1. INTRODUCTION
That urban land use and transport are closely inter-linked is common wisdom among planners and the public. In facts, that the spatial separation of human activities creates the need for travel and goods transport is the underlying principle of transport analysis and forecasting. Following this principle, it is easily understandable that the suburbanisation of cities is connected with increasing spatial division of labour, and hence with ever increasing mobility.

The analysis of the impacts of land-use on the transportation system is well-established as well as the modelling approaches (e.g. the traditional four-stages model); on the other hand, the reverse impact from transport to land use, is less well known.

In order to evaluate long-term impacts on travel demand due to changes in transport supply, it is not possible to disregard the impacts on land-use and, indirectly, on travel demand. The problem of simulating such effects has been tackled by different modelling approaches, labelled in literature as “integrated land-use/transport models” (Wilson, 1997).

In this paper the focus is on the impacts that transport supply has on the distribution of urban activity locations (e.g. residents, services, commerce, etc) and, consequentially, on travel demand (e.g. spatial distribution, modal split and so on). The analysis is carried on by means of models dealing with the complex interactions between transportation and urban activities. With respect to other models present in literature, what actually is pointed out in the proposed modelling approach, is the transport component. The latter is typically represented in terms of generalised transportation cost, while here it is explicitly represented by means of demand models and transportation networks.

Individual choices of residential and activity location are simulated through Random Utility Theory. The interaction between different individuals (i.e. residents, firms, etc) is simulated through a static (or equilibrium) approach. The latter seems more suitable for practical applications since equilibrium models are easier to be calibrated and implemented, with respect to more complex dynamic modelling framework (Simmonds, 2000).

In order to provide the context, a review of studies on the impact of transport on land-use is described in section 2. Section 3 and 4 deal with the adopted modelling framework and its applications to the urban area of Rome (Italy) in order to predict the land use and the travel demand long-term variations induced by changes in transport supply system. The results of such applications are discussed and compared with those carried out by means of traditional four-stages demand model calibrated on the same urban area. Conclusions and further research issue are dealt with in section 5.
There exists a great number of empirical studies investigating the impact of urban form on transport behaviour, the reverse direction of impacts, the impact of transport on urban form, has attracted much less attention of empirical researchers. One reason for this may be that land use changes occur much more slowly than changes of travel behaviour and are subject to many other influences other than transport, such as population growth, economic development changes in lifestyles, household formation, consumption patterns and production technology and are therefore difficult to isolate (Wegener and Furst, 1999).

One of the earliest study analysing the effect of transport on urban land use is the one by Hansen (1959), in which he demonstrated for Washington, DC, that locations with good accessibility had a higher chance of being developed, and at a higher density, than remote locations.

However, there is also counter-evidence. For instance, Giuliano and Small (1993) observed that in the Los Angeles metropolitan area commuting cost has little impact on residential location choice.

Kreibich (1978) analysed suburbanisation in the Munich metropolitan area after the opening of the Munich S-Bahn system in 1972 and found increasing residential growth rates along the S-Bahn lines fanning out into the Munich hinterland.

Miller et al. (1998) reviewed studies of the impacts of commuter rail projects in North America. A common observation is that, at least in the North American context, land-use impacts of rail development tend to be small and concentrate on downtown and few suburban stations (Knight and Trygg, 1973; 1977; Guiliano, 1995; Cervero and Landis, 1997). Knight and Trygg (1973; 1977) reported wide differences in the strength of impacts between cities, ranging from significant in Boston, Montreal, Toronto and Philadelphia to negligible in Cleveland and Chicago. Significant concentrations of development near metro stations were found in Washington, DC (Green and Jones, 1993) and Portland, OR (Arrington, 1989). Nelson and Sanchez (1997) reported that in Atlanta employment around metro stations increased, whereas population decreased. According to Hunt et al. (1994) residential location preferences in Calgary are strongly influenced by distance to light-rail stations. Increasing property values near metro stations were reported from Philadelphia (Knight and Trygg, 1973; 1977) and the San Francisco Bay Area (Workman and Brod, 1997), but property value impacts were difficult to identify in Portland, OR (Al-Mosaind et al., 1993; Workman and Brod, 1997).

There is a lack of before-and-after studies of urban transport investments in Europe. One notable exception was the Glasgow Rail Impact Study by Gentlemen et al. (1983), which found increased planning applications and some reversal of population decline near rail stations. However the study was conducted only one year after completion of the rail improvements in Glasgow.

Pharoah and Apel (1995) in their comparison of transport concepts in European cities observed that policies to promote public transport over car tend to have strong positive effects on the economic development of city centres, whereas the negative effects of car restraint policies frequently feared by local businessmen have in no case been confirmed by empirical evidence. They note, however, that the causal relationship may work in the opposite
direction: that city centres are not attractive because they are accessible by car but that attractive city centres can afford to be less accessible by car. There are few systematic studies but ample common-experience evidence of the importance of accessibility for the location of firms in urban areas. Everybody knows the road-side development of manufacturing, wholesale and service establishments along major thoroughfares and suburban motorways. The Route-128 and M5 strip developments of high-tech firms near Boston and London have their counterparts in many European countries. Garreau (1991) phrased the term ‘edge city’ to describe car-based office and retail developments at the outer edge of metropolitan areas in the United States. Besides the small number of studies on the impacts of transport on land use, most of them suffer from methodological problems. Miller et al. (1998) note that in virtually no case the study design provided an adequately controlled ‘experiment’ to properly isolate the impacts of transport investments from other evolutionary factors at work in the urban region. They make the point that this can be achieved only by integrated land-use transport models.

3. THE OVERALL MODELLING FRAMEWORK

The overall modelling framework is depicted in figure 1; here the interaction between the different models, together with their input and output variables, are highlighted. As it can be seen, the framework consists of three integrated submodels: the transportation system, the residential location, and the activity location submodels.

3.1. The Transportation System Model

The Transportation system model consists of:

- a system of traditional demand models which, given the land-use pattern (i.e. distribution of the population and of the activities within the study area) simulates individual travel choices (such as tour frequency, trip distribution and mode choices) and allows to estimate the OD matrices by trip and mode;
- a system of supply models aiming at representing the transportation networks for different modes (i.e. car, motorbike, public transport and foot);
- supply-demand interaction models which provides estimates of users’ flows and network performances (i.e. level of service).

For sake of brevity, in this paper only the variables affecting location choices (i.e generalised transportation cost and zonal accessibility) will be pointed out. Generalised travel cost is here calculated through the inclusive value (Cascetta, 2001) of mode choices. Accessibility, on the other hand, is made up of two functions, one representing the activities or the opportunity to be reached for a given purpose and one representing the effort (e.g. time, cost, distance, etc) needed to reach them (Wegener et al., 2000). We here consider two type of accessibility referred to as “active” and “passive” accessibility.
Figure 1 – Schematic representation of the overall framework
The active accessibility of zone \( o \) is a proxy of the opportunity of reaching the activities located in different zones of the study area for a given purpose (e.g. shopping, workplace, ...) moving from \( o \). For instance, we can calculate the active accessibility of zone \( o \) to the services of the study area, as:

\[
A_{\text{act}}^o = \sum_d E_{\text{serv}}(d)^{\alpha_1} \cdot \exp(\alpha_2 \cdot Y_{\text{Other}}(o,d))
\]

where \( E_{\text{serv}}(d) \) is the number of people employed in services (e.g. banks, insurance institutes, etc) of zone \( d \); \( Y_{\text{Other}}(o,d) \) is the inclusive values of the mode choice for “Other purposes” (i.e. shopping, personal care, etc); \( \alpha_1 \) and \( \alpha_2 \) are calibrated parameters.

On the other hand, the passive accessibility is a proxy of the opportunity of an activity located in a given zone \( d \) to be reached from the potential consumers moving from all the various zones of the study area for a given purpose. For instance the passive accessibility of zone \( d \) with respect to households (or equivalently to the whole population of the study area) can be calculated as:

\[
\text{Acc}_{\text{pas}}^o (d) = \sum_o R(o)^{\gamma_1} \cdot \exp(\gamma_2 \cdot Y_{\text{Other}}(o,d))
\]

where \( R(o) \) is the number of people leaving (i.e. residents) in zone \( o \); \( \gamma_1 \) and \( \gamma_2 \) are calibrated parameters.

It is worth noting that variations of network performances (i.e. variations in the generalised travel cost and in the accessibility of the zones) induce variations in housing and activity location (i.e. land use pattern). The land use modification impacts the structure of the demand and, in case of congested networks, can modify in turn the performance of the transport supply. Thus, there is a circular dependency between network performances and activity location which can be seen as an equilibrium problem or, from a mathematical perspective, as a fixed-point problem (Cascetta, 2001).

The analysis of such a mutual dependency is a current issue of research and is out of the scope of this paper. Here we focus on other two equilibrium problems, concerning the location of residents and economic activities, which will be discussed in the following sections.

### 3.2 The Residential Location Model

The residential location model gives the number of residents in each zone of the study area as a function of the location advantages and characteristics of the supply transportation system. Following a behavioural approach, it is assumed that the choice of the residential zone is the result of the decision-making process of workers present in the study area. Thus, each worker chooses his/her residence zone according to the characteristics of the zone itself (price per square meters, services, etc.), but mainly according to his/her workplace. The probability that each worker \( i \) chooses zone \( o \) as residential one, \( P_{\text{res}}^i(o) \), is given by:

\[
P_{\text{res}}^i(o) = \sum_d P_{\text{res-cond}}^i(o \mid d) \cdot P_{\text{work}}^i(d)
\]

where:

\( P_{\text{res-cond}}^i(o \mid d) \) is the probability that worker \( i \) chooses to live in zone \( o \) conditional to working in zone \( d \);
\( P_{\text{work}}^i(d) \) is the probability that worker \( i \) is employed in zone \( d \).

It is assumed that the labour market is saturated. Therefore the probability \( P_{\text{work}}^i(d) \) is simply given by the ratio between the employed of type \( i \) in a given zone \( EMP_{\text{tot}}^i(d) \) and the total number of employed of the same type present in the study area \( EMP_{\text{tot}}^i \):

\[
P_{\text{work}}^i(d) = \frac{EMP_{\text{tot}}^i(d)}{EMP_{\text{tot}}^i}\]

In order to estimate the conditional probability \( P_{\text{res-cond}}^i(o|d) \), consistently with Random Utility theory it is assumed that each worker \( i \), in choosing his/her residential zone, associates an utility, \( U_{o|d}^i \), to all the available zones and chooses the one which maximises the utility. \( U_{o|d}^i \) is assumed to be a random variable consisting of two terms: the systematic utility \( V_{o|d}^i \) and the random residual \( \varepsilon_j \). If random residuals \( \varepsilon_j \) are independently and identically Gumble \((0,1)\)-distributed, the conditional probability \( P_{\text{res-cond}}^i(o|d) \) is given by the well-known Logit formulation:

\[
P_{\text{res-cond}}^i(o|d) = \frac{\exp(V_{o|d}^i)}{\sum \exp(V_{o'|d}^i)}
\]

The systematic utility of locating a residence in zone \( o \), given the workplace in zone \( d \), is a function of the following attributes:

- transportation system performances, obtained as the inclusive value of mode choice between \( o-d \) pair for “Workplace” purpose and for users of type \( i \), \( Y_{\text{work}}^i(o,d) \);
- attributes of the attractiveness of a residential zone \( o \) like the logarithm of the number of available houses, \( Ln\text{Houses}(o) \), the price of houses in zone \( o \), expressed in thousands of Euro per square meters, \( Price(o) \), and the occupancy rate of houses in zone \( o \), \( x(o) \);
- socio-economic attributes of the zone like the indicator of the quality of the estate of zone \( o \), \( IACP(o) \), an index of prestige of the zone, \( Pres(o) \), as well as dummies dealing with the characteristics of the area to which each zone belongs, i.e. presence of green, panorama, etc.

In order to point out that income may influence residential location choice, residents of the study area have been disaggregated into two socio-economic categories, identified according to the income as it is reported in table 1.

Table 1 – Socio-economic categories of the residential location model

<table>
<thead>
<tr>
<th>Type of job</th>
<th>High income</th>
<th>Medium-low income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manager, self-employed, etc</td>
<td>Employee, craftsman, merchant</td>
<td></td>
</tr>
</tbody>
</table>

The parameters estimation of each attribute present in the model has been carried out through a survey employed in Rome. The method used is that of Maximum Likelihood relative to a zoning of 463 zones of the urban area of the city of Rome. The results obtained are reported in table 2.

Table 2– Parameters (and relative t-ratios) of the residential location model
<table>
<thead>
<tr>
<th></th>
<th>$Y_{work}^{i}(o,d)$</th>
<th>Intra$(o,d)$</th>
<th>Price$(o)$</th>
<th>$x(o)$</th>
<th>LnHouses$(o)$</th>
<th>IACP$(o)$</th>
<th>Pres$(o)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>$0.476$ (6.9)</td>
<td>-</td>
<td>-</td>
<td>-0.536</td>
<td>$0.246$</td>
<td>-0.639</td>
<td>$0.196$</td>
</tr>
<tr>
<td>Medium/Low</td>
<td>$0.482$ (11.8)</td>
<td>0.736</td>
<td>-0.716</td>
<td>-0.231</td>
<td>$0.297$</td>
<td>-0.335</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It can be noted that the sign of the estimated coefficients is consistent with the behavioural assumptions at the basis of the model, e.g. the coefficient of the $Ln-Houses$ attribute is positive while that relative to the price $Price$ is negative. The coefficient relative to the inclusive value of the mode choice, $Y_{work}^{i}(o,d)$, is almost the same for the two categories considered. However, the dummy variable $Intra(o,d)$, equal to 1 if the residential zone $o$ and the employment one $d$ coincide, is positive and significant only for low income workers. This means that the distance from the workplace zone is a factor affecting residential location choice for low income workers more than for high income ones. This is mainly due to the more flexible working-time of the former, which imply work trips not necessarily in the peak period, when the transportation system is usually congested.

The houses occupancy rate function is given by the following expression:

$$x(o) = \left( \frac{Res(o)}{sq(o)} \right)^\alpha$$

where $Res(o)$ and $sq(o)$ are respectively the residents and the square meters of houses available in zone $o$, and the constant $\alpha$, calibrated together with the other model parameters, is equal to 1.88. The coefficient of $x(o)$ is almost double for high income workers compared to the one for low income ones. The attribute $Price(o)$ is not significant for high income categories, while $Pres(o)$ is not significant for low income ones. This points out the different residential location choice behaviour, which justify the introduced workers categorisation.

*The equilibrium problem in the residential location*

The probability that the generic worker $i$ chooses zone $o$ as a residence zone multiplied by the total number of workers of the study area, $W^i$, gives the number of workers $i$ in each zone $o$, $w^i(o)$.

It follows:

$$w^i(o) = P_{res}^i(o) \cdot W^i$$

or equivalently, under the assumption that the total number of workers $i$ is equal to the number of employed of the same category, $EMP^i=W^i$, it results:

$$w^i(o) = \sum_d P_{res-cond}^i(o \mid d) \cdot Emp^i(d)$$

Given the number of workers for each zone of the study area, it is possible to get the number of residents in the same area through a coefficient $k(o)$, which represents the ratio between residents and workers in zone $o$: 

$$k(o) = \frac{Res(o)}{w^i(o)}$$
From the previous section, it is deduced that the probability of living in a zone conditional to the workplace, \( P_{\text{res-cond}}(o | d) \), depends on a set of attributes, among them the occupancy rate of houses in zone \( o \), \( x(o) \). The latter depends itself on the number of residents of the zone. Therefore, let \( R^i \) be the \([n\text{\_zone} \times 1]\)-vector of residents of type \( i \), \( A^i \) the \([n\text{\_zone} \times 1]\)-vector of the total employed of type \( i \), \( x \) the \([n\text{\_zone} \times 1]\)-vector of occupancy rates of the zones of the study area, \( k^i \) the \([n\text{\_zone} \times 1]\)-vector of the ratios between the workers and residents of type \( i \), \( P^i \) the \([n\text{\_zone} \times n\text{\_zone}]\)- matrix of the residential conditional probabilities relative to workers of type \( i \), it follows:

\[
R^i = k^i \cdot P^i(x) \cdot A^i \quad \forall i
\]

\[
x = x\left(\sum_i R^i\right)
\]

Therefore, there is a circular dependency among residents, occupancy rates and houses availability. This can be treated as a fixed-point problem, whose solution is represented by vectors \( R^i^* \) and \( x^* \):

\[
R^{i^*} = k^{i^*} \cdot P^{i^*}(x^*) \cdot A^{i^*} \quad \forall i
\]

\[
x^* = x\left(\sum_i R^{i^*}\right)
\]

The existence of the equilibrium solution is proved by the fact that the possible solutions set \( R^i \) and the occupancy rate function follow the conditions imposed by the Brouwers' theorem (Cascetta, 2001). The uniqueness of the solution is given by the fact that the function \( x(\cdot) \) is strictly monotone and the residential choice model is additive.

### 3.3 The Economic Activity Location Model

The economic activity location model allows to determine the distribution of the number of employed in the economic sectors \( a \), \( \text{Emp}_a(d) \), in the single zones \( d \) of the study area through the estimate of the probabilities, \( P_a(d) \), of locating an activity of sector \( a \) (e.g., retail, wholesale, etc.) in a given zone \( d \). Be \( \text{EMP}_a \) the total number of employed in the economic sector \( a \) of the study area, it follows:

\[
\text{Emp}_a(d) = P_a(d) \cdot \text{EMP}_a
\]

In the model under analysis, activities are grouped in the following economic sectors:

- basic activities, i.e. industrial and public service activities (Health board, education, etc.)
- services (banks, offices, etc.)
- commerce (wholesale and retail)

Basic activities are those activities whose location is exogenous with respect to transportation system (e.g. location of industries, universities, etc.). Non-basic activities are those activities whose location depends on land use and transport interactions. As shown in figure 1, basic activities location is input
data for the models, while location of non-basic activities derives from several interactions with both the housing location and the transportation system. To simulate these location choices a behavioural approach consistent with Random Utility theory is followed. Private investors (i.e. firms, craftsmen, companies, etc.) in choosing the zone \( d \) where to locate their activity, associates an utility, \( U_a^d \), to all the available zones and chooses the one which maximises \( U_a(d) \). Utility is assumed to be a random variable consisting of two terms: the systematic utility \( V_a(d) \) and the random residual \( \varepsilon_a \). If random residuals \( \varepsilon_i \) are independently and identically Gumble \((0,1)\)-distributed, the probability \( P_a(d) \) of locating activity \( a \) in zone \( d \), is given by the well-known Logit formulation:

\[
P_a(d) = \frac{\exp(V_a(d))}{\sum_{d'} \exp(V_a(d'))}
\]

The systematic utility \( V_a(d) \) is a linear combination of the attributes taking into account:
- transportation system performances, i.e. accessibility (active and passive) of the zone;
- attributes of the attractiveness of the zone, like the number of residents and the number of employed in the basic sector present in the same zone;
- dummies taking into account the characteristics of the area to which a given zone belongs, like Centre, which is equal to 1 if the zone is central 0 otherwise.

Two different activity location models have been calibrated: one for the services and one for the commerce. The calibration has been carried out on Census data of the urban area of the city of Rome. The calibration results are reported in table 3. Passive accessibility has the expression reported in section 3.1; in this case the constant \( \gamma_1 \) and \( \gamma_2 \), calibrated together with the other model parameters, are equal to 0.85 and 1.22 respectively.

<table>
<thead>
<tr>
<th></th>
<th>( \text{Acc}^{\text{pas}} )</th>
<th>( \text{Res}(d) )</th>
<th>( \text{Emp}_{\text{basic}} )</th>
<th>Centre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Services</td>
<td>0.137 (3.6)</td>
<td>0.011 (2.8)</td>
<td>-</td>
<td>1.585 (3.0)</td>
</tr>
<tr>
<td>Commerce</td>
<td>0.105 (1.9)</td>
<td>0.075 (2.6)</td>
<td>0.049 (2.4)</td>
<td>1.397 (2.1)</td>
</tr>
</tbody>
</table>

All the estimates are statistically different from zero and have the expected sign. As it can be noted, the parameters \( \beta_{\text{Acc}^{\text{pas}}} \) are positive meaning that the more accessible a zone is to residents the more it is convenient to locate there an activity. While the values of \( \beta \)’s relative to accessibility are comparable for “Services” and “Commerce”, this is not true for those relative to population. The \( \beta_{\text{Res}} \) is almost seven times bigger for “commerce” than for “Services”, as if the distribution of commercial activity resembles very closely the distribution of population among the zones. Furthermore, basic sector activities of the zone are not significant for “Services” sector. Finally, location
in a central area is very convenient both for services and commercial activities due to the historical and social factors typical of such area.

3.4 The Equilibrium Problem between Economic Activities and Residence Location

Given the number of employed in each economic sector $a$ and zone $d$, $Emp_{a}(d)$, it is possible to get the number of employed in zone $d$ of type $i$, $Emp_{i}(d)$, as:

$$Emp_{i}(d) = \sum_{a} h'_{a}(d) \cdot Emp_{a}(d)$$

where $h'_{a}(d)$ represents the rate of workers of type $i$ employed in an activity of the sector $a$ in zone $d$.

From the assumptions on the residence location, it follows that the number of residents of type $i$ in a given zone depends on the distribution of the employed. Vice versa, the number of employed (of the same type) in a given zone depends on the number of residents in the same zone. Therefore, let $A^{i}$ be the $[n\_zone \times 1]$-vector of employed of type $i$ in a given zone, it follows:

$$\begin{align*}
R^{i} &= R \sum_{i} A^{i} \quad \forall i \\
A^{i} &= A \sum_{i} R^{i} \quad \forall i
\end{align*}$$

Therefore, an equilibrium problem exists in the activity and residential locations, whose solution is given by the vectors $R^{i*}$ and $A^{i*}$:

$$\begin{align*}
R^{i*} &= R \sum_{i} A^{i*} \quad \forall i \\
A^{i*} &= A \sum_{i} R^{i*} \quad \forall i
\end{align*}$$

The existence of the vectors $R^{i*}$ and $A^{i*}$ is once again proved by the conditions of the Brouwers’ theorem.

4. APPLICATIONS

The models system described in the previous sections have been validated by an application to the urban area of Rome (Italy). It has been applied to the detailed zoning system of the study area, consisting of 463 zones, however the results, reported in the scatter diagrams of figure 2, are shown for an aggregation of such zoning consisting of 54 “macro-zones”. Concerning housing location, the percentage error between observed and estimated workers for the 54 macro-zones ranges from -8% to +8% with peaks of 20% for few more aggregated suburban ones. The scatter diagrams show a bigger dispersion for low income than for high-income workers: a more disaggregate segmentation of low income could probably better off the estimates. Concerning employment location, the percentage error between macro-zones ranges from −4% to +4%, no peaks are observed as in the case of housing location.
Figure 2 - Housing and employment distribution: observed vs. estimated data.

Once validated, the model system has been applied to the study area in order to evaluate the effects of changes in the transport supply configuration. The analysis of the impacts of such changes has been carried out in terms of changes in housing and activity locations as well as in demand flows (e.g. zonal emission/attraction, modal split). In this respect, a comparison with the estimates carried out by traditional *four-stages* demand models, is presented.

### Table 4 – Residents and employees for each “macro-zone”.

<table>
<thead>
<tr>
<th></th>
<th>Workers</th>
<th>Residents (&gt;14 y.o.)</th>
<th>Employed in commerce</th>
<th>Employed in services</th>
<th>Employed in basic sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Centre</strong></td>
<td>16.052</td>
<td>45.347</td>
<td>18.019</td>
<td>42.990</td>
<td>63.971</td>
</tr>
<tr>
<td><strong>Ring 1</strong></td>
<td>159.745</td>
<td>430.012</td>
<td>39.941</td>
<td>145.238</td>
<td>161.866</td>
</tr>
<tr>
<td><strong>Ring 2</strong></td>
<td>381.082</td>
<td>968.927</td>
<td>60.789</td>
<td>69.698</td>
<td>137.508</td>
</tr>
<tr>
<td><strong>Ring 3</strong></td>
<td>412.729</td>
<td>961.864</td>
<td>46.927</td>
<td>55.954</td>
<td>112.870</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td>969,608</td>
<td>2,406,150</td>
<td>165,676</td>
<td>313,880</td>
<td>476,215</td>
</tr>
</tbody>
</table>

The typical case of the introduction of Travel Demand Management (TDM) policies in the highly congested zones of the city centre, has firstly been analysed. In doing so, the study area has been split into four different “macro-area”: the “Centre” consisting of the historical centre of the city and three concentric circular sector, namely the “ring 1”, the “ring 2” and the “ring 3”.
In table 4 the number of residents and of employed for different sector is reported for each macro-zone. With respect to a reference scenario in which only the zone of the “Centre” are already subject to TDM policies (i.e. parking fares and access limited only to residents), the extension of parking fares to all the zones of the ring 2 has been simulated. The result of this first run of simulation are reported in table 5, in terms of percentage variation of the number of residents, employed in commerce and employed in services.

Table 5 – Percentage variation of residents and employed due to the introduction of parking fare in the sub-central zone

<table>
<thead>
<tr>
<th>zone</th>
<th>residents</th>
<th>employed in commerce</th>
<th>employed in services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centro</td>
<td>3%</td>
<td>5%</td>
<td>8%</td>
</tr>
<tr>
<td>Ring 1</td>
<td>9%</td>
<td>-7%</td>
<td>-10%</td>
</tr>
<tr>
<td>Ring 2</td>
<td>-4%</td>
<td>3%</td>
<td>7%</td>
</tr>
<tr>
<td>Ring 3</td>
<td>-2%</td>
<td>2%</td>
<td>5%</td>
</tr>
</tbody>
</table>

As it can be seen, for a given zone \( o \), the introduction of parking fares induces an increasing number of residents and a decreasing number of activities such as services and commerce. This can be explained that the parking fares increases the generalised travel cost towards the zone \( o \) and determines a reduction of the passive accessibility of this zone. Therefore, people working in \( o \) (i.e. the zones subject to new parking fares) tend to move residence towards these zones to minimise the effect of the increased generalised travel cost to their workplaces. On the other hand, consultants, banks and other private investors tend to locate their activity in other zones which results more attractive for potential clients, having an higher (passive) accessibility.

The introduction of a new underground railway and the extension of existing ones have then been simulated. The results in terms of variation in housing and economic activities location are depicted in figures 4 and 5. It can be observed that the effects of the changes in the transport supply system in this case, induce an increasing number of both housing and economic activities in the zone served by the new Public Transport infrastructure. This increasing on the average is between 5% and 15% and is higher in the peripheral zones, where the marginal increase of accessibility is higher.

In terms of demand flows it can be observed an increasing of 24.9% of the trips generated by the zones served by the new underground railway and of 8.0% of the trips attracted. Table 6 shows that the same indicators are underestimated using traditional four-stages demand models.

Table 6 – Percentage variation of trip on Public Transport modes generated/attracted by zone served by the new Public Transport infrastructure.

<table>
<thead>
<tr>
<th>Land-use/transport interaction model</th>
<th>Traditional four-stages demand model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trip generated</td>
<td>24.9%</td>
</tr>
<tr>
<td>Trip attracted</td>
<td>8.0%</td>
</tr>
<tr>
<td></td>
<td>19.5%</td>
</tr>
<tr>
<td></td>
<td>1.6%</td>
</tr>
</tbody>
</table>
Figure 4 - Housing percentage variation within the study area due to new underground railways (depicted with blue lines).

Figure 5 – Services percentage variation within the study area due to new underground railways (depicted with blue lines).

Finally, in terms of modal splits table 7 shows the modal shares in a scenario with the introduction of TDM policies and of the new Public Transport infrastructures, estimated by means of four-stages demand models and the adopted modelling framework. Also in this case the estimates obtained by
mend of traditional *four-stages* models seems to underestimate the impacts of the simulated transport changes.

Table 7 – Modal shares using different models in case of new Public Transport infrastructure and TDM policies.

<table>
<thead>
<tr>
<th>Modal share</th>
<th>Private modes share</th>
<th>Public transport share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference scenario</td>
<td>63.6%</td>
<td>36.4%</td>
</tr>
<tr>
<td>New underground railway and TDM policies</td>
<td>Traditional <em>four-stages</em> demand model estimates</td>
<td>58.3%</td>
</tr>
<tr>
<td></td>
<td>land-use/transport interaction models</td>
<td>55.7%</td>
</tr>
</tbody>
</table>

5 CONCLUSION AND FURTHER RESEARCH

In this paper a system of spatial interaction models aiming at simulating land-use and transport interaction is presented. The overall framework consists of integrated behavioural submodels in which land-use pattern derives from the location choices of different decision-makers (i.e. households, workers, firms, companies, etc.). Preliminary version of the models system, though fully operational, is characterised by an aggregate definition of economic sectors and worker typology. This leads to estimates values which, however promising, could be easily better off by further segmentation. Calibration of further attributes (e.g. accessibility to services in the housing location submodels, prices of commercial surfaces in the commerce submodels, etc.) to include in the utility functions could be tested as well. Interactions between different submodels (i.e. different components of the urban system) are simulated through an equilibrium approach. Conditions for existence and uniqueness of the equilibrium solution are discussed. Although preliminary applications of the models system show a fast convergence to an equilibrium solution, the properties of convergence of the adopted algorithms needs to be investigated more deeply.

Applications to the urban area of Rome (Italy) showed a reasonable elasticity of housing and activity location with respect to changes in transportation supply pattern induced by TDM policies and/or new infrastructures. This allows improving the estimates of demand flow obtained using traditional demand models.

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