocation a sufficient share of trips from private transport to public transport, and specifically to the mass transit system, since it is well known the potentiality of urban rail and metro services in reducing the negative effects of private car use (D’Acierno et al., 2013). The model follows a macroscopic aggregated approach, that can be easily replicated for different city contexts and that generates as output the 1) location of areas where activities could be moved; 2) the intensity of activities to be moved.

The model has been applied in the city of Rome, Italy. Results demonstrated its capability to be a useful support system to suggest activities relocation pursuing the goal of sustainability for a short-term horizon.

2. A new land use-transport model for activities relocation

The proposed model consists in a sequence of steps designed to modify the current urban land use structure and the current mobility habits through a relocation of existing activity volumes close to the existing mass transit links of the city with available residual capacity. The output of the model are: 1) location of areas where activities could be moved; 2) the intensity of activities to be moved.

The model works on a subset of activities; specifically, it does not work on relocating residences, but only on relocating business volumes: residences are not taken into account, since it could be difficult to develop appropriate
policies for residences relocation. This is true especially in Italy for both economic and social reasons. Firstly, in Italy the real estate market considers only marginally the rental market, while residences are generally owned. Moreover, mostly of people in Italy try to locate their residence as close as possible to their parents or in the neighborhoods where they have lived and grew. Those aspects affect the possibility to “push” people to change their residence and then the applicability of the results of the model.

The model follows an iterative procedure and stops when a certain benefit is reached: this benefit is identified by the achievement of a fixed reduction of the residual capacity of the mass transit system.

Fig. 1 shows a simplified flow-chart that explains the main steps of the model:

1. Point 1: urban zones with high attraction, but with a low transit accessibility are identified;
2. Point 2: urban zones close to the links of the mass transit system, with residual capacity and availability to host the activity volumes, are selected;
3. Point 3: a share of activity volumes are relocated from the urban zones of point 1 to the urban zones of point 2;
4. Point 4: the relocation of activity volumes has to interact with the transport demand in order to take into account current and resulting (after the relocation) transit accessibility, as well as the distribution of trips respect to the configuration of the mass transit network (to be sure of the use of the public transport system after the relocation);
5. Point 5: check of constraints on both the land use and the transport system side;
6. Point 6: evaluation of the residual capacity of the mass transit system after the relocation: if it decreases more than a threshold set at the beginning of the procedure, the procedure stops, otherwise a new iteration is performed restarting from point 1.

Fig 1. Main steps of the proposed LUTI.
Input of the model are: current activities intensity and location; accessibility measures to the final destination points; residual capacity of the mass transit system; available space and/or urban constraints for urban areas where activities have to be relocated; private and public transport travel demand; the public transport network. All these input are usually at the disposal of Urban Planning Administrations, which makes the model easily applicable. Each step of the procedure involves a sequence of operations and needs the definition and calibration of a set of parameters, as will be explained in details in the following sub-section.

2.1. In-depth description of the procedure

Each operation needed and each parameter to be set is here explained in details, with reference to each one of the six points previously described.

Starting from point 1, i.e. from the identification of urban zones with high attraction and low transit accessibility, it is performed as follows:

- from the total demand (sum of the current public transport travel demand and private transport travel demand) the zones with higher attractions are selected. The zones \( z_i \) to be selected are those with a value of attracted trips higher than the average attraction of the total demand plus the standard deviation; these zones will be inserted in the list of zones \( L_1 \);
- the next step is to generate the list of zones \( L_2 \), a subset of \( L_1 \), which includes all zones \( z_j \) outside the pedestrian basin of the considered mass transit system: that is, all zones not directly accessible with pedestrian movements (the pedestrian basin could be defined by a circular area of 500-800 meters for each station/terminal, Gori et al. 2014). This list should exclude those zones with strong attractiveness due to the presence of non-transferable activities. Examples are railway stations and hospitals. Therefore, the designer, to introduce definitely a zone in list \( L_2 \) has to proceed firstly in verifying this constraint.

Following with the point 2, i.e. the selection of urban zones close to the links of the considered mass transit system with residual capacity and with availability to host the relocated volumes, it is performed as follows:

- the assignment of public transport demand matrix is run and the residual capacity \( c_i \) for each link \( m_i \) belonging to the considered mass transit network is computed;
- links \( m_k \) with high residual capacity are fixed and these links generate the list \( M \);
- subsequently the zones \( z_k \) within the pedestrian basin of links included in the list \( M \) and that can accept activities are derived; they create the zone list \( L_3 \).

Passing to points 3 and 4, i.e. to define the share of activity volumes to be relocated, their relocation and the interaction with travel demand:
the sum $S$ of trips made by private transport and attracted by zones of the list $L_2$ is computed;
then a percentage of trips $S$ to be transferred on public transport demand matrix, since their destination is relocated near the pedestrian basin of the mass transit system, is considered. This percentage is not a constant value, but it is fixed by the designer as a function of different elements, including:
- the size of the urban area (it defines the total demand value);
- the extension of the considered transit network (it defines the possibility to find available zones near the transit system and with residual capacity, as the possibility to find zones not easily accessible with the transit system);
- the modal split between private and public transport (the starting modal split has to be taken into account, since a low value of the public transport demand could also represent a supply deficit that cannot be easily solved with the only relocation);
- the degree of initial oversaturation of the considered transit network (more trips are moved to the transit system and more the capacity of possible already oversaturated transit links is exceeded);
- the number of iterations (with the progress of iterations, so as not to disrupt the public and private transport matrices, necessarily this share must decrease).

at each destination zone $z_k \in L_3$ is associated a portion $s_k \in S$, established in accordance with the percentage of available residual capacity on links $m_k$ associated with the zone $z_k$ (previous link respect to the centroid representing the zone where we want to enhance the attraction);
a select link analysis on the transit demand on links $m_k$ is performed in order to know the origin/destination OD pairs that pass on such links and that have as destination the zones belonging to list $L_3$;
the distribution of the attracted trips $s_k \in S$ between the OD pairs is done accordingly to the results of the select link analysis: the trips are distributed proportionally to OD pairs with destination belonging to the zones in list $L_3$. This criterion is adopted to correctly represent what happens in terms of transport demand in the urban context and to give higher weight to OD pairs actually more charged;
The model explicitly considers current and resulting transit accessibility: this is done 1) when urban zones where activities have to be moved are selected, based also on their location respect to the pedestrian basin around the transit stations; 2) when the interaction with the transport demand is considered making use of the select link analysis procedure: at this stage both the locations of the starting points of the trips are considered as well as the distribution of the trips respect to the configuration of the mass transit network.
Once the trips $s \in S$ have been allocated to the urban zones in the pedestrian basin of the considered mass transit system, with availability to host the activities and with potential residual capacity of the mass transit system, once they are distributed between OD pairs, some constraints have to be verified (point 5):

- restrictions on short trips;
- restrictions on overlenght trips;
- restrictions on the number of acceptable transfers.

Due to the presence of the above constraints, the initial value $S$ to be moved is decreased as consequently each portion $s \in S$. The share of trips relocated are then moved from the private mode to the public transport mode, so defining an increment of the current public transport demand matrix and a decrease of the private demand matrix.

The last point is about the evaluation of the use of the considered mass transit system in terms of residual capacity:

- an assignment of the public transport demand obtained as the current demand plus the previous defined increment is run and the results in terms of simulated flows on the transit network links are extrapolated;
- the reduction of residual capacity is computed over all the links belonging to the considered transit network; its average value is compared with the threshold value $\alpha$ that indicates the desired reduction: if the average reduction of residual capacity is lower than $\alpha$, the procedure needs a new iteration, otherwise the procedure can stop (the $\alpha$ parameter is fixed by the designer before applying the model and it is a function of the same elements, previously described, which influenced the share of movements $S$ to be transferred);
- in parallel to the investigation of the decrease of the residual capacity, also the growth of saturation degree on the transit links is analysed: if a huge growth of the overload is observed, the designer has to limit these increments going back to find the OD pairs that generate the overload. In particular, a threshold value $\beta$ has to be fixed representing the maximum saturation degree that can be achieved on the transit network links. If the threshold is not respected on some links, the planner must proceed with a select link analysis on these links, in order to deduce the movements that have the destination belonging to the list $L_3$ and that have generated the problem. If instead the possible growth of saturation degree is within the threshold, then the procedure may continue.

In Fig. 2 a detailed flow chart of the procedure is showed.

3. Real case application

3.1. Case study

The model has been applied in the city of Rome, Italy. The urban area of Rome is actually characterized by a population of 3 million with 1.1 million employees, contributing to about 552,000 trips in the morning peak hour. There are two metro lines (A, B with its branch called B1) extending for a total of 45 km. These lines have a radial structure with the main interchange in the city center (Termini rail station).

Actually, about 11 km of the metro network (24% of the total extension, Fig.3,a) present a value of the passenger flow higher than the capacity (maximum saturation degree equal to 1.48, with an overflow ranging between 3,000 and 7,000 pass/h, Fig.3,a). The remaining extension of the network presents residual capacity, especially in the peripheral links (values of residual capacity ranging from 4,000 to 18,000 pass/h, Fig.3,b). The actual modal split in Rome is equal to 66% private transport, 34% public transport.

3.2. Results

The model has been applied considering the existing metro system of the city and its residual capacity, where the assignment phase has been conducted using the EMME software (Florian, 2014).

The fixed threshold values to stop the procedure are:
• $\alpha$ parameter, corresponding to the eligible reduction of residual capacity, amounting to 30% (minimum average residual capacity value to be obtained);
• $\beta$ parameter, corresponding to the maximum increase in overflow, amounting to 25% (maximum increment on each link already congested).

The thresholds are city-specific and for the city of Rome they derived by the balance between the reduction of the residual capacity that can be achieved and the maximum increase of overflow that the procedure could generate.

Two iterations of the model have been performed: in the first iteration, 38 zones have been selected for their high attraction (higher than 2,400 attracted trips/h, list $L_1$) and only 14 of them generated the list $L_2$ (urban zones with high attraction but not in the pedestrian basin of the metro network, Fig. 4, a). Urban zones in the pedestrian basin of the metro network and near metro links with residual capacity were equal to 11 (Fig. 4, b) and generated the list $L_3$. The share $S$ of trips to be moved has been set initially to 18,500 pass/h, amounting to the 60% of trips attracted from the zones $z_j$ belonging to $L_2$; in the second iteration this share $S$ decreased to 9,600 pass/h, amounting to the 30% of trips attracted from the zones $z_j$, due to the constraints on trip length.

At the end of the procedure (after the second iteration), the average residual capacity reduction is equal to -33%, the average increment of transit flow on the metro network is equal to +26%. About the overflow increment: 1) the saturation degree of the metro links with available residual capacity and considered by the procedure ($m_k \in M$) increases until +70% (links of a saturation degree equal to 0.28 have switched to a value of 0.48), 2) links of the metro system actually congested get to a maximum increase of the overflow of +14%, with a maximum value of the saturation degree equal to 1.74, 3) links of the metro system not actually congested, but become congested after the application of the procedure, get to a maximum increase of the overflow of +22%, with a maximum value of the saturation degree equal to 1.22.

In summary, the new formulated model, only relocating the activities from zones with a poor connectivity of the metro network to zones close to the links of the metro network and with available residual capacity (Fig. 4, b), has permitted to increase the use of the mass transit system, subtracting the 5% of trips made by private transport and achieving the following modal split: 38% public transport and 62% private transport. It is a relevant increment of the public transport modal split, also considering the poor development of the metro network in Rome. Moreover, the metro links previously unused, now reach satisfactory values of the saturation degree.

About the main drawback of the procedure, that is the possibility to increment the overflow of the actual congested links, it is quite limited in this application, since the maximum registered saturation degree is 1.74 and it is obtained on a link with a previous saturation degree value of 1.60.

Finally, the average travelled distances were unchanged after the relocation and, since the activities have been now moved in the influence basin of the metro system, the accessibility at destination has been improved.
Table 1 shows the most significant results of the application.

![Fig 4. Zones from which the activities are moved (a) and zones where activities are relocated (b).](image)

Table 1. Results of the application (residual capacity of metro lines) and comparison with the current state

<table>
<thead>
<tr>
<th>Metric</th>
<th>Current State (Metro Network)</th>
<th>After Model Application (Metro Network)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual capacity</td>
<td></td>
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<tr>
<td>min</td>
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<td>0</td>
</tr>
<tr>
<td>average</td>
<td>5,951</td>
<td>4,000</td>
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<tr>
<td>max</td>
<td>17,865</td>
<td>17,134</td>
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<tr>
<td>min</td>
<td>317</td>
<td>1,048</td>
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<tr>
<td>Transit flow [pass/h]</td>
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<td></td>
</tr>
<tr>
<td>average</td>
<td>9,536</td>
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<tr>
<td>max</td>
<td>26,937</td>
<td>31,631</td>
</tr>
<tr>
<td>min</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>Saturation degree</td>
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<td></td>
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<tr>
<td>average</td>
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<td>0.79</td>
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<tr>
<td>min</td>
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<td>352</td>
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<tr>
<td>Overflow [pass/h]</td>
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<td></td>
</tr>
<tr>
<td>average</td>
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<tr>
<td>min</td>
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<td>0.02</td>
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<tr>
<td>overflow/capacity</td>
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<tr>
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<tr>
<td>max</td>
<td>0.48</td>
<td>0.74</td>
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</tbody>
</table>

4. Conclusions

The main objective of this study has been to develop an integrated land-use-transport model that could provide a useful decision-making tool for local authorities to allow for urban sustainability, reducing the use of private transport by encouraging the use of the mass transit system currently available. Attention has therefore been concentrated on a procedure aimed at reducing the residual capacity of the mass transit system by the relocation of activity volumes.

The model permits to evaluate the expected increase of the transit modal share after the relocation: the application of the procedure for the city of Rome permitted to reach an average residual capacity reduction of the metro network equal to -33%, subtracting the 5% of trips made by private transport and achieving the following final modal split, 38% public transport and 62% private transport.

Moreover, the procedure has been demonstrated to be sufficiently manageable, since the increment of the
overflow of the actual congested metro links resulted to be quite limited and the average travelled distances were unchanged after the relocation.

Now, the second step will be to move from the output of the model to the definition of urban policies. Only with appropriate urban policies, the relocation.

No behavioural models are incorporated at this stage of the research; future developments could incorporate a modal shift model to verify the effective use of public transport for the travel demand involved in the relocation. Moreover, it could be possible to calibrate a behavioural model describing the willingness to move by the different kinds of businesses as a function of different policies: this can help Administrations in validating the applicability of the policies.

References


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