Review of existing land-use transport models

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rapport d'étude

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This report was made in the CERTU, which is working in the land-use transport field (with the TRANUS system, developped by Tomas de la Barra). It was reused in an european project called ESTEEM, program JOULE, directed by the DGXII. This report concerns only a review, based on a bilbiography analysis. So, there are no tests on the models themselves.</td></tr>
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This report presents a review of existing land-use and transport models, i.e. which can be purchased on the market, in a software package's form, and could be applied to any appropriate city. It considers also, the models that consultants or academic people can applied to a city and put at the disposal of the customers, and the model developed for a particular city but which will be used to test policy for client or to do researches.
After a distinction between important terms, we precise the position of the land-use and transport model through the different kinds of existing models. In a third part we present an history of the land-use and transport modelling approach which conducts to a review of the land-use and transport models (LUTM). Afterwards, we give others information about LUTM, and discuss about their limits.</td></tr>
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SUMMARY

This report presents a review of existing land-use and transport models, i.e. which can be purchase on the market, in a software package's form, and could be applied to any appropriate city. It considers also, the models that consultants or academic people can applied to a city and put at the disposal of the customers, and the model developed for a particular city but which will be used to test policy for client or to do researches.

After a distinction between important terms (I.), we precise the position of the land-use and transport model through the different kinds of existing models (II.). In a third part we present an history of the land-use and transport modelling approach (III.) which conducts to a review of the land-use and transport models (LUTM) (IV.). Afterwards, we give others information about (V.), and discuss about their limits (VI.).

1. MODELS, SOFTWARE AND MODELLING TECHNIQUES

Broadly speaking, the term "model" refers to a representation and to a reduction of the "reality". A model have for objective to recreate a situation of reference for which we have data (base year) for establishing forecasts for a term at which we don't have data (horizon year). So, we can test scenarios of transport policies, and, perhaps land use policies. Outputs of models can be used in the framework of the ex-ante evaluation procedures (cost-benefit analysis, to choose one project among a set of others), or into an analytical point of view.

We can make a model with a software, which is a model sold by a supplier on the market, in a package form. To be operational a model or a software, needs to have modelling techniques. These techniques must be organised in a coherent manner.

2. FAMILIES OF MODELS : TO PRECISE THE POSITION OF THE LAND-USE AND TRANSPORT MODELS

We can distinguish two important families of models [1]. For both, we can specify their general and traditional characteristics. The first family gathers models which are used for the establishment of accurate scenarios (i.e., very complete in their contents). The second gathers models used for the establishment of contrasting scenarios (i.e., a lot of measured are tested, put in parallel, and their impact are assessed). We consider, here, an area indented in zones.

2.1. FIRST FAMILY : MODELS FOR TESTING ACCURATE SCENARIOS

Usually they are going to an important spatial detailed level, which involves a lot of time for their development. Existing software could be unimodal (only one transport mode is taken into account) or multimodal (many transport modes are taken into account : the networks are defined together, but in a separately way), or intermodal (many modes are taken into account : the networks are defined together, but in an integrated way).

[1] This typology is not relevant for a lot of people, is made only in a pedagogical point of view, and is not based on a technical approach, but on an empirical one (traditional using).

2.1.1. Urban Transportation Modelling Systems (UTMS)

They represent the most important usage in France (more than 95% of studies carried out).

As defined in "Urban transportation planning", chapter seven, "Their objective is to predict the number of trips made within an urban area type (work, nonwork,...), time of day (peak hour, daily,...) and zones origin-destination (O/D pairs), the mode of travel used to make these trips. The final product of UTMS is a predicted set of modal flows on links in a network. As such, it represents an "equilibrium" procedure in which the demand for transportation (represented by zones O/D flows by mode) is assigned to the modal networks constituting the transportation system as a function of these network's performance characteristics (supply)." They are used for all the compulsory, or not, transport planning files (plan de circulation, short term : 1-2 years; PT network reorganisation, middle term : 5-8 years; Dossier de Voirie d'Agglomération, long term : 15-25 years).

With UTMS we try to define the level of the future demand, which will be compared to the present supply. Necessaries infrastructures to take into account the new demand will be defined.

For this, we use a four stages procedure, corresponding to a sequential decision process, in which people decide to make trip (generation), decide where to go (distribution), decide what mode to take (modal split), and decide what route to choose (assignment) :

> <u>Trip generation :</u> predicts total flows into and out of each zone in the study area.
> <u>Trip distribution :</u> predicts where the flows of each zone are coming from or going to (interchange matrices).
> <u>Modal choice :</u> predicts the percentage of flow which will be used by each of the modes that are available for travel between each O/D pair.
> <u>Trip assignment :</u> places the O/D network flow for each mode on specific routes of travel through the respective model networks.

UTMS don't give a behavioural representation of trip making. They represent a pragmatic approach to reducing the extremely complex phenomenon of travel behaviour into analytically manageable components [2]. UTMS software present in the market are defined to do the four previous stages, or are rather specialised in the assignment phase. In the software defined for one mode, there is no modal split stage.

[2] The purpose of this paper is not to present and to discuss the modelling techniques used in the UTMS. For more information, we can consult [Ortuzar (JdD), Willumsen (L.G.), 1995]. Nevertheless, we can precise that for trip generation, the most important ones are the regression and the category analysis techniques, for trip distribution they are the growth factor techniques such as Fratar method, and combine with generation's stage, the gravity technique. For modal split, the aggregate logit curve technique is very much used, and for trip assignment the all-or-nothing and equilibrium techniques are also very much used (in that case is particularly the Individual Wardrop procedure).

2.1.2. Discrete choice models (DCM)

They are not very much used in France (in the past : Nantes, Grenoble, Rennes, and always used in Paris, by RATP), but a new methodological approach is under testing by the French transport Ministry in the city of Lyon.

They are used for the analysis and the prediction of trip behaviour for middle term. DCM refers to the procedure of the choice, for a lot possibilities. The modelling approach is used to defined "comportemental rules" from utility functions. Thus, we try to explain how a group of people or a group of household, reacts faced to a set of alternatives [3]. For transport, it could concerns : generation choice, distribution choice, mode choice, route choice. But one of the most important interest of the DCM is the possibility to define crossed choices (choice of mode and destination for example). This possibility is a very important one. Thus DCM can combine two or more stages of the fourth present on UTMS in a choice procedure frame (i.e., in a disaggregated point of view).

The most common starting point for quantitative choice models is the notion of utility maximisation, which assumes that the decision maker is able to assign at least an ordinal ranking to alternatives available in terms of their relative desirability. Being a rational person, the decision maker will then choose the alternative with the maximum utility (i.e., the one which maximises the benefits). In the case of transport, and because the nature of transportation demand, it seems reasonable that people will want to minimise their travel time and cost, and maximise their comfort and convenience. In this context, utility simply represents a convenient generalised function which accounts for the good aspects and the bad aspects involved in trip making and which forms the basis for the traveller's decision making.

Generally, results we obtaine provide probabilities of choice. Perhaps, DCM gives also the weight of the variables which occur in the decision procedure, as characteristics of :

- people (sex, age,...)
- household (number of persons, number of cars per capita in household,...)
- supply of public transport (network, comfort,...)
- supply of individual transport (parking, network, cost,...)
- zones (equipment,...)

2.2. Second family : models for testing contrasted scenarios

Usually, they are not going to an important spatial detailed level. They allow to test a wide range of contrasted scenarios, because the building of these scenarios and the analysis of the outputs of the models, are lesser time consumers than those of the first family. As in the previous case, existing software could be unimodal, plurimodal or intermodal.

[3] It is important to keep in mind that they are the characteristics of the good, and not the goods themselves, which are supposed to generate utility.

2.2.1. Strategic models (SM)

They are under development in France [4], so they are not operational, but, few societies recently establish into the country can provide software for doing this king of modelling [5].

Their objective is to predict the level of few important traditional outputs of UTMS for assessing long term tendency. The type of output is : flows, modal split, generalised cost by O/D pairs,... Generally, the results are given from one macro-zone to another [6]. In a practical point of view, they are based on the sequential structure of the UTMS (4 steps model) and try to be very simple in their using. This point is a very important one, because the development of this kind of models is also for alleviating the use of the modelling approach in the planning process. Nevertheless, this possibility means that the outputs will be more simplified and less numerous than those of the UTMS models. Another interest put it in advance by the developers of the SM, is their "flexibility", allowing to go <u>rapidly</u> from one phase to another. For example, if there is congestion, the results of the assignment stage could modify the modal choice of people and/or their destination, or even, the possibility to do the trip (trip generation will be delayed into an other period of time).

2.2.2. Land-use and transport model (LUTM)

They are not used in France, but they were imported a few month ago, and are presently tested, but they are operational in a lot of other countries.

Their objective is the analysis and the prediction of comportemental rules of trip and location and the prediction of the level of traffic flows (cars and PT), modal split,..., but not at a very detailed level (in great part, because the gathering of the data for the land-use is not easy at a very disaggregated level [7]). Used for the transport system planning and/or town planning, they allow to recreate the functioning of the transport system (as the UTMS), but also the functioning of the town (because they take into account the actors present on the city). Thus, the interest of these models is that they allow, in addition of what the UTMS make, to asses the impacts of the policies we want to test, on the location on people and on activities. Nevertheless, the logic to which they refer is not very easy to understand and they need to calibrate a lot of parameters. Also, they can go to the opposite way of few thesis present in the socio-economic research field (structural effects of transport infrastructures).

Table 1 puts in parallel the two families of models, for having one representation of the positioning of the land-use and transport models.

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[4] By the French transport Ministry with private engineering and a researcher's team, applied on the city of Lyon. Another city, Marseille beging the development of a SM.

[5] They are a lot of example. We could consult : [Jones (D.), May (T.), Wenban-Smith (A.); 1990]; [Coombe (D.), 01/1991] ; [Coombe (D.), 04/1991]; [Skinner (A.), Haynes (C.), 1992].

[6] One macro-zone is : the centre, an other is : the first periphery,...

[7] We can see, in annexe 1, different cases.

TABLE 1 : FAMILIES OF MODELS : ONE TYPOLOGY BASED ON THE TRADITIONAL USING

	ACCURATE SCENARIOS		CONTRASTING SCENARIOS	
	UTMS	**DCM**	**SM**	**LUTM**
PRINCIPAL OBJECT	Thin forecasts of traffic	Analysis and prediction of trip behaviours	Forecast the level of few important traditional outputs of UTMS : flows, modal split,...	Analysis and prediction of trip and location behaviours Forecast of traffic and prediction of flows, modal split,...
FIELDS OF USE	Planning of important transport infrastructures	Programming in term of urban and transport policies	Assessment of the great tendencies	Programming and planning of important infrastructures of transport and town planning
TERM	Short, middle and long term	Short and middle term	Long term	Middle and long term
TRADITIONAL OUTPUTS	Data about traffic, and others variables associated, for PT and cars	Comportemental rules If we want to go to until the assignement procedure : as for the UTMS	Level of flows to one macrozone to one another Level of modal split to one macrozone to one another	Trips and location comportemental rules Location choice, and traditional outputs of the UTMS
SPATIAL DETAILED LEVEL	Very important (a lot of zones) (For Lyon * : 400 zones)	Very important to important (For Lyon : 400 and 90 zones)	Not important (For Lyon : 18 zones)	Not really important (For Lyon : 65 zones)
NETWOK DETAILED LEVEL	Very important	Very important to important	Global (shadows links)	Not really important
TRANSPORT MODES	Unimodal or multimodal	Multimodal (VP, PT), Integrated networks	Multimodal (VP, TC), Non integrated networks	Multi and intermodal (VP, PT) Integrated networks
LAND USE ASPECT	Very bad (only a the hypothesis level)	Few development are present (characteristics of each zone)	Not developped, exept for the MVA software START, coupled with DELTA	Very important, completly integrated with transport part

* Lyon is a city of 1 200 000 inhabitants which cover 550 km².

2.3. Methods for using models

2.3.1. For UTMS, SM and LUTM

It is organised around six points :

1. Description of the reference situation (data base, network,...)
2. Constitution of trip matrices (trip generation, trip distribution, modal choice). For LUTM the land-use application can produce matrices itself and the transport module corrects them. The matrices can be produced by UTMS (as output of UTMS and input for LUTM).
3. Assignment of the variants on the network(s)
4. Comparison between model and reference
5. Calibration by checking, modification of the input parameters
6. New hypothesis and prediction for the term defined

2.3.2. For DCM

It is composed of 5 steps, as defined by M. Clarke, Director of the MVA Consultants France :

1. Preparation : concerns the preparation of the data base about the choice of the people, which takes into account all the characteristics of the alternatives, and of the people, households,...
2. Assessment : concerns the more interesting specification and combination of the variables and the research of the most adapted mathematical form. Here, the coefficients are defined. They give a different weight to the variables which compose the trip behaviour.
3. Calibration : concerns the adjustment of the model (i.e. research of the best coefficients)
4. Validation : it can be disaggregated (when we try to define comportemental rules), or aggregated (when we want to defined a model as an alternative of the UTMS, i.e. which are making assignment procedure)
5. Forecast : last phase, when we are testing scenarios.

2.4. Traditional fields of investigation for the models

The four types of models presented above, have differentiated areas of use. They respond to different objectives. If the typology can be easily discussed, it has for interest to define the field of investigation of the models, on which we make the distinction between the different levels of the urban transport policy [8] :

First options : it concerns the strategic orientations, which come from the urban policy in general and have a translation in term of general objectives (modify the use of PT, reducing pollution,...)

Choice of transport scheme : it concerns the final view, but not always formalised, of the present systems. At this level, the "important lines"

[8] As defined in "Transport 2010", Paris, Commissariat Général du Plan.

which will be written in the future are underlined and presented by the politicians in their speaches and public papers.

Choice of project : it concerns the transcription of the previous level in term of investment project and rhythm of completion. At this level, the coherence of the previous systems is defined, while taking into account the budgetary constraint and internal dynamic of the city. It is here that the economic calculation for the "a priori" assessment is defined, in a financially and social point of view.

Choice of variant : it concerns the quasi-definitive version of the project. After the translation of the "first option" in "transport scheme", and after the decision to do the project, it is realised. Here, a lot of detailed studies are carried out.

The four previous levels of decision allow to have a better representation of the transport and urban policy. In the reality, it is clear that they overlap each other. But this distinction can be used to precise the field of investigation of each type of models, as shown in **table 2**. So, we can see, that only UTMS and DCM are really able to analyse the "choice of variant", but in a different way. SM and LUTM are more specialised for the analyse of the "choice of transport scheme". All the models, to the exception of SM, can be used for the "choice of project". **Table 2** presents also, the name of the software's available on the French market, with no ranking.

2.5. RELATIONS BETWEEN MODELS (IN A STRUCTURAL AND TECHNICAL POINT OF VIEW)

Our typology doesn't put forward the fact that the models are very much linked together, because they have a lot of modelling techniques in common and because their structure is often very similar. **Table 3** presents the relation existing between the different kinds of models.

Therefore :

- SM have generally the same structure as UTMS (4 stages). Sometimes, SM are defined from software's used for UTMS (as TRIPS, MINUTP,...). So, only the number of zones, inputs and outputs are very much modified (to have a lower level of detail, and to have a more quickly handling).

- The 4 stages procedure of the UTMS is also provided by a lot of software allowing to do LUTM (transport part).

- Modelling techniques used in DCM are often used in UTMS and LUTM (as logit form curve, based or not on utility functions), and LUTM are sometimes defined as a link between Land Use modelling techniques and UTMS outputs.

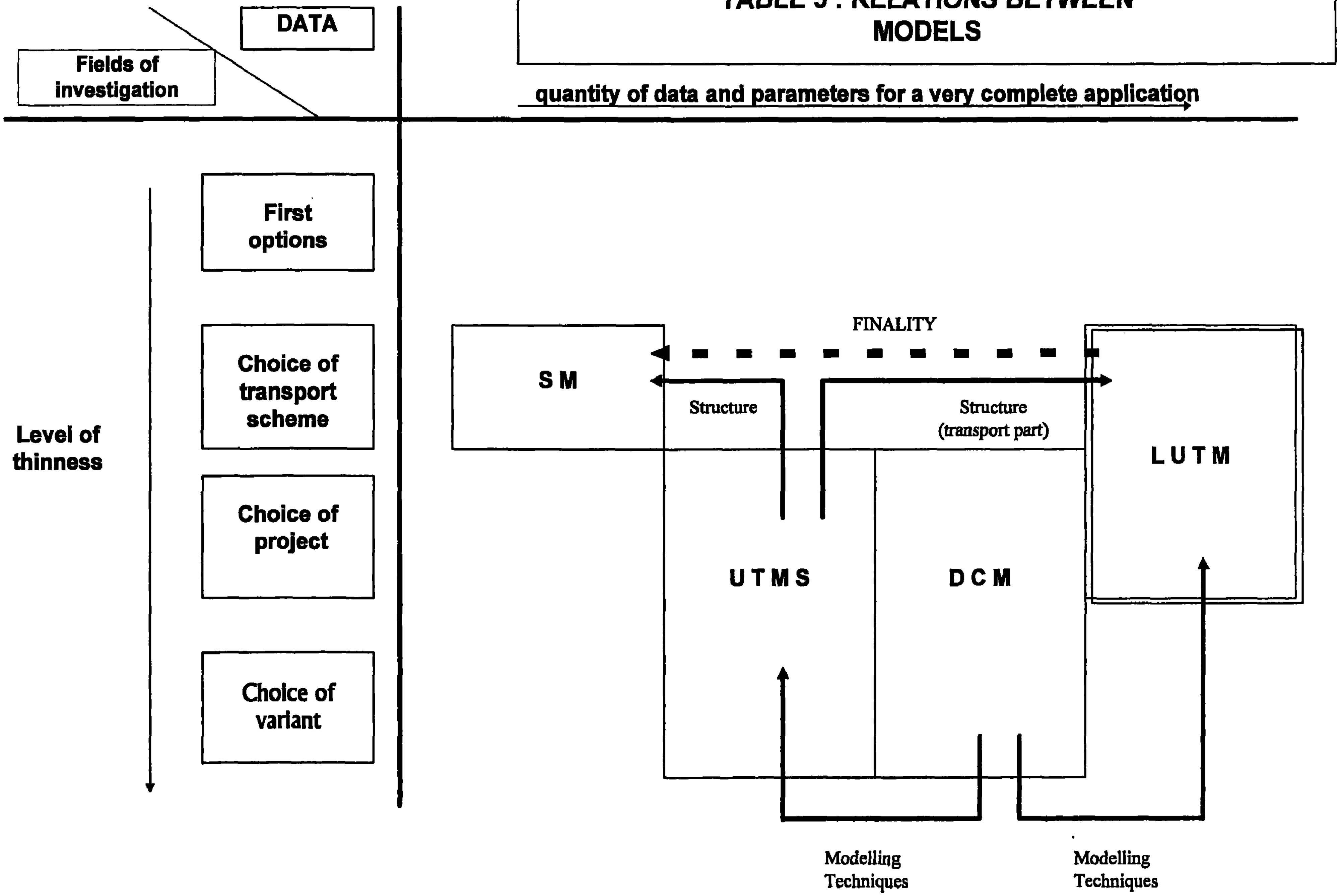
- LUTM can have the same finality as SM [9] : in that case a land-use approach is linked to the transport approach. We can see that a work with a LUTM software at a very global level is very near to do the same work which a SM, but with a land-use component. The difference will be essentially due to the complexity of the model (number of parameters to calibrate)

[9] Don't forget that is the same "family".

Table 2 : TRANSPORT POLICY PHASES AND KIND OF MODELLING APPROACH : FIELD OF INVESTIGATION OF THE SOFTWARE'S

	UTMS	**DCM**	**SM**	**LUTM**
	Thin forecasts of traffic	Analysis and prediction of trip behaviours	Forecast the level of few important traditional outputs of UTMS : flows, modal split,...	Analysis and prediction of trip and location behaviours Forecast of traffic and prediction of flows, modal split,...
FIRST OPTIONS				
CHOICE OF TRANSPORT SCHEME			START **French Ministry model**	<u>Land use and transport well integrated :</u> LILT MEPLAN, TRANUS
CHOICE OF PROJECT	**DAVIS (CARS)** **TERESE (PT)** POLYDROM (CARS / PT) VISEM / VISUM (CARS/PT) TRANPLAN (CARS /PT) **OPERA (CARS / PT)** EMME 2 (CARS /PT) TRIPS (CARS / PT)	ALOGIT MVLOGIT TRIO HIELOW		IRPUD MASTER <u>Land use only, but integrated with transport by the mean of a link with UTMS :</u> IMREL, DSCMOD, ITLUP, DELTA <u>With no important attention to transport</u> : SALOC, TOPAZ-TOPMET TRACKS-TRANSTEP AMERSFOORT, OSAKA
CHOICE OF VARIANT	MINUTP (CARS /PT)	FIDELIO		

TABLE 3 : RELATIONS BETWEEN MODELS



3. HISTORY OF THE DEVELOPMENT OF THE LAND-USE AND TRANSPORT MODELLING APPROACH

There was two important phases on the history of the development of land-use transport modelling approach.

The first concerns the models driving from the micro-economy theory, based on the V. Thünen work (19 Th. century), which will be adapted in the urban context by Alonso during the 60's, and recently completed by M. Fujita. Others authors worked in the same direction (Beckmann, Muth, Wingo, and also Isard and Ponsard, but only Alonso tried to develop a general approach of the land using). M Fujita [Fujita (M.), 1989] uses the Starret's process for giving a new expression of the Alonso's model in term of partial equilibrium of the economic actors for different kinds of cities. His research has demonstrated, for example and for the United States and in a theoretical point of view, that there are white collars who are located in peripheral zones (availability of land, and possibility to bear an important transportation cost) and blue collars who are located near the centre of the city, in a dynamically point of view. But these models haven't had an empirical application, and have no operationality. The most important problems are the hypothesis about the propriety of land and the description of the relations between activities which are simplified, and the problem of the aggregation of the individual utility functions [10].

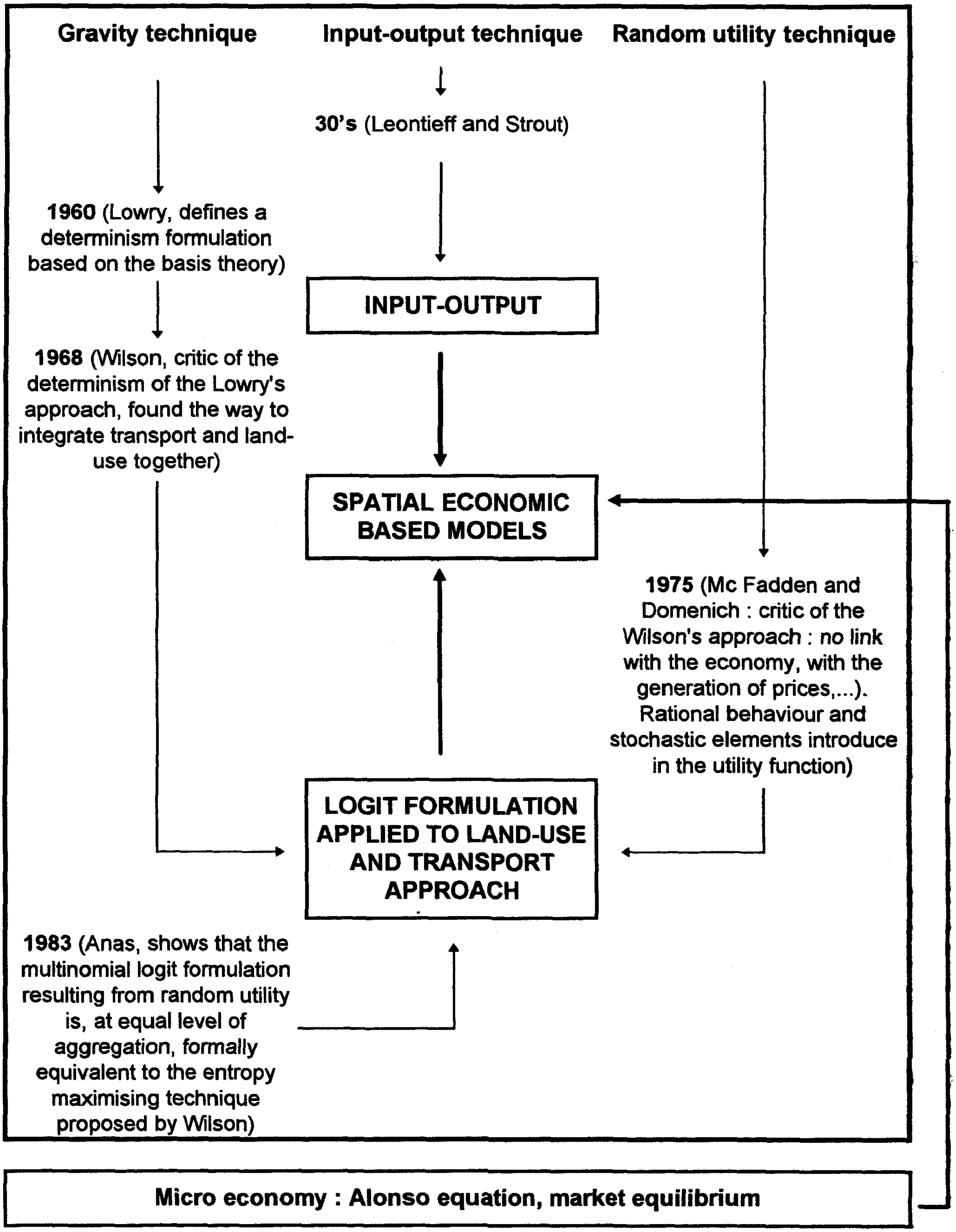
The second concerns the approach which comes from the work of Lowry, enriched by methodological innovation as maximising methods and stochastic elements in the utility aggregation process (A.G. Wilson). These works will be linked with the random utility theory (Domenich and Mc Fadden).

It is important to note that the persons who developed the LUTM have reacted as if the micro-economic theory didn't given satisfaction. So, they tried to use other modelling techniques and tried to organise them in a coherent framework, in relation with the transport approach well known and very much used in UTMS. For example, and as we can see on **table 4**, the spatial economic based model (as MEPLAN or TRANUS, we will presented later in more details), are placed in the second historical phase. They organise many important modelling techniques.

[10] Nevertheless, a lot of people think that the work of M. Fujita should have a more empirical application, but it seems that the researchs demand time. In an other hand, M. Fujita, and J.F. Thisse have made a recent paper about the "economics of agglomeration" on which they present and analyse the problem of the externalities in the development of the agglomerations. This paper considers also the spatial competition and the problems of the monopolisitic competition. Not directly, they show that the research of a modelling approach to understand and translate the urban functioning and the urban developpement, is not a simply one, and geographical and economic approaches have to be taking into account both [Fujita (M.), Thisse (J.F.), 1995].

TABLE 4 : The spatial economic based models in the history of the development of the land-use and transport modelling approach

(Source : T. de la Barra, Tranus training, CERTU, 01/96)



4. REVIEW OF LAND-USE AND TRANSPORT MODEL (LUTM)

All the LUTM used all around the world are based on different modelling techniques, which are organised for giving a structure to each of them. We are going to present them in first, and find again in detail previous aspects shown in 3. In a second and a thrid approach, we will present the LUTM themselves.

4.1. MAIN MODELLING TECHNIQUES USED IN LAND-USE AND TRANSPORT MODELS

As we said before, the purpose of this paper is not to present and to discuss the modelling techniques used in transport modelling. But is not the same thing for land-use and transport model. So, we must present the principal techniques used in land-use and transport model, principally for the land use part, or for the link between land-use and transport.

4.1.1. Lowry's equation and Garin-Lowry's equation (spatial interaction 1.)

Spatial interaction was quantitatively first defined by the use of gravity models. The model of Lowry is one of the descendant of the gravity model. It has three fundamental characteristics :

- priority to the location
- allocation by a gravity model
- multiplying effect

This kind of model aims to assess employment and population in the zones of an area, and trips flows between these zones. It refers to the **basis theory**, developed by O. Hoyt during the 30's, which says that the activity of an agglomeration can be divided in two sectors. One concerns activities for the needs of the population (induced activities) and one concerns exporting activities (basics activities), which concerns a great part of industrial activities. This second sector structures the agglomeration, because it is the driving force of urban growth : it forms a basis which drags the constituting of a first wave of population having needs and which will involve the development of induced activities. In term of spatial approach, this analysis allows to postulate that basic activities are already located, whereas induced activities are going to be located in function of this first location, which is given.

So it implies to define both location principles: people and activities. For this, Lowry doesn't take into account socio-economic variables. He deduces the location of people and of induced activities with a system of equations linking their location at the accessibility to employment (basic or not) and at the activity induced by the population in place and by a part of the population of each zones weight by indices of accessibility.

We obtain two major equations :

*** The first one gives the level of employment of each induced activity for each zone :**

$$E_{kj} = b_k \left(\sum_i c_k \frac{P_i}{T_{kij}} + d_k E_j \right)$$

With :

E_{kj} is the level of employment for activity k in zone j,
P_i is the population of the zone i,
T_{kij} is an indicator of accessibility for the activity k, from i to j (trip flows between i and j, for the activity k),
E_j is total employment of the zone j,
b_k, c_k, et d_k are parameters defined during the calibration of the model.

Therefore, we have the level of employment of the activity k function of the attractivity of the zone j for the others zones for this activity, and of the total employment of the zone j, because the frequenting arise on the activity.

*** The second induces the population of each zone j :**

$$P_j = g \sum_i \frac{E_i}{T_{ij}}$$

With :

P_j is the population of the zone j,
T_{ij} is an indicator of accessibility from i to j,
E_i is total employment of the zone i,
g is one parameter which allows the equalisation $\sum_j P_j = P$.

Therefore, we can see that is a generalised model of accessibility on which transport costs have an important role, in an aggregate approach, without specification to the micro-economic theory. The accessibility is the central element of the model which define the final result, in both the structuration of the space and the induced flows. As in the gravity model, the Lowry model says that the flows to one zone to another are proportional to the number of activities in each zone, and inversely proportional to the transport cost summarised by the distance between these two zones.

For the assessment of the accessibility from one zone to an other, Lowry tkaes into account :

$$T_{ij} = f^{-1}(d_{ij})$$

With :

T_{ij} is an indicator of the accessibility from i to j,
d_{ij} is the distance between i and j.

Lowry gives an exponential inverse form to T_{ij} : $T_{in} = A\, d_{ij}^{\ -\alpha}$, for population groups.

The result of this system of equation allows an iteration until the convergence of the system, with respect to the constraints about space used, employment by zone,...

4.1.2. Models based on the entropy maximising technique (often called maximum likelihood) (spatial interaction 2.)

Wilson's models are a very good example. Wilson used entropy maximising, because he was afraid by the important determinism of the Lowry's model.

Wilson proposed an approach which takes into account the location of services activities. His model allows to calculate flows (monetary flows or number of consumer) between zone i (origin, residential zone) and zone j (destination, in which the service is located) :

$$F_{ij} = \frac{P_i * W_j^{\alpha} * e^{-\beta c_{ij}}}{\sum_l W_l^{\alpha} * e^{-\beta c_{il}}}$$ [11]

With :

W_j represents the commercial attractivity of the zone j,
P_i is the number of consumers living in the zone i,
c_{ij} is the transport cost from zone i to zone j,

When flows throughout the agglomeration are defined, we obtain the demand Dj, induced by all the agglomeration in zone j :

$$D_j = \sum_i F_{ij}$$

In others models, attractivity of a zone j is an exogenous variable, measured by number of services offered in zone j, commercial surfaces, etc. This factor defines supply of services, and the model defines the distribution of the flows of consumers in function of this supply (the distribution of the supply is given "a priori"). The great interest of the Wilson's model is to consider the supply as an endogenous variable and to model is evolution in the time. It assumes that the suppliers of services are interested by the distribution of the demand, and try to adapt their behaviour to it. The system tend to rise an equilibrium between production costs, function of attractivity W_j and income products, function of demand D_j.

To translate these hypothesis, Wilson's choice is based on differential equation, which describes the variation of W_j by unity of time dt :

$$\frac{dW_i}{dt} = \varepsilon * (D_j - k * W_j)$$

With :
k is a parameter which translates the cost production linked to W_j in the same units that the income product by D_j,
e describes the speed of the supply and demand adjustment

[11] Can be express with a logit formulation (to find p (F_{ij})).

We have presented only one formulation example of the Wilson's model, others can be developed easily.

4.1.3. Random utility maximising technique (from Domenich and Mc Fadden)

It is possible to try to deduce a land-use / transport model based on the utility maximising of people. At the beginning, we have to take into account :

- a continuous approach of the space, when defining the different zones (with their characteristics)

- the problem of the aggregation of individual utilities. For this, we work with homogeneous groups of people. Each of them is defined by a utility function such as this function must be close to the function of each person present on the group..

To be near the reality, we leave from an utility which have this form :

$$U_{sk} = U_s(X_k, a)$$

With :

U_{sk} is the utility perceived by the person s who takes the option k,
U_s is the aggregate utility function,
X_k are the characteristics of the option k,
a is a stochastic parameter of the utility function.

Leaving to this function, we can say that the probability to choose the option k, is equal to the probability that the utility allows from the option k, is more important to the utility of others options :

$$p_{sk} = \Pr(U_s(X_k, a) > U_s(X_q, a), \forall q \in E)$$

With :

E is the set of options,
p_{sk} is the probability that the option k is choice by person s.

After hypothesis (independence, Gumbel distribution), we lead to a logit formulation (in a lot of cases, because the probit formulation is hard to develop) :

$$p_{sk} = \frac{\exp(\beta * V_{sk})}{\sum_q \exp(\beta * V_{sq})}$$

With :

V_{sk} is the uncertain element if the utility function U_{sk}.

4.1.4 Input-output economic base technique

Generally, the central element of a land use model is the spatial input-output procedure defined by the economic sectors, and describing the relation between production and consumption. Main elements of an input-output model are final demand, intermediate demand, primary inputs (including wages, imports, profit, taxes). The vector of final demand (including private consumption, consumption of the government, export and investment) represents the final destination of the production. The economic system has to product quantities demanded in each sector. For this, intermediate inputs are needed, generating production and consumption chain. The sum of final demand and of intermediate demand is equal to the total production in the system. The sum of intermediate production and primary input is equal to the total production.

The input-output system (non spatial application, for one zone only), can be described like that :

To produce a sum X^n into the sector n, in the production process, inputs x^{mn} of each sector m are needed. We suppose that we have linear function of production, so :

$$x^{mn}=a^{mn}*X^n$$

Final demand for each sector m is divided in 4 external sectors : investment, domestic consumption, government consumption, export. We note this : Y^m.

If X^n is total production of sector n, the demand total for the sector m is the sum of the final demand plus intermediate demands of the others sectors :

$$D^m = Y^m + \sum_n a^{mn} * X^n$$

In a matrix form, the equation of the compensation market ($X^m = D^m$) gives :

$$X=Y+A.X$$

in which : $X=(1-A)^{-1}.Y$
with Y= forecast of the demand and A : technical coefficient.

The input-output system with spatial declension can be write as follows:

The exit of the sector n, product by zone i, is : X^n_i

We have : $Y^m = \sum_i Y_i^m \quad X^n = \sum_i X_i^n$

A proportion q^n_{ij} of X^n_i can be used in zone j. P^n_{ij} is the probability that the demand in zone j, for an exit of sector m will be satisfied by zone i.

If, in zone j, we have a final demand Y^m_j, with a production X^n_j for each n, so, the total demand of zone j for an exit of m is :

$$D_j^m = Y_j^m + \sum_n a^{mn} * X_j^n$$

and a proportion p^m_{ij} of this total demand, will be made in zone i.

To have a market "clean", we oblige for each zone i, and sector m :

$$X_i^m = \sum_j Y_j^m * p_{ij}^m + \sum_n \sum_j a^{mn} * X_j^n * p_{ij}^m$$

So, we have M*I equations with the same number of unknowns. So, matrixes p^m_{ij} of probabilities are knows. Estimate this matrices of probabilities is equivalent to do a model of distribution in a modelling transport point of view. We can generalise if we said that the technical coefficient can vary by zone. Also, we can simplified, if we said that the matrix of probabilities can be independent of the sector m.

We must have in mind, that the matrix of technical coefficient is formulated in term of physical flows. In input-output analysis, we can see this as expenditure flows; on which unit will be money.

4.1.5. Spatial equilibrium (Alonso's equations)

The Alonso's equation (called Alonso model), assumes a market dominated situation in which each individual will bid for different pieces of land according to his own objective function. The latter is made of two components, one related to the individual's cost of transportation, and one related to his need for space. Since individuals have different needs, and hence will place different values on a given piece of land, it is assumed that each piece of land will go to the highest bidder. This lead to a solution in which consumer surplus is maximised.

The individual demand is define by :

$$\max V(x_1, x_2)$$

Under the constraint :

$$p_1(u)x_1 + p_2x_2 = w\text{-}tu$$

With :

u : distance from the CBD (central business district) for one person, or one household
$x_1(u)$: consumption of space
$x_2(u)$: consumption of other goods
w : income (same for everybody)
t : unit cost of transport
$p_1(u)$: bid rent
P_2 : price of standard goods
$V(x_1,x_2)$: utility function of the consumer (same for everybody)

4.1.6. Linear regression

Linear regression allows to test hypothesis concerning the relation between an endogenous variable and exogenous variables (motorising rate for example). It assumes a linear relation between them, and is very much used to do easy predictions :

$$Y_i = b_0 + b_1X_{1i} + b_2X_{2i} + u_i$$

The least square method allows to adjust the "better straight line" on the data (X_1-X_2/Y), for reaching the minimum of the square remainders sum, as :

$$\Sigma\, e_i^2 = \Sigma\, (Y_i - Y_i^*) = \Sigma\, (Y_i - b_o^* - b_1^* X_{1i} - b_2^* X_{2i})^2$$

With :
i : specifies a year or an individual.
b_0 : is the ordinate at the origin (is a constant)
b_1, b_2 : parameters which asses the variation dY/dX_1 and dY/dX_2

Assessment of b_0 and b_1 (b_0^* and b_1^*), allows to obtain linears relations which correspond to the general linear relation. b_1^* and B_2^* measure a Y variation for a unitary variation of X_1 or X_2 while X_1 and X_2 stay constant.Called "partials regression coefficients", they are linear estimators, without bias, and should not be confused with elasticities [12].

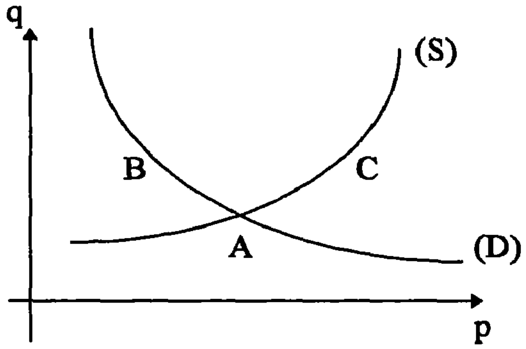
X_{1i} and X_{2i} , are values taken by the individual i on the variable X_1 or X_2, u_i refers to the stochastic term, because is not sure that all the couples (X-Y) are into the straight line regression. The linear model is based on 5 important hypothesis (not described here).

4.1.6. Market equilibrium

The market equilibrium is an equilibrium between supply and demand. Both supply and demand functions must be used. Volume of demand and supply is determined by equilibrium. For the case of transport (infrastructure), the supply function is translate in a vertical line curve. Prediction of demand requires consideration of the interactions of demand and supply to find an equilibrium demand in the market.

Supply function : S=f(D)
Demand function : D=g(S)

Usually, we obtain functions like this ones :



In this example, the equilibrium point is A. At the point B, the demand is greater than the supply, the supply increases up to the reach equilibrium point A. At the point C, the demand is smaller than the supply, the supply decreases up to reach the equilibrium point A.

[12] Elasticity vary at each point of the couple (X_1,Y) or (X_2,Y). Thus, for example : $eX_1Y= b_1^*X_1 / Y$. Neverthless, if we consider a non linear fonctional relation, the b_1^* and b_2^* parameters are estimators without bias of the elasticities (for a double log function, for example).

In the case of a land-use application, we can use for q, the number of households in a zone, and for p, the price of the square meter. Another parameter, in this case, is the limit of the area. The demand in housing in a zone is function of the price of the square meter, and the price of the square meter is function of the demand. If too many people try to live in a zone, the price increases, and the demand decreases. On the contrary, if only few people try to live in a zone, the price decreases, and the demand increases.

4.1.7. Elasticities

The concept of elasticity is a characteristic often used in DCM and UTMS, and sometimes in LUTM. It allows to assess

the impact of the variation of one variable upon an other. For an individual n, the direct elasticity of the probability of the alternative i, will be in relation to a characteristic X_{ink} of this alternative. The crossed elaticity will be in relation to a characteristic X_{jnk} of an other alternative. In the case of a logit formulation, we obtain :

As direct elasticity :

$$E_{x_{ink}}^{P_n(i)} = \frac{\partial P_n(i) / P_n(i)}{\partial x_{ink} / x_{ink}} = \frac{\partial \ln P_n(i)}{\partial \ln x_{ink}} = (1 - P_n(i)) x_{ink} \beta_k$$

With :
b_k : coefficient of x_{ink} in the utility function of the alternative i.

As crossed elasticity :

$$E_{x_{jnk}}^{P_n(i)} = \frac{\partial P_n(i) / P_n(i)}{\partial x_{jnk} / x_{jnk}} = \frac{\partial \ln P_n(i)}{\partial \ln x_{jnk}} = -P_n(j) x_{jnk} \beta_k$$

Crossed elasticity is uniforme : crossed elasticity of all the alternatives in relation to a change of one attribute concerning only the utility of the alternative j are equal for all the alternatives $i \neq j$.

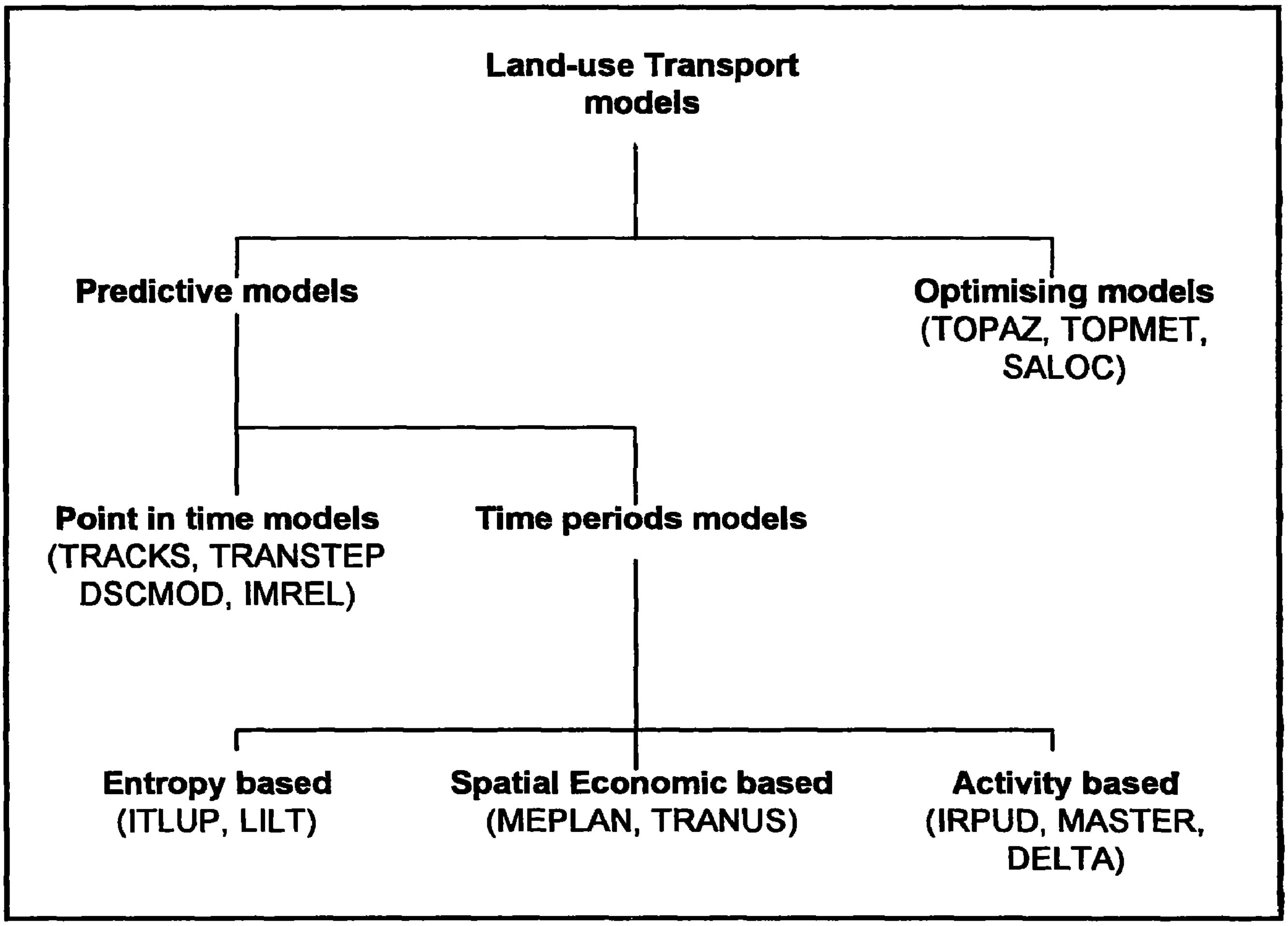
4.2. General presentation of LUTM

As precised by M. Wegener [Wegener (M.), 1993], below their apparent uniformity, LUTM have important differences between their theoretical foundations. The more important concerns the aims of the model to treat the urban system as a *market* system, with *equilibrium procedures*. Moreover, all the models which have a transport sub-model use the *utility maximising technique* or the *entropy maximising technique*, for modelling the destination choice and the mode choice. For D.B. Lee [Lee (D.B.), 1973], who realised a very critical paper about the LUTM, which did a big noise at this date, the more important default of the LUTM is the problem of the calibration. Now there are methods do calibrate, and the better used is the *maximum likelihood*, but the problem is always present. It is impossible to say that their is reliable and efficient techniques to do the calibration of the parameters, and the better correspondence of the model comes from the observance with the "reality". If we can check the "quality" of the model with the amount of vehicles for the transport on screen lines, it is more difficult to have this king of approach for the land-use part...

4.3. CLASSIFICATION OF MODELS GROUPS [13]

In this point, we are going to present many LUTM, in a critical point of view. All the elements presented here are based on studies. We took into consideration important aspects, which must be underlined. Later, we will provide more information, but only for a selection of LUTM.

D. Simmonds [14], have made a typology of the land-use transport models used in the world. We change it a little (the term *dynamic* is changed by the terms *: time period*, and the term *static* is changed by the terms : "*point in time*") [15] :



[13] Annexe 2 presents the block diagramm of the main land-use transport models
[14] [Simmonds (D.), 1996]
[15] Because, for us, the term static refers to models used when the area is intented in zones and when the results of the assignement procedure gives amount of traffic in number of equivalent vehicules by periode of day : daily, peak period,... The term dynamic is used when we are working at a very important detailed level, when the assignement procedure gives vehicules for a very short periode of time, and when we can see the vehicules moved on the screen.

For D. Simmonds, the first layer of the tree separates out a group of models whose purpose is to optimise urban system rather than to predict their behaviour. These models (SALOC, TOPAZ) are intended as tools which can fin a "design" that optimises a particular function, and are therefore quite distinct from the majority of models which respond to a "design" input by the user. For him, these models are difficult to link with the specific planning problems of individual cities.

The second layer of the tree distinguishes between "point in time" and "time period" models. The first represents a single point in time, with the more limited objective of adding a land-use dimension to more standard "horizon year" transport models. The second concerns model which run for a series of time periods, with transport change taking one or more periods to have an impact upon land-use.

We can add to the list, others models, such as : CALUTAS, OSAKA and AMERSFOORT, which have been developed for particular application, but which have an interest to be presented.

4.3.1. Optimising models [16]

SALOC was developed first in Stockholm and TOPAZ (TOPMET) was applied to the area of Melbourne. Both try to optimise the urban structure to isolate the more desirable evolution, but don't allow to define plausible evolution.

SALOC tries to optimise the residential location while considering the location of activities given. It takes into account the transport system only through an indicator t_i, which corresponds to the average time we can assign at each zone, in function of this average distance to the employment and retail zones.

TOPAZ (TOPMET [17]) allows to evaluate in a more detailed manner the impacts of changes to components of the urban system. These components include traffic flows, network, congestion, energy use, greenhouse emissions and air polluant diffusion, service water demands and loadings, accessibilities, and elemental and total benefits and costs. TOPAZ can be used to search for the best land use development pattern that satisfies a given objective function. Alternatively, it can also provide a "what if" evaluation of any change in land use on urban components subject to a given set of constraints. It provide a Geographic Information systems interface and a menu driven command structure with various data manipulation tools to generate a range of alternative solutions. During the optimisation, TOPAZ allocates a set of activities to a set of spaces and time periods on the basis of maximising benefits less cost of : establishing these activities in these spaces and time periods and establishing interactions between new activities in spaces and time periods via networks linking these zones, with taking into account existing activities in spaces and their interactions, discounting benefit and costs. TOPAZ considers the transport system not as a predefined form, because we have :

[16] Derived from [Duchier (D.), 1991] for SALOC, and from information directly sent by the conceptor of TOPAZ and SUSTAIN [Brotchie (J.) and Alii, 1994], [Brotchie (J.) and Alii,.

[17] TOPMET is a development of TOPAZ which has been tailored to the more detailed level of planning.

- a distribution of flows based on the *entropy maximising technique*, in relation with precedent phase (the transport submodel allocates trips from origins to destinations, and computes the cost of the trips based on the minimum level of congestion that can be attained, with double constraint : balancing factors).
- a modal choice phase made by a *logit formulation*.

We must note that TOPAZ can be link with the model SUSTAIN, comming from the same developpers. SUSTAIN is an interactive urban simulation model for evaluating land-use, transport development and policy scenarios. It simulates the interaction between residential location, job location, transport congestion and land prices. This is accomplished by incorporating two key feedback mechanisms in urban land use transport interaction, short term netwok congestion equilibrium, and long term land pricing equilibrium. Thus, SUSTAIN provides a sketch outline of the urban plan in preparation for the more thorough analusys to be performed in TOPAZ.

4.3.2. Predictive models

4.3.2.1. Point in time models [18]

IMREL was created within a series of transport studies in connection with plans for transport investment in Stockholm and the surrounding Mälar Valley region. It has only been applied to those two areas and depends upon a separate transport model implemented using the software EMME2. It's main function is to estimate the relocation of households and of employment in response to changing the accessibility within the study area. The households and employment are totally aggregated (one category of each). One objective of IMREL is to extend the discussion of the impacts of major transport investments in a situation where a transport model already exists. If it does not compare alternative patterns of accessibility, it calculates the land uses corresponding to one run of the transport model. If, in IMREL, employment and residence both adjust to changes in the other (service employment may "follow" the population), space is not explicitly considered as a factor influencing employment location, although constraints can be introduce to the model. IMREL uses *optimising technique* to locate residents. It assumes that they will locate in a way that maximises their "utility", given by the transport supply.

DSCMOD was developed in the UK as a land-use add-on able to work with a variety of transport models. The necessary modal split and accessibility calculation can be carried out either by the transport model of by the DSCMOD program, but in either case it requires an independent transport model using either a standard package or an ad-hoc program. As IMREL, the main function of DSCMOD is to estimate the relocation of households and of employment in response to changing the accessibility within the study area. But, in DSCMOD households and employment can optionally be disaggregated into any number sectors or categories requiring different kinds or levels of accessibility, or competing in different parts of the land market. DSCMOD calculates changes in land-use based upon the changes of accessibility between two sets of inputs

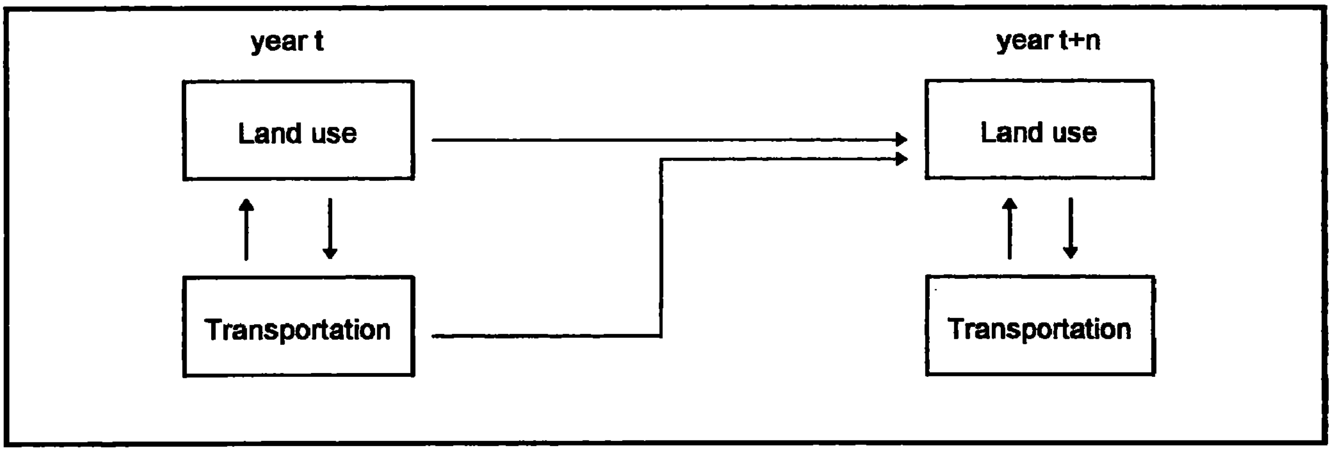
[18] All the information comes directly from [Simmonds (D.), op. cit.];

(transport model run base scenario and transport model run alternative scenario). In DSCMOD, as the difference in IMREL, the different activities are independent, except in so far to the expetion of space.

TRACKS and TRANSTEP are software's packages developed in New Zealand and Australia, mainly as traffic and transport modelling suites, but incorporating some simples models of the effect of accessibility upon land use. These are understood to work simply within the "horizon year" traditionally used in transport planning. For D. Simmonds [19], the land-use model appears to be equivalent to the simpler ones present in DSCMOD. An other study, carried out by Cambridge Systematics and HCG [CS, HCG, 1991], present this packages as having a land use component not very much developed and dominated by ITLUP, in great part because the land-use part is based on the ITLUP's approach but in a less well developed way.

4.3.2.2. Time period models [20]

Time period models are based on the following logic :



In this "category", three type of model must be distinguished:

Entropy based models : fairly complete models, but without important theoretical backgroud

Spatial economic based models : complete and fairly much used models, with an important theoretical background, which give them a certain reliability.

Activity based models : lastest development in term of logic to treate land use modelling

Entropy based models

ITLUP, was developed in 1971. ITLUP is a generalised interaction spatial model without reference to *basis theory* (presented in 4.1.1.). With ITLUP and a transport

[19] [Simmonds (D.), 1996, p. 6]
[20] Derived from critical studies [Duchier (D.), 1991], [Webster (F.V), Bly (P.H.), Paulley (N.J.), 1985], and. [CS, HCG, 1991]. And from [Putman (S.H.), 1995] and [Putman (S.H.), 1996].

model, we can define the residential location of households and activities by economic sectors and categories of population and in relation with the existing transport network. DRAM and EMPAL represent the land-use components of ITLUP. They used the *utility maximising technique*, represented in a set of logit models for resident an employment location. The transport components of ITLUP (MSPLIT and NETWK) have fallen into disuse, leaving the land-use component linked to various transport models.

People are located in function of the access to employment and of the neighbourhood of quantity of land available. The accessibility is based on transport model outputs from the previous time period, introducing a time lag (EMPAL).

Activities are located in function of the access to the manpower as defined at the previous period and in function of the level of activities observed during the previous period and of land availability (DRAM).

The land used by the activities located can be calculated after running DRAM and EMPAL, but the supply of dwellings or other buildings is not considered. However, there is no *market equilibrium procedure*. So, if an individual or an activity is assigned to a zone, the density grows up. There is no scope to introduce planning policies other than land zoning !. These aspects are important limits, as the fact ITLUP is not based on any explicit economic theory. Nevertheless, a recent development appears. DRAM and EMPAL are now superseded by a new package, METROPILUS, developed in 1995. It adds, to the previous structure, nested logit formulations, and the possibility to model the land market, and to improve interfaces with a range of transportation packages as EMME2, TRANPLAN or MINUTP.

LILT, follows the Wilson's tradition. Developed originally for the city of Leeds, it is very complete one. It represents the relationships between transport and the spatial distribution of population, employment, jobs, shopping, dwellings and land utilisation, with *market equilibrium* for transport and land-use. It links the trip distribution and modal split phases of UTMS with a *Lowry-type land use model*. It takes into account the building of dwellings, the location of employment and all the aspect concerning the transportation system (also the car ownership aspect). For the building of homes, their number is fixed in an exogenous manner and distributed between zones, following variation of accessibility in zones and considering a demolition coefficient defined from past. Dwellings are available for different categories of people, without modelling of any market (no *equilibrium procedure* too). Employment by zone is also defined in an internal point of view, from exogenous data about future employment by sector. But it's really available employment and not total employment, employment occupied from one period to another aren't available. For the level of global employment, different mechanism exist, for each sector of activities. Before the assignment of people, LILT assess, from data issue to past, the level of motorising and the generalised cost of public and private transport modes. At this step, it uses the *Wilson technique*, with little changes (modal choice is integrated). We obtain locations and disaggregated flows by modes. At the end, flows are assigned to the networks with traditional algorithms. As said before, the problem is that LILT doesn't consider land and property as a market, and prices are not considered. However, as it is a more complex model, the implementation and the calibration is a major exercise.

Spatial Economic based

MEPLAN and TRANUS are two software's with the same framework and a very important foundation in economic theory. J.D. Hunt and D. Simmonds have made a synthetic but complete presentation of this framework, few years ago [21]. The teams who developed MEPLAN and TRANUS have been based in the Centre for Land Use and Built Form Studies (LUBFS) of Cambridge University, and since 1978 in the independent firms of Marcial Echenique and Partners (MEP) for MEPLAN, and Modelistica for TRANUS (in Venezuela). This packages were applied in a lot of cities all around the world, in an urban and in an interurban point of view.

As specified in [Wegener (M.), 1993], MEPLAN and TRANUS are the only LUTM systems [22] which takes into account the 8 sub-systems of the urban development :

Network, Land-use, Workplaces, Housing, Employment, Population, Goods Transport, Travel,

and also, a more complex one : urban evaluation and environment (but not with a lot of details).

MEPLAN and TRANUS are very similar in their functioning, they integrate three important and distinct modelling techniques : *input-output economic base, utility maximising technique* and function based on the *Alonso's equations* (spatial equilibrium : rent density function). They used the *basis theory* and take into account *market equilibrium procedure*. So, they are very complete, but difficult to calibrate, due to in great part, by the fact that the distinction between dependant and independent variables is not applied. Also, to do an application, we need to have good and complete data for the base year which are not very easy to gather. These disadvantages are the corollary of a very coherent, complete, and good theoretical basis package. So, if we know that we have to spend a lot of time to produce the data base for the base year and that a great part of this data will be used for other studies, what we have called "disadvantages" are in fact necessary steps to pass for having a complete and coherent application.

In MEPLAN and TRANUS, the land-use part assesses the location of induced activities in the zones of the area and makes a *market equilibrium* (the increment of basic activities must be done). The location process of activities comes from a set of no spatial matrices representing functional flows from zone i to zone j by sector (for each activities). In the interface part, flows matrices are changed in trip matrices [23], and adjusted in the transport part [24] by the generation/distribution stage. So, the activities in the period n defined the transport demand in the period

[21] [Hunt (J.D.), Simmonds (D.C.), 1993], we can also consult [Simmonds (D.C.), 1994].

[22] "System", because the transport and the land-use parts are considered, via an interface, in the same package.

[23] No test exists about the "quality" of the trips matrices production.

[24] The transport model has a four stages procedure.

n+1,... The transport model calculates the generalised cost, which is one of the component of the utility function in the land-use model. Transport costs are used to generate the location model, but it is assumed that their is a period of time to take into account the effects (when there is new facilities in term of transport, activities react with time for changing their location). TRANUS makes all the relations and interaction in a logic of decision chain, using nested and scaled logit formulations.

Activity based [25]

Three models have to be distinguished. All modelling change over time in contrast with spatial economic based models which concentrate on representing interactions between land-uses at particular point in time. The modelling is done by *Monte-Carlo simulation* [26] on which the precise outcome of each choice is random, because one of the difficulties is the number of possible changes. IRPUD and MASTER model what happens to a sample of households rather than DELTA, which uses the same calculation for the probability of choosing of each location, but would apply these probabilities as proportions of the total locating households.

IRPUD, is the new name of the model developed by M. Wegener (DORTMUND). It is exclusively based on the DORTMUND city case, which give it to it a limited operationnality. IRPUD is a very detailed model. It's objective is precise and ambitious, because it proposes to make an appraisal of the consequences of the economic evolution in term of spatial structuration and transport. The economic evolution is taken into account by the intermediate of the evolution of employment in each sector, and the evolution in population, at a very disaggregated level. It allows to analyse the ageing of population and infrastructure, while it considers the car ownership rate in this links with the economic activity. The major variables of the model are : population, employment residential buildings and non residential buildings. Interactions occur in the competitive choice processes, represented by markets (labour and transport market, housing market, non-residential property market and market in development of land). Choices in the market are constrained by supply and guided by attractiveness, which is generally a function of zonal quality and accessibility. Therefore, IRPUD represents the various markets through explicit, dynamic sub-models of the many different processed involved. The independence of different sub-model allows to apply different modelling techniques. So, all the process is modelise with the help of the *random utility*, and with specific models for the evolution of population and infrastructures and determination of the motorisation rate. It's important to note that we have a very complete approach of the transport field, with a distribution stage from *entropy maximising* with constraints to origin from destination and also a modal choice and a assignment stages.

MASTER was developed to address a range of problems which were found to be too complex to be represented at the aggregate level of the LILT model. MASTER

[25] For Master and Delta, all the information comes from [Simmonds (D.C.), 1996, pp. 18-28], for IRPUD it comes from [Simmonds (D.C.), op.cit] and [Duchier (D.), op. cit.], [Wegener, op.cit.].
[26] Entirely random.

deals with employment, residence, transport choices of people and labour demand. As IRPUD it treats the interrelated choices made by people in some details. So it makes it possible to consider combinations of variables which cannot be practically handled at the aggregate level. MASTER is more limited than IRPUD. For both model the principal criticism is that the choice process is random. So, it implies a randomness in the total results, though this decreases as the sample involved increases.

DELTA is a new land-use model, developed by D. Simmonds. DELTA could be linked to any suitable transport model. As IRPUD is built upon the idea that the different processes of urban change have their own dynamics which only gradually respond to other aspects of the system. It consists of a set of sub models, linked with a web of time lags. DELTA is incremental and calculates the change in land-use to occur over a particular period. these changes are "driven" by a mixture of demographic and economics dynamics, other exogenous inputs and past changes in property prices or rents, quality variables, environmental factors and accessibility (taken from the "database", including the environmental and accessibility ouputs of the transport model. In DELTA, there are five sub-models. The development sub-model has to predict the normal operation of the private sector development process. The transition and growth sub-model represents processes of demographic and economic change. The location sub-model concerns both the "location and relocation sub-model" and the "property market sub-model". In this sub-models, mobile activities respond to change in accessibility, the local environment, area quality and the cost or utility of location. Mobile household choose both their location and the size of dwelling, given a fixed budget and the level of price in each zone. The operation of the model consists largely of adjusting the rents until all the locating households and all the available housing are accounted for, using a *market mechanism* similar from those of MEPLAN and TRANUS, but finding a temporary equilibrium only for those components of the system that are "in the market" during this period. The employment sub-model calculates the demand for labour, and the area quality sub-model attempts to capture something of the quality of different areas of the city.

4.4. Others models

Three other models can be presented. They are not very often used, because they are specific to individual cities.

AMERSFOORT was applied on the city of Amersfoort in Netherlands (150 000 inhabitants). It is based on the *entropy maximising technique*. It gives the location of people in function of exogenous data as : location of activities, and accessibility between different zones, with home to work trip flows induced by this location. So, in term of transport, only home to work flows are represented and the transport part in the residential location is not important : only the distances are taking into account (there is no representation of the modal split !).

OSAKA is an empirical location model. It was applied on the city of Osaka, in Japan (15 000 000 inhabitants). It is based on *linear regression* technique, oriented upon accessibility. It is entirely formalised in the *basis theory* logic. It use data on the location of basic activities and the level of bid rents of each zone, to assess the residential location of induced activities and individuals in these zones. Two levels of zones are taken into account. Big zones for the location of induced activities and individuals (location in function of the accessibility of these zones with generalised cost for trains (very much used in Osaka city), and cars, with constraints on density). Little zones for modelling the land market. As in AMERSFOORT, the transport part is not important. Transport is only on element which intervene in the location process.

CALUTAS was developed to assess the impact of a new bridge in the Tokyo bay. Transport part is well developed, even if the motorisation is not present. But this is not a problem, because the most important transport mode in this city is the train (but it is a limit for others applications). As in OSAKA there are two levels in zoning. In the land-use part, the location of activities and people is based on the *random utility technique* and accessibility : basic activities are located in an exogenous manner, and induced activities are located in accordance with the first and in accordance with the characteristics of each zones, with constraint about the available of land. In the transport part, we find the four stages of the UTMS (generation, distribution, modal split and assignment) in a simplified logic. The impact in transport will have an impact in the location of activities with a step of 5 year. CALUTAS is a complete model very integrated, but it makes a link between the land use part and the transport part, rather than an overlapping.

After this last presentation, we can see the **Table 5** which present a summary of the previous development

4.5. CONCLUSIONS : WHAT IS THE BEST CHOICE ?

It is not easy to conclude about the performance of the previous land-use models. As we have made a review, our approach is rather descriptive than critic, even if we used critic's surveys for is purpose. Nevertheless, we can say that the choice of a land-use model is very dependent on the finalities of the survey [27] we will carried out (linked to outputs), on the data needed (inputs) and on the sensitivity of each person (from theoretical aspects). The choice will be realised under constraints of time and money resources.

> For example, the study carried out for the LUTRAQ project [CS, HCG, op. cit.] concluded, that among the models examined (ITLUP, MEPLAN, TRANUS, TOPAZ-TOPMET, TRACKS, TRANSTEP), ITLUP, MEPLAN (TRANUS) and TOPMET were the three best developed and potentially most useful packages. They recommended the application of the ITLUP package, because the complexity of calibration, verification and application of any interactive land-use model, the availability of Dr. Putman, the model developer was highly advantageous.

[27] If we want to search the optimal location of households and activities, optimising model (as TOPAZ), will be very adapated. If we want to work on planning process, point in time and time period models will be more appropriate.

For example, when the CERTU decided to choose a land-use/transport software in 1994 [CLEMENT (L.), 1995] [28] among 10 softwares, TRANUS was choosen. The finality was to try and to test one LUTM, because they wasn't used in France, and after, broadcast the information and perhaps the software in the technical network of the French transport Ministry. CERTU didn't want an optimising model or a point in time model, but a time periods model (to take into account the delay between transport and land-use). It was also interested by an integrated package (transport and land use in interaction and in the same package), with an important theoretical basis and a large operationality (it was necessary that the software have had a lot of applications) and a good interface (windows). The availability of the model developer was also necessary for training and help (for example, M. de la Barra came rapidly in France, and could give more information in a very short term by e.mail).

The CERTU wanted to have "free hands" with the software, and a software having regulars developments (availability of new versions and improvement by internet). The price, wasn't a criterion, but was a good surprise (5 000 USD !!). As the work with the land-use transport model was defined to take few years, with an important data base to be collected from others studies, the duration of the calibration was not considered as a problem.

Nevertheless, it's seems necessary to present more information about software's which seems to have an interest. If we don't consider models which have an application only into one city, which are not available for purchase and which modelise the urban structure without an important attention to transport, we can keep :

TRANUS, DELTA, TOPAZ, TRANSTEP, and **ITLUP.** TRANUS is a very used package, DELTA seems to have a good future, because it considers new development in the field of land-use and takes into account the good aspects of the majority of the other models (but its not an integrated package. It can be linked with UTMS as TRIPS, START,...), TOPAZ (with SUSTAIN) is the reference of the optimising models, TRANSTEP seems also to be complete in this field of investigation, even if it is not the opinion of D. Simmonds (see his comparative study), and ITLUP its the more important representant of the entropy based model, with recent developments. **We can see, that we have one representing of each group of the D. Simmond's tree.**

A questionnaire was made and sent to each model developer to have more information. The results are presented in point 5. A this date, the conceptors of TRANSTEP and of ITLUP haven't considered the interest to give us a response in spite of sent back demand coming from us. So, their models are not presented in detail.

[28] This little report is the result of a first approach based on different works (including those of the ISGLUTI).

TABLE 5 : SUMMARY OF THE REVIEW OF THE LAND-USE AND TRANSPORT MODELS

available for purchase	OPTIMISING MODELS	PREDICTIVE MODELS				VERY EMPIRICAL MODELS
		Point in time models	Time priod models			
			Entropy based	Spatial economic based	Activity based	
Land use and transport part well integrated			LILT	MEPLAN TRANUS	IRPUD MASTER	CALUTAS
Land part only, but integrated with transport by the mean of a link with UTMS			IMREL DSCMOD	ITLUP	DELTA	
Land use, with no important *attention* to transport	SALOC TOPAZ-TOPMET	TRACKS TRANSTEP	AMERSFOORT			OSAKA

5. OTHER INFORMATION ABOUT LAND USE AND TRANSPORT MODELS

To have complete information about the model which is the better representant of each group of the D. Simmonds tree [29], we made a questionnaire, composed of 11 cards. It was send to the developers.. Their tittle are :

1. General information
2. Price and associated services
3. Software characteristics and equipement
4. Software structure
5. Software and subsystems of the urban system
6. Theoretical basis for land use application
7. Modelling techniques for transport application
8. Input data
9. To take into account the data
10. Description of output data
11. Limits of the software

The following tables present the information by cards and for each sofware. Each card give recent information (i.e. concerning the last version), and allows to have a global, but synthetic, presentation by software. As define in card 1, the developpers can be join directly if more information is needed, by post, fax, or E.mail. Conceptors can provide a software, and can also provide a consultancy project (project with or without the model installed in the customer

[29] In our point of view.

1. GENERAL INFORMATION

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
date of the begining of the conception	1980 (updated : 1996)	1995	1970 (updated : 1993)		
The Society	MODELISTICA PO BOX 47709 CARACAS 1041-A VENEZUELA	DAVID SIMMONDS CONSULTANCY 10, Jesus Lane CAMBRIDGE CB5 8BA ENGLAND	CSIRO P/O BOX 56 Graham road HIGHETT VICTORIA 3190 AUSTRALIA	R.J. NAIRN and Partners Pty. Ltd. Box 2579 BMDC Belconnen ACT 2614 AUSTRALIA	SH PUTMAN associated Dpt of city and regional planning University of Pensylvania 19104 USA
Phone	(+582) 761 54 32	(+44) 1223 316 098	(+61) 3 9252 6000		(+21) 5898 6207
Fax	(+582) 761 73 54	(+44) 1223 313 893	(+61) 3 9252 6249	(+61) 6 2517 927	(+21) 5573 2034
E.Mail	73000.1534@compuserve.com http://www.modelistica.com	david@dsc.win-uk.net	leom@mel.dbce.csiro.au	rjnpcan@netinfo.com.au	
Contact	Mr. de la BARRA	Mr.. SIMMONDS	Mr. BROTCHIE	Mr. NAIRN	Mr. PUTMAN
Langages of the interface of the software	English	English	English, Bahasa Indonesia	English	English
Langages of the instructions	English and Spanish	English	English, Bahasa Indonesia	English	English
Main customers (without university)	Minsitry of transport and communication (Venezuela) Ministry of public works, Guatemala Ministry of public works and transport of El Salvador CA metro de Caracas ; de Valencia; de Maracaibo The electricity cie of Caracas Insurbeca consult., Venz. Transplan consult, Venz. Rickaby Thompson consult. UK Stratec consult, Belgium Procad (consult), Mexico Royal Institue of Technologie, Sweden CERTU, France	Institue of transport studies Greater Manchester Passenger	Australia Indonesai		

2. PRICE AND ASSOCIATED SERVICES

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
Price in USD (01/1996)	6 000	3 875 *	On consultancy term		
SERVICES					
Before installation					
demo disk	Y (free)	N	Y (15 min)		
demo in situ	Y (free)	N			
Installation					
diskettes	Y (number : 3)	Y	Y		
manual	Y (included,	Y	Y		
installation in situ	Y (time : 10 mins)	Y provide as part of a	Y provide as part of a		
training	Y (3200 USD per week)	Y consultancy project	Y consultancy project		
After installation					
maintenance in situ	Y (free, one year)	Y	Y		
assistance phone	Y (idem)	Y	Y		
assistance fax	Y (idem)	Y (775 per year)	Y		
assistance e.mail	Y (idem)	Y (idem)	Y		

* This price and all details expet those on sheet are for the Delta land-use model alone, Exclusive of a transport model with which Delta must be link.

3. SOFTWARE CHARACTERISTICS AND EQUIPEMENT

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
User interface	Windows 3.1., and 95 NT	DOS	Windows 3.1 and 95 NT		
Input files format					
data	Custom and ASCII	ASCII	ASCII, Mapinfo tables		
network	Custom and ASCII	ASCII	ASCII, Mapinfo tables		
graphics	Windows metafile, Bitmap				
Output files format					
data	TXT, Delimited TXT	ASCII, TXT	ASCII, Mapinfo tables		
graphic	Windows metafile, Bitmap				
Programming langages	Delphi, visual basic, C++, Fortran	Fortran			
Exploitation system	DOS	DOS	DOS		
Relations with others softwares	Cut and pass with all popular windows programs, Copy pass with Excel	Needs to be intergated with an apprapriate transport model . Interface exist for integration with START (MVA), others could be created	DATA interface with SUSTAIN		
Relation with GIS	ARCVIEW GIS 3.0. INTEGRATION (under development) CUSTOM GIS (Under developement)	NO	Yes : MAPINFO		
Kind of computer	PC 486 or better	PC 486 or better	PC 386 or better		
Memory					
Disk	40 mb min	50 mb min 1 gb : with Start	2 mb		
Ram	8 mb min	640 kb min 16 mb with Start	8 mb		

4. SOFTWARE STRUCTURE

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
Land use only		X			
Land use + interface + transport (4 stages models)	X				
Land use + transport (4 stages model)			X		
Land use + interface + transport (without four stages model)					
Land use + transport (without 4 stages model)		X (with START)			

5. SOFTWARE AND SUBSYSTEMS OF THE URBAN SYSTEM

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
Network	Y	N	Y		
Land use	Y	Y	Y		
Workplaces	Y	Y	Y		
Housing	Y	Y	N		
Employement	Y	Y	Y		
Population	Y	Y	Y		
Goods transport	Y	N	N		
Economic evaluation	Y	N (not yet)°	N		
Emmision of polluants	Y	N	Y		

6. THEORETICAL BASIS FOR LAND USE APPLICATION

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
Lowry and Garin Lowry equation	X				
Wilson equation			X		
Random utility	X	X			
Input-output technique	X				
Linear regression					
Market equilibrium	X		X		
Elasticities	X	X			
Markov chians		X			
Stone-geary utility abd consumpyion function		X			
Social accounting matrix		X			

7. MODELLING TECHNIQUES FOR LAND USE TRANSPORT APPLICATION

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
TRIP GENERATION	Elastic demand function	It depends on the transport software linked wxith DELTA	Normative (Cars + PT)		
TRIP DISTRIBUTION	Derived from land use application	Idem	Gravitary		
MODAL SPLIT	Nested logit	Idem	Logit		
ASSIGNMENT	Multi-path logit based on multi-path multi-mode search/.	Idem	All or notinhg Equilibrium procedure (Franck Wolfe algorithm)		

8. INPUT DATA

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
Networks description	Lenght, capacity and type, for each link Transit routes in each link	Not in Delta	Attributes of nodes and links, depends on network being modelled		
Description of the zones	Production (exogeneous and induced) Population Employment Floorspace and/or land by type Prices (for activities or land) Attractors	Households by Composition and socio-economic group Population by category in each household type Employment by sector For each space type : rent, total quantity, quantity vacant, quality Area of land occupied by floorspace Land available for building Accessibility, environmental qualitu, (for tranport model)	Expected population Expected Density Establishment / operation / maintenance costs Areas of zone reserved for each type of activity Areas of zone with existing developments		
Sources of datas	Revelead preferences Stated preferences Accounting surveys Demand function for land Income level of households Land prices Values of time Operating cost Tariff functions Road maintenance cost function energy consumption functions Emmissions functions	Base data should be obtainable mainly from census, employment and taxation records Coefficients should be obtained from reviex of previous research	Surveys, Report, GIS		

9. TO TAKE INTO ACCOUNT THE DATA

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
Help for the network description	The graphical interface includes many tools to check the network		Online help		
Tests about the coherence of the seizure of the network	The programm include a number of chekcks for the network, such as connectivity, consistency,...				
How many paramter for calibration ?	There are two types of parameters (very numerous) : -parameters than can be estimated from data -paramters to be estimate by calibration	12 parameters per activity 8 parameters per development process			

10. DESCRIPTION OF OUTPUT DATA

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
LINKS OUTPUT					
flows	Y		Y		
average speed	Y		Y		
costs (by O/D pair)	Y		Y		
time (by O/D pair)	Y		Y		
distances (by O/D pair)	Y		Y		
saturation	Y		Y		
number of veh x km	Y		Y		
number of passangers x km	Y		Y		
diagramm of charge	Y		N		
traffic :					
old	Y		N		
modal report	Y		N		
new (induction)	Y		N		
path by O/D pair	Y		Y + fuel use by O/D pair		
NODES OUTPUT					
waiting time	Y		Y		
nodes charges	N		Y		
crossroads size	N		N		
exchanges	N		N		
nodes by O/D pair	Y		Y		
LAND USE OUTPUT					
Population location	Y	Y	Y		
Induced activities location	Y	No disntinction in Delta,	Y		
Basic activities location	Y	between Induced and Basic	Y		
Prices of economical sectors	Y	Y	Y		
Location utilities	Y		N		
Consumption costs	Y		N		
Changes in rents	Y	Y	N		

11. LIMITS OF THE SOFTWARE

	TRANUS	DELTA	TOPAZ	TRANSTEP	ITLUP
Number of nodes	Undefined		Undefined		
Number of links	Undefined		Undefined		
Number of activity sectors	Undefined	100	Undefined		
Number of zones	Undefined	60	Undefined		
Number of trip purposes	Undefined		Undefined		
Number of trips modes	Undefined		Undefined		
Optimal geographich space precision					
agglomeration					
borough			X		
quarter		X	X		
block			X		
no preferecne	X				
Number of public transport lines	Undefined				
Possible use in interurban	Y	Y	Y		

6. THE MAIN LIMIT OF THE LAND-USE AND TRANSPORT MODELS (LUTM): SYNTHESIS AND LESSONS LEARNED FROM THE ISGLUTI

A few years ago, with the impulse of the Transport Research and Road Laboratory (TRRL, and now TRL), a very important study was carried out about the land use and transport models based upon the Lowry or the Wilson modelling techniques. A working group was created : the International Study Group on Land Use and Transport Interaction (ISGLUTI). A book [Webster (F.V.), Bly (P.H.), Paulley (N.J.), 1988], and a lot of articles have disseminated this work [Paulley (N.J.), Webster (F.V.), 1990]; [Paulley (N.J.), Webster (F.V.), 1991], [Mackett (R.L.), 1990]; [Mackett (R.L.), 1991]; [Mackett (R.L.), Simmonds (D.C.), Wegener (M.), 1990];...

6.1. WHAT IS THE CONTENT OF THE ISGLUTI ?

The ISGLUTI took into account models which were applied on one city, or more, but the TRANUS system wasn't considered (but it is very similar to MEPLAN). The ISGLUTI tried to understand the problem of the interaction between transport and space location and tried to compare the different behaviours of the models. It tried to keep the best of them, even if they are applied into different geographical frame.

Two kind of models were distinguished :

- those which are made to modelling the urban structure without a great attention to transport : AMERSFOORT, OSAKA, SALOC, TOPAZ.

- those which are made to help the policy maker, with a great attention to transport : CALUTAS, ITLUP, LILT, MEP(LAN), DORTMUND.

The ISGLUTI has made tests to assess the operationnality of each model. It tried to understand the behaviour of the model in this original area of application when the exogenous data are modified (shift in location of basic activities, level of population, transportation prices,...).

Two phases were defined.

6.1.1. Phase 1

It concerns tests for the operationality of the models. Seven were taken into account (SALOC and ITLUP wasn't assessed because the tests were difficult to do for them). Nevertheless, a lot of problems appeared to give a commentary on the results, because the models were calibrated on different cities.

The results of the phase 1 are interesting, they show that :

- the endogenous location of the activities seems to be a very important aspect (example of AMERSFOORT).

- models using simple modelling techniques give results which are less relevant than for other models (show the example of OSAKA, with the linear regression).

- separation of population and activities in different categories seems to be a very important aspect, because these categories have different behaviour rules (impact of income for population, relation with other partners for the activities,...).

- car ownership is a very important variable for models which have a great attention to transport (problem of the jams). It must be defined in an exogenous manner, because the endogenous resolution is not reliable (as in DORTMUND and LILT).

At this stage, only 4 models can pretend to an important operationnality : CALUTAS, DORTMUND, LILT and MEP(LAN). Members of the ISGLUTI decided to test them in an a second phase.

6.1.2. Phase 2

Two aspects are considered.

1. Each model is tested on different cities and the results are compared. When one model is applied on different cities, the results are different. The conclusion is that each city has its own characteristics in term of spatial organisation, behaviour of inhabitants...

2. Different models are applied on one city, but they give different results. This is the real problem of the ISGLUTI, which concerns the reliability of the LUTM. Moreover, it is very difficult to assess if one model is better than another : what kind of basis has to be kept for this ? : members of the ISGLUTI can't take up one position.

For example, when they compare LILT and MEPLAN (applied on the city of Leeds) [30], the results are very different and lead to different ways. This is very clear for test 15.3., 15.6. and 15.8. :

Elasticities and cross-elasticities of mode use to changes in the cost of car travel (test 15.3. : car operating cost quadrupled)

	LILT		MEPLAN	
	Work trips	**All trips**	**Work trips**	**All trips**
Car	-0.30	-0.28	-0.27	-0.33
Public transport	+0.20	+0.19	+0.13	+0.12
Walk	+0.05	-0.01	+0.23	+0.13

Percentages transferring to other modes when the cost of car travel is increased (test 15.3.)

	LILT		MEPLAN	
	Work trips	**All trips**	**Work trips**	**All trips**
Public transport	91.1	90.8	22.6	22.0
Walk	8.9	9.2	77.4	78.0
Total	100.0	100.0	100.0	100.0

[30] [Mackett (R.L.), 1990, pp.17-21]

Percentages travelling by each mode for trips in Leeds (test 15.3.)

	LILT (1991)		MEPLAN (1991)	
	Work trips	**All trips**	**Work trips**	**All trips**
Car	54.9	27.5	42.5	34.7
Public transport	32.1	22.4	28.4	13.0
Walk	13.0	50.1	29.1	52.2
Total	100.0	100.0	100.0	100.0

All these differences are due to the structure of each models, as explain by the ISGLUTI (car ownership rule, popularity of public transport for work trip in LILT but not for all trips, mainly because so many education trips are walked,...).

Percentages transferring from other modes when public transport fares are made free (test 15.6.)

	LILT		MEPLAN	
	Work trips	**All trips**	**Work trips**	**All trips**
Car	67.9	13.8	14.9	7.8
Walk	32.1	86.2	85.1	92.2
Total	100.0	100.0	100.0	100.0

If the models are agree for all trips considered together, is not the case for work trip. The difference would be due to the large slowing down in the rate of car ownership growth.

Differences are also very important for test 15.8. (public transport fares doubled) :

Elasticities and cross-elasticities of mode use to changes in public transport fares (test 15.8.)

	LILT		MEPLAN	
	Work trips	**All trips**	**Work trips**	**All trips**
Car	+0.17	+0.13	+0.17	+0.04
Public transport	-0.50	-0.81	-0.24	-0.34
Walk	+0.57	+0.35	+0.16	+0.07

Percentages transferring to other modes when public transport fares are increased (test 15.8).

	LILT		MEPLAN	
	Work trips	**All trips**	**Work trips**	**All trips**
Car	46.5	11.4	14.6	25.2
Walk	53.5	88.6	85.4	74.8
Total	100.0	100.0	100.0	100.0

The same cases may be shown for the application of DORTMUND, LILT and MEPLAN on the city of Dortmund [Mackett (R.L.), Simmonds (D.C.), Wegener (M.), 1990]. But, in that case, the problem is more important because there is a great difference in the results and the models don't react in the same way for a lot of tests. Thus, there is no convergence. The authors conclude that "*In virtually all cases where the model results differ, the average over the individuals models, i.e. the collective results of all three models represent a surprisingly plausible and consistent forecast*" [31] !!! Therefore, the ISGLUTI refuse the global analysis of the divergence of the models and put them on equal footing, as mentioned by D. Duchier [Duchier(D.), 1991].

All the differences can be explained, as the ISGLUTI said. But, the person who has to make the choice of a model, will be very disappointed if he has read the part 2 of the ISGLUTI's work : he will consider that he must purchase three or four models to make a good analysis ! The few previous examples show that if you make one choice or another choice, the results of the policy you have to test will be very different ... and the conclusions will be very different too !

6.2. LESSONS LEARNED FROM THE ISGLUTI

The ISGLUTI has made a very interesting presentation of the LUTM and of their field of investigation. The results arising from the part 1 are very important for the modeller. The result arising from the part 2 could be linked with the paper of D. Lee... [Lee (D.), 1973]. Thus, we think that we must use LUTM in a very conscious manner, as a tool to complete socio-economic and urban studies. This is right for the results coming from the land-use part, because, generally, there is no socio-economic studies to do comparisons (see scenarios as 13.1, 13.2., 13.3., 14.1. and 14.2. of the ISGLUTI [32]). This is not the case for the transport part. Here, we can compare the results with socio-economic surveys about elasticities, modal report, etc... For example, in the previous tests 15.8. the elasticities obtain by MEPLAN is very much closer to reality (i.e. coming from socio-economic survey) than those obtain by LILT...

The problem of LUTM is the same for all the models. A. Bonnafous [Bonnafous (A.), 1989, p.101] showed that the performance of a model is function of "*son aptitude à réaliser les objectifs qui lui étaient assignés*". The level of performance is define by the "operationnality". For A. Bonnafous, this term refers to three necessary and sufficient conditions, we can sum up like this :

- a model will be relevant if the mathematical structure upon which it is founded is close to the reality.
- a model will be coherent if its objective can be reached in a theoretical point of view. A model can present contradiction in an internal point of view and in relation with is objective.
- a model will be measurable when the variables and the parameters could be assessed with accessible statistical sample.

But these three rules are in conflict. For example, if we want to improve the coherence of the model with the introduction of new hypothesis, its relevance could be impared. If we want to have a better measurability, we risk to desert variables : the coherence will be affected and the relevance reduces.

[31] [Mackett (R.L.), Simmonds (D.C.), Wegener (M.), 1990, p.27]
[32] Idem, p. 18.

Therefore, if LUTM are complete models, and because they are complete, they are very much subject to the previous contradiction rules. This is reinforced by the fact that, generally, the land use part and the transport part have "a different weight". Perhaps socio-economic surveys about land-use should be developed to complete studies carried out by LUTM, and LUTM should be tested in their functioning, by comparison between two base run year from which we have data (with a forecasting and backcasting procedure).

CONCLUSION

As we saw it in this report, the LUTM can be used for many kinds of applications. A lot of tests can be realised, for both land use and transport fields. Because they have, or they haven't, an important theoretical background, and because they take into account or not, a delay between transport and land-use interaction, they propounded a wide range of choice for the modellers. It is possible to say that the last development propounded by the Delta software have to be considered for the future, perhaps, they will be considered as a new generation of LUTM.

The LUTM can be used in a coherent way : predictive and optimising models are not independent. The results of predictive models can be compare from those coming from the optimising models : in this case, a new dimension is given to the analysis. Thus, for the predictive year, the results of the scenario on which "nothing is doing" and the results of the scenarios on which the tests of policies are make, could be compare to the state of the optimised location in the city. The analysis will conduct to see what is the scenario which is very near to this state. It should be a criterion to adopt the policy tested in it.

So, if we think that LUTM could be a very interesting alternative to the using of the UTMS and of the SM (but only at two levels : choice of transport scheme and choice of project), they have nevertheless a very important limit that we must considered.

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ANNEXES

1. Number of zones for land-use transport models applications

2. Shematic block diagramm of the main land-use transport models :

IMREL

DSCMOD

ITLUP

LILT

Martin center models (MEPLAN, TRANUS)

IRPUD

MASTER

DELTA

AMERSFOORT

OSAKA

CALUTAS

3. The example of the TRANUS modelling system : a spatial economic based model

1. NUMBER OF ZONES FOR LAND-USE TRANSPORT MODELS APPLICATIONS

MODEL	City	Year	Population (Thousands)	Area (km^2)	Number of internal zones
AMERSFOORT	Amersfoort	1988-89	153	202	**26**
DORTMUND	Dortmund	1988-89	1075	833	**30**
ITLUP	San Francisco	1988-89	4064		**30**
LILT	Leeds	1988-89	497	164	**28**
MEPLAN	Bilbao	1988-89	970	355	**28**
SALOC	Uppsala	1988-89	160		**49**
TOPAZ	Melbourne	1988-89	2697	3000	**41**
MEPLAN	Cambridshire	1991			**11**
MEPLAN	Naples	1992			**42**

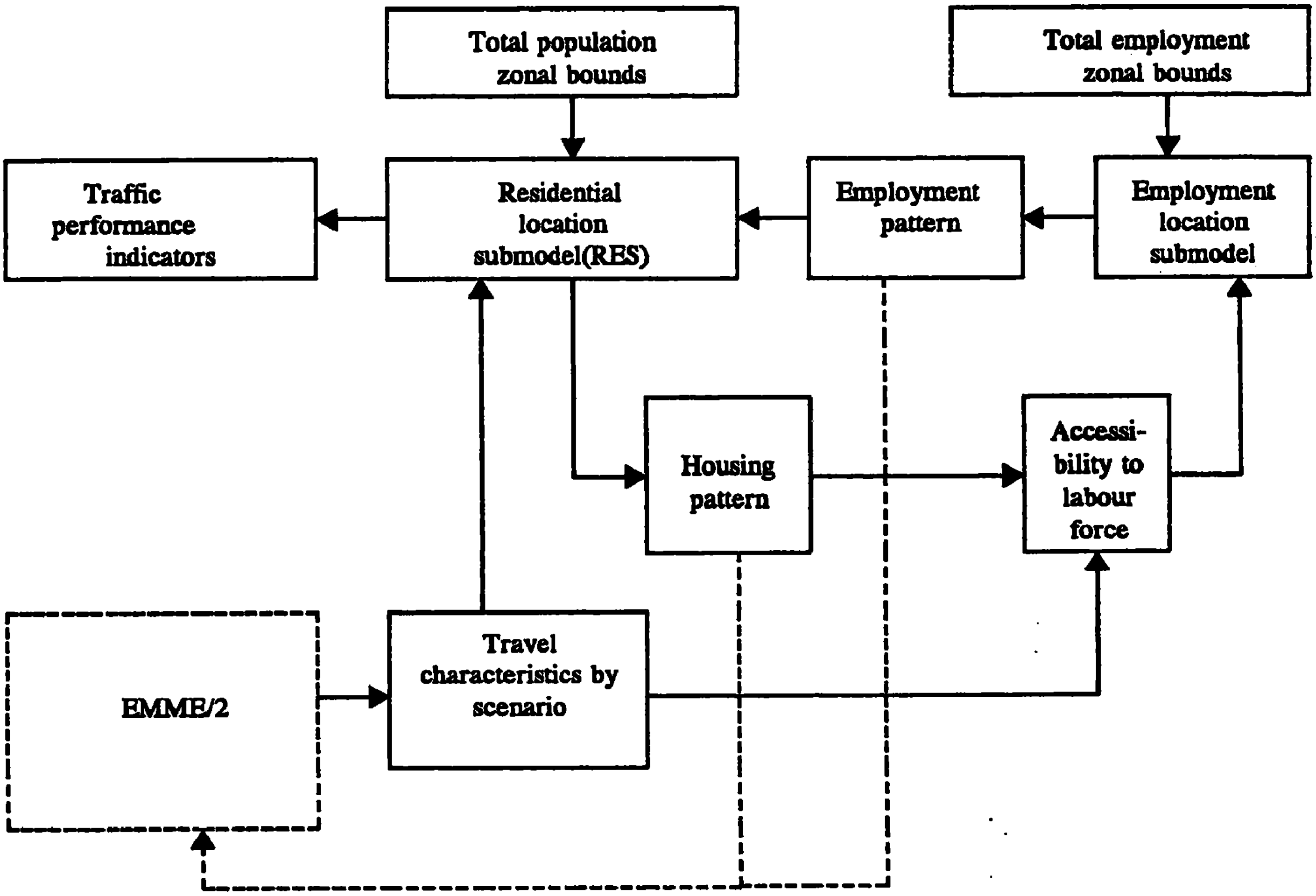
Sources :

[Paulley (N.J.); Webster (F.V), (1991)]

[Hunt (J.D.), Simmonds 'D.C.), (1993)]

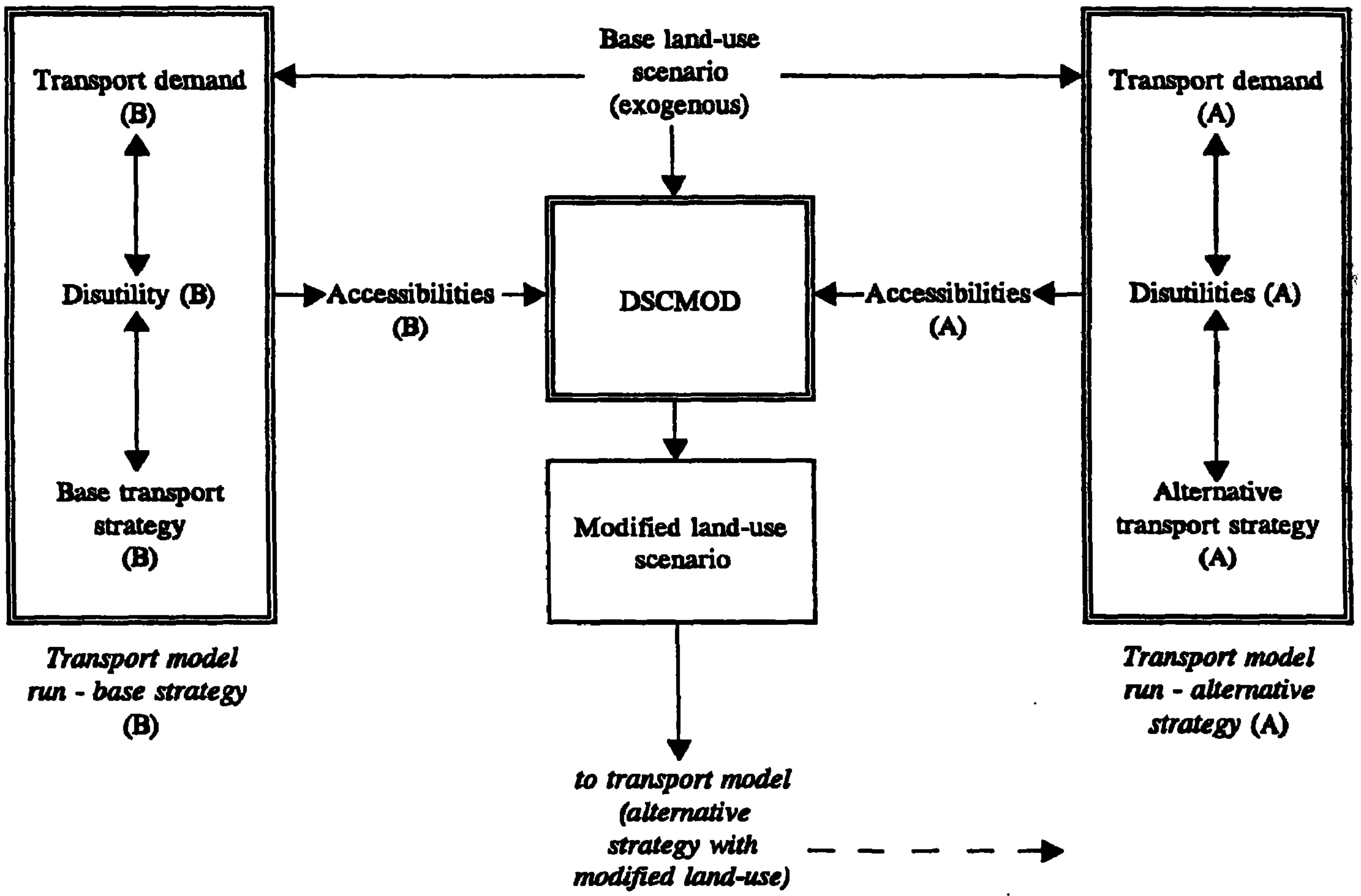
2. SHEMATIC BLOCK DIAGRAMM OF MANY LAND-USE TRANSPORT MODELS

IMREL



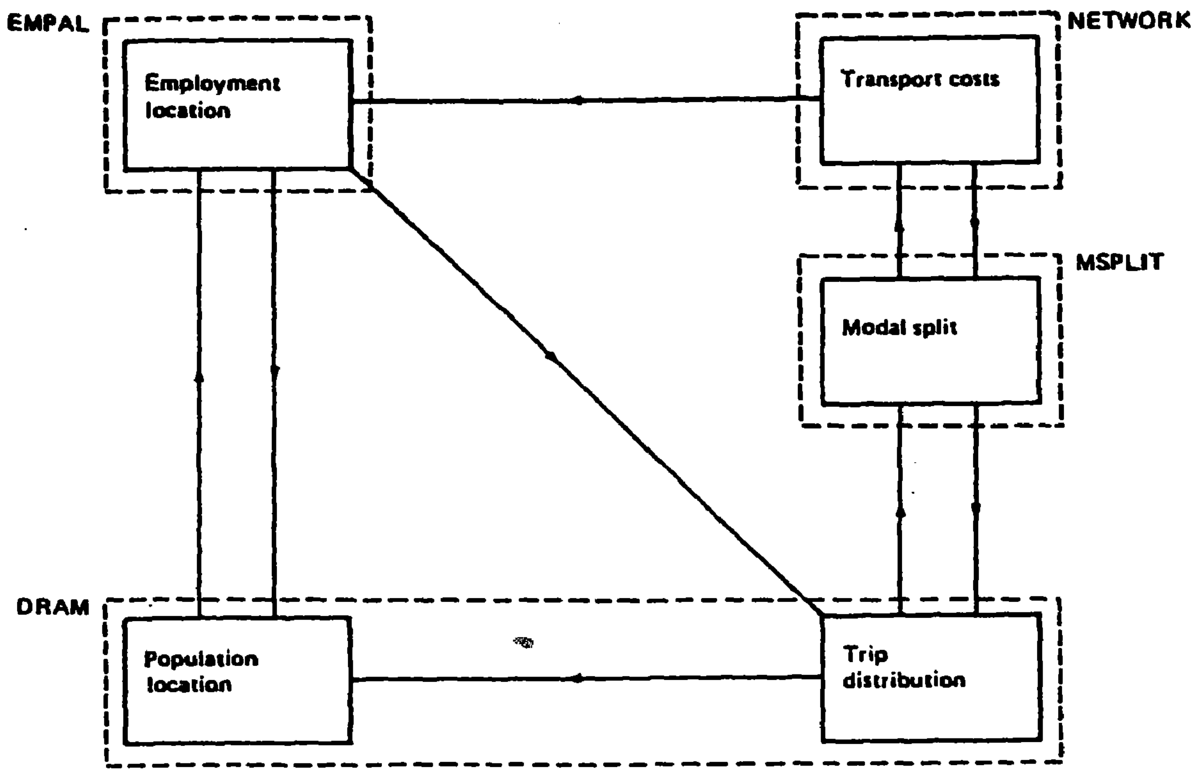
Source: Anderstig and Mattson, 1994

DSCMOD



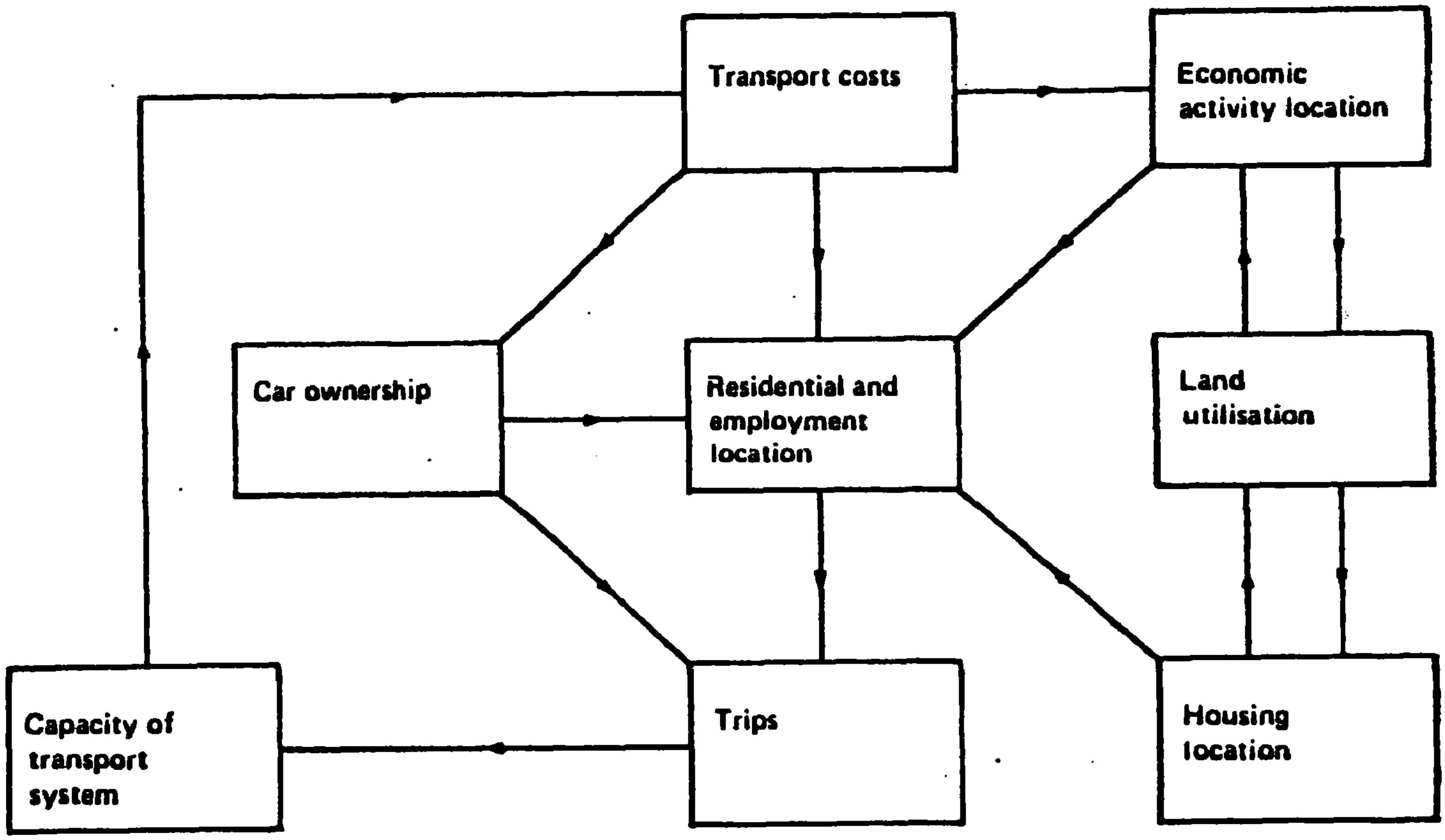
Source: David Simmonds Consultancy

ITLUP



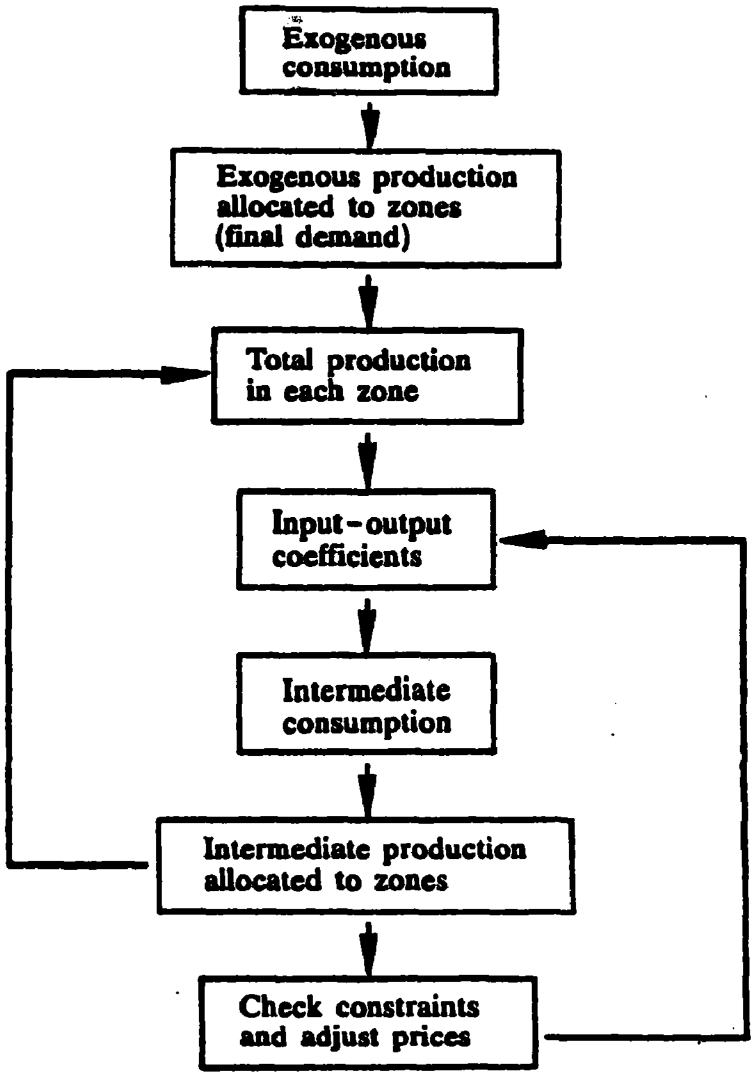
Source : Webster et al, 1988

LILT



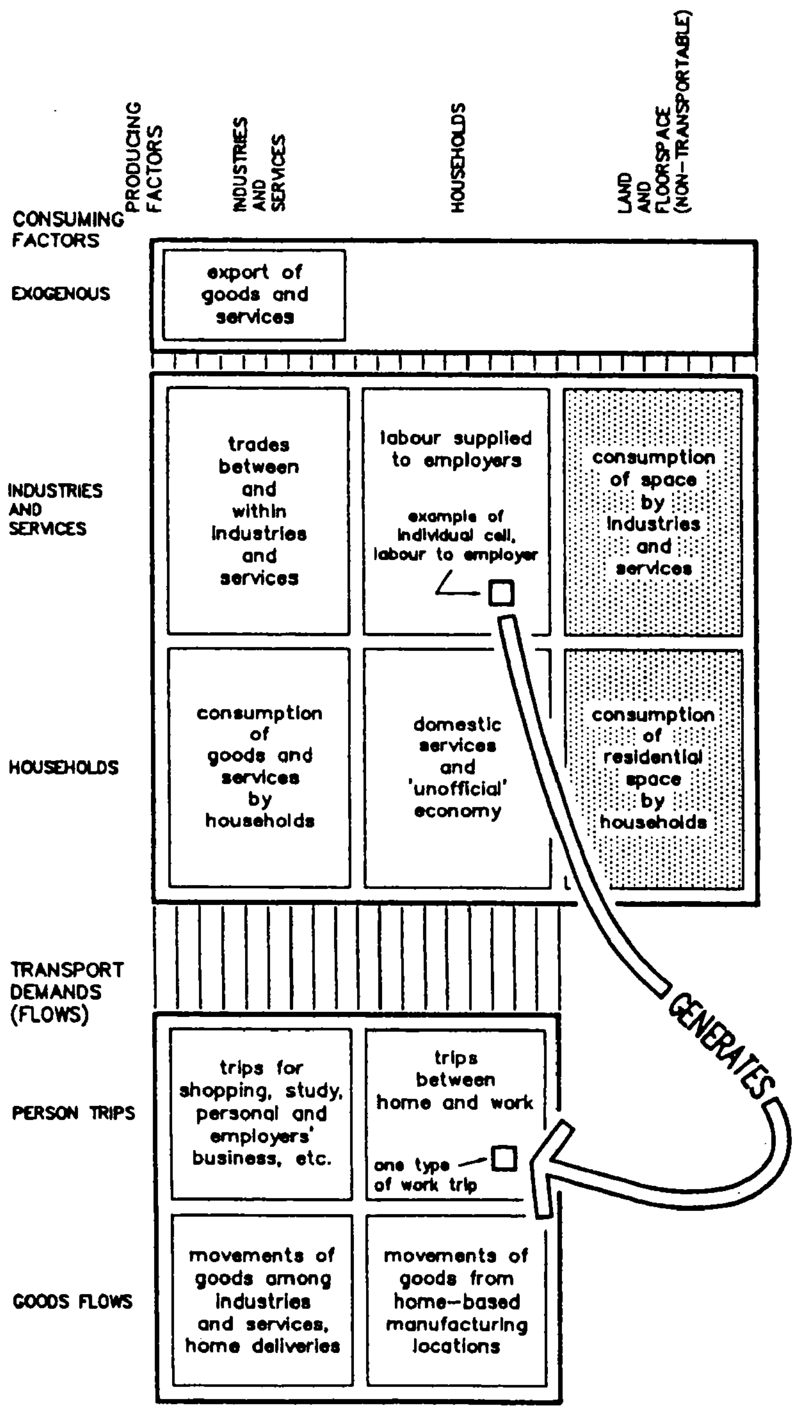
Source: Webster et al, 1988

THE MARTIN CENTRE LAND-USE MODELS (MEPLAN and TRANUS)



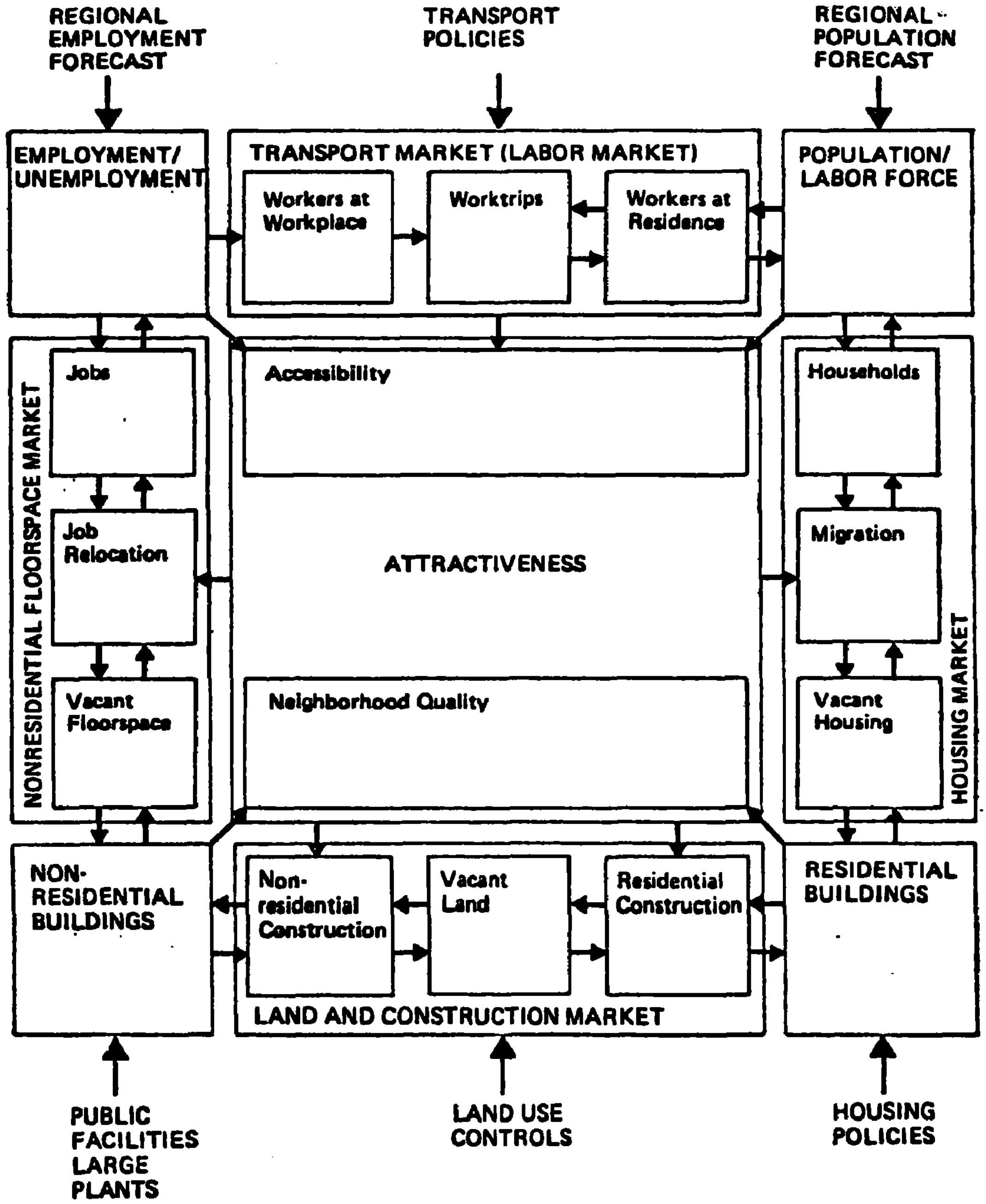
Source: Hunt and Simmonds, 1993

OVERALL STRUCTURE OF THE MARTIN CENTRE MODEL FRAMEWORK (MEPLAN and TRANUS)



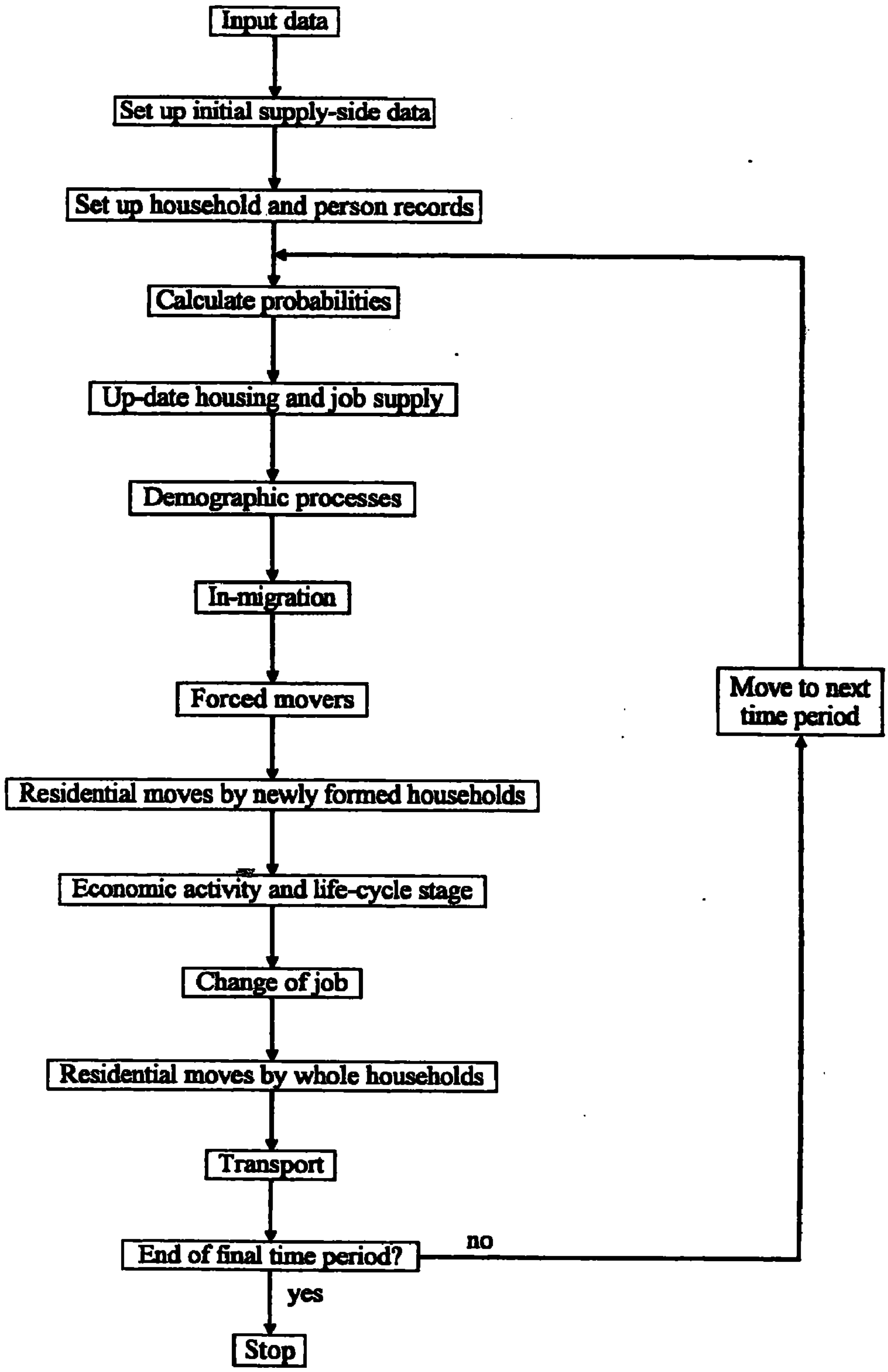
Source: Hunt and Simmonds, 1993

IRPUD



Source: Wegener, 1982

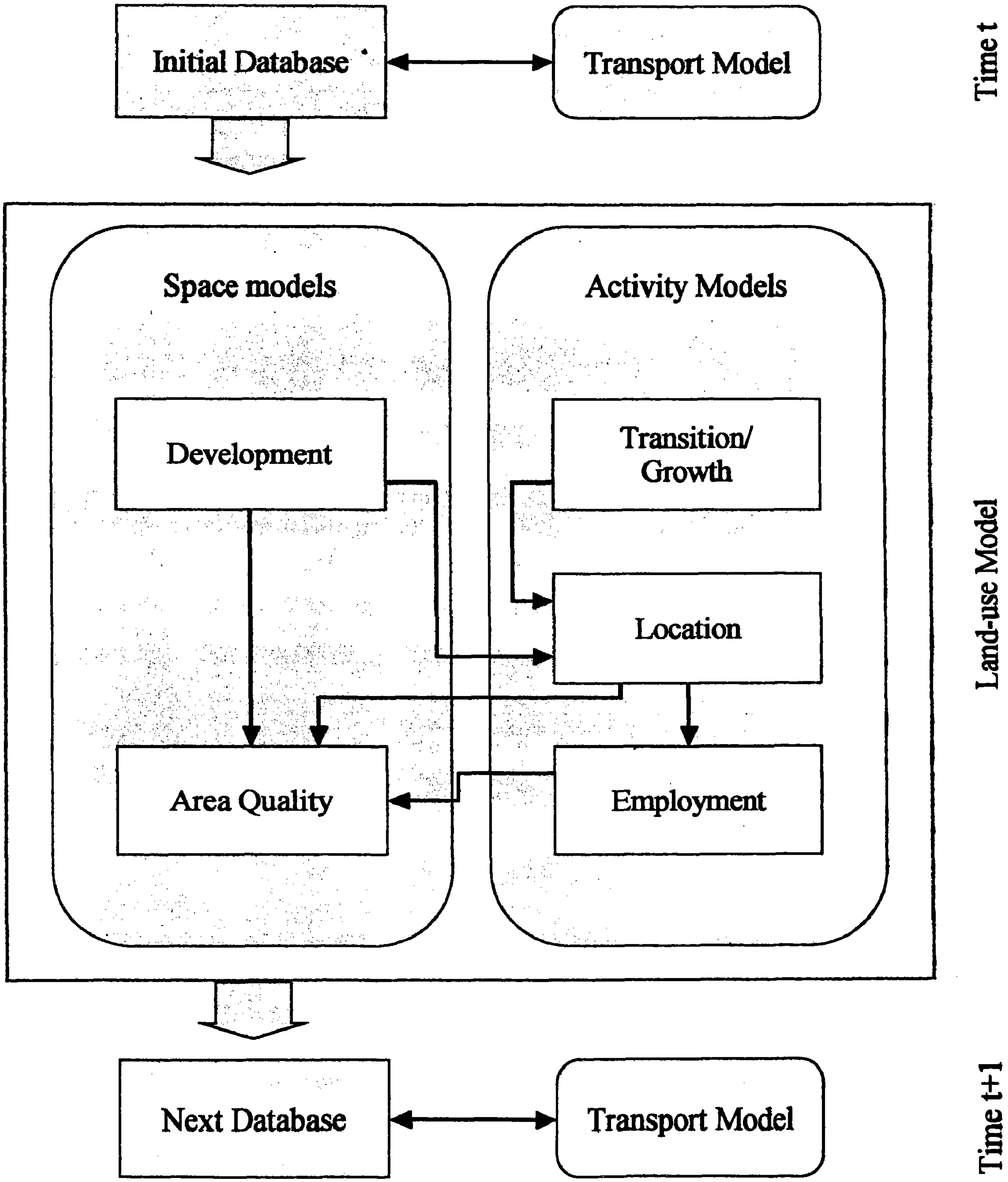
MASTER



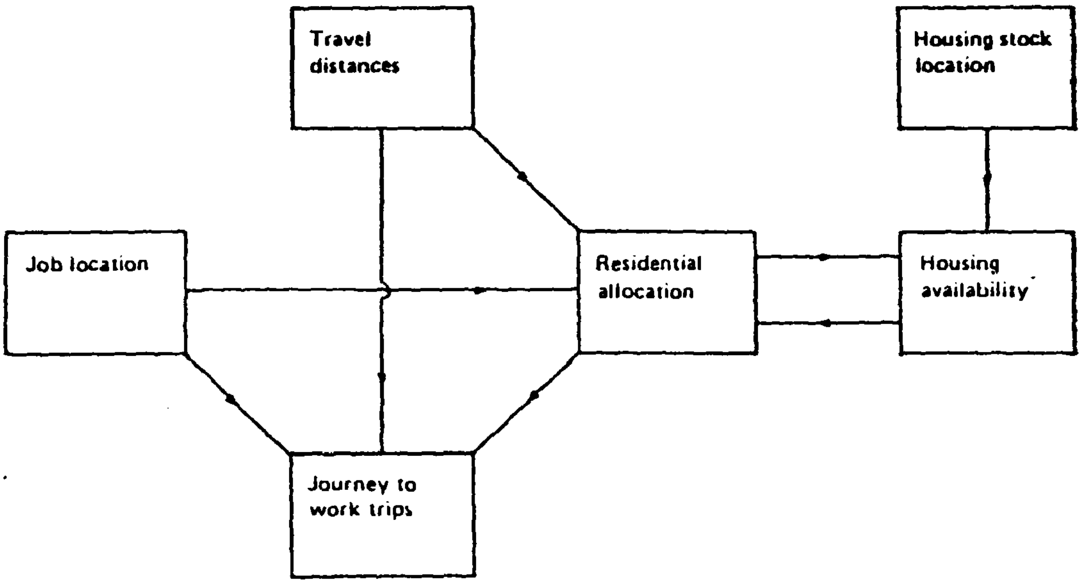
Source: Mackett, 1990a

DELTA

DAVID SIMMONDS CONSULTANCY

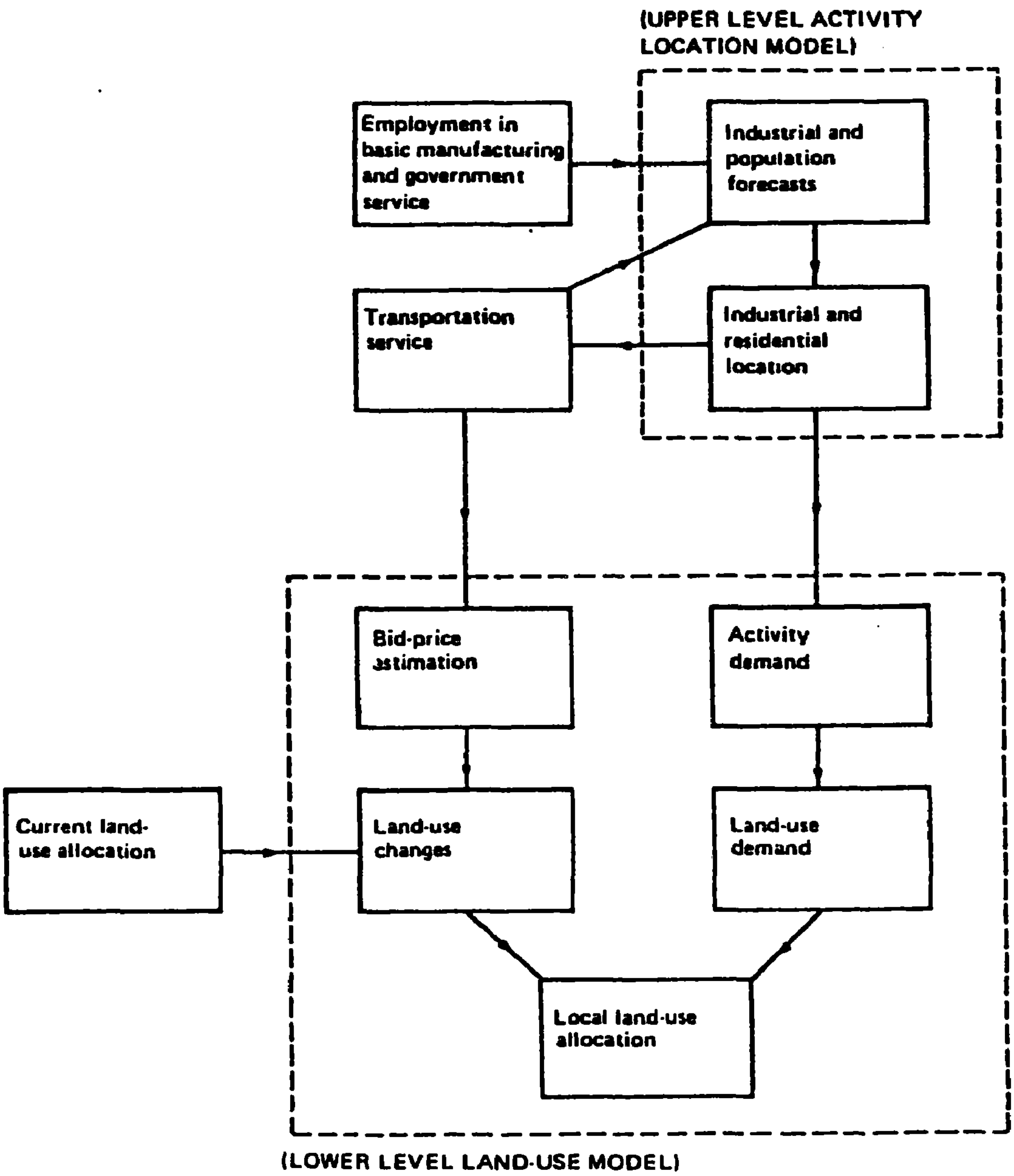


AMERSFOORT



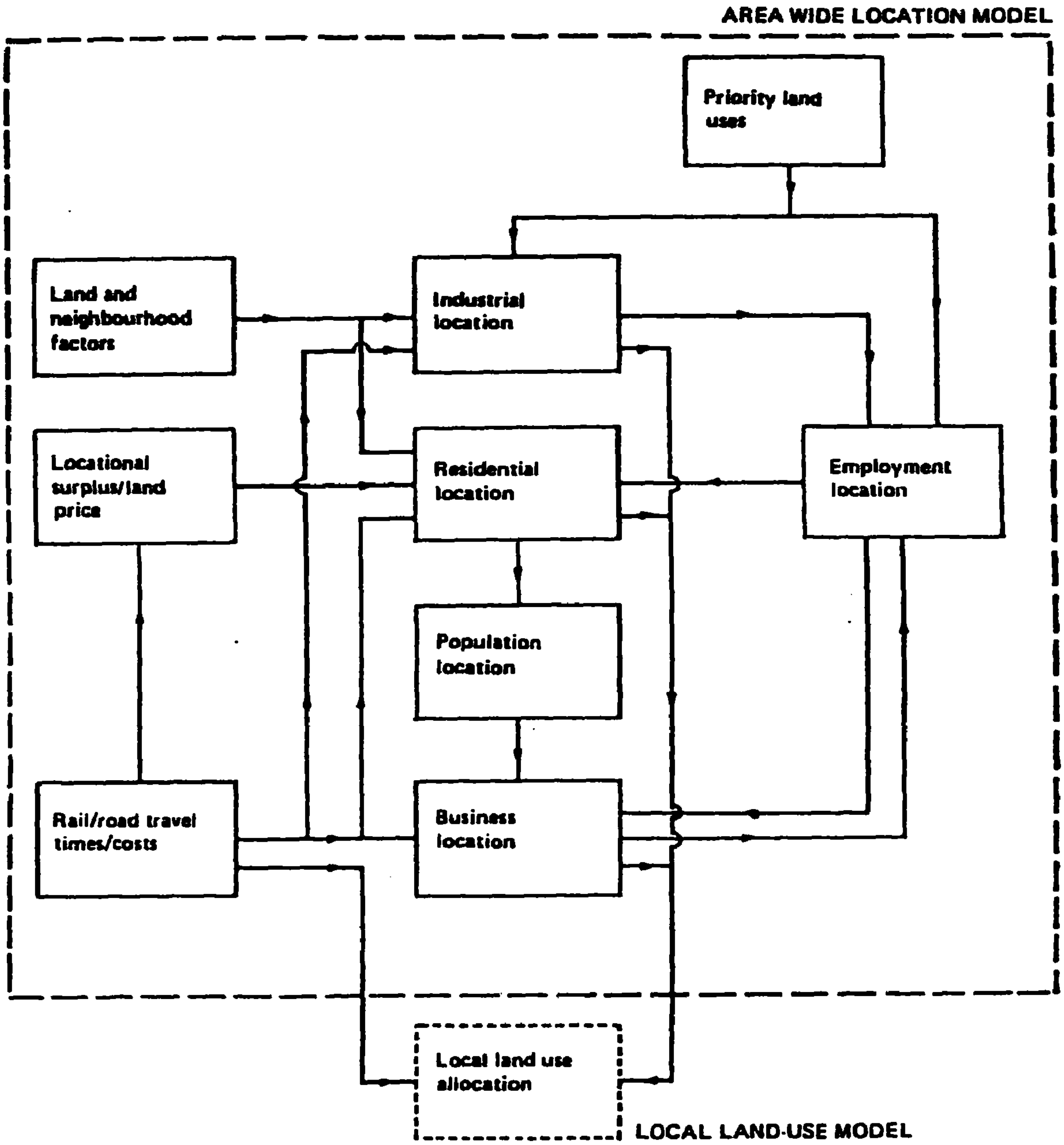
Source : Webster et al, 1988

OSAKA



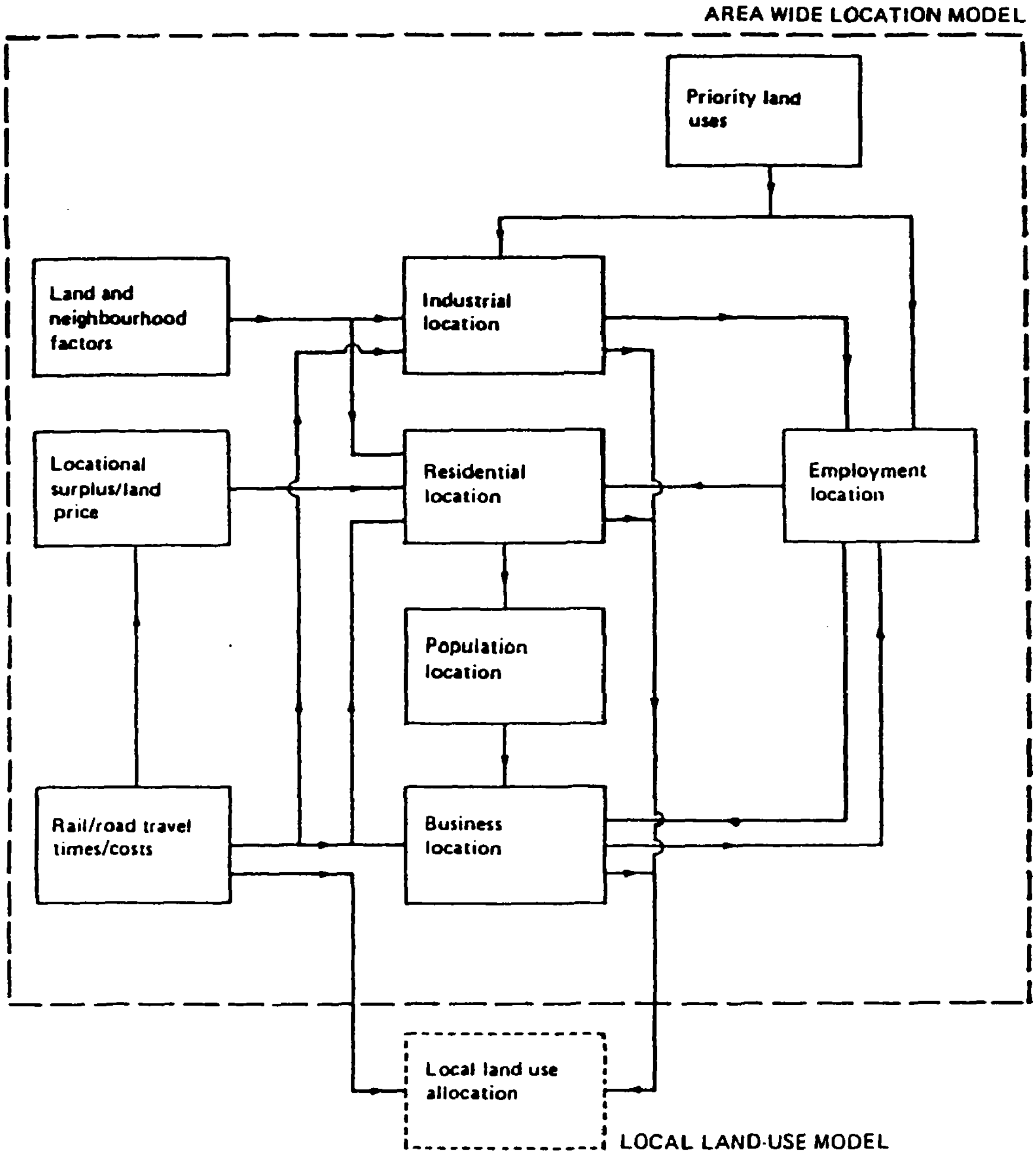
Source : Webster et al, 1988

CALUTAS



Source : Webster et al, 1988

CALUTAS



Source : Webster et al, 1988

3. The example of the TRANUS modelling system : a spatial economic based model

Tranus is a software developped by Mr De La Barra in Caracas (Venezuela, society MODELISTICA) since 1980.

1. GENERAL PRESENTATION

TRANUS is composed of 3 parts : Land use (LU), Interface (I), Transport (T). It takes into account the 9 subsystems of the urban system : network, land-use, workplaces, housing, employment, population, goods transport, economic evaluation, emmission of polluants.

Theoretical basis for LU :
The theoretical basis of TRANUS are : Basis theory, input-output matrices, utility theory and discret choice models, market equilibrium prices, Garin-lowry formulation (may be accomodated).

Main characteristics of T :
Discret choice models and 4 stages procedure (with possibility to combine modal split and assignment)

Zoning :
The criterions for the building of the zoning are : urban cuts (rivers, mountains,...), urban continuation (urban spreading), PT and road network structure, administratives limits, respect of the data sources.

2. LAND USE PART :

The functionning of the city is represented by the mean of "sectors" as :

Urban sectors :
- As : residential collective, residential individual, mixte, industrial, and residual...
- Each zone is divided into sectors. The sector "residual" have an important role for the forecasting. If we want to do a very good and detail work (if we have a lot of zones), this work is very hard and very hard to do.

Activity sectors :
- Distinction between basic and induced activities (based into specific surveys)
- Population sectors (based into transport mobility and residential mobility surveys)

Sectors have a "production" and a "consumption" :

	Urban sector	Activity sectors		Population
		Basic	Induced	
"Production"	m² of land	employement	employment	households
"Consumption"		m² of land household	m² of land household	m² of land household

Sectors are in relation :
- urban sectors with basic activities, induced activities and population
- induced activities with population
- population with basic activities and induced activities

3. TRANSPORT PART

- PT and road networks have to be describe in an integrated manner (with speed-flows curves, capacity, lengh of links, etc.).
- "Categories" are in relation with the sectors of the LU part (for example home to work; home to studies, home to others). Modes are defined by the users (categories of PT and roads).

4. METHODOLOGY AND ARCHITECTURE OF THE TRANUS SYSTEM

4.1. The three steps of the modelling :

Initialisation : calibration of the parameters (that can be estimated from data, or with calibration), definition of the base year scenario.

Simulation : modelling of the city in term of economic activities, population, land-use and transport, for each time or iteration

Interpretation : results, exploitation of these results (with Excel, SIG,...), suggestion of scenario for simulation

4.3. Inputs, outputs, transposition, tests of the system

Main inputs :
LU part :production, population, employment, land use types, prices, attractors
T part : lenght, capacity, type of each link, transit routes in each link, speed (free flow) by operator, operating cost by operator, tolls and others charges, maintenance costs

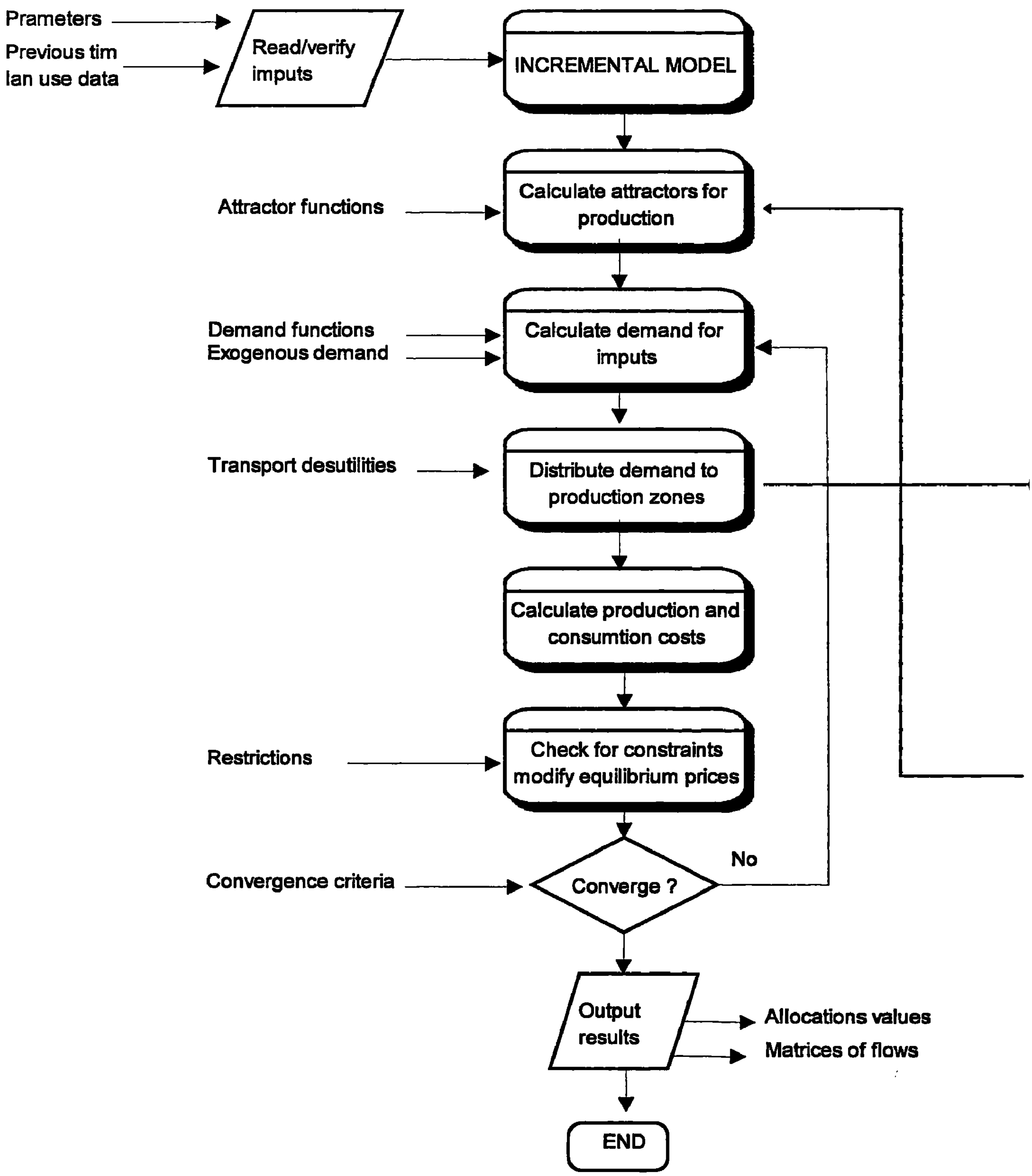
Main outputs :
LU part : location of induced sectors (activity, population), location utilities, equilibrium prices, consumption costs.
T part : average speed, saturation, number of vehicules-km, number of passenger-km, diagramm of charge, old, modal report and induced traffic, matrices of flows by categories (and by mode), generalised cost and time and distances by O/D pairs. energy consumption by operators and unit of distances function. Waiting time by nodes.
Global : large of economic indicators for evaluation of the policy tested

Transposition :
As a lot of LUTM, the TRANUS system need a lot of data, a lot of parameters to be calibrate. It involves also time for the understanding of the theoretical mecanism and of its functionning. These two elements must be taking into account for transposition to others sites or to other team.

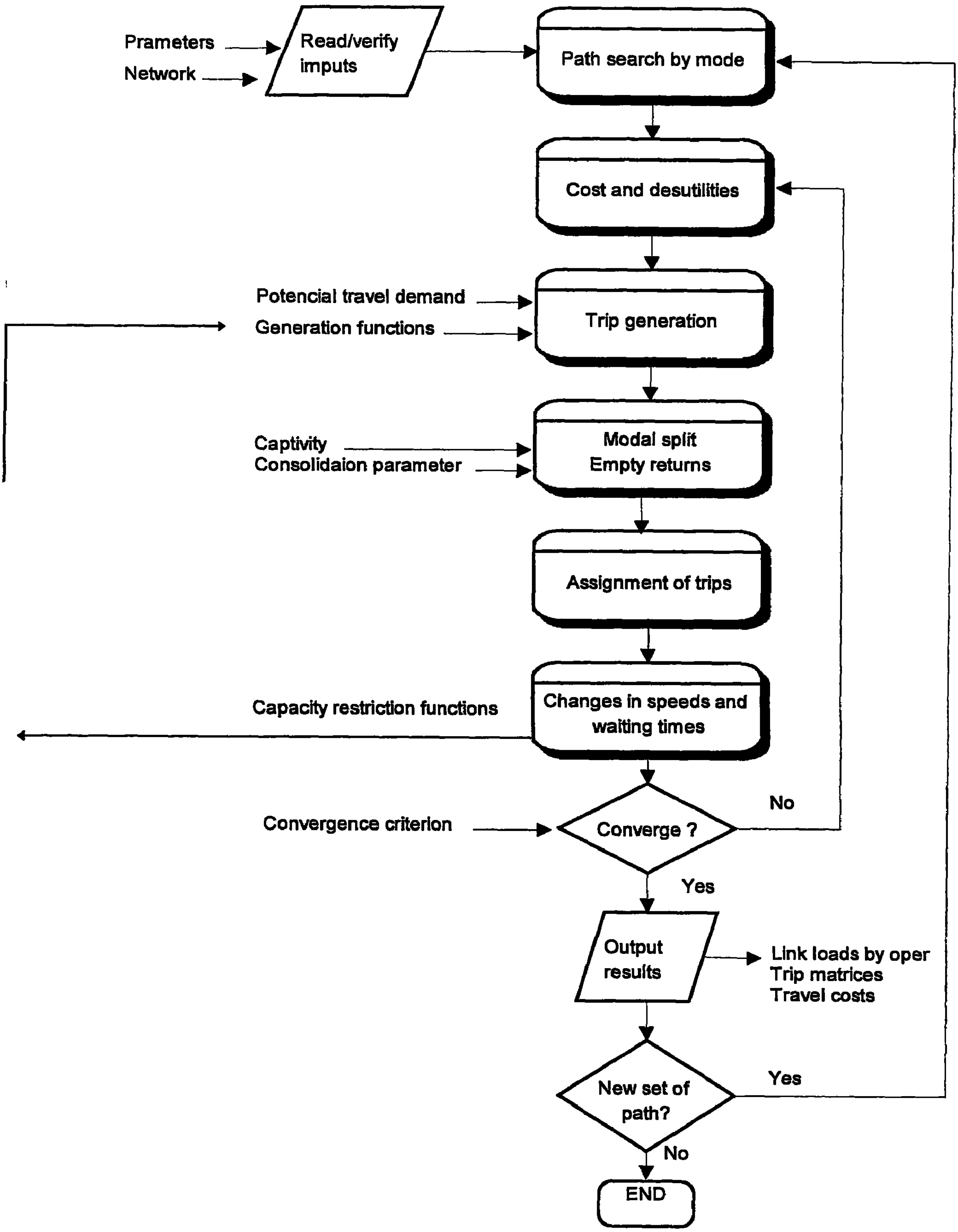
Tests of the system :

-TRANUS produces with the LU part matrices we will be translate into trip matrices into the T part. This production must be validate by comparison, at a significative statistical level, with matrices coming from revealed surveys.
-The forecasts have to be compare at two horizon past years (from which we have all the socio-economic datas), to test the stability of the model.

Calculation sequence of the location model



Calculation sequence of the transport model



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