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TRANSPORT AND LOCATION IN INTEGRATED SPATIAL MODELS

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TRANSPORT AND LOCATION IN INTEGRATED SPATIAL MODELS+

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Abstract. Modelling the interaction between transport and location decisions is one of the fundamental problems of Regional Science. In this paper current approaches to this problem are reviewed in terms of kind of interaction, dynamic structure, and causality assumptions. It is demonstrated that many current land-use transport models suffer from incomplete representation of the subsystems affected, lack of endogenous cost or capacity variables, and neglect of the specific dynamics of the transport-location interface. In particular, it is shown that virtually all current land-use transport models are based on the work-to-home relationship in the form of the singly constrained spatial-interaction location model. Starting from a critique of that model, the paper argues in favour of a more balanced consideration of spatial and aspatial locational factors.

Introduction

That transport opportunity codetermines location decisions, is one of the fundamentals of Regional Science. Human settlements, commerce, and industry first developed and prospered at river crossings, natural harbours, or along important trade routes, later along railway lines or canals, still more recently near motorways and international airports. The contributions by von Thünen, Weber, Lösch, and others introduced space, i.e. transport cost, into economics and thus paved the way for new disciplines like urban or regional economics. In the fifties the notion that transport was also a major force behind the internal spatial structure of regions became generally recognized. It was obvious that the urban sprawl observed in American metropolitan areas could not have occurred without the mass diffusion

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of the private automobile. Empirical investigations followed, and Hansen (1959) could demonstrate "how accessibility shapes land use". It was soon recognized that transport and location decisions are mutually dependent, and so the "land-use transportation feedback cycle" became a widely-used stereotype in the planning literature.

However, it took more than a decade to develop tools to effectively deal with this kind of two-way interaction in analytical models. For virtually all urban and regional models of the sixties the transport-location interface was a one-way street: Transport affected location via fixed travel times or costs, and no impacts of land use on transport were modelled. This was particularly true for the broad stream of modelling approaches following Lowry's (1964) model, including many of its later extensions and refinements. Even the "land-use transportation studies" conducted in large American cities, despite their name, applied separate models for land use and transport and nowhere achieved their integration (Boyce et al., 1970).

It was only when Putman in the early seventies developed the first version of his ITLUP model package that land-use transport interaction modelling really began (for a retrospective see Putman, 1983). Now the transport cost matrix itself became part of the model and reflected the impacts of location on transport in terms of congestion, capacity bottlenecks, and cost differentials, which again would have their impact on location in the next round.

From there on the number and variety of approaches to tackle the transport-location interaction problem increased tremendously. It is impossible to review all of them in a short paper. There exist a number of excellent reviews of the area (see, for instance Senior, 1973; 1974; Los, 1979; Berechman and Gordon, 1984). So the review undertaken here does not strive for completeness, but focusses on a few aspects thought to be of particular relevance to the ongoing discussion about new theoretical developments in the modelling of spatial dynamics.

The paper proceeds as follows. First it is briefly spelt out what is understood by integrated spatial models, and what are the major links leading from the transport sector to other subsystems of the urban or regional system and vice versa. Next current model approaches addressing the transport-location interface are reviewed in terms of kind of interaction, dynamic structure, and underlying causality assumptions. It is demonstrated that virtually all current land-use transport models are based on the work-to-home relationship and that most of them are expressed in the form of the singly constrained spatial-interaction location model. Starting from a critique of that model, it is argued that future land-use transport models should be based on a more balanced consideration of spatial and aspatial locational factors.

1. Integrated Spatial Models

Models are simplified representations of objects of scientific investigation designed in order to gain insight into their behaviour under changing conditions. Simplification is the essence of model building, and the success of the modelling exercise depends on the skill with which it is done. Basicly there are two ways of simplification: reduction in scope or in detail.

In regional science, model builders have predominantly opted for reduction in scope. In their search for understanding the complex behaviour of urban or regional systems, regional scientists have tried to identifiy groups of actors behaving in similar, regular, and predictable ways, such as travellers, shoppers, workers, households, firms, or organizations. Next they have tried to separate the decision fields in which these actors pursue their specific activities such as travel, shopping, finding a job or residence, establishing a business, investing, producing or shipping commodities. Such decision fields are commonly called markets: the transport market, the labour market, the retail market, the housing market, the construction market, the land market, and other less visible markets like the ones for knowledge and capital. Finally they have constructed models of these markets: transport, retail, employment, housing, or land use models.

Characteristically, such models focussed only on one, at most two, of the decision fields or markets at a time and thus comprised only a small section of the activities relevant for regional development at large. However, the markets interact and these interactions cannot be ignored without missing essential feedback information. This was the motivation for building more comprehensive, multi-activity urban and regional models that explicitly addressed the interconnectedness of the various urban and regional markets.

Such models are called "integrated" spatial models in this paper. In particular, the term is used for empirically oriented, spatially disaggregated, multi-activity mathematical models built for the purpose of forecasting the spatio-temporal development of urban and regional systems, where "multi-activity" indicates that the model includes more than one sector or field of human activity such as employment, population, housing, and transport, and "urban and regional systems" may be anything from a town to a system of regions in a nation.

To fix ideas, an "ideal-type" multi-activity urban/regional model will now be sketched out. Figure 1 represents one possible realization of such a model, with each box standing for a group of variables and adjacent boxes being closely interrelated by causal links. The arrows indicate the direction of the most important links, however, at this level of aggregation most links are bidirectional.

It is noted that the model in Figure 1 is only a part of a multi-level model system as information flows enter it from above and leave it at the bottom. The model can be conceived of as representing the "urban" level in a two-level spatial system where the top level represents the larger region or a system of regions within the nation, e.g. a state or province or any larger spatial entity for which aggregate economic and demographic forecasts exist (for a discussion of the two-level system model see Wegener, 1984). The "urban" level is subdivided into geographical subunits called zones.

It can also be seen that the model is organized by markets. Four markets are distinguished:

- the urban transport market,
- the urban market for nonresidential buildings,
- the urban housing market,
- the urban land market.

These four markets form the four sides of the model diagram linking the corner boxes or major stock variables of the urban system:

- zonal employment,
- zonal population,
- zonal nonresidential buildings,
- zonal housing.

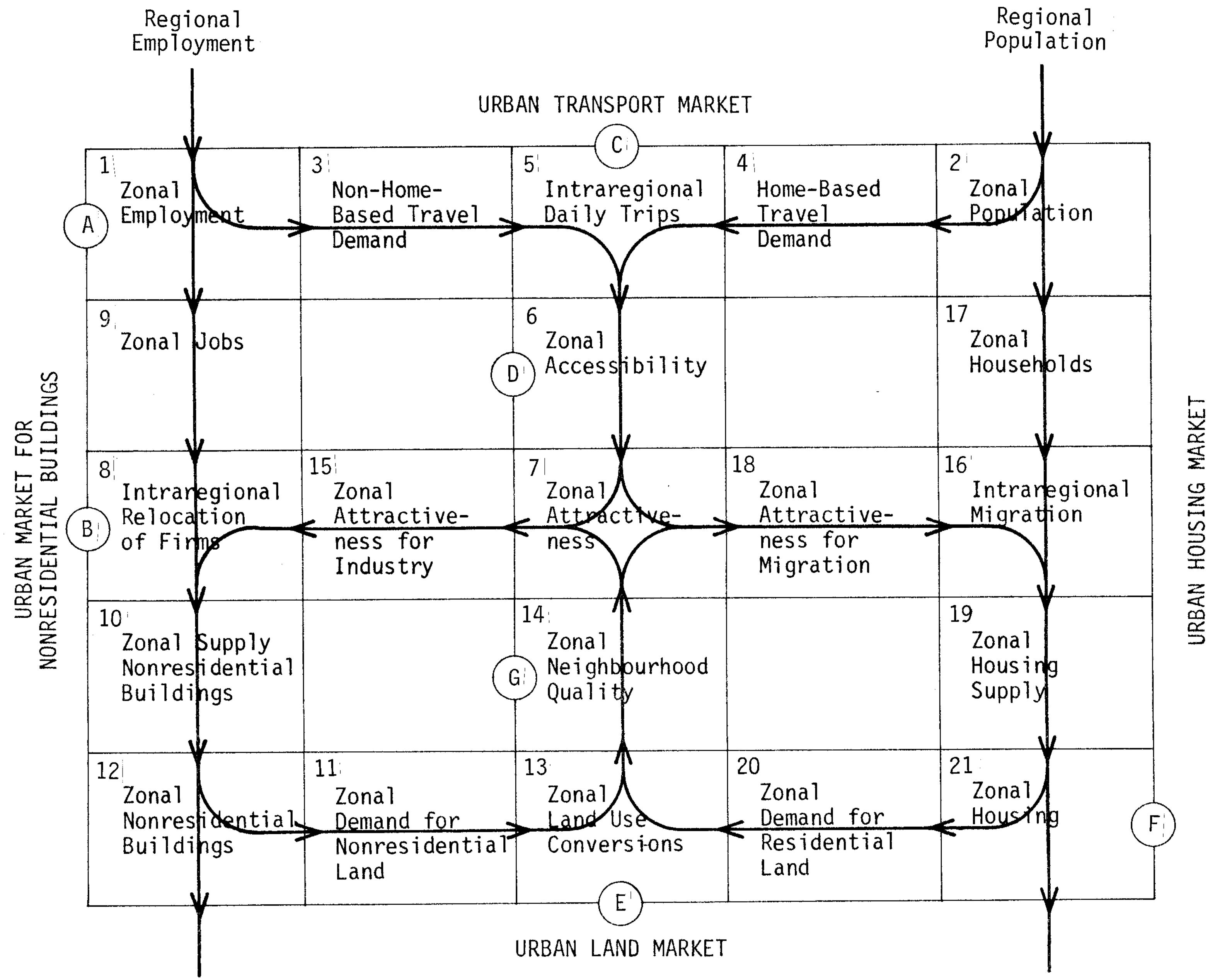

Figure 1. A model of an integrated spatial model.

Of these, the two on the left-hand side refer to the production or employment sphere, the two on the right to the population or household sphere. Each market is represented by two outer boxes identifying demand and/or supply and a central box containing the relevant transactions occurring in each market:

- intraregional daily trips,
- intraregional relocation of firms,
- intraregional migration,
- zonal land use conversions.

The four markets are interconnected by the central boxes of the diagram representing attractiveness indicators, each composed partly of spatial, or accessibility, and partly of aspatial, or place utility, attributes.

One possible way of tracing the most important causal links and feedbacks in this paradigmatic model is to follow the numbers in the boxes: In a top-down perspective, total regional employment and total regional population are disaggregated to zonal employment (1) and zonal population (2). These are the causes of non-home based (3) and home-based (4) travel demand which, in conjunction with transport supply, results in intraregional daily trips (5). The accessibility (6) derived from such trips represents an essential component of the locational attractiveness of the zones (7).

For predicting intraregional relocations of firms (8), employment needs to be converted into jobs or workplaces (9). They represent the demand for floorspace in the market for nonresidential buildings, where new or vacant such buildings represent supply (10). New factory or office buildings consume land (11) and are added to the existing stock (12), which also changes through degradation, rehabilitation, or displacement. Changes in land use (13) affect the neighbourhood quality of a zone (14), the other important component of zonal attractiveness (7), and as such is an input to relocation decisions of firms (15).

For predicting intraregional migration (16), zonal population has to be aged and converted into households (17), the demand side of the housing market. The supply side of the housing market is represented by zonal attractiveness for migration (18) and housing supply (19). The latter may be new housing competing with nonresidential buildings in the land market (20), or vacant existing stock (21). Also residential buildings change through degradation, rehabilitation, or displacement.

The letters in the circles on the edges of boxes of Figure 1 indicate local government policy instruments. Economic policies include direct subsidies (A) or relocation assistance (B) given to individual firms. Policies to improve the residential quality of the region may include upgrading of the public transport system (C), new road construction (D), land use controls (E), public housing programmes (F), or neighbourhood improvement schemes or new public facilities (G).

Of course, no existing model can be expected to contain all the subsystems, causal links, and policies listed in this section. However, the ideal-type model may serve as a useful benchmark to evaluate current model approaches in terms of their claim to represent the relevant aspects and interactions of the modelled system. This will now be done for some land-use transport models.

2. Models of Transport and Location

With the above comprehensive model framework in mind, the "land-use transportation feedback cycle" can be represented as in Figure 2:

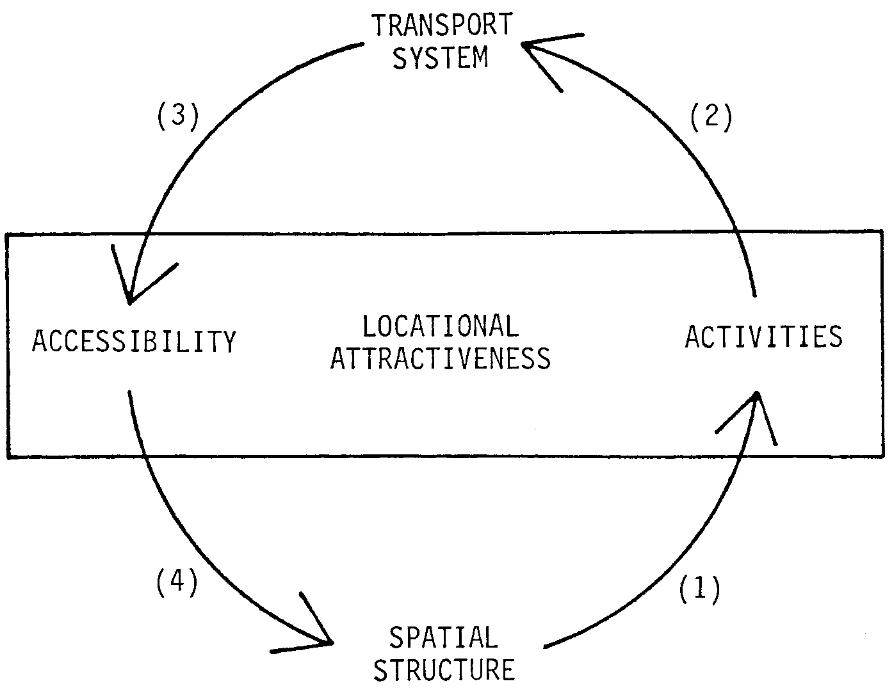

Figure 2. The "land-use transportation feedback cycle".

(1) The spatial structure of the region determines the distribution of activities in space.
(2) Activities generate traffic in the transport system.
(3) The response of the transport system affects the accessibility of locations.
(4) Locations with high accessibility attract more development than less accessible ones thus changing the spatial structure.

Hence a location is characterized (a) by the activities it accommodates and (b) by its accessibility. Activities and accessibility together constitute the locational attractiveness of a location.

If that is a valid description of the interaction between transport and location, it may be asked how they are represented in models claiming to address the transport-loaction interface. For this purpose, a sample of 20 urban models documented in the literature have been selected for this review. Although most of them are fairly well known, they will briefly commented in chronological order:

2.1. The Sample of Models

The sample starts with two historical examples. The first one is the Herbert-Stevens (1960) residential location model using linear programming to allocate households and housing in a region, the other the celebrated "Model of Metropolis" by Lowry (1964) later put into matrix form by Garin (1966). Lowry for the first time used the singly constrained gravity or spatial-interaction location model to allocate households to residential locations as a function of workplace locations and work-to-home travel costs. In addition he introduced feedback between household and service locations by nesting two spatial-interaction models into each other. Wilson (1970) generalized the gravity model subject to marginal constraints to produce a "family of spatial interaction models", and replaced its power function by the negative exponential or entropy function, which later turned out to be consistent with various concepts of utility (Williams, 1977) and choice theory (Anas, 1983).

As indicated earlier, modelling the transport-location interface really began with Putman (1973, 1983) who developed the first land-use transport model explicitly taking account of traffic congestion. Nearly in parallel, the POLIS model was applied to the cities of Cologne and Vienna (Wegener, 1973; 1974). It was also congestion-sensitive, but differed from the Lowry model in that it used the original Hansen (1959) accessibility to drive its location models rather than the spatial interaction model.

With the work of Anas (1975; 1982) and the NBER model (Kain et al., 1976) microeconomic theory was introduced into residential location modelling. Now for the first time land and housing prices and rents figured in the models not as exogenous data, but as endogenous indicators of the supply-demand relationship. The NBER model also demonstrated that micro simulation, nearly forgotten since Chapin and Weiss (1968), was a powerful tool for simulating event-based processes too intricate to be modelled analytically.

The next three models deal with the problem of simultaneous equilibrium of transport and location. Berechman (1976; 1980) showed that previous transport-location models with endogenous travel costs were inconsistent because the travel costs used to drive the location model were not normally the same as the ones that resulted from the activity pattern so derived. He as well as Boyce (1977) and Los (1978; 1979) suggested model frameworks to derive a general equilibrium of transport and location based on network equilibrium techniques known from transport engineering. Later, Boyce et al. (1981) generalized these ideas into a comprehensive scheme of transport-location equilibrium models including location, destination, mode, and route choice. With less sophisticated assignment techniques, the same was achieved by the Bilbao version of the ARC model by Echenique (Geraldes et al., 1979), which in addition contained a floorspace price adjustment mechanism similar to the microeconomic NBER and Anas models.

TRANSLOC (Lundqvist, 1978) and TOPAZ (Brotchie et al., 1980) are different from the other models in that they are optimization models. Both seek to find a distribution of activities in the urban region that minimizes and objective function containing both location and interaction costs, however, in the TOPAZ model the interaction component of the objective function may also contain entropy terms to account for the dispersion of travel choices by private actors. In that TOPAZ is close to the multi-activity location model proposed by Leonardi (1981), in which the spatial interaction location model is embedded into a nonlinear optimization model allowing choice dispersion. The Leonardi model is also important because it takes account of capacity constraints at the destinations.

The LILT model (Mackett, 1980) and the Toronto model (Said and Hutchinson, 1980) both are highly disaggregated multi-activity spatial-interaction location models in the Wilson tradition. However, the LILT model stands out by its explicit distinction between physical structure (jobs, houses) and activities (workers, households), which makes it possible to model phenomena such as vacant jobs and unemployment, housing vacancies and overcrowding.

The last group of models is characterized by their interest in dynamics, i.e. these models do not suppose that the urban system comes close to equilibrium at any point in time. The Turin model (Bertuglia et al., 1980) is in essence an incremental multi-activity Lowry model, in which the levels of activity in each zone are progressively altered through time by the variation of the attraction of the zone. The "Brussels" model (Allen et al., 1981) and the model by Wilson and his colleagues (Beaumont et al., 1981), while derived from different theoretical positions, are very similar: They both interprete the difference between a spatial-interaction demand model and supply at the trip ends as unsatisfied demand or excess supply, depending on its sign, and their convergence as an adjustment process over time thus arriving at a fully dynamic model. The Dortmund model (Wegener, 1982) is a multi-level, multi-activity composite model containing various types of submodels, among them an equilibrium-type transport model, accessibility-based location models, and a microanalytic housing market and migration submodel, linked together in a recursive fashion.

2.2. Model Classification

There are innumerable ways of categorizing models of this kind. Earlier reviews (e.g. Berechman and Gordon, 1984) have concentrated on technical aspects such as the solution method used. This one will proceed in a much simpler way by first asking three basic, substantive questions: How are the subsystems of transport and land use represented in the models? Are transport and location costs endogenous in them? What is their dynamic structure?

The answer to the first question is given in Table 1. In the case of transport, the question means whether the transport system is represented in network (or some equivalent) form which permits transport policies as well as congestion effects to be investigated. It can be seen that eight of the 20 models do not contain a representation of the network. With respect to the location side, it is asked if the location submodels include some notion of land and physical stock such as housing or nonresidential buildings, or if they just locate activities. The latter is true for 11 of the 20 models, and this means that with these models no land scarcity can be modelled.

The second question extends the last point. How are costs (prices) determined in the models? Are they exogenous or endogenous? This question is crucial because with fixed prices no supply-demand interaction, no market behaviour, no congestion, no capacity bottlenecks can be expected to be exposed by the models. Table 2 displays the result of this analysis. It is disappointing to see that 7 out of the 20 models have no price mechanism, neither on the transport nor on the location side. Seven models endogenously generate transport costs as a function of congestion, but have no price signals on the location side, four models do have endogenous land or housing prices, but have exogenous transport costs, and only two models have both endogenous transport and location costs.

The third question is concerned with the dynamics of the transport-location interaction built into the models. Table 3 shows that the majority of models are equilibrium models assuming that transport and location are always in equilibrium, i.e. that the pattern of activity locations and spatial interactions at all times reflects the current transport cost structure, and vice versa. This statement needs to be qualified. A transport network equilibrium in the strict sense of user equilibrium (Wardrop, 1952) is achieved only in the models by Boyce, Los, and in the Toronto and Dortmund models. Other models use more traditional techniques to approach transport equilibrium such as incremental assignment (Putman, POLIS, Berechman). Obviously, in the models that do not calculate endogenous transport costs, travel demand is always in equilibrium by definition. In six models the response of the land use system to changes in transport costs is lagged in a recursive fashion, with instantaneous adjustment to changes in activity location assumed on the transport side. There are only two models which assume a delayed response also on the transport side.

Table 1. Representation of Transport and Land Use.

		Representation of transport	
		Network not represented	Network represented
Representation of land use	Physical stock not represented	Lowry Wilson Leonardi Allen et al. Beaumont et al.	ITLUP Berechman Boyce Los TRANSLOC Toronto
	Physical stock represented	Herbert-Stevens NBER TOPAZ	POLIS Anas ARC LILT Turin Dortmund

Table 2. Transport and Location Costs.

		Transport costs	
		exogenous	endogenous
Location costs	exogenous	Herbert-Stevens Lowry Wilson TRANSLOC TOPAZ Turin Beaumont et al.	ITLUP POLIS Berechman Boyce Los LILT Toronto
	endogenous	NBER Anas Leonardi Allen et al.	ARC Dortmund

Table 3. Transport and Location Dynamics.

		Transport Dynamics	
		Network equilibrium	Lagged response
Location Dynamics	Land use equilibrium	Herbert-Stevens Lowry Wilson Anas NBER Berechman Boyce Los TRANSLOC TOPAZ Toronto Leonardi	
	Lagged Response	ITLUP POLIS ARC Turin Allen et al. Beaumont et al.	LILT Dortmund

2.3. Types of Location Models

The preceding analysis has demonstrated that only very few of current urban models claiming to address the transport-location interface are able to do so because the majority of the models (a) fail to adequately represent the transport and/or land-use systems, (b) treat crucial variables such as transport and/or location costs as exogenous, or are equilibrium models that ignore the time dimension of the adjustment processes they postulate. In a final step of the analysis, it will be shown that, on top of these deficiencies, these models are victims of a confusion about what is cause and what is effect in the relationship between transport and location.

To illuminate this point, a few remarks about the temporal characteristics of urban change processes need to be made. Following Snickars et al. (1982), urban change processes can be classified with respect to their temporal characteristics as in Table 4 (Wegener et al., 1983).

Table 4. Urban Change Processes.

Level	Change process	Stock affected	Response time (years)	Response duration (years)
1 Slow	industrial construction	industrial buildings	3-5	50-100
	residential construction	residential buildings	2-3	60-80
	transport construction	transport system	5-10	>100
2 Medium speed	economic change	employment/ unemployment	2-5	10-20
	demographic change	population/ households	0-70	0-70
	technological change	transport equipment	3-5	10-15
3 Fast	labour mobility	workplace occupancy	<1	5-10
	residential mobility	housing occupancy	<1	5-10
	daily mobility	traffic	<1	2-5

It can be seen from Table 4 that the average response time of urban change processes ranges from less than a year to a human lifetime, and the duration of the response can be even longer. The implications of this for the design of urban models are straightforward: Urban change processes are slow in relation to human life and planning perspectives, and therefore urban models intended for planning should take account of the retarding forces, frictions, and delays responsible for that inertia.

However, this seemingly simple and common-sense conclusion is disregarded by most existing urban models. With few exceptions, they are based on the concept of the <u>spatial-interaction location model</u>. The spatial-interaction model itself, first developed in transport planning, predicts traffic flows in equilibrium subject to given activity locations---a reasonable proposition given the fast adjustment of travel patterns. The problems start when this model is used to predict activity locations by interpreting the trip destinations of the traffic model as residences, workplaces, and the like rather than taking them as given. The spatial-interaction model used as a location model, as pioneered by Lowry (1964) and later systematized by Wilson (1970), assumes that there exists in urban areas an equilibrium between traffic flows and activity locations. In reality, however, as it has been attempted to show in Table 4, changes of location, due to contractual or habitual constraints and long planning and construction times, are many times slower than changes of travel behaviour. In fact, the spatial-interaction location model predicts a slow and inert process, location, from a volatile and flexible process, travel, and this exchange of cause and effect is a common feature of current mainstream urban modelling.

This can be demonstrated by looking at Table 5. Table 5 lists nine types of spatial choice models differing by the choice process represented. For each model it is indicated which variables are predicted and which are taken to be known. In addition, the models are classified as "doubly constrained", "singly constrained", or "unconstrained" depending on the number of constraints (or "known" entries) in each row.

The first three models in Table 5 are doubly constrained. In doubly constrained models both, the decision makers and the choices made are known, while the pattern of choices linking decision makers to choices (the "choice matrix") is to be predicted. The most widely known doubly constrained spatial choice models are <u>traffic models</u>, in which the decision makers are, say, workers at their place of residence (the "origins"), the choice set are jobs at places of employment (the "destinations"), and the choice matrix to be predicted is the matrix of worktrips. In <u>migration models</u>, households willing to move from their old residence are the origins, new or vacant dwellings the destinations, and the choices to be predicted are migrations. Similarly, in <u>employment change models</u>, labour mobility is predicted as spatial interactions between old and new jobs.

The next three models are singly constrained, i.e. constrained only in their origins. <u>Residential location models</u> are models predicting residence locations from a known distribution of employment as destinations, or column totals, of the worktrip matrix. Similarly, in <u>employment location models</u>, household-serving (or "non-basic") employment is predicted from residential locations as destinations of shopping and service trips. Residential locations are also predicted by <u>housing market models</u>, but here the decision makers are households at their old place of residence and the spatial interactions modelled are migrations.

Table 5. Types of Spatial Choice Models.

Model type	Constraints	Residence		Workplace		Interactions			Number of models
		old	new	old	new	Trips	Migration	Labour Mobility	
Traffic models	doubly constrained	known	-	known	-	predicted	-	-	3
Migration models	doubly constrained	known	known	-	-	-	predicted	-	1
Employment change models	doubly constrained	-	-	known	known	-	-	predicted	1
Residential location models	singly constrained	-	predicted	known	-	predicted	-	-	17
Employment location models	singly constrained	known	-	-	predicted	predicted	-	-	14
Housing market models	singly constrained	known	predicted	-	-	(known)	predicted	-	2
Housing location models	singly constrained	-	predicted	(known)	-	-	-	-	3
Job location models	singly constrained	(known)	-	(known)	predicted	-	-	-	1
Resid./empl. location models	un-constrained	-	predicted	-	predicted	predicted	-	-	2

There are two more singly constrained models in Table 5, although their origins are not shown in the table. In housing location models, the decision makers are housing investors looking for sites for new dwellings, while in job location models they are firms deciding on new firm locations. In both cases vacant land by zoning type, possibly weighted by attractiveness indicators, constitutes the choice set or destinations, and no spatial interactions are involved.

Finally, there are residential and employment location models, in which residential and employment locations are simultaneously determined by an unconstrained spatial interaction location model. This type of model is typically applied in an optimization framework.

The last column of Table 5 shows how many times each model type is represented among the 20 models of the sample or any of their submodels. It can be seen that indeed nearly all models of the sample contain a residential location model of the singly-constrained spatial-interaction type simultaneously predicting residential locations and worktrips, and that most contain an employment location model constructed along the same lines. In other words, most of the models examined in their core submodels are founded on the reversal of cause and effect between transport and location discussed above. Such models are unable to take account of the frictions and delays slowing down the response of the location system to transport changes, and hence are likely to overestimate the impacts of such changes. In contrast, only very few models of the sample explicitly predict longer-term changes of the location system such as household or labour mobility or changes of the physical stock of the city through industrial or housing construction.

3. Conclusions

In summary, if the sample of models investigated is only nearly representative, the art of modelling the transport-location interface is not nearly as well developed as one might believe considering the high degree of sophistication achieved in terms of mathematical theory and modelling technique. As the main deficiencies of most current modelling approaches can be identified: (a) incomplete representation of the subsystems affected, (b) lack of endogenous cost or capacity variables, (c) neglect of the specific dynamics of the transport-location interaction, and (d) inappropriate preoccupation with one particular model type.

The conclusions to be drawn out of this analysis are very simple and straightforward. It has to be realized that location decisons are different from transport decisions and are made in a decision environment where transport considerations tend to become less important in the face of changing work and leisure patterns and new communication technologies. What is necessary then is to free location modelling out of its transport fix and bring it back to a more balanced view where spatial and aspatial locational factors play an equal role. This would mean to invest more effort and talent into designing and empirically testing housing market models or models of job choice or workplace location rather than spatial interaction models.

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