1. Introduction
In this paper, a review of the research on the two-way interaction between urban land-use and transport, i.e. the locational and mobility responses of private actors (households and firms, traveller, shippers) to changes in the urban land-use and transport system at the urban-regional level, is first presented. However, the main objective is the proposal of a land-use/transport model calibrated on the urban area of the city of Naples. That urban land-use and transport are closely interlinked is common wisdom among planners and the public (Wegner and Furst, 1999). 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 understood that the suburbanisation of cities is connected with increasing spatial division of labour, and hence with ever increasing mobility. However, the reverse impact from transport to land-use, is less well known. There is some vague understanding that the evolution from the dense urban fabric of medieval cities, where almost all daily mobility was on foot, to the vast expansion of modern metropolitan areas with their massive volumes of intraregional traffic would not have been possible without the development of first the railway and in particular the private automobile. The latter has made every corner of the metropolitan area almost equally suitable as a place to live or work. However, exactly how the development of the transport system influences the location decisions of landlords, investors, firms and households is not clearly understood even by many urban planners.
In this paper the major theoretical approaches to explain the two-way interaction of land-use and transport in metropolitan areas are summarised.
In the 1950s first efforts were made in the USA to study systematically the interrelationship between transport and the spatial development of cities. Hansen (1959) was able to demonstrate for Washington, DC, that locations with good accessibility had a higher chance of being developed, and at a higher density, than remote locations ("How accessibility shapes land use"). The recognition that trip and location decisions co-determine each other and that therefore transport and land-use planning needed to be co-ordinated, quickly spread among American planners, and the "land-use transport feedback cycle" became a commonplace in the American planning literature.
The set of relationships implied by this term can be briefly summarised as follows (see Figure 1).

- The distribution of land uses, such as residential, industrial or commercial, over the urban area determines the locations of human activities such as living, working, shopping, education or leisure.
- The distribution of human activities in space requires spatial interactions or trips in the transport system to overcome the distance between the locations of activities.

![Figure 1. The "land-use transport feedback" cycle](image)

Section 2 contains an update review of models present in literature and a proposal of their classification. Section 3 describes the model proposed, while in section 4 the results of the parameters calibration have been reported. Section 5 contains conclusions and some further research.

2. State-of-the-art
This section gives an account of the core models and their
origins, by describing their underlying theory, and the advances in mathematics which from the late 1970s onwards have made it possible to address more fully the issues of dynamic modelling.

It will be noted that the problem of modelling land-use/transport has been tackled by different disciplines. "These different approaches should be integrated into a unified multidisciplinary approach under the umbrella of something like urban analysis", but this remains a difficult task" (Wilson 1997).

The large number of models proposed in literature, can be categorised into many classes depending on the adopted criteria. Table 1 shows a proposal of the most relevant classification.

Models can be divided by considering the type of use. The analysis models are those aimed at studying, through different formulations, sometimes very simple, the relationships among some relevant variables. This is the case of the first models based on classical urban economics of the 19th century and in particular those coming from the German school. We must go back to Von Thunen (1826) and later Weber (1909), who wrote specifically about the interrelationships of location and transport; and to Christaller (1933), Losch (1940) who have contributed to the question of a general location theory which implicitly takes into account transport costs as well.

The most natural "descendent" of this line of research is Beckman, who managed to combine systematically geographical theory and urban economics with the methods and techniques which operational research had made available from the late 1940s (Bertuglia et al, 1990). The alliance of geographic theory and urban economics forged ahead thanks to the work of, among others, Wingo (1961) and Alonso (1964).

From the 1960s onwards there was a parallel development of powerful mathematical models. Unlike the types of study referred to above, each based on specific interpretative paradigms, usually from economics, this branch had its roots in quantitative formulations of empirical regularities. These developments were built on two objectives: the building and testing of tools for direct application in town planning, and the building of an alternative to strictly neo-classical approaches.

Therefore, another models' type of use is that of application; i.e., if the objectives are the building and the analysis of tools for the direct application to the planning of a city or more in general of a land-use system.

The most significant of the various early attempts was the "Model of Metropolis" (Lowry 1964). This was not by any means the most sophisticated of the early models, but it was probably the more influential because it took a simple, recognisable economic theory and applied it to the urban situation in a demonstrably practical manner. Something of an academic industry grew up focussed on the improvement and elaboration of the Lowry model.

Models can be classified also considering modelling aggregation. Models are aggregate, if the variables (attributes) are relative to an aggregate of individuals, typically belonging to a zone or region, and this is the case of the first models based on economic theory; they are disaggregate if the variables refer to the single individual or market segment. Systems of models, which are completely disaggregate do not exist.

In particular, considering the second aspect of model development referred to (that of the formulation of alternatives to the traditional neo-classical approaches), particular relevance to the present literature were the "entropy modelling" approach and the models developed at the Centre of Land Use and Built Form Studies in the University of Cambridge. The "entropy" approach, associated in particular with Alan Wilson, drew upon mechanical analogies to determine the most appropriate functional forms for models. The key analogy related to the most likely pattern of movement of individuals particles (persons or gas molecules) when only certain aggregate properties (average travel cost, temperature of the gas) are known. The Cambridge models were (and are still) characterised by particular attention to the stock of buildings as an influence on the location of activities. The Lowry-type models, and the various other parallel activities, can be seen as a "first generation" of urban models that flourished approximately between 1964 and 1974. A distinction relevant to all the land-use and transport models.
discussed is the extent to which the entities (households, workplaces, etc.) to be located are *endogenously* generated by the models themselves or are *exogenously* specified by the model user. Urban regions are not self-contained, but depend to a large degree on processes occurring in the "rest of the world", such as national and international trade, technological progress, or long-term social or cultural developments. These external trends have to be entered into the model in order to form a realistic "scenario" for regional forecasts. MEP and OSAKA (Bertuglia et al., 1988) stand out in that they need only a forecast of the future development of basic employment. These two models employ the theoretical framework of economic base theory, whereby basic economic activities generate other economic activities, which in turn generate employment and thus support more population, which then requires local services and thus further employment, and so on.

From 1974 onwards, it was widely believed that urban land-use modelling had ceased. In fact, research and a limited amount of practice continued, on a relatively modest scale and with more realistic expectations and claims (Simmonds 2000). These activities refined the models already introduced, and developed a new generation of models based on micro-economic theory rather than on physical analogies. A key theoretical development was the growth of discrete choice theory (McFadden 1978) (Ben-Akiva and Lerman 1985), which provided a much better basis for the representation and explanation of choices between locations, between modes of transport, and so on. Therefore, the choice modelling approach can be considered *behavioural*, if it derives from explicit assumptions on the behaviour of the individuals; while it is considered *descriptive* if models simply describe relationships without formulating specific hypotheses on the behaviour of the individuals. There also exist mixed systems, where some sub-models are considered behavioural, while others are considered descriptive.

A continuous stream of both research and application have been the "Martin Centre models". This collective term refers to the various spatial-economic models whose origins were the Martin Centre of the University of Cambridge. The main characteristics of these models are that they are typified by the integration of three different economic theories in spatial form. The latter are input-output modelling, utility-maximising consumer behaviour for non-spatial choices and discrete choice theory (Hunt and Simmonds 1993). Since the mid-1980s, they have been represented by the TRANUS and MELAN packages.

As for the system components interaction, it could be *static", if the development law of the system is not examined. Only the final state is relevant to the analyst. In this case, an algorithm of fixed point representative of the equilibrium can be used. The approach is *dynamic", if it is assumed for reasons extrinsic to the system that it could assume different admissible states. The objective is to simulate the evolution of the system and the mechanisms of interaction among the elements determining them.

At the beginning of the eighties, the UK Transport and Road Research Laboratory (TRRL) initiated a collaborative exercise on land-use transport interaction, which developed into the International Study Group on Land-Use/Transport Interaction (ISGLUTI). The initial search for potential participants identified a number of centres of land-use transport modelling activity, of which nine participated in the first phase of the ISGLUTI project. This phase involved discussion and comparison of the models, and a programme of scenario or strategy tests carried out by seven of the teams using their different models of different cities. Three models or packages are worth mentioning and they are LILT, IRPUD and MEPLAN. LILT (Mackett 1990) can be regarded as a late flowering of the first generation of models, in that it relied mainly on entropy-maximising rather than on market-and price-related mechanisms. IRPUD (Wegner 1999) was by far the most complex of three models mentioned above, as its approach appeared to offer a number of very attractive characteristics. A focus entirely on processes of change over time, whereas the Martin Centre models work largely by producing an "instant metropolis" for each point in time. Nevertheless, the Martin Centre approach has significant advantages. The adjustment of rents as the interaction of supply and demand is carried out so as to find a partial equilibrium condition within one time period, rather than by setting the rents for each period in response to the outcome of the previous period.

It appeared feasible to develop a model package, which would combine the focus on processes and dynamics, which characterises IRPUD, with the practicality and explicit rent-determination of the Martin Centre models. It also seemed desirable for several practical reasons to concentrate on developing a land-use package which could be linked to any appropriate transport model, rather than to invest in providing the new package with a transport model of its own. In the light of these considerations, DELTA model was developed (Simmonds 2000).

Finally, another classification criterion is of the approach to the transportation system simulation. In particular, the representation could be explicit, if models explicitly define the components of the transportation subsystem (demand, supply, networks, costs, etc.). The representation of the transportation subsystem could be *implicit*, if it introduces a generalised transportation cost between each O-D pair, without an explicit representation of the supply system and without clearly define how it influences such cost on the congested phenomena. In all the models reported above there is a clear representation of the transportation system, apart from the models of the first generation (Von Thunen, etc.). The treatment of transport and travel involves a huge amount of mathematical modelling in total across the various models. Much of the general format is familiar since it is derived from the standard four-step transport model. It is clearly described the way in which the effect of traffic congestion on speed may be modelled using a detailed representation of the transport network. Some models (CALUTAS, DORTMUND, ITLUP, LILT) contain a representation of the networks (at
varying levels of detail) serving each mode on a link-by-link basis, including such information as link length, travel time, link capacity and level-of-service and routining of public transport lines (Webster et al., 1988). As seen earlier, the development of dynamic models was followed by the advent of the PC and better computer graphics. Therefore, this was really useful to represent explicitly city network and transportation indicators. Another advantage also facilitated the development of Geographical Information Systems (GIS). There were two major consequences: first, model-based planning systems became more user-friendly, and this, in principle, facilitated application; second, the possibility of combining human and machine intelligence in tackling problems which are analytically intractable was opened up.

Traditional GIS are essentially mapping systems with added facilities for overlays among other aids. That there is a potential for constructing model cities in graphic detail can be seen from best-selling computer game SimCity. Unfortunately, the underlying model, which drives it, is not realistic as it could be, but GIS potential can arise from unusual directions. In a modelling context, GIS can be used to present not only core maps, but also model outputs and performance indicators on a customer-driven basis. In this way, real intelligence can be added to GIS, and this leads to the concept of intelligent geographical information systems or IGIS. From the first models of the classical urban economics of the 19th onwards many steps have been made, especially if we consider the level of simulation of all the models proposed. In particular, we are referring to how many and which components are described. Population, economic activities, transportation networks, land market are clear examples. This classification criterion of land-use/transport models comes at the end so that it can be seen that especially the models of the last years embrace and simulate almost all of the components reported, because of the more sophisticated techniques of representation and simulation.

3. The model proposed

Referring to the classification above reported, the model is based on an explicit simulation of the whole multimodal transportation system which integrates road, pedestrians and transit networks. Travel demand model system is based on a Nested Logit functional specification and the stochastic equilibrium assignment is made on congested transportation networks. In particular, simulated land-use interactions are relative to residential and economic activities location, based on behaviorally consistent accessibility measures (logsum variables) as well as potential demand for economic activities and available floorspace. Active and passive accessibility have been both defined and considered. The model, even if it is not yet implemented, but it could be to any case study, follows a static equilibrium approach.

3.1 Land-use models

This section examines the land-use or, more precisely, the location of activities in space.

Residential location model

Wilson systematised and made more rigorous the gravity models used in the Lowry and similar models, suggesting four types of models to fit four types of behaviour:
1. Households seeking both residence and a job: unconstrained model.
2. Households with a residence and seeking a job: production-constrained (origin-constrained) model.
3. Households with a job and seeking a residence: attraction constrained (destination-constrained) model.
4. Households seeking neither residence nor job: doubly constrained model.

The residents location parts of the Lowry model are of type 3 and the model proposed is of the Lowry type as it uses transport-type gravity models directly as a means of allocating residents to zones from their workplaces. The problem of simulating the clearing of an urban residential market can be described as that of allocating w types of residents in i subareas or zones of the city from j places of employment. If this case w refers to the income level; two groups are identified: a high/medium and a low income group.

The probability of living in zone i can be expressed as follows:

\[ p^r(liv = i) = \sum p^r(liv = i, work = j) \]

\[ p^r(liv = i, work = j) = p^r(liv = i, work = j) \cdot p(work = j) \]

\[ p^r(liv = i, work = j) = \text{probability of living in zone } i \text{ for residents of type } c; \]

\[ p^r(liv = i, work = j) = \text{joint probability of living in zone } i \text{ and working in zone } j \text{ for residents of type } c; \]

\[ p^r(liv = i, work = j) = \text{conditional probability of locating a residence in zone } i \text{ for residents of type } c, \text{ who are employed in zone } j; \]

\[ p(work = j) = \text{probability of working in zone } j \text{ for residents of type } c. \]

The conditional probability may be expressed as follows:

\[ p^r(liv = i, work = j) = \frac{\exp(V^r(liv = i, work = j) / \theta)}{\sum \exp(V^r(liv = h, work = f) / \theta)} \]

The attributes of the systematic utility are in the following reported:

\[ \ln \text{STOCK } (i) = \ln \text{ of the housing stock in zone } i; \]

\[ \text{PRICE } (i) = \text{price per square meter of the houses in zone } i; \]

\[ \text{ACA }_\text{SER}(i) = \text{active accessibility to services in zone } i \text{ for type } c \text{ of residents; } \]

\[ Y_{\text{work}}(i, j) = \text{logsum of the mode choice } m \text{ between } i \text{ and } j \text{ for work purpose and type } c \text{ of residents; } \]

\[ \text{PREST } (i) = \text{dummy variable: it is equal to } 1 \text{ if zone } i \text{ is prestigious, } 0 \text{ otherwise; } \]

\[ CH(i) = \text{council houses ratio in zone } i. \]
The probability of working in zone \( j \) for residents of type \( c \) is the rate of workplaces in \( j \), given by:

\[
p^c(j = \text{work}) = \frac{\text{Emp}^c(j = \text{work})}{\sum_h \text{Emp}^c(h = \text{work})}
\]

where:

\( \text{Emp}^c(j = \text{work}) \) = number of workplaces of type \( c \) in zone \( j \).

**Employment and workplaces models**

In the model proposed, allocation of population depends upon the distribution of employment, and so forecasts of employment location, whether exogenously prepared or endogenously estimated, are an essential component. The ways in which the model describes employment and the general process implicit in its representation of employment location are in the following reported.

A distinction needs firstly to be made between employment and jobs or workplaces (Webster et al., 1988). All the models present in the literature are commonly called employment location models. Actually it would be more accurate to call them jobs and/or workplaces such as factories or office buildings, and to use the term employment location models only where such jobs or workplaces are actually filled by the labour force.

Most of the models differentiate between so-called “basic” and “non-basic” types of employment. This categorisation stems from economic base theory, where “basic” employment refers, for the most part, to the sectors which are largely externally driven, while “non-basic” employment contains the more locally-driven types. This distinction reflects notions of local markets and suppliers, and the presumed sensitivity of location to these as well as other factors. Thus, “basic” employment contains all primary sectors and most secondary sectors, while “non-basic” employment contains some secondary sectors and all the tertiary sectors.

The model proposed allocates workplaces rather than employment. Although it uses the same structure for all types of workplaces, each structure contains equations referring to three different location processes. In all cases, the functions allocate a change of workplaces to zones according to a locational utility function, which contains accessibility as one of its components.

The models proposed, of the Logit type, allocate workplaces in the wholesale, retail and services sectors.

The attributes of the systematic utility of the wholesale sector are:

\[ \ln FL^w(i) = \ln \text{of the available floorspace in the wholesale sector in zone } i; \]

\[ PA_{\text{Emp}}^w(j) = \text{passive accessibility of zone } j \text{ to the employed in the retail sector}; \]

\[ MJ(i) = \text{number of motorway junctions within and nearby zone } i; \]

\[ CENTRE(i) = \text{dummy variable: it is equal to 1 if zone } i \text{ belongs to the centre, 0 otherwise}; \]

For the retail sector, the attributes of the systematic utility are:

\[ \ln FL^r(i) = \ln \text{of the available floorspace in the retail sector in zone } i; \]

\[ \text{PRICE}^r(i) = \text{price per square meter of the floorspace in the retail sector in zone } i; \]

\[ PA_{\text{POP}}(j) = \text{passive accessibility of zone } j \text{ to population}; \]

\[ POP(i) = \text{population living in zone } i; \]

\[ EMP_{\text{ser}}(i) = \text{number of employed in the services sector in zone } i; \]

\[ CENTRE(i) = \text{dummy variable: it is equal to 1 if zone } i \text{ belongs to the centre, 0 otherwise}; \]

\[ FR(i) = \text{dummy variable: it is equal to 1 if zone } i \text{ belongs to the first ring, 0 otherwise}. \]

The attributes of the systematic utility for the services sector are:

\[ \ln FL^s(i) = \ln \text{of the available floorspace in the services sector in zone } i; \]

\[ \text{PRICE}^s(i) = \text{price per square meter of the floorspace in the services sector in zone } i; \]

\[ PA_{\text{POP}}(j) = \text{passive accessibility of zone } j \text{ to population}; \]

\[ CENTRE(i) = \text{dummy variable: it is equal to 1 if zone } i \text{ belongs to the centre, 0 otherwise}. \]

**3.2 Transport models**

The characteristics of the transport system most frequently represented in the models are the interzonal travel times and monetary costs incurred by the users of each mode. Times and costs are combined into an aggregate measure of travel impedance between each pair of zones using a monetary value of time, or some other weighting system, and these form a matrix of the generalised cost or “disutility” of travel by each mode. In those models where interzonal trips are not specifically modelled, interzonal travel impedances may be used to calculate a single value for each zone representing some composite measure of its “accessibility” or “utility” in relation to all other zones.

Accessibility is the attribute stressing the presence of the transport component. It determines the locational advantage of a city or region relative to all cities or regions (including itself). Indicators of accessibility measure the benefits households and firms in a region enjoy from the existence and use of the transport infrastructure relevant for their city or region. In general terms, accessibility is a construct of two functions, one representing the activities or opportunities to be reached and one representing the effort, time, distance or cost needed to reach them:

\[ A_i = \sum g(W_j) f(c_{ij}) \]

where \( A_i \) is the accessibility of zone \( i \), \( W_j \) is the activity \( W \) to be reached in zone \( j \), and \( c_{ij} \) is the generalised cost of reaching zone \( j \) from zone \( i \). The functions \( g(W_j) \) and \( f(c_{ij}) \) are called activity functions and impedance functions, respectively. They are associated multiplicatively, i.e. are weights to each other. That is, both are necessary elements of accessibility. \( A_i \) is the total of the activities reachable at \( j \) weighted by the ease of
getting from \( i \) to \( j \).

It is easily seen that this is a general form of potential, a concept dating back to Newton's Law of Gravitation and introduced into regional science by Stewart. Here the attractors are the activities or opportunities in zone \( j \) (including region \( i \) itself), and the distance term is the spatial impedance \( c_{ij} \).

The interpretation here is that the greater the number of attractive destinations in zones \( j \) is and the more accessible zones \( j \) are from zone \( i \), the greater is the accessibility of zone \( i \). This definition of accessibility is referred to as destination-oriented or active (Cascetta 2001) accessibility. In a similar way an origin-oriented or passive accessibility can be defined: the more people live in zones \( j \) and the easier they can visit zone \( i \), the greater is the accessibility of zone \( i \). Because of the symmetry of most transport connections, destination-oriented and origin-oriented accessibility tend to be highly correlated.

From our point of view, the accessibility attributes introduced are calculated referring to the conventional four-step transport model, improved by the use of logsum variables which configure the system structure as a partial information Nested Logit. The numbers of trips from each zone are generated and then distributed to the various destination zones with behavioural models. In the modal split stage where the proportion of trips by each mode for each zone pair is calculated and finally the trips are assigned to the network appropriate for each mode.

4. Operational aspects of the model

Previous sections have examined the various components of the model and the interactions between them and have compared its structure and theoretical underpinnings. This section looks at the operational aspects of the model: how it can be used, what data sources are required.

A model must first be calibrated so that it is able to replicate the existing system as well as possible; then, it must be validated by testing its predictive powers and then, if necessary, modified in the light of the knowledge gained during validation in order to improve its performance.

Inputs to calibration

The inputs to the calibration of the model include direct observations data. These inputs are of two different types and they are Population Census 1991 (ISTAT, 1991) and a mobility survey employed by the company ITER (1996). The information got from the latter are mainly related to transport rather than to land-use.

The study area is the urban area of the city of Naples, which has been divided in 145 zones, without considering the neighbouring.

Results

The utility function parameters have been estimated with the Alogit software package for the residential location choice model. The results are reported in tables 2 and 3.
All the $\beta$ parameters are of the expected sign. In particular, the location dummies (CENTRE and FIRST RING) are significant, while they were not considered in the residential location models, because not relevant. Again the transportation variables are significant, but in this case what mainly counts is the available floorspace by sector. The CENTRE dummy variable is positive for all the sectors and, as expected, the highest weight is relative to the retail sector. Its low value for the services sector is probably due to the presence of a CBD, out of the centre, which concentrate a large number of activities. Coefficients relative to passive accessibility to population or employed are statistically significant and their low weight is probably due to the high absolute values of the accessibility variables. Moreover the number of junctions can be assumed as an indicator of accessibility of the zone with respect to the external zones, where the goods come.

In the retail sector utility function, the number of employed justify the presence of retail activity in zone having a low number of residents. The value of its coefficient seem to be greater than the one relative to the population, due to the low absolute value of employed in the services sector.

5. Conclusions
This paper has set out the problem of specifying and calibrating an urban model for the city of Naples. Although the transportation database, the results obtained are consistent with the models present in literature.

The calibrated models have confirmed the validity of the land-use variables introduced (such as floorspace, price, etc) as already confirmed by the literature. Moreover, they have pointed out the importance of the transportation system both from the calculation of the accessibility variables and level-of-service attributes point of view. To obtain this, also respecting the theoretical consistency of the models, it is necessary to specify the transportation models with a greater level of detail.

Further research will consider a better database with more information dealing with the land-use component. Other objective is the application and validation of such model and a comparison with the Meplan (Hunt 1994). The idea is to add some more variables, especially considering the more sophisticated available database.

There is much to improve on in land-use transport models, and in understanding of the processes they represent, desires for better data and further research should not obscure the possibilities for making greater and better use of the presently available models based upon existing data sources. Land-use transport models can help in finding and, most importantly, agreeing upon workable answers to the widening range of urban planning problems.

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