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Strategic Long-Term Transportation Planning and Dynamic Transportation models: a Life Cycle Interpretation

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Abstract

In the recent past a wide variety of strategic transportation planning issues has come to the fore, at both the supply and the demand side. Land use problems, environmental externalities, lack of capacity, and high speed transport systems have dramatically altered the conventional scene of transportation planning. The paper will give an overview of emerging transportation planning issues from a perspective ranging from local to international developments. The dynamic evolution of these planning issues will be interpreted from the viewpoint of the so-called policy life cycle hypothesis.

The main question to be answered is whether the wide variety of multi-temporal or dynamic transportation models (e.g., dynamic models of discrete choice, Lotka-Volterra models, dynamic programming models, etc.) are able to provide analytical support to the above mentioned strategic planning issues. Much attention will be given here to the problem of 'predicting the unpredictable' and the potential of recently developed models in this context (e.g., based on theory of chaos). In this context, the life cycle concept appears to provide a meaningful frame of reference.

1. Introduction

It has often been stated that transport is a derived demand. In other words, transport demand is not an autonomous factor but is a result of major driving forces in society: demographic, economic, social and technological.

It is evident that these driving forces have many consequences for spatial behaviour of people. On the one hand they determine the evolutionary pattern of their activities (including their transport needs); on the other hand, they are also facing the related feed-back effects, which are to a large extent the result of strong bottlenecks such as lack of safety, low quality of life, resource exploitation, energy use, environmental degradation, etc. (see Nijkamp, 1989). In particular it is noteworthy that in the sixties these driving forces have moved transportation policy toward network and capacity expansion, while from the mid seventies onward the attention has been devoted to a more efficient use and management of existing networks.

In parallel to the broad expansion (in the sixties) of transport systems, the scientific development of research on transportation showed, in almost the same period, the need for and the emergence of macro-oriented mathematical tools (e.g., spatial interaction models, linear programming, etc.), which were capable of understanding and analyzing the transportation patterns and configurations, at least at a static level of an aggregate network. However, the relationship between transportation research on the one hand and policy interest and implementation in a practical planning context on the other hand, has not always been satisfactory.

Only in recent years, the awareness of the possibilities of a strong analytical support to management issues has moved planners in the direction of more emphasis on the practical usefulness of transport planning studies or models. At the same time new mathematical tools emerged (such as dynamic or multitemporal models of a discrete choice type, Lotka-Volterra models, master equation models, catastrophic or chaotic models, etc.) with the aim of representing the spatial dynamics of mobility and transportation.

The aim of this paper is to show some recent trends in transportation planning issues, at both the supply and the demand side, together with emerging bottlenecks (Section 2). Then the policy life cycle idea which describes the policy orientation toward transport analysis and modelling will be described (Section 3). At the same time attention wil be paid to the potential of the new emerging dynamic transportation models (Section 4) by showing also their links to these strategic planning issues in the light of a life cycle analysis (Section 5).

2. Recent Trends in Transportation Issues

In the past few years transportation planning issues have increasingly come to the fore, since transport is rightly regarded as a decisive determinant for the economic and urban future development, both at local and international levels.

In this context we can outline in a qualitative sense a series of emerging trends on the basis of activities mainly conducted in the Network on 'Transport, Communication and Mobility' (see Nijkamp, 1989).

2.1 Emerging trends

The main emerging trend in spatial interaction patterns is the increase of mobility at both national and international level. In fact, if we consider, for example, the emerging megatrends from an economic viewpoint we observe a structural growth in mobility owing to the increase in leisure time, the rapid penetration of telecommunication and information technology, the foreseeable open market in Europe in the year 1992, the trend towards more deregulation and privatisation, the internationalisation of the economy, etc.

Next, socio-demographic megatrends show a new life style (e.g., the increased participation of female labour force, the intensification in business relationships, the foreseeable higher education levels) leading to a higher local and international mobility.

It should also be noted that technological megatrends (e.g., the increasing importance of telematics, of new technologies, of new logistic structures) will surely increase the efficiency of commodity transport.

Obviously, the above mentioned trends determine the emerging consequences in both transport and all subsystems connected with transport, such as the environment, energy, land use, etc. In this respect, we are often facing capacity problems and external costs. Consequently, some of these bottlenecks will be briefly described in the following subsection.

2.2 Emerging bottlenecks

In general we may expect a structural incompatibility of long-term transport developments with socio-economic environmental and safety conditions. In fact serious threats to the transport sector are likely to emerge, such as lack of parking space in urban areas, increasing congestion in both urban agglomerations and air traffic, lack of capacity and service levels of conventional public transport, an increasing deterioration of environmental quality, etc.

In the light of the previous observations it is clear that policy options need an elaborated and advanced analytical support system for coping with these problems. In the next section the development of transportation research linked to various important policy issues will be examined, in the framework of the so-called life-cycle concept.

3. A Life Cycle Interpretation for Transportation Issues

3.1 General background

Transportation issues come and go; transportation models come and go. Such phenomena are well-known from industrial economics, especially in the area of product life cycle analysis. Such views on dynamic evolutionary processes may also be hypothesized for transportation issues.

The so-called policy life cycle hypothesis (see Winsemius, 1987; Zoeteman, 1987) is fundamentally based on the idea that the political interest in new transportation issues -and related analytical tools- passes essentially through four stages of development, viz. design, introduction, market penetration and saturation. These four stages can be described in more precise terms as follows:

a) Recognition and awareness in society (which implies the identification of new (transportation) problems, based inter alia on scientific research or general feelings among the public at large).

b) Policy formulation (which represents a phase of political attention in order to explore and formulate policy principles and policies on the basis of more solid scientific research and adequate information).

c) Policy implementation (which implies the policy implementation of proposed solutions for the (transportation) issues concerned).

d) Management and control (based on appropriate information and monitoring systems, once the policy measures have been fully accepted and/or enforced).

The life cycle interpretation of policy issues is thus indeed rather similar to the well-known product life cycle phenomenon in industrial management and organizational processes. This life cycle concept has also been applied to environmental phenomena (see Brouwer and Nijkamp, 1989) and to services planning for elderly (see Nijkamp and Vollering, 1989).

As regards the transportation context, we may visualize the life cycle hypothesis by means of continuous trajectories as follows (see Figure 1)

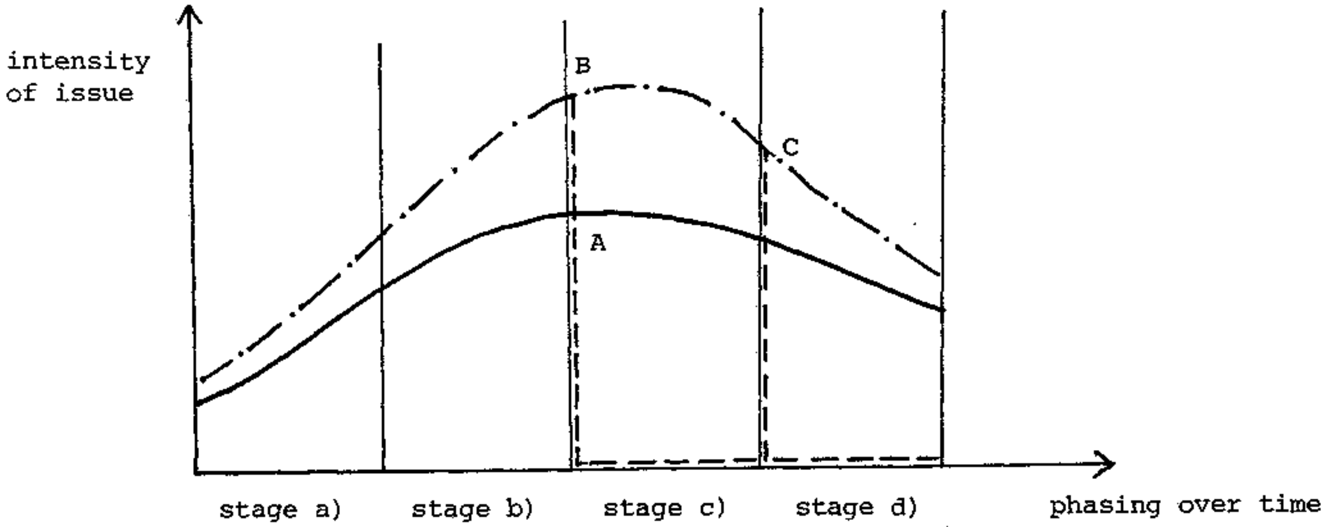

Figure 1 Life Cycle for a Given Transportation Issue:
—— continuous trajectory in the policy interest
—·— continuous trajectory in the research interest
– – – catastrophic trajectories
A,B,C,: bifurcation points

Clearly it should be noted that the life cycle hypothesis does not necessarily follow a continuous development. It may, for instance, happen that an issue suddenly disappears from the political agenda or from the research interest, as it is overshadowed by another phenomenon. Thus the passage from one stage to another can be discontinuous with bifurcations, implying essentially a catastrophic change in the life cycle; for example stage c) in policy interest (and consequently stage d) may not materialize, so that a point A can emerge that acts as a bifurcation point, from which two different paths might arise depending on policy-makers' decisions or external conditions (see Figure 1).

Such a phenomenon is entirely similar to a product life cycle path, in which a new product fails to enter the market. It should also be pointed out that fluctuations such as feed-back effects between the various stages would have to be taken into account. Obviously also the time span of the stages may be expected to vary in reality.

Since the development of scientific research is strictly connected to policy signals, in the next subsection we will describe more deeply the evolution of the two trajectories depicted in Figure 1 with their underlying links.

3.2 A life cycle view on transportation planning and modelling

Against the background of the policy life cycle hypothesis, we face nowadays an increasing awareness and recognition of the severity of transport problems in policy-making agencies, given the determinant and critical role played by transport in the future development of our societies (see Section 2). This recognition of the first stage of a policy life cycle is reinforced by statistical information and scientific research on transportation (see stage a) in Figure 1), with a particular emphasis on the conflicting role of transportation as a source of economic potential and as a source of high external costs (e.g., lack of safety, congestion and environmental interest). This attention for the social costs of transport (and related physical planning issues) is also reflected in the research issue trajectory (see Figure 2) designed on the basis of the number of theses published in the U.S.A. - Canada - U.K. on this subject (see Santos and Braga, 1988).

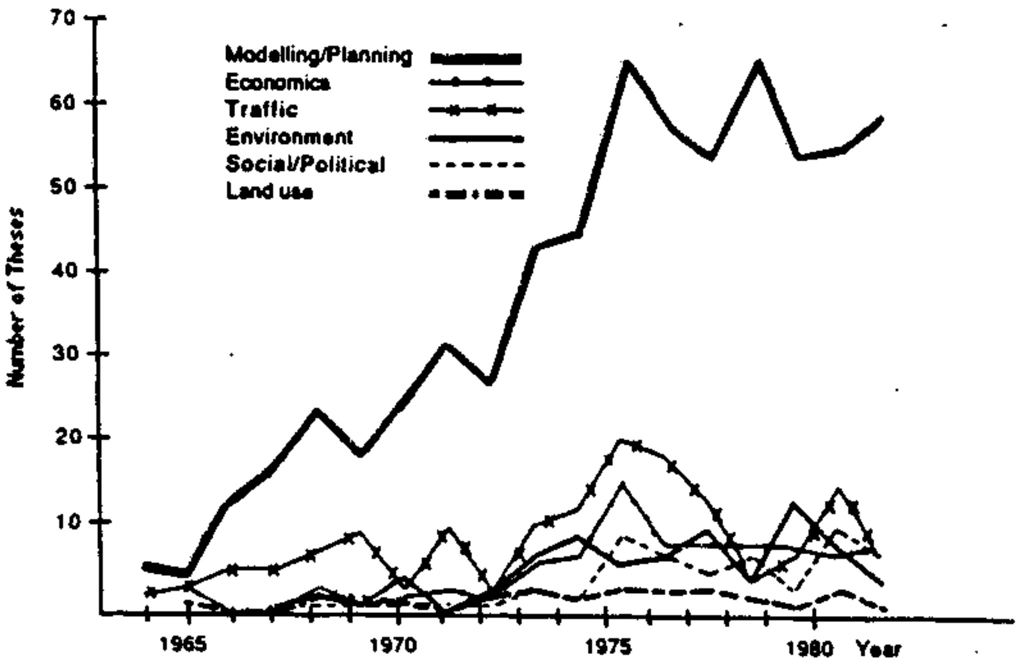

Figure 2 Number of Theses according to the Main Subject of the Research

It should also be noted that a great deal of interest in the externalities connected with transport has also been expressed in the broad framework of the ESF (European Science Foundation) network on 'Transport, Communications and Mobility' (see also Nijkamp and Reichman, 1987). In a recent cross-national comparative study on 19 European countries (see Nijkamp et al., 1989) the main themes in transportation planning and research have been described, inter alia:

- the influence of exogenous socioeconomic conditions upon the spatial interaction patterns in an economy, not only in terms of person movements but also in terms of transport of commodities or information;
- the implications of changes in the technological 'environment' upon the spatial behaviour of individuals or groups;
- the impacts exerted by policy/planning decisions upon transport systems and also the related behavioural responses (such as changing work conditions, changes in income, changing life styles and cultural attitudes, etc.).

From Figure 2 we can also clearly see the increasing interest in modelling/planning tools in the past decades. In this context it is interesting to observe that scientific research has shown in the sixties and seventies:

- a broad number of models, mostly based on static Spatial Interaction Models of the gravity type (SIMs), widely applied in various regions in the U.S.A. and Europe (see also Reggiani, 1985).

On the other hand the eighties have shown:

- much more emphasis on the analysis of individual motives and on the impact of micro behaviour on the functioning of transport systems (in view of the need to a better understanding of the complexity of transport systems);
- a strong interest in theoretical dimensions of modelling in order to incorporate newly emerging relevant aspects of system dynamics, such as slow and fast dynamics, uncertainty, bifurcations, catastrophic changes, chaotic behaviour, fractal structures, etc.

In order to satisfy these analytical and planning needs, a wide variety of new behavioural approaches, mainly based on Discrete Choice Models (DCMs), and Dynamic Models (DMs) has recently emerged, at both the supply and demand side of transportation analysis, inter alia by focussing the attention on behavioural foundations and the level of change in spatial systems (macro-micro/meso). (See also Section 4 and 5 for a typology of such models and their specific development, respectively).

It is therefore evident that in parallel to policy life cycle issues also research interest shows its own life cycle in phase a) of Figure 1. It should also be noted that this first stage a) in a research life cycle is directly linked to stage b) of policy formulation, which, as already indicated in Section 3.1, is characterized by an increasing consensus on the seriousness of issues and a growing political attention for formulating policies, so that various similarities may emerge between these two stages.

The same happens in the context of life cycle research since the first phase of information and exploration is directly connected with modelling and formulations of statistical techniques, with return-effects determined by signals in a policy life cycle.

Moreover, in the specific context of stage b) it is noteworthy that transportation research and planning is recently also showing an increasing interest in subsystems that directly or indirectly interact with transport, such as the population and household subsystem, which -through their evolution- determine the demand side in a transport-network; or the facilities sector, which -by means of an improved or advanced transportation technology- have a far-reaching impact on the supply side; or the freight transport sector, determined by the evolution of economic/technological/ productive subsystems and interrelated with both the demand and supply side in a transportation system. Thus nowadays transportation research and policy formulation are clearly becoming a **multidimensional** activity focusing on multiple (public and private) interests and linkages (see Nijkamp et al., 1989).

As regards the last two stages (stages c) and d)) of the life cycle hypothesis, we have to stress that in many countries a gap between the increasing technical sophistication of transport planning studies and models and their implementation in the planning process seems to emerge. Consequently, a point B of bifurcation can arise in the scientific research (see Figure 1) clearly connected with point A of bifurcation in the policy life cycle mentioned in Section 3.1).

Clearly, one way to bridge this gap would be an improvement of the operational character of the models by increasing the information-processing capacity (e.g., by means of the installation of computerized transport planning and management information systems). Complementary to this approach, it would also be necessary to make the methods used more transparent and accessible to planners and politicians , e.g., on the basis of an interactive decision-support system (see again Nijkamp et al., 1989).

Finally it should be noted that the emergence of new models displaying irregular behaviour (as we will describe subsequently) and hence 'unpredictable movements', can create, in certain cases, also a gap between implementation and management of the models, so that a bifurcation point C can appear in the presence of the problem of 'predicting the unpredictable'.

4. Typology of Dynamic Transportation Models

4.1 Introduction

In this section, we will give a more in-depth overview of dynamic transportation models (at the demand side) in order to show in more detail various aspects of the above mentioned life cycle phenomenon. As we noted in Section 3 the last decade has shown a boom in the interest in the development of both behavioural and dynamic models, as it is generally expected that such models are capable to describe and represent the behavioural mechanisms underlying the evolutionary changes in complex spatial systems. In this context transportation -and spatial interaction models in general- have been a focal point of analysis, since they deal with the complicated and interwoven pattern of human activities in space and time. Consequently a wide variety of multi-temporal or dynamic transportation models has arisen in the past decade with the aim of providing a stronger and more useful analytical support to planning processes than conventional static tools (such as static spatial interaction models, linear programming, etc.).

However, despite all progress made in this new research direction (mostly from a theoretical viewpoint), still some important research questions remain, which largely concern the applicability of these dynamic models in relation to the scale of analysis at which various operational developments of these models are taking place. In particular, this important field of reflection concerns the advantages and disadvantages related to the use of macro-meso-micro approaches.

On the one hand, it is evident that aggregate representation may become extremely cumbersome and inefficient when it is necessary to represent complex systems, especially where there is considerable heterogeneity amongst the actors in those systems (see Clarke and Wilson, 1986). On the other hand, it is clear that the problems of data availability and computational processing requirements are often in contrast with the need to use a micro-oriented approach. Moreover, the response of a population in aggregated models does not always correspond to an aggregation of the individual responses obtained from a micro model, so that is seems evident that the phenomena being studied require a careful consideration as regards the nature of their level of analysis (see again Clarke and Wilson, 1986). This problem has also been treated in analytical attempts focussing the attention on the interdependencies between micro- and macro-responses, which also depend on the interaction between demand and supply.

In this context of a clearer interpretation of the life cycle evolution of such analyses, we will now briefly present the main groups of dynamic analyses which have been developed so far, viz. macro and and meso-micro approaches.

4.2 Macro-dynamic approaches

Several dynamic models of spatial structure have recently been developed at a macro level. We will give here a few illustrations. An example is the model developed by Allen et al. (1978), in which the evolutionary growth of zonal activities is assumed to follow a logistic pattern. Allen et al.' model is a comprehensive model representing urban activities such as employment and residential population. A major finding in this model is that random fluctuations (e.g., changes due to infrastructure constructions) may alter the related urban evolution.

Another dynamic model of the logistic type is the one developed by Harris and Wilson (1978) and Wilson (1981). In this case the standard static spatial interaction model for activity allocation has been embedded into a dynamic evolutionary framework, again of a logistic type. Bifurcations and catastrophic behaviour emerge from this model, depending on particular values of the parameters. Obviously owing to this logistic structure also oscillations and cycles may occur.

These two important models have induced a wide spread production of related models both from theoretical and empirical viewpoints, also in a stochastic framework (see also Nijkamp and Reggiani, 1988). However, it should also be noted that the above mentioned two models primarily focus on the supply side, without clear dynamic equations of the demand side.

Another stream of research at the macro-level is the series of models based on ecological dynamics of the Volterra-Lotka type (see Dendrinos and Mullally, 1981); in this formulation of interacting biological species, each species is characterized by a birth-death process of the logistic type. Recent papers on this topic show the integration between ecological models and optimal control models (Nijkamp and Reggiani, 1987), between ecological models and random fluctuations of a white noise type (Campisi, 1986) or between ecological models, spatial interaction models of a gravity type and turbulence (Dendrinos, 1988).

Obviously, since a Lotka-Volterra system is a system of interrelated equations, we get by necessity here interaction mechanisms of supply and demand. Furthermore, given the related logistic form, it is also here again possible to get -for critical parameter values- oscillations and complex behaviour.

The last group of macro approaches can be found in the area represented by models based on optimal control approaches or dynamic programming analysis. Also here different forms of equilibrium/disequibrium may emerge (e.g., saddle points, borderline stability) which show the possibility of unstable motions.

As a synthesis we may conclude that a common trend in these groups of macro-approaches is the development of models that are able to exhibit (under certain conditions) complex or chaotic behaviour and hence outcomes which are hardly foreseeable by modellers and planners. This lack of predictability of future events is clearly also a major concern in transportation planning and reflects essentially the beginning of a new phase of a life cycle. Thus another important research problem is emerging, i.e., the relevance of critical parameter values, such as their speed of change in a geographic or planning context in order to understand whether the system at hand is moving towards a predictable or complex (unpredictable) evolution.

4.3 Micro-meso dynamic approaches

In this subsection we will briefly pay attention to the considerable body of literature based on micro simulation models (see Clarke and Wilson, 1986). Given the above mentioned drawbacks related to a macro-approach, a mixture of aggregate dynamic models in conjunction with micro-simulation (the micro-meso approach) has recently been advocated and adopted for various spatial applications (see also Birkin and Clarke, 1983). In this way also an integration between demand and supply results is possible. In other words, micro-meso dynamic approaches utilize individual data in conjunction with aggregate equations.

Another interesting micro-meso approach is the well-known logit model, based on a micro-economic foundation. It has recently been shown (see Nijkamp and Reggiani, 1989) that the growth over time of people choosing such alternatives as travel choice mode, destination, etc. according to a logit procedure can follow again a logistic pattern. In general, a system of a Lotka-Volterra type with limited prey results. Thus development can also lead to a chaotic or irregular behaviour for particular values of the utility function.

In this area also the master equation/mean value equation models (see Haag and Weidlich, 1984; Haag, 1989) have to be mentioned. These models have been used extensively in spatial flow analysis. This framework models the uncertainties in the decision process of the individuals via the master equation approach. The mean values are then obtained from the master equation by an aggregation of the individual probability distributions. Thus this approach provides the link between micro-economic aspects and the macro-economic equation of motions for aggregate mean values.

In this context also compartmental analysis should be mentioned (see De Palma and Lefevre, 1984) which consists of equations which are the approximate mean-value equations. It has recently been shown (see Reiner et al., 1986) that also these meanvalue equations may display chaotic behaviour with strange attractors, given particular conditions for the group interaction. On the other hand, this result is not surprising, since the mean value equations are strongly related to logit models. Hence it is plausible that interrelated logistic functions underlie the emerging chaotic motions.

After this brief review based on a typology of dynamic models and their potential in transportation planning with respect to the scale of analysis, we will now incorporate them in the framework of a life cycle (evolutionary) pattern.

5. Life Cycle of the Transportation Models

5.1 General results

The models discussed in the previous section can be unified in the broad area of DMs and then compared, in their evolution, to the groups of static SIMs and DCMs, in the light of life cycle concepts. As a synthesis, we can represent the series of the transportation models studied and adopted so far according to the scheme of overlapping generations illustrated in Figure 3.

In Figure 3 we have essentially depicted the generation and diffusion of the three main families of models which have received a great deal of attention in the last century, i.e., Spatial Interaction Models (SIMs), Discrete Choice Models (DCMs) and Dynamic Models (DMs).

From Figure 3 we can see that -while SIMs present a smooth development at the beginning of the century with more emphasis after the sixties- DCMs and DMs exhibit a rapid growth (from both a theoretical and empirical point of view). It should be noted that in DMs we have included the whole group of dynamic models treated so far, so that we can observe that after the mid seventies a broad number of mathematical models emerged.

Altogether we can notice an overlapping generation of models: in particular we can unify all these models in a unique-general logistic shape evolving nowadays; consequently we can expect that we are likely to approach a saturation level of the development of the above mentioned models.

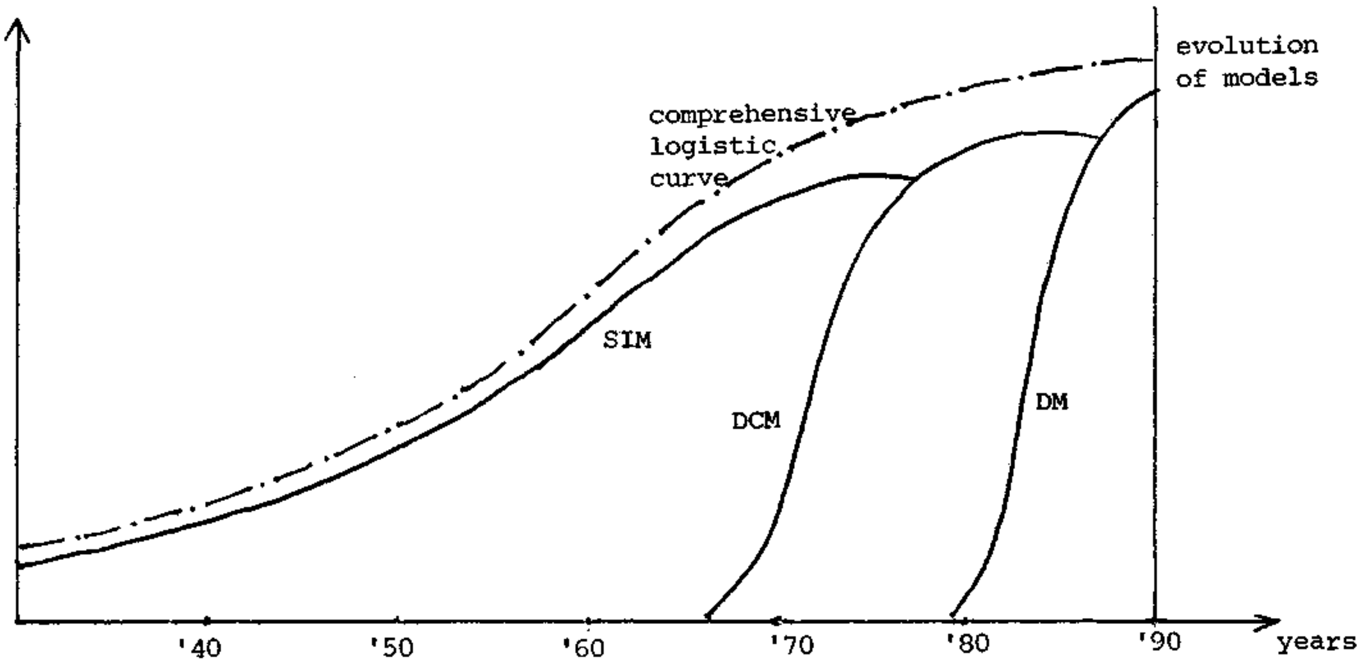

Figure 3 Overlapping Generations of Models

Legend: SIMs = Spatial Interaction Models
DCMs = Discrete Choice Models
DMs = Dynamic Models
Y-axis = Development of the models
X-axis = Years

Probably, from this upper level, new tools will emerge in the next century, in response to new activity patterns. This upper level can likely be linked to the analytical structure of the models, since there are inevitable constraints in their formulation, so that also from a mathematical point of view the potential of such models will certainly reach a limit.

An example can be found by analyzing the contents and evolution of recent dynamic models (see Section 4). It has become clear that most of these models can be reformulated in terms of a logit-logistic formulation, so that the potential of those models is essentially governed by a logistic structure.

In the next subsection a specific discussion on the use of SIMs, DCMs and DMs will be presented in the light of their link to the above mentioned life cycle idea.

5.2 Spatial interaction models

SIM is the most widely used type of models: firstly its theoretical origin is manifold since it may emerge from physics, information theory and economic utility theory. Secondly its application in several contexts is easy to handle so that SIM can give, in principle, a general understanding of spatial patterns such as general predictions on the variables concerned. Consequently, SIMs were very successful in research connected with policy issues oriented to a capacity transport system expansion (in the sixties and the seventies).

5.3 Disaggregate choice models

The need of explaining and predicting the mobility patterns by regarding also the individual behaviour and its perception with respect to some policy constraints (such as cost, time, lack of capacity, etc.) have focussed the attention, in the seventies, toward DCMs. DCMs in fact, by regarding the micro-scale of analysis (see also Section 3), provide a clearer understanding of behavioural patterns (in comparison to SIMs).

The rapid growth of this type of models is the consequence of these needs mostly with respect to long-term forecasts related to various spatial policies (e.g., mobility reaction to changes in infrastructures, etc.).

5.4 Dynamic models

The awareness that non-linear systems can show disequilibrium patterns (with evident problems in predicting the long-time behaviour of these systems) had led the research development towards this group of models (see also Section 4). In particular phenomena like bifurcations and chaos received much attention due to their capability of representing dramatic changes or irregular behaviour.

In Section 4 we have shown how many models can be reconducted as constituents of the evolutionary framework of a logistic type: consequently, depending on the parameter values and initial conditions, these models may show bifurcation cycles and irregular behaviour when they are treated in a discrete context (see May, 1976).

Much attention, therefore, should certainly be paid to the initial conditions or critical parameter values which seem to govern the transition from order to bifurcation and chaos.

Consequently in this third group of models, policy issues are not concerned any more with the movements of aggregate variables, or of individual behaviour, but with the speed of change of the parameters in the systems at hand.

The manipulation by politicians of these parameters is at the end the only way of governing these kinds of models and reconducting them to the well-known area of 'predicting the predictable'.

6. Conclusions

In this paper the link between transportation planning issues and transportation models has been investigated in the light of the life cycle concept. The booming interest in dynamic transport models, which are able to describe and explain the evolutionary mobility patterns, was outlined, with particular reference to the emergence of new models displaying irregular behaviour and hence (seemingly) unpredictable movements. It has been argued that the different typologies of dynamic approaches (macro, meso/micro) can be reconducted, under certain conditions, to the well-known family of logistic models, capable to capture unstable behaviour.

Consequently, it seems necessary to focus the attention on the study of critical parameter values which can be manipulated by planners in order to avoid unpredictable or uncontrolled movements.

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