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Land-Use Transport Interaction: State of the Art

Deliverable 2a of the project TRANSLAND (Integration of Transport and Land Use Planning) of the 4th RTD Framework Programme of the European Commission

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Contents

Figures

Tables

Executive Summary

Introduction

The EU research project TRANSLAND is a study on innovative policies and future research needs in the field of integrated urban transport and land-use planning. TRANSLAND serves two objectives. It looks backward in identifying good planning practice examples, insights from conducted research in this field and institutional conditions and barriers for integrated policy making and it looks ahead to advise on best planning practice and to recommend future research and policy development.

This TRANSLAND Deliverable 2a is part of a review on the state of the art in the theory of land-use transport interaction at the urban-regional level. The review covers both technical, behavioural and institutional issues of land-use transport interaction at the urban-regional level, i.e.

- impacts of local land use policies on the behaviour of travellers and, vice versa, impacts of transport policies on the location behaviour of households and firms within urban regions ('What');

- potentials and problems of co-ordination of land use and transport policies at the urban-regional level in different national and regional institutional contexts ('How').

This TRANSLAND Deliverable 2a addresses the 'What' issues, i.e. the technical and behavioural aspects of the integration of urban transport and land use. It reviews theoretical and conceptual work on land-use transport interaction and land-use transport policy integration at the urban-regional level existing in the Member States and from previous and ongoing RTD projects for the European Commission. Relevant national research exists particularly in the Netherlands, Germany, Austria and the Nordic countries, in which the integration of transport and land-use transport planning has been an integral part of urban and regional planning for several decades. The review includes a summary of theoretical results from transport science, urban economics and urban geography as well as an overview of the state of the art in land-use transport models including the work of the International Study Group on Land-Use Transport Interaction (ISGLUTI). The focus is on the identification of theoretically promising policies or policy mixes. Although the emphasis is on European research, relevant results from North America are considered. Among work for the European Commission, RTD projects such as DANTE, EUROSIL, LEDA, SESAME and SPARTACUS and the work connected with COST 332 are examined.

In the companion TRANSLAND Deliverable D2b (Greiving and Kemper, 1999), the 'How' questions, i.e. the institutional potential for and barriers to the co-ordination of land use and transport policies at the urban-regional level in the different institutional settings of the member states and the potential barriers to such co-ordination are reviewed.

Theory of Land-Use Transport Interaction

Theories on the two-way interaction between urban land use and transport address the locational and mobility responses of *private* actors (households and firms, traveller) to changes in the urban land use and transport system at the urban-regional level.

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

However, the reverse impact from transport to land use, is less well known. There is some vague understanding that the evolution from the dense urban fabric of medieval cities, where almost all daily mobility was on foot, to the vast expansion of modern metropolitan areas with their massive volumes of intraregional traffic would not have been possible without the development of first the railway and in particular the private automobile, which has made every corner of the metropolitan area almost equally suitable as a place to live or work. However, exactly how the development of the transport system influences the location decisions of landlords, investors, firms and households is not clearly understood even by many urban planners.

The recognition that trip and location decisions co-determine each other and that therefore transport and land-use planning needed to be co-ordinated led to the notion of the 'land-use transport feedback cycle'. The set of relationships implied by this term can be briefly summarised as follows (see Figure 1):

- The distribution of *land uses*, such as residential, industrial or commercial, over the urban area determines the locations of human *activities* such as living, working, shopping, education or leisure.

- The distribution of human *activities* in space requires spatial interactions or trips in the *transport system* to overcome the distance between the locations of activities.

- The distribution of infrastructure in the *transport system* creates opportunities for spatial interactions and can be measured as *accessibility*.

- The distribution of *accessibility* in space co-determines location decisions and so results in changes of the *land-use* system.

The major theoretical approaches to explain this two-way interaction of land use and transport in metropolitan areas include technical theories (urban mobility systems), economic theories (cities as markets) and social theories (society and urban space). The results of these theories of land-use transport interaction are summarised in Tables 1 and 2 in terms of expected impacts of essential factors such as urban density, employment density, neighbourhood design, location, city size, accessibility, travel cost and time.

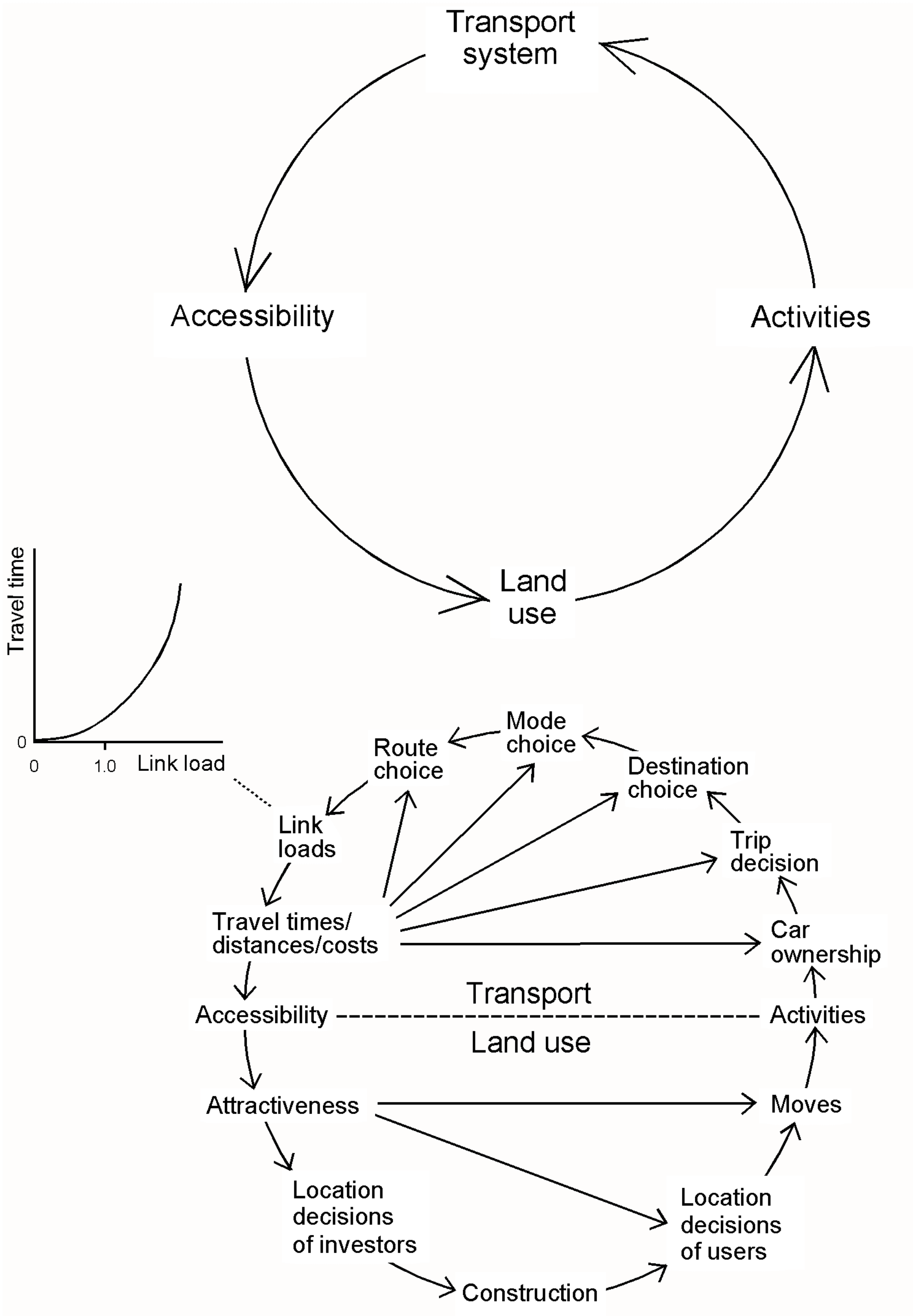

Figure 1. The 'land-use transport feedback cycle'.

Table 1. Theoretically expected impacts of land use

Direction	Factor	Impact on	Expected impacts
Land use ⇓ Transport	Residential density	Trip length	Higher residential density alone will not lead to shorter trips. A mixture of workplaces and residences can lead to shorter trips if travel costs are increased.
		Trip frequency	Little impact expected. If trips are shorter, more trips may be made.
		Mode choice	Minimum residential densities are a prerequisite for efficient public transport. More walking and cycling trips will be made only if trips become shorter (see above).
	Employment density	Trip length	Concentration of workplaces in few employment centres tends to increase average trip lengths. A balance of workplaces and residences in an area would lead to shorter work trips only if travel becomes more expensive.
		Trip frequency	Little impact expected. If trips are shorter, more trips may be made.
		Mode choice	Concentration of workplaces in few employment centres may reduce car use if supported by efficient public transport. More walking and cycling trips will be made only if trips become shorter (see above).
	Neighbourhood design	Trip length	Attractive public spaces and a variety of shops and services can induce more local trips.
		Trip frequency	If trips are shorter, more trips may be made.
		Mode choice	Street layout, pedestrian spaces and cycling lanes could lead to more walking and cycling.
	Location	Trip length	More peripheral locations tend to have longer trips.
		Trip frequency	No impact expected.
		Mode choice	Locations close to public transport stations should have more public transport trips.
	City size	Trip length	Trip length should be negatively correlated with city size.
		Trip frequency	No impact expected.
		Mode choice	Larger cities can support more efficient public transport systems, so more trips should be made by public transport in larger cities.

Table 2. Theoretically expected impacts of transport

Direction	Factor	Impact on	Expected impacts
Transport ⇓ Land use	Accessibility	Residential location	Locations with better accessibility to workplaces, shops, education and leisure facilities will be more attractive for residential development, have higher land prices and be developed faster. Improving accessibility locally will change the direction of new residential development, improving accessibility in the whole urban area will result in more dispersed residential development.
		Industrial location	Locations with better accessibility to motorways and railway freight terminals will be more attractive for industrial development and be developed faster. Improving accessibility locally will change the direction of new industrial development.
		Office location	Locations with better accessibility to airports, high-speed rail railway stations and motorways will be more attractive for office development, have higher land prices. Improving accessibility locally will change the direction of new office development.
		Retail location	Locations with better accessibility to customers and competing retail firms will be more attractive for retail development, have higher land prices and be faster developed. Improving accessibility locally will change the direction of new retail development.
Transport ⇓ Transport	Accessibility	Trip length	Locations with good accessibility to many destinations will produce longer trips.
		Trip frequency	Locations with good accessibility to many destinations will produce more trips.
		Mode choice	Locations with good accessibility by car will produce more car trips: locations with good accessibility by public transport will produce more public transport trips.
	Travel cost	Trip length	There is a strong inverse relationship between travel cost and trip length.
		Trip frequency	There is a strong inverse relationship between travel cost and trip frequency.
		Mode choice	There is a strong relationship between travel cost and choice of travel mode.
	Travel time	Trip length	There is a strong inverse relationship between travel time and trip length.
		Trip frequency	There is a strong inverse relationship between travel cost and trip frequency.
		Mode choice	There is a strong relationship between travel cost and choice of travel mode.

Table 1 illustrates the impact of land use policies on transport patterns from a theoretical point of view. The impact of high residential density in reducing average trip length is likely to be minimal in the absence of travel cost increases, whereas a high density of employment is positively correlated with average trip length. Attractive neighbourhood facilities can be seen as a 'pull' factor for reducing trip length. Since more peripheral locations usually have longer trips, trip length can be expected to be negatively correlated with city size. With regard to trip frequency little or no impact is to be expected from land use policies according to Zahavi's theory of fixed travel budgets. Residential and employment density as well as large agglomeration size and good public transport accessibility of a location tend to be positively correlated with the modal share of public transport, while neighbourhood design and a mixture of workplaces and residences with shorter trips are likely to have a positive impact on the share of cycling and walking.

Table 2 illustrates the impact of transport policies on land use and the impact of transport policies on transport patterns. The latter impacts are included because they tend to be much stronger than those of land use on transport or transport on land use. The impact of transport on land use is mediated by a change in the accessibility of a location. Higher accessibility increases the attractiveness of a location for all types of land uses thus influencing the direction of new urban development. If, however, accessibility in an entire city is increased, it will result in a more dispersed settlement structure.

The impacts of transport policies on transport patterns are clearer and stronger compared to the interplay of land use and transport. While travel cost and travel time have a negative impact on both trip length and trip frequency, accessibility has a positive impact on trip length and frequency. Mode choice is dependent upon the relative attractiveness of a mode compared to all other modes. The fastest and cheapest mode is likely to have the highest modal share.

In general, the theoretical considerations support the conclusion that the impact of 'pull' measures, i.e. land use measures, is much weaker than the impact of 'push' measures, i.e. increases in travel time, travel cost etc.

'Ideal' Land-Use Transport Systems

A variety of 'ideal' land-use transport systems as optimal solutions to urban land-use and transportation problems have been formulated since the late 19th century. These systems vary with regard to spatial structure, residential density, distribution of land uses and predominant transport mode. Since some of these systems evolved from earlier concepts based on similar assumptions, it is useful to illustrate the interrelationships between these structural types. Each of the approaches towards an 'ideal' land-use transport system can be assigned to three basic types of urban spatial structure:

- Point structures. These are city types oriented towards the central point of the urban system, usually the inner city, as exemplified by the compact city model.
- Linear structures. These are city types built along a line, usually a large transport infrastructure, as exemplified by Soria y Mata's linear city concept.
- Area structures. These are city types with low density development which lack a clear spatial hierarchy and central structure, as exemplified in Wright's Broadacre City.

Departing from these three basic types, various hybrid forms of land-use transport systems can be identified. The axial system, for instance, is a formation of several linear structures aligned towards an urban centre, thus being a hybrid form between a linear city and a compact city.

Attempts to determine the 'ideal' land-use transport system in contemporary cities have yielded different results. While it has almost become common wisdom that systems involving dispersed development are much less favourable with regard to average trip length, energy consumption, greenhouse gas emissions and land take, there is no unequivocal evidence for the advantages of either compact-city or decentralised-concentration policies. Eventually, the appropriateness of a certain land-use transport system depends on a variety of case-specific factors, such as agglomeration size and the pre-existing spatial structure.

The definition of 'ideal' land-use transport systems cannot directly help to identify policies for sustainable urban transport. However, the value of defining such 'ideal' land-use transport system is to be seen in the structured categorisation of options for urban structures to be systematically investigated by other approaches.

Empirical Studies of Land-Use Transport Interaction

The results of empirical studies of land-use transport interaction are summarised in Tables 3 and 4 with regard to factors identified in such studies.

Table 3 describes the impact of land use policies on transport patterns. Residential density has been shown to be inversely related to trip length. Centralisation of employment results in longer trips, while trip lengths are shorter in areas with a balanced residents-to-workers ratio. American studies confirm that attractive neighbourhood facilities also contribute to shorter average trip lengths. The theoretical insight that distance of residential locations to employment centres is an important determinant of average trip length has been confirmed empirically. The larger a city is the shorter are mean travel distances with the exception of some of the largest metropolises. None of the studies reported a significant impact of any factor on trip frequency.

Residential and employment density as well as large agglomeration size and rapid access to public-transport stops of a location were found to be positively correlated with the modal share of public transport. 'Traditional' neighbourhoods showed a higher share of non-car modes.

Table 4 illustrates the impact of transport policies on land use and the impact of transport policies on transport patterns. The latter impacts are included because they tend to be much stronger than those of land use on transport or of transport on land use.

Accessibility was reported to be of varying importance for different types of land uses. It is an essential location factor for retail, office and residential uses. Locations with high accessibility tend to be developed faster than other areas. The value of accessibility to manufacturing industries varies considerably depending mainly on the goods produced. In general, ubiquitous improvements in accessibility invoke a more dispersed spatial organisation of land uses.

Table 3. Impacts of land use in empirical studies

Direction	Factor	Impact on	Observed impacts
Land use ⇓ Transport	Residential density	Trip length	Numerous studies support the hypothesis that higher density combined with mixed land use leads to shorter trips. However, the impact is much weaker if travel cost differences are accounted for.
		Trip frequency	Little or no impact observed.
		Mode choice	The hypothesis that residential density is correlated with public transport use and negatively with car use is widely confirmed.
	Employment density	Trip length	In several studies the hypothesis was confirmed that a balance between workers and jobs results in shorter work trips, however this could not be confirmed in other studies. Mono-functional employment centres and dormitory suburbs, however, have clearly longer trips.
		Trip frequency	No significant impact was found.
		Mode choice	Higher employment density is likely to induce more public transport use.
	Neighbourhood design	Trip length	American studies confirmed that 'traditional' neighbourhoods have shorter trips than car-oriented suburbs. Similar results are found in Europe.
		Trip frequency	No effects are reported.
		Mode choice	'Traditional' neighbourhoods have significant higher shares of public transport, walking and cycling. However, design factors lose in importance once socio-economic characteristics of the population are accounted for.
	Location	Trip length	Distance to main employment centres is an important determinant of distance travelled.
		Trip frequency	No effect observed.
		Mode choice	Distance to public transport stops strongly influences public transport use.
	City size	Trip length	Mean travel distances are lowest in large urban areas and highest in rural settlements.
		Trip frequency	No effect observed.
		Mode choice	Public transport use is highest in large cities and smallest in rural settlements.

Table 4. Impacts of transport in empirical studies

Direction	Factor	Impact on	Observed impacts
Transport ⇓ Land use	Accessibility	Residential location	More accessible locations are developed faster. If accessibility in the whole region grows, residential development will be more dispersed.
		Industrial location	There is little evidence of impacts of accessibility on location of manufacturing, but ample evidence of the importance of accessibility for high-tech and service firms.
		Office location	Office development occurs predominantly at highly accessible inner-city locations or in office parks or 'edge cities' at the urban periphery with good motorway access.
		Retail location	Retail development occurs either at highly accessible inner-city locations or on peripheral sites with ample parking and good road accessibility.
Transport ⇓ Transport	Accessibility	Trip length	Suburban dispersal accelerated by good accessibility to the central city generates longer work and shopping trips.
		Trip frequency	No systematic studies on the impact on trip frequency are known.
		Mode choice	Accessibility differences generate modal shifts via travel time and travel cost (see below).
	Travel cost	Trip length	Price elasticity of trip length was found to be in the range of -0.3.
		Trip frequency	No systematic studies of trip frequency as a function of travel cost are known.
		Mode choice	Travel cost differences influence modal choice; making public transport free will not induce many car drivers to switch to public transport, mainly former walkers and cyclists.
	Travel time	Trip length	Travel time savings through transport system improvements are partly spent on longer trips.
		Trip frequency	Travel time savings through transport system improvements are partly spent on more trips.
		Mode choice	Travel time improvements on one mode strongly influence modal choice.

Regarding impacts of transport policies on transport patterns, causal relationships are relatively undisputed and empirical studies largely agree on the impact mechanisms. While travel cost and travel time tend to have a negative impact on trip length, high accessibility of a location generates longer work and leisure trips. Studies on changes in trip frequency are only known for travel time improvements, where time savings were found to result in more trips being made. Mode choice depends on the relative attractiveness of a mode compared to all other modes. The fastest and cheapest mode is likely to have the highest modal share. However, offering public transport free of charge will not induce a significant mode switch of car drivers, rather of walkers and cyclists.

Models of Land-Use Transport Interaction

Predicting the impacts of integrated land-use transport policies is a difficult task due to the multitude of concurrent changes of pertinent system variables. In general, there are three groups of methods to predict those impacts. The first one is to ask people about their anticipated reaction to changes such as increased transport costs or land use restrictions ('stated preference'). The second possibility is to draw conclusions from empirically observed behaviour of people ('revealed preference'). The third group of methods comprises mathematical models to simulate human decision making and its consequences. While all of the three possibilities have shortcomings, mathematical models are the only method to forecast still unknown situations and to determine the effect of a single factor while keeping all other factors fixed.

Urban land-use transport models incorporate the most essential processes of spatial development including all types of land uses. Transport may be modelled either endogenously or by an exogenous transport model. Urban systems represented in land-use transport models can be divided into nine subsystems according to the speed by which they change. The urban fabric consisting of infrastructure networks and land use patterns is subject to very slow change over time. Workplaces and housing change relatively slow while the employment and residential population adjust their spatial behaviour fairly quickly to changing circumstances. Goods transport or travel destinations are the most flexible phenomena of urban spatial development. They can be modified almost instantly according to changes in congestion or fluctuations in demand. A ninth subsystem, the urban environment, is more complex regarding its temporal behaviour.

A number of integrated land-use transport systems are in use today. There are significant variations among the models as concerns overall structure, comprehensiveness, theoretical foundations, modelling techniques, dynamics, data requirements and model calibration. Despite the achievements in developing these models further, there remain some challenges to be met. The transport submodels used in current land-use transport models do not apply state-of-the-art activity based modelling techniques but the traditional four-step travel demand model sequence which is inadequate for modelling behavioural responses to many currently applied travel demand management policies. The most promising technique for activity-based transport modelling is microsimulation which makes it possible to reproduce the complex spatial behaviour of individuals on a one-to-one basis.

In addition, the spatial resolution of present models is still too coarse to model neighbourhood scale policies and effects. In the future, the integration of environmental submodels for air quality, traffic noise, land take and biotopes are likely to play a prominent role. Issues of spatial equity and socio-economic distributions are expected to gain similar importance in model building.

Figure 2 presents a summarising matrix in which the past and future evolution of urban land-use transport models are charted. The rows correspond to different levels of land-use modelling capability, the columns represent different levels of travel demand modelling capability.

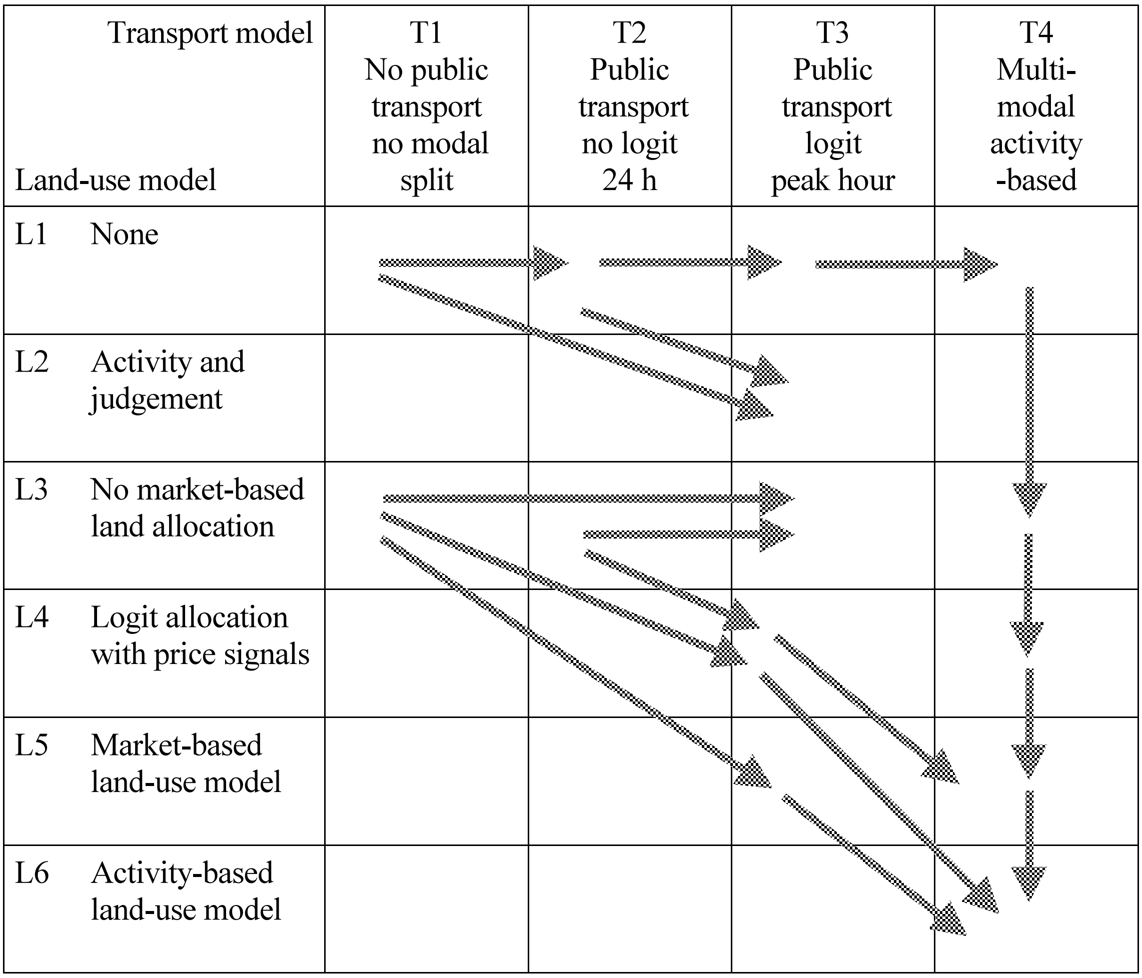

Figure 2. Evolution of urban land-use transport models (adapted from Miller et al., 1998)

Modelling Studies of Land-Use Transport Interaction

The following Tables 5 and 6 summarise how typical land-use and transport policies performed in modelling studies.

Different types of policies affecting the location of workplaces were investigated including the construction of peripheral industrial estates and out-of-town shopping centres as well as an equal distribution of employment and population. It was found that decentralisation of facilities negatively affects the economy of the inner city while trip length and mode choice depend on the specific location and spatial configuration of population and facilities in the decentralised areas. Regarding housing policies, neither the centralisation of population nor residential development in subcentres were found to have a significant impact on key transport indicators.

Land use planning policies have a major impact not only on spatial development but also on travel patterns. Development restrictions, e.g. a green belt around the city, can retard the suburbanisation of population and workplaces thus strengthening the economy of the city centre.

As concerns the impact of transport policies, a number of common examples were examined. One of them concerns the construction of an outer ring road which results in further decentralisation, relief of congestion and increasing travel distances. New public transport lines have little impact on location choices, except where new radial lines significantly improve the accessibility of suburban locations, but tend to strengthen the inner-city economy. Introducing speed limits results in shorter trips and increased use of public transport. The effect of increased fuel taxes on the number and length of car trips is particularly strong. Significant fuel tax increases curb the further dispersal of residences and workplaces. Higher downtown parking fees generate negative economic effects in the centre and make out-of-town shopping centres more attractive. Public transport use free of charge reinforces a pattern of centralised employment and decentralised residential locations. Volume and length of car trips remain by and large unaffected by this measure.

EU 4th RTD FP Studies of Land-Use Transport Interaction

The findings of the studies carried out within the European Commission's 4th RTD Framework Programme are largely in line with other theoretical and empirical results reviewed in this report. The SESAME study showed that the share of automotive travel in modal choice decreases with increasing size for cities above a threshold of over 750,000 inhabitants. For cities below the threshold, a slightly positive relationship between city size and the modal share of cars was found. The study reports that urban density and the share of non-motorised travel and public transport modes are positively correlated. Car ownership rate and the car share in modal choice were found to be positively related. However, the assumption that the daily time budget allocated to travel is fixed regardless of prevailing land-use and transport patterns could not be verified. The mean total time used for daily travelling varied between 50 and 90 minutes in the case study cities and was found to be heavily dependent on the particular modal split of a city.

The EUROSIL project found that infrastructure investments will only induce significant economic growth in areas where isolation and bottleneck situations are being resolved. Similarly, infrastructure investment enhances economic growth only in areas where economic basis and growth were already existing prior to the investment. The only factors relevant for mode choice seem to be travel/transport times and costs.

Table 5. Impacts of land-use policies in modelling studies (examples)

Policy area	Policy type	Policy	Examples	Model impact
Land use	Investment and services	Work places	Peripheral industrial estate	Decentralisation of non-service employment, negative economic impact on city centre, little effect on population. Travel distance may increase but also decrease if location closer to already decentralised population.
			Out-of-town shopping centre	Strong decentralisation effect on retail employment and population, negative economic impact on city centre. Distances increase or decrease depending on the location. Car use increases.
			Employment distributed as population	Travel distances and travel times decreasing. Effect on modal choice ambiguous: share of car increases in some cities as work places are more dispersed. Walk and cycle trips increase as trips become shorter.
		Housing	New residential development concentrated in subcentres	Little impact on travel distances, mode choice and energy consumption.
			Centralisation of population as employment	Only slightly reduced trip distances, share of car trips and energy use.
	Planning	General land use plan	Development restrictions (green belt)	Significant retardation of suburbanisation of population and retail, positive economic effects on city centre. Travel distances and times decrease, increase of public transport use.
			Peripheral land made available for development	Acceleration of suburbanisation, increasing travel distances and car use.

Table 6. Impacts of transport policies in modelling studies (examples)

Policy area	Policy type	Policy	Examples	Model impact
Transport	Investment and services	Road construction	Outer ring road	Further decentralisation of population, uncertain effect on non-service employment location. Less congestion in the city centre, positive effect on downtown retail. Travel distances increase, mainly by car.
		Public transport lines	New public transport lines	Little impact on residential location, except where new radial lines significantly improve the accessibility of suburban locations, small centralisation effect on employment. Positive economic effect on city centre. Increased public transport use at the expense of car and walking.
	Regulation	Traffic regulations	Speed limits on car travel	Significant reduction of trip length by car and increase of public transport trips. Little impact on residential location; somewhat faster decentralisation of employment.
	Pricing and subsidies	Fuel taxes	Higher fuel taxes	Strong reduction of number and length of car trips and significant shift to public transport. Retardation of decentralisation of employment and population.
		Parking fees	Higher central area parking fees	Negative economic effects on inner cities and longer shopping trips (by car) to out-of town shopping centres
		Public transport fares	Public transport free	Less decentralisation of employment and more of population. Benefits for inner-city retail. Strong increase in distance travelled but little reduction in car trips.

Successful Land Use and Transport Policies

The following findings for successful land-use and transport policies based on theories, empirical and modelling studies investigated can be summarised:

- Land-use and transport policies are only successful with respect to criteria essential for sustainable urban transport (reduction of travel distances and travel time and reduction of share of car travel) if they make car travel less attractive (i.e. more expensive or slower).

- Land-use policies to increase urban density or mixed land-use without accompanying measures to make car travel more expensive or slower have only little effect as people will continue to make long trips to maximise opportunities within their travel cost and travel time budgets. However, these policies are important in the long run as they provide the preconditions for a less car-dependent urban way of life in the future.

- Transport policies making car travel less attractive (more expensive or slower) are very effective in achieving the goals of reduction of travel distance and share of car travel. However, they depend on a spatial organisation that is not too dispersed. In addition, highly diversified labour markets and different work places of workers in multiple-worker households set limits to a optimum co-ordination of work places and residences.

- Large spatially not integrated retail and leisure facilities increase the distance travelled by car and the share of car travel. Land-use policies to *prevent* the development of such facilities ('push') are more effective than land-use policies aimed at *promoting* high-density, mixed-use development ('pull').

- Fears that land-use and transport policies designed to constrain the use of cars in city centres are detrimental to the economic viability of city centres have in no case been confirmed by reality (except in cases where at the same time massive retail developments at peripheral greenfield locations have been approved).

- Transport policies to improve the attractiveness of public transport have in general not led to a major reduction of car travel, attracted only little development at public transport stations, but contributed to further suburbanisation of population.

In summary, if land-use and transport policies are compared, transport policies are by far more direct and efficient in achieving sustainable urban transport. However, accompanying and supporting land-use policies are essential for in the long run creating less car-dependent cities.

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- Michael Wegener and Franz Fürst (1999): *Land-Use Transport Interaction: State of the Art*. Berichte aus dem Institut für Raumplanung 46. Dortmund: Institut für Raumplanung, Universität Dortmund.
- Claude Noel (1999): *Integration of Land-Use and Transport Planning: Review of Practice*. Lyon: Centre d'Études des Transports Urbains.
- Carlo Sessa and Mario Gualdi (1999): *Integration of Land-Use and Transport Planning: Structured Overview*. Rome: Istituto di Studi per l'Informatica e Sistemi.

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1. Introduction

The EU research project TRANSLAND is a study on innovative policies and future research needs in the field of integrated urban transport and land-use planning. TRANSLAND serves two objectives. It looks backward in identifying good planning practice examples, insights from conducted research in this field and institutional conditions and barriers for integrated policy making and it looks ahead to advise on best planning practice and to recommend future research and policy development. Important activities within TRANSLAND to fulfil these objectives are:

- identifying existing good practice and its transferability;
- overviewing administrative and legal provisions influencing integrated policies;
- deriving recommendations for enhancing instruments and planning procedures at the EU level; and
- selecting and prioritising areas for further research and institutional development.

TRANSLAND consists of eight main work packages:

1. Outline of concept
2. Review of the state of the art
3. Inventory of current practice
4. Structured overview
5. Workshop
6. Research agenda and priorities
7. Best practice
8. Dissemination

Work Package 2 reviews the state of the art in the theory of land-use transport interaction at the urban-regional level and to develop a conceptual framework for the analysis of current practice in this area in Work Package 3. The review covers both technical, behavioural and institutional issues of land-use transport interaction at the urban-regional level, i.e.

- impacts of local land use policies on the behaviour of travellers and, vice versa, impacts of transport policies on the location behaviour of households and firms within urban regions ('What');

- potentials and problems of co-ordination of land use and transport policies at the urban-regional level in different national and regional institutional contexts ('How').

This TRANSLAND Deliverable D2a addresses the 'What' issues, i.e. the technical and behavioural aspects of the integration of urban transport and land use. It reviews theoretical and conceptual work on land-use transport interaction and land-use transport policy integration at the urban-regional level existing in the Member States and from previous and ongoing RTD projects for the European Commission. Relevant national research exists particularly in the Netherlands, Germany, Austria and the Nordic countries, in which the integration of transport and land-use transport planning has been an integral part of urban and regional planning for several decades. The review includes a summary of theoretical results from transport science, urban economics and urban geography as well as an overview of the state of the art in land-use transport models including the work of the International Study Group on Land-Use

Transport Interaction (ISGLUTI). The focus is on the identification of theoretically promising policies or policy mixes. Although the emphasis is on European research, relevant results from North America are considered. Among work for the European Commission, RTD projects such as DANTE, EUROSIL, LEDA, SESAME and SPARTACUS and the work connected with COST 332 are examined.

In the context of this report the term transport does not explicitly include freight transport, which is dealt with in other 4th RTD Framework Programme projects. Also a thorough discussion of the growing importance of telecommunications both as a substitute for travel and as a new intra-urban location factor (which may lead to substantial revisions of traditional theories of intra-urban locational behaviour) is not possible in this report and will have to be left to future studies.

In the companion TRANSLAND Deliverable 2b (Greiving and Kemper, 1999), the 'How' questions, i.e. the institutional potential for and barriers to the co-ordination of land use and transport policies at the urban-regional level in the different institutional settings of the Member States and the potential barriers to such co-ordination are reviewed.

2. Theory of Land-Use Transport Interaction

This chapter reviews research on the two-way interaction between urban land use and transport, i.e. the location and mobility responses of *private* actors (households and firms, travellers) to changes in the urban land use and transport system at the urban-regional level.

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

However, the reverse impact from transport to land use is less well known. There is some vague understanding that the evolution from the dense urban fabric of medieval cities, where daily mobility was on foot, to the vast expansion of modern metropolitan areas with their massive volumes of intraregional traffic would not have been possible without first the railway and then the private automobile, which has made every corner of the metropolitan area almost equally suitable as a place to live or work. However, exactly how the development of the transport system influences the location decisions of landlords, investors, firms and households is not clearly understood even by many urban planners.

In this section the major theoretical approaches to explain the two-way interaction of land use and transport in metropolitan areas are summarised.

2.1 Technical Theories: Urban Mobility Systems

Cities appeared in human history when technological innovation required the division of labour, i.e. when specialised crafts separated from agricultural labour (Sombart, 1907). The concentration of specialised skills in larger settlements released a 'tremendous expansion of human capabilities' and called for protection and exchange: the citadel and the market became the primeval urban functions (Mumford, 1961).

Based on this paradigm, the first explanations for the location and growth and decline of cities are technical: cities were established on trade routes, ports or river crossings. Classic examples of transport-generated cities are Venice and Genoa, the wealth of which was based on their sea routes, or the many cities in Europe with names ending in -ford or -furt, such as Hereford or Frankfurt. These cities declined once their locational advantage disappeared, as happened to Venice and Genoa when the discovery of the sea passage to India took their sea trade away.

Andersson (1986) speaks of 'four logistical revolutions' that have shaped the European urban system. In the Middle Ages, *safe highways* made possible long-distance trade which led to the enormous prosperity of cities in northern Italy and Germany. Safe *money exchange* facilitated international trade and the rise of London and Paris as banking capitals in the 17th and 18th centuries. The *industrial revolution* brought the railways and the explosive growth of industrial cities like Manchester and Essen in the 19th century. Today, the *integration of transport and telecommunications* (the 'real' logistical revolution) is creating the 'global' city and, in the European context, again favours London and Paris.

The technical paradigm of urban development is at the base of many theories of why some cities flourish and some stagnate or decline. Törnqvist (1968; 1970; see also Erlandsson and Lindell, 1993) developed the idea of city systems built on *contact networks* describing interactions of people and information between cities. A similar understanding of the importance of spatial interactions lies behind the concept of *employment* or *population potentials* as factors to explain the growth of centrally located cities compared with peripheral ones. On a European scale, potential analyses (e.g. Keeble et al., 1986; Bruinsma and Rietveld, 1992; Rietveld and Bruinsma, 1998; Vickerman et al., 1998) demonstrate the dominance of the high-accessibility corridor between north-west England and northern Italy, including the 'three-capital region' (London-Brussels-Paris) and the Randstad, Ruhr and Rhine-Main metropoles, a result confirmed by Brunet (1989) as the 'Blue Banana'.

The technical paradigm of urban development has gained new impetus from the appearance of new transport systems, such as high-speed rail travel and advanced telecommunications such as ISDN or satellite communication:

- One school of thought sees them as essential ingredients of 'knowledge networks', in which telecommunications carry (routine) information and high-speed rail and air (nonroutine) knowledge in the form of human experts (Batten, Kobayashi and Andersson, 1988). Being linked to the new networks is becoming vital for the success of a city; successful cities are 'network cities'.

- Hypotheses about the likely impacts of advanced telecommunications on spatial development point to the provision of high-capacity data transmission in only the largest business centres, a fact which creates zones of informational advantage around nodes of telecommunications trunk lines (Gillespie, 1991).

- Castells (1989) envisages a fundamental restructuring of spatial relations from a 'space of locations' to a 'space of flows', in which spatial interactions *between* places become more important than activities *within* places.

As the real spatial impacts of the new technologies are yet largely unknown, it is difficult to sort out myth from fact among these hypotheses. It may well be that once the new technologies become more widely available, their discriminating effect may be dissipated. For instance, it is possible that the evolving technology of satellite communication may make *all* locations equivalent in terms of high-speed data transmission. On the other hand it is likely that centrally-located cities will already be adopting the next innovation while the first innovation is being diffused to the periphery, and so maintain their advantage. There is, however, sufficient evidence that the potential of telecommunications to substitute physical transport is limited. In as much as face-to-face contacts remain important, so will the importance of high-speed rail and air transport. This speaks for the hypothesis that being a node in the high-speed rail and air networks will remain an important locational asset for successful cities.

In the technical paradigm of urban development, technical conditions also determine the *internal* organisation of cities. The high density or crowdedness of the medieval city resulted from the need for fortifications and from the fact that most trips had to be made on foot. When these two constraints disappeared in the 19th century, urban development, following this paradigm, largely became a function of transport technology.

The workers' housing areas of the early 19th century were still built in the immediate vicinity of the factories, and, after the introduction of the railways, the *Mietskasernen* ('rent barracks') of the large cities were the most efficient way to concentrate large numbers of workers around the commuter railway stations. Consequently large cities expanded on both sides along the railway lines fanning out from the traditional city centre in a star-like pattern. With the diffusion of the private automobile, first in America and after World War II also in Europe, the areas between the railway lines could also be used for housing, and so the expansion of urban areas became less directed and more dispersed ('urban sprawl').

In the 1950s first efforts were made in the USA to study systematically the interrelationship between transport and the spatial development of cities. Hansen (1956) was able to demonstrate for Washington, DC, that locations with good accessibility had a higher chance of being developed, and at a higher density, than remote locations ("How accessibility shapes land use"). The recognition that trip and location decisions co-determine each other and that therefore transport and land-use planning needed to be co-ordinated, quickly spread among American planners, and the 'land-use transport feedback cycle' became a commonplace in the American planning literature.

The set of relationships implied by this term can be briefly summarised as follows (see Figure 2.1):

- The distribution of *land uses*, such as residential, industrial or commercial, over the urban area determines the locations of human *activities* such as living, working, shopping, education or leisure.

- The distribution of human *activities* in space requires spatial interactions or trips in the *transport system* to overcome the distance between the locations of activities.

- The distribution of infrastructure in the *transport system* creates opportunities for spatial interactions and can be measured as *accessibility*.

- The distribution of *accessibility* in space co-determines location decisions and so results in changes of the *land-use* system.

This simple explanation pattern is used in many engineering-based and human-geography derived urban development theories.

The theories based on this paradigm start from observed regularities of certain parameters of human mobility, such as trip distance and travel time, and from these try to infer those trip origins and destinations that best reproduce the observed frequency distributions. It had long been observed by Ravenstein (1885) and Zipf (1949) that the frequency of human interactions such as messages, trips or migrations between two locations (cities or regions) is proportional to their size, but inversely proportional to their distance. The analogy to the law of gravitation in physics is obvious.

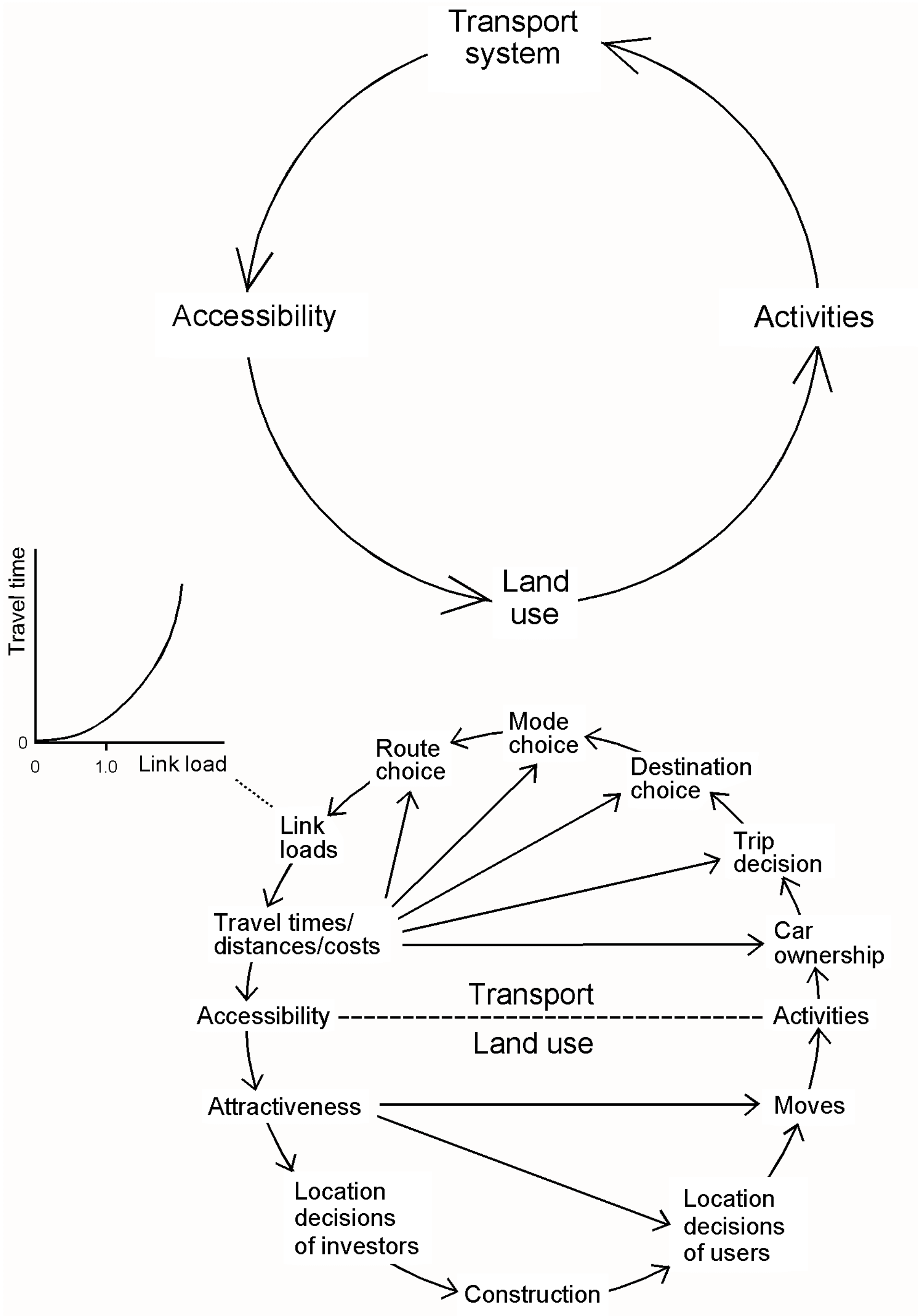


Figure 2.1. The 'land-use transport feedback cycle'.

The gravity model was the first *spatial interaction* (or in short *SIA*) model. Its straightforward physical analogy has later been replaced by better founded formulations derived from statistical mechanics (Wilson, 1967) or information theory (Snickars and Weibull, 1976), yet even after these substitutions the SIA model did not provide any *explanation* for the spatial behaviour modelled. Only later did it become possible (Anas, 1983) to link it via random utility theory (McFadden, 1973) to psychological models of human decision behaviour (Luce, 1959).

From the SIA model it is only a small step to its application as a location model. If it is possible to make inferences from the distribution of human activities to the spatial interactions between them, it must also be possible to identify the location of activities giving rise to a certain trip pattern. Wilson (1970) distinguishes four types of urban *spatial interaction location models* (see Table 2.1):

Table 2.1. Wilson's four spatial interaction location models

Type	Constraints	Residence	Work-place
1	unconstrained	predicted	predicted
2	production-constrained	known	predicted
3	attraction-constrained	predicted	known
4	doubly constrained	known	known

Source: Wilson (1970; 1974)

Model type 1 deals with households having neither residence nor work-place, model type 2 with households looking for a job and model type 3 with households looking for a residence. Model type 4 is actually not a location model but the familiar transport model. The column 'constraints' refers to the marginal totals of the interaction matrix, which act as constraints to its elements if they are known.

Lowry's (1964) *Model of Metropolis* essentially consists of two singly-constrained spatial-interaction location models, a residential location model and a service and retail employment location model, nested into each other. The Lowry model stimulated a large number of increasingly complex modelling approaches such as the work by Goldner (1971), Echenique (Geraldes et al., 1978), Putman (1983; 1991), Mackett (1983) and Webster et al. (1988). Boyce et al. (1981) developed combined equilibrium models of residential location, mode and route choice.

The limits of location models based on the SIA paradigm lie on two levels:

- First, the SIA location model in principle assumes equilibrium between transport and location. In reality, however, this equilibrium does not exist. Urban processes have very different speeds and response times. For instance, the behaviour of transport users very quickly adjusts to changing conditions in the transport system. Conversely, transport investment takes a long time from planning to final implementation. In a similar way the distribution of activities reacts only very slowly to changes in accessibility. Even a simple change of residence or work-place may take months or even years between planning and realisation, whereas the planning and implementation of housing, offices or work places as a rule requires several years (Wegener, 1985; 1986a; Wegener et al., 1986). This kind of disequilibrium, however, cannot be represented by the SIA location model.

- The second criticism is that the SIA location model lacks economic content. The only variable explaining location behaviour in the model is transport costs, and even these only in so far as they are necessary to model the choice between mobility alternatives. In particular, there is no link between transport costs and other expenditure by households and firms. This makes the model incapable of considering wider choices than between transport modes or destinations, such as choices involving trade-offs between transport and location or between housing and work-place location - unless it is embedded into a more comprehensive framework of factors determining the decision behaviour.

It is unfortunate that the mainstream of urban land-use transport theory-building and modelling adopted this most restricted, engineering-based perception of the urban system as a system of movements. The spatial interaction model, after some twenty years of refinement and generalisation (Williams and Senior, 1978; Coelho and Williams, 1978; Leonardi, 1981; Anas, 1983, Fotheringham and Kelly, 1989; Fischer, 1999), is essentially still the atemporal equilibrium model it always was and with each advance in mathematical rigour and elegance seems to move farther away from reality.

In particular the spatial interaction paradigm itself (the myth that workers choose their place of residence on their way home from work) turned out to be a veritable straitjacket which forces things together which should be analysed separately, i.e. the decision to move, to choose a job, to make trips, etc. - although of course these are interrelated, but only in a time-lagged and indirect way. Moreover, there are no people in this paradigm, no households, no entrepreneurs, no landlords, no developers; there are no distorted perceptions, no incomplete information, no uncertainty, no biases, no heuristics, no adaptation, no learning. There are no real change processes, no construction, no upgrading, no demolition, no real supply and demand variables, no rents and land prices, no interaction between supply and demand, no markets and no market distortions such as oligopolies, price controls, legal constraints, public interventions.

Some of these issues have been taken up by more recent approaches. One line of research was stimulated by a new interest in dynamics. A first dynamic urban model had been already proposed by Forrester (1969), but his model was aspatial and contained no transport and land only as a capacity constraint. The rediscovery of time was motivated partly by new results in the biosciences with respect to the behaviour of complex ecosystems, such as the theory of dissipative structures (Allen et al., 1981), and partly by the availability of new mathematical instruments such as catastrophe and bifurcation theory (Wilson, 1981; Dendrinos and Mullaly, 1985) or the theory of nonlinear dynamic systems (Weidlich and Haag, 1983; 1988; Nijkamp and Reggiani, 1992a; 1992b). Another important direction has tried to take account of the heterogeneity of travel behaviour by discrete choice analysis (Kutter, 1972; Ben-Akiva, 1974; Domencich and McFadden, 1975; Ben-Akiva and Lerman, 1985).

Despite its shortcomings, the spatial interaction paradigm has led to a better understanding of important dimensions of individual mobility and location behaviour and their interrelationships. It has made it clear that daily mobility depends on prior more long-term location decisions, and that these are in turn co-determined by the daily need for travel.

Figure 2.2 portrays these interrelationships in a format proposed by Brotchie (1984). The 'Brotchie Triangle' represents the universe of possible constellations of spatial interaction and spatial structure. Spatial structure is represented on the horizontal axis as spatial dispersal (for instance, mean travel distance of employment from the centre of the region), spatial interaction on the vertical axis as some measure of total travel such as mean travel distance to work. Any city will lie between three hypothetical points in the diagram. Point A represents a situation in which all jobs are at the centre, i.e. dispersal of employment is zero. Both points B and C represent regions in which all jobs are as equally dispersed as the population. Point C represents a situation in which all workers walk to work, point B a situation in which they maximise travel. Spatial interaction models may answer the question in which direction the real city, point D, will move.

2.2 Economic Theories: Cities as Markets

A second set of theories focuses on the *economic* foundations of city growth. Following this paradigm, it is the market function that distinguishes the city from the countryside (Weber, 1921; 1925). Other authors define trade and crafts as the two activities constituting a city (Sombart, 1907): cities come into being if craftsman and farmer are different persons. Thus the city is a product of specialisation and the division of labour. Historically city growth in Europe has been closely linked to economic structural change as, during the first industrial revolution, rural-to-urban migration went hand-in-hand with the reduction in agricultural and the growth in industrial employment.

Jacobs (1969) explains city growth as a three-step process of (1) developing exports and producers' goods and services, (2) converting producers' goods and services into exports and (3) replacing imports by goods and services produced locally, which may lead to more exports, and so on. If this self-reinforcing process fails, i.e. the city is unable to develop new exports, it starts to stagnate or decline.

In regional economics this is called the *economic base* theory, which implies that the regional income, and hence the number of people a region can support, depends on its exports. In its dynamic form, the economic base theory comes in two versions, one equalising and one polarising. The theory of *spatial economic equilibrium* assumes perfect competition and perfect factor mobility and hence predicts equal factor prices, productivity and commodity prices in all regions (Ohlin, 1933). The theories of *growth poles* (Perroux, 1955) or *circular cumulative causation* (Myrdal, 1957), however, predict polarisation between central and peripheral regions because of economies of scale and enhanced possibilities of innovation in the larger industries at the centre.

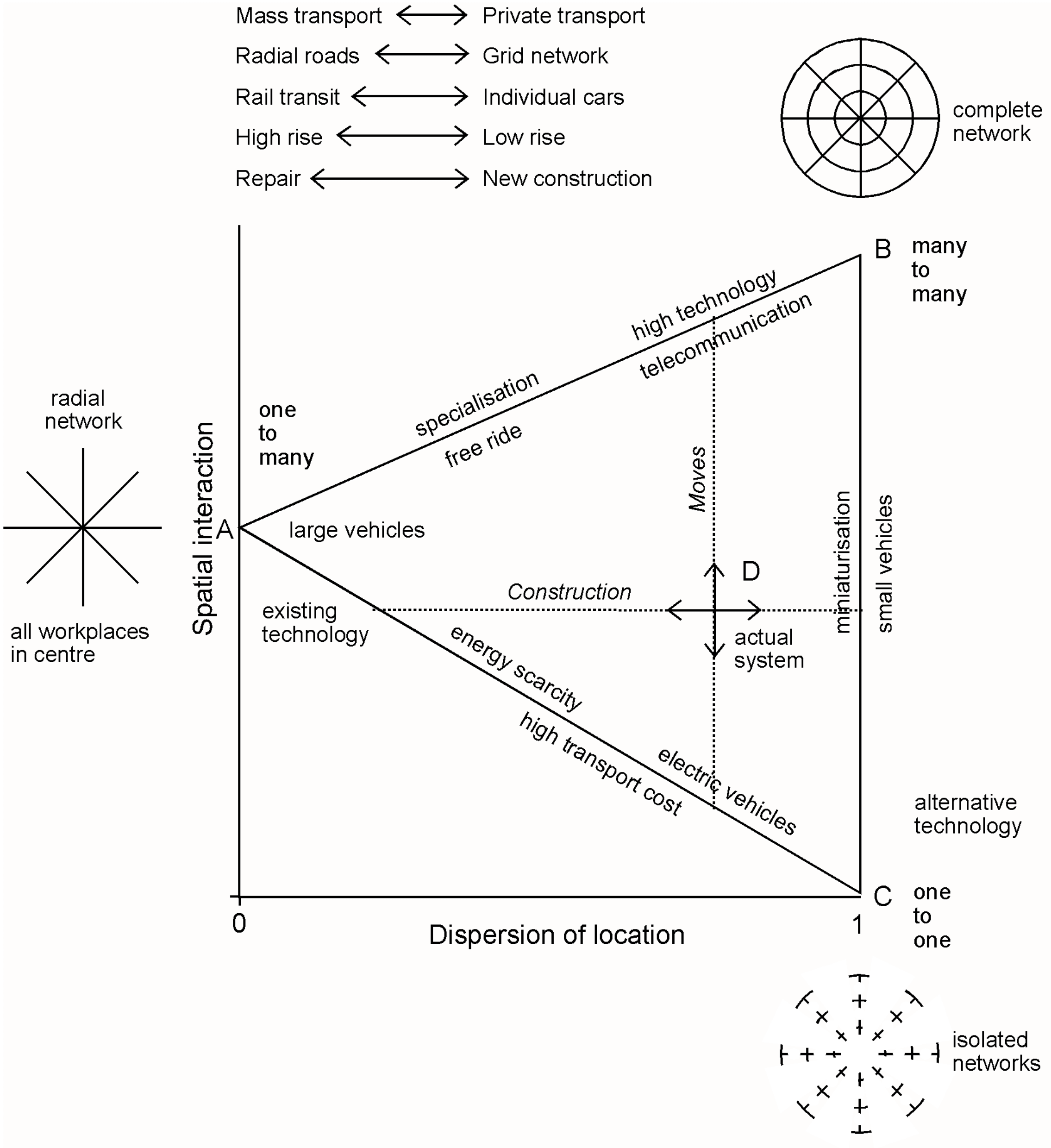


Figure 2.2. The 'Brotchie Triangle'.

If transport costs are explicitly taken into account, a hierarchical pattern of market areas around *central places* emerges (Christaller, 1933; Lösch, 1940). Central places of higher levels have all the functions of lower levels, which explains the existence of small and large cities. Manufacturing industries tend to locate close to the locations of raw materials and other inputs or close to their markets depending on the cost of shipping goods of different weight (Weber, 1909); if they also take account of economies of scale or labour cost, agglomeration or dispersal may occur (Isard, 1956).

Following Krugman (1991; 1996), a great part of spatial development can be explained by the interplay of two major driving forces, economies of scale and transport cost. All types of land uses experience increasing returns to scale: on the level of the firm *internal* economies of scale through labour savings through mass production, on the level of cities and regions *external* economies of scale or agglomeration economies through synergies between firms and access to large diversified labour and customer markets. The consequence is a trend to ever larger units of production and distribution. Transport, however, has since the introduction of the railways been characterised by acceleration and decreasing costs. Dematerialisation of production and the transition to a service-based economy have contributed to reducing the importance of physical transport.

Economic location theory becomes more complex if location costs in the form of land prices are taken into account. In this case firms look for the optimum constellation of size (economies of scale) and location (agglomeration economies) given their specific mix of products, production technology and pattern of suppliers and customers, whereas households try to match their space needs and location preferences with their budget restrictions. Both firms and households trade off accessibility for space or vice versa.

A fundamental assumption of all spatial economic theories is that locations with good accessibility are more attractive and have a higher market value than peripheral locations. This fundamental assumption goes back to von Thünen (1826) and has since been varied and refined in many ways. In macroanalytic approaches spatial development is the result of spatial production functions incorporating among labour and capital such spatial factors as agglomeration advantages, transport costs and land prices, and it is still disputed under which conditions spatial equilibrium (von Böventer, 1962) or spatial polarisation (Pred, 1966) will occur, or whether there is a cyclical sequence of agglomeration and deglomeration phases (van den Berg et al., 1982). Microanalytic approaches, on the other hand, start from the locational behaviour of individual players such as firms, landlords or households in the urban land or housing markets.

Probably the most influential example of the latter kind is the model of the urban land market by Alonso (1964). The basic assumption of the Alonso model is that firms and households choose that location at which their bid rent, i.e. the land price they are willing to pay, equals the asking rent of the landlord, so that the land market is in equilibrium. Figure 2.3 shows the principles of the Alonso model for firms and households. The bid rent of firms results from the cost structure of their production function, i.e. sales price minus production and transport costs plus profit divided by size of land. A firm with higher added value per unit of land is therefore able to pay a higher price than a firm with less intensive land utilisation, everything else being equal.

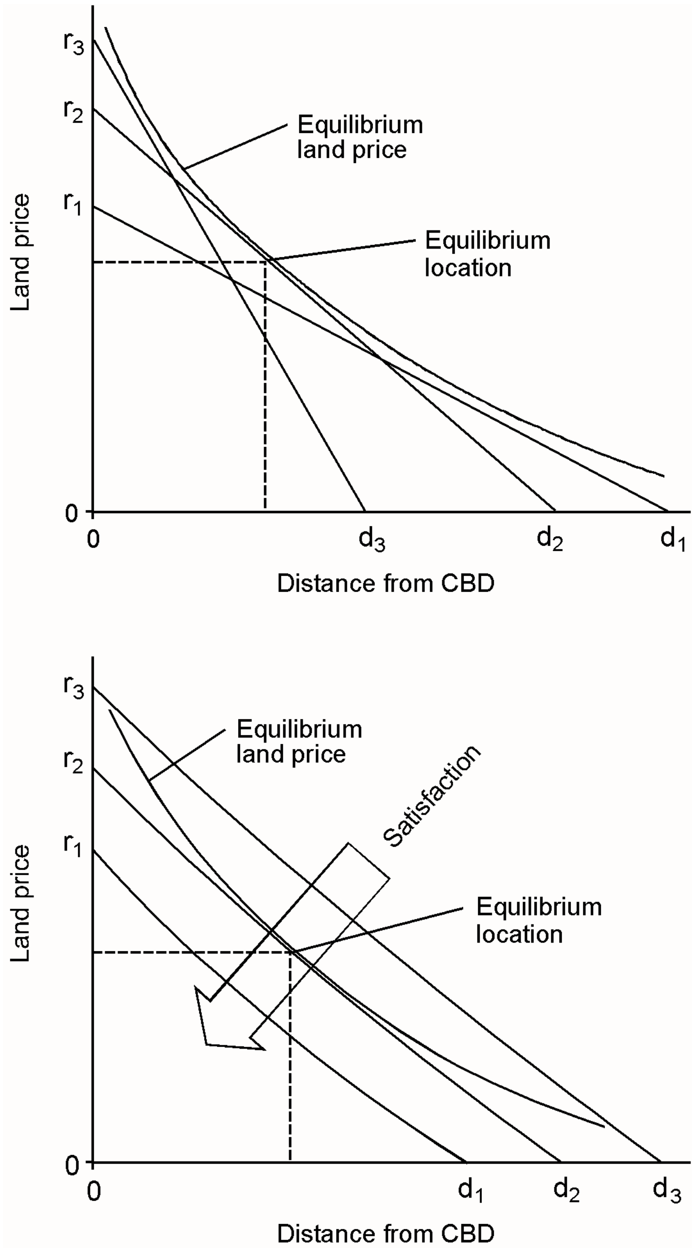


Figure 2.3. The model of urban land markets by Alonso (1964).

So it is not surprising that, say, jewellers are found in the centre, whereas trucking companies have their yards on the periphery. Under the simplifying assumption that all goods are sold in the city centre (and need to be transported there), the bid rents of different types of firms follow curves sloping outward from the centre with different degrees of slope; their envelope curve is the equilibrium asking rent (see Figure 2.3, top). The optimum location for a firm is where its bid rent curve is tangential to that curve. As households have no cost functions like firms, it is necessary in their case to use indifference curves indicating their trade-off between land consumption and distance to the centre (see Figure 2.3, bottom). Each household type has a linear budget restriction, i.e. has to divide its expenditure between land and transport costs. The optimum trade-off between land consumption and accessibility for a household is where its budget line and indifference curve are tangential; it optimum location is where its resulting bid-rent curve is tangential to that of the equilibrium asking rent.

Alonso's model has been the point of departure for a multitude of urban economics model approaches (see Nijkamp and Mills, 1987). In more advanced variations of the model, restrictive assumptions such as perfect competition and complete information or the monocentric city have been relaxed (e.g. Anas, 1982). Other extensions include models to deal with land speculation (Seo, 1989) or the behaviour of landlords in neighbourhoods undergoing gentrification (Smith and Williams, 1986) or the incorporation of intersectoral and interregional factor and commodity flows into the model (Williams and Echenique, 1978).

Other theoretical contributions have drawn attention to the importance of *innovation* for urban development. These approaches refer to the *theory of long waves* first proposed by Kondratieff (1926) and Schumpeter (1939). According to this theory, economic history is a succession of growth phases triggered by 'basic innovations' such as the steam engine, the railway or the automobile. Each of the earlier technologies went from invention through take-off and rapid growth to saturation and was eventually superseded by a more advanced technology. The technology of the 'Fifth Kondratieff' is information technology. The fourth 'logistical revolution' (Andersson, 1986) has fundamental implications for the spatial organisation of society (Marshall, 1987).

The product-cycle theory applied to urban development explains why in the history of cities formerly powerful and prosperous cities went into decline: Florence, Venice, the Hanseatic League, Lisbon, Amsterdam and Liverpool declined because innovations in transport technology shifted trade flows away from them to other regions or cities. This was discussed above under the heading of technical theories of urban development, but here the argument goes further: even cities with excellent transport links decline if they stick to older products and production technologies, and this explains why industrial cities in the heart of Europe decline, while new centres of electronics and other high-tech production rise.

Today these shifts signal more fundamental changes in the economic environment (see Scott and Storper, 1986; Läpple, 1986; 1989; Bremm and Danielzyk, 1991): The most advanced industrial sectors are undergoing what is described as the transition from 'Fordism' to 'post-Fordism': Fordism indicates the era of mass production dominated by economies of scale. In the post-Fordist economy a new flexibility of the production process is achieved in response to increasingly selective tastes in more and more saturated markets: economies of scale are complemented or replaced by 'economies of scope' made possible by vertical integration of all steps of the production process from supply to delivery by computer control and telecommunications in 'logistic chains'. Earlier steps in the assembly chain are contracted out to out-side suppliers, who have to synchronise their operations with the production schedule by 'just-in-time' delivery, thus making large inventories redundant.

This theoretical framework helps to explain the current pattern of urban growth and decline found in many countries. As industrial cities are linked to the Fordist production system, they lack the flexibility to respond to rapidly shifting market demands, and this explains why de-industrialisation in these regions continues. Advanced industries prefer other regions not associated with the negative image of the smokestack industries; this explains the appearance of specialised high-tech regions such as Silicon Valley, the M4 corridor west of London or the success of Munich or Stuttgart, and why in some countries urban growth and urban decline exist side by side. The theory also explains the rise of the global metropolis as a corollary of the global economy and the emergence of a new hierarchy of cities based on high-level service functions not related to production.

Similarly the theory helps to explain the spatial polarisation observed *within* urban regions. Flexible production and distribution systems require extensive, low-density sites with good access to the regional and local road network, and this explains why new manufacturing firms prefer suburban locations. Retail facilities tend to follow their customers to the suburbs and similarly prefer large suburban sites with good road access. High-level services, however, continue to rely on face-to-face contacts and, despite e-mail, fax and electronic data interchange, remain in the city centre. The result is the spatial dispersal of all economic activities except high-level services and the progressive erosion of activities in the city centre.

Also based on a theory of cycles is the theory of *urban life cycles*. This theory identifies typical phases of urban development from growth to decline in terms of differential growth in the core and periphery of metropolitan areas (Hall and Hay, 1980; van den Berg et al., 1982 and van den Berg, 1987) and was related to the economic and social development of a country by Friedrichs (1985) and Hayashi (1992):

- In the *urbanisation phase* urban growth occurs predominantly in the core where nearly all jobs and most residences are located. The lower-density suburbs wholly depend on the core. Urbanisation is the consequence of the economic transition from an agricultural to an industrial society. Mechanisation of agriculture makes rural labour redundant and leads to rural-to-urban migration, while in the cities the growing industries develop an increasing demand for labour.

- In the *suburbanisation phase* the suburbs grow faster than the core. Residential development in the core declines for lack of space. The majority of work places is still in the centre, but gradually jobs follow people. Eventually the core starts to lose population and later jobs, but the region overall still grows. Suburbanisation begins when the country also enters the demographic transition, i.e. the sequence of declining mortality and subsequent declining fertility, which in its first phase results in rapid population increase which cannot be accommodated within the core cities.

- In the *deurbanisation phase* development further shifts to the urban periphery and beyond. The core loses more people and jobs than the suburbs gain, i.e. the city region overall declines. Deurbanisation is the result when both the economic and the demographic transition have completed their course, i.e. when natural population decline continues without a major economic upswing attracting immigration.

Theses phases of urban development are experienced by *all* cities irrespective of their economic growth or decline. However, economic success retards the transition to deurbanisation or leads the city into a new phase of urbanisation, whereas economic decline does the converse. *Reurbanisation*, i.e. a reconcentration of the population in the core in a period of total population decline, is a rare phenomenon because it implies one or a combination of the following unlikely events: (a) massive housing construction in the core, (b) a recession or rising housing costs leading to overcrowding, (c) restrictions on mobility such as drastic price increases for petrol making suburban living unaffordable.

The most likely scenario of urban development therefore, is continued spatial dispersal. In the absence of effective public intervention, the same trends in socio-economic context and life styles that were also responsible for suburbanisation in the past, such as rising incomes, more women going out to work, smaller households, more leisure time and a consequential change in housing preferences, will continue to create a demand for more spacious living in attractive neighbourhoods, and this will continue to be easier to realise on the urban periphery, preferably in the vicinity of small towns with attractive town centres and up-market shopping facilities. Retail and service facilities will continue to follow their clients to the suburbs, as will the new 'clean' industries which depend on the highly skilled middle-class labour living in the suburbs. The result will in the best case be a park-like rural-urban continuum and in the worst case a nightmare of urban sprawl (Fishman, 1987; Rowe, 1991; Sieverts, 1997).

From a social and environmental point of view the results of the deconcentration process are generally considered to be negative: longer journeys to work and shopping trips, more energy consumption, pollution and accidents, excessive land consumption and problems of public transport provision in low-density areas. A dispersed settlement structure relies on access to car travel as a prerequisite for taking advantage of employment and service opportunities, and thus contributes to social segmentation. Inner cities, except for the largest and most successful metropoles with a prosperous, 'international' central area, are victims of the exodus of people and jobs and can at best hope to survive as one among several regional centres. Inner-city housing areas will continue to become marginalised as the younger and more active segments of the population leave because of the run-down housing stock, traffic noise and lack of parking space, unless the total existing population is displaced by gentrification or tertiarisation - though these are themselves signs of economic prosperity and hence occur predominantly in successful cities.

However, one should be careful not to draw a too bleak picture based only on one scenario. There are other tendencies potentially working into other directions. Teleworking and teleshopping are still in their infancy but may fundamentally change daily mobility patterns and hence location behaviour. There is a growing diversity of life styles and housing preferences which may challenge the dominance of suburban living as the ultimate manifestation of the 'good life'. In some countries there are signs of a re-appreciation of urban life and a trend to return to inner cities 'back from the edge' (Gratz and Mintz, 1998). On the other end of the spectrum, there are new ideas in urban and landscape design towards new forms of integration of housing and nature under ecological perspectives.

2.3 Social Theories: Society and Urban Space

In social sciences theories of urban development the spatial development of cities is the result of individual or collective appropriation of space.

Since Durkheim and Simmel there are in sociology traditions in which the city is a fundamental dimension of human existence. Other authors have defined the city as the interface between public and private society (Bahrdt, 1969), the stage for social interaction and self-expression (Goffman, 1959), the medium for the world of daily life (Lefebvre, 1968) or the field of action of social movements (Harvey, 1973; Castells, 1977). However, as a rule, these approaches remained essentially social theories and failed to deal explicitly with the spatial and temporal dimensions of urban development.

The study of the urban past remained the domain of urban historians like Mumford (1938; 1961) or Gutkind (1964-72). Their method was essentially hermeneutic, i.e. aimed at understanding individual processes as unique constellations of specific causes and effects. Beyond the observation of similarities in different places at different times, no regularities or law-like covariations of variables were sought.

This changed when, between the wars, the Chicago school of urban sociologists looked more closely into processes of social change on the neighbourhood and urban levels. Based on an adaptation of evolutionist thoughts from philosophy (Spencer) and biology (Darwin), they interpreted the city as a multi-species ecosystem, in which social and economic groups fight for 'ecological positions' (Park et al., 1925; 1936).

In spatial terms the ecological position is a territory such as a neighbourhood or a region. Appropriation of space takes place as invasion of different ethnic or income groups or tertiary activities in a residential neighbourhood and uses concepts of animal and plant ecology such as 'invasion', 'succession' or 'dominance' to describe the phases of such displacement.

These concepts were empirically testable and could be used for generalisations and theory building. Consequently, a number of qualitative theories of urban development were put forward to explain the spatial expansion of American cities, such as the concentric (Burgess, 1925), sector (Hoyt, 1939), or polycentric (Harris and Ullman, 1945) theories of city growth. However, despite their spatial labels, these theories, too, were essentially social theories. Space and time were included in them only in categorical terms, since analytical methods for treating intervals in space and time were only rudimentarily developed. Moreover, all urban ecology theories were in effect anti-evolutionist in that they assumed, in a questionable analogy to biological systems, an inherent tendency of social systems to converge to a stable equilibrium.

Despite these shortcomings, concepts from social ecology continue to be useful for understanding the mechanisms of social change in cities beyond the economic processes on the land market. For instance, they have been used to explain 'gentrification' processes, the invasion of upper-middle-class households into inner-city or suburban working-class neighbourhoods (Smith and Williams, 1986).

Social geography theories are related to social ecology concepts, but go beyond their macro perspective by referring to age-, gender- or social-group specific activity patterns which lead to characteristic spatio-temporal behaviour, and hence to permanent localisations. Action-space analyses (e.g. Chapin, 1965; Chapin and Weiss, 1968) identify the frequency of performance of activities reconstructed from daily space-time protocols as a function of distance to other activities and draw conclusions from this for the most appropriate allocation of housing, work-places, shopping and recreation facilities or the optimum level of spatial division of labour in cities.

Hägerstrand (1970) made these ideas operational by the introduction of 'time budgets', in which individuals, according to their social role, income and level of technology (e.g. car ownership) – subject to various types of constraints – command *action spaces* of different size and duration. Action spaces are limited by three types of constraints:

- *capacity constraints*: personal, non-spatial restrictions on mobility, such as monetary budget, time budget, availability of transport modes and ability to use them,

- *coupling constraints*: restrictions on the coupling of activities by location and time schedules of facilities and other individuals,

- *institutional constraints*: restrictions of access to facilities by public or private regulations such as property, opening hours, entrance fees or prices.

Only locations within these action spaces can be considered. Figure 2.4 shows two typical action spaces of a person with a car (top) and one without a car who has to walk, cycle or use public transport. It is the achievement of the 'time geography' of the Hägerstrand school to have drawn attention to the various kinds of captiveness caused by a land-use and transport system designed for the needs of the affluent and able: the restricted mobility of women with children, the elderly and the handicapped.

On the basis of Hägerstrand's action-space theory, Zahavi (Zahavi, 1974; 1979; Zahavi et al., 1981) proposed the hypothesis that individuals in their daily mobility decisions do not, as the conventional theory of travel behaviour assumes, *minimise* travel time or travel cost needed to perform a given set of activities but instead *maximise* activities or opportunities that can be reached within their travel time and money budgets. He studied a large number of cities all over the world and found that the time and money budgets devoted to transport vary within urban regions as a function of age, income and residential location, but that they showed a remarkable stability over time when averaged across whole urban regions. It was found that in developed countries the average time spent in travel by an active person per day is slightly more than an hour and the average travel expenditure accounts for about 15% of disposable household income. The temporal stability of time and money budgets for transport explain why in the past gains in travel speed have not been used for time savings (as is usually assumed in transport cost benefit analysis) but for more and longer trips. It also explains why the fact that over the last forty years in most European countries petrol prices have declined by more than half in real terms has not led to a reduction in travel expenditure but to a vast expansion in automobile travel. Zahavi's theory finally explains why acceleration and cost reduction together permit more and more people to choose residential locations on the far periphery of urbanised areas, without increasing their time and money budgets for travel, and why shopping centres in sparsely populated peripheral locations are able to attract customers from larger and larger catchment areas.

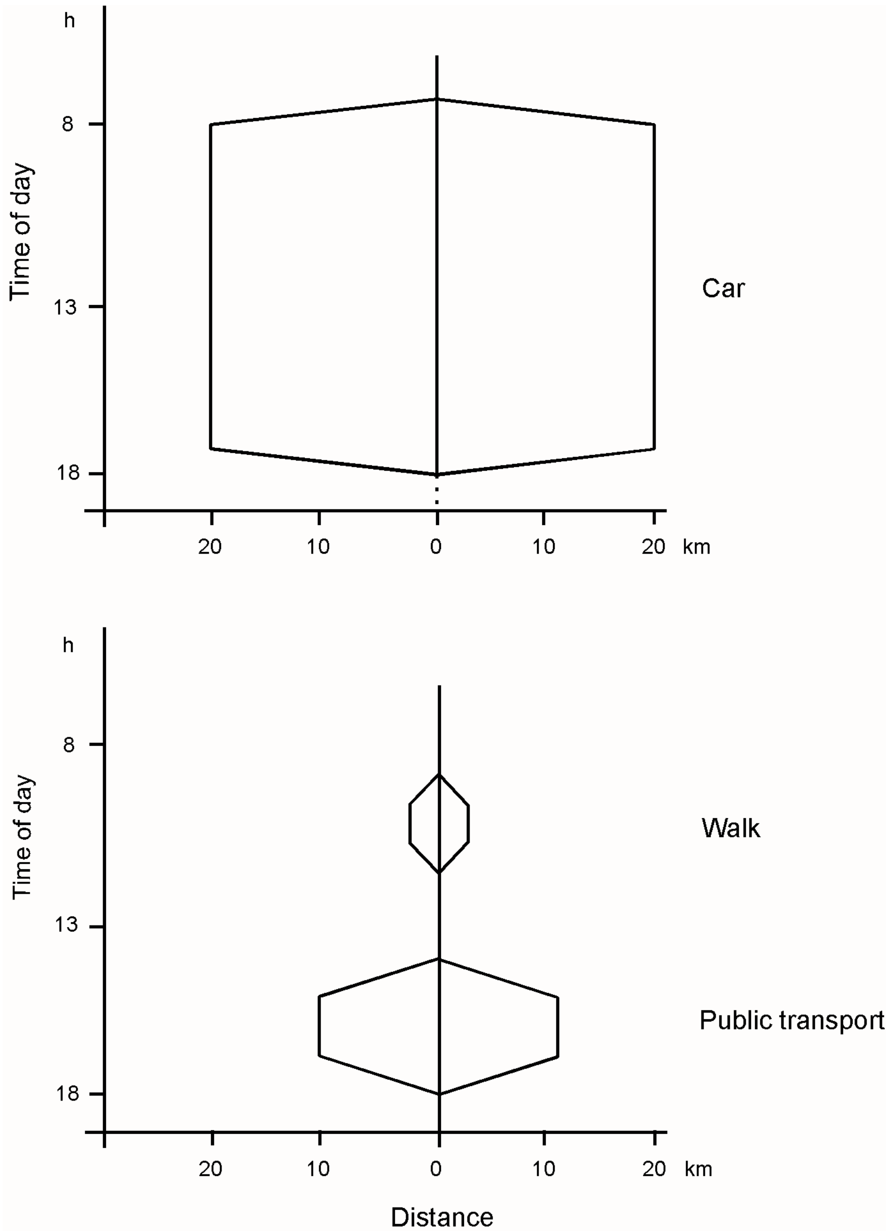


Figure 2.4. Action spaces of persons with and without a car (Hägerstrand, 1970)

Zahavi's theory of fixed travel budgets has since been extended by the concept of flexible time and money budgets responding to external constraints (Downes and Emmerson, 1985). The extended theory allows to model also the variation in time and money budgets across socio-economic groups and different parts of an urban area and has proved to be more plausible and theoretically sound.

The theory of time and travel budgets permits to speculate what would happen if speed and cost of travel were deliberately changed by environment-oriented planning policies. Acceleration and cost reduction in transport lead to more, faster and longer trips; speed limits and higher costs lead to less, slower and shorter trips. In the long run this has effects on the spatial structure. Longer trips make more dispersed locations and a higher degree of spatial division of labour possible; shorter trips require a better spatial co-ordination of locations. However, making travel slower and more expensive does not necessarily lead to a re-concentration of land uses back to the historical city centre. In many urban regions population has already decentralised so much that further decentralisation of employment would be more effective in achieving shorter trips than re-concentration of population.

2.4 Summary of Relevant Factors and Expected Impacts

The results of theories of land-use transport interaction are summarised in Tables 2.2 and 2.3 in terms of expected impacts of essential factors such as urban density, employment density, neighbourhood design, location, city size, accessibility, travel cost and travel time.

Table 2.2 illustrates the impact of land use policies on transport patterns from a theoretical point of view. The impact of high residential density in reducing average trip length is likely to be minimal in the absence of travel cost increases, whereas a high density of employment is positively correlated with average trip length. Attractive neighbourhood facilities can be seen as a 'pull' factor for reducing trip length. Since more peripheral locations usually have longer trips, trip length can be expected to be negatively correlated with city size. With regard to trip frequency little or no impact is to be expected from land use policies according to Zahavi's theory of fixed travel budgets. Residential and employment density as well as large agglomeration size and good public transport accessibility of a location tend to be positively correlated with the modal share of public transport while neighbourhood design and a mixture of workplaces and residences with shorter trips are likely to have a positive impact on the share of cycling and walking.

Table 2.3 illustrates the impact of transport policies on land use and the impact of transport policies on transport patterns. The latter impacts are included because they tend to be much stronger than those of land use on transport or of transport on land use. The impact of transport on land use is mediated by a change in the accessibility of a location. Higher accessibility increases the attractiveness of a location for all types of land uses thus influencing the direction of new urban development. If, however, accessibility in an entire city is increased, it will result in a more dispersed settlement structure.

Table 2.2. Theoretically expected impacts of land use

Direction	Factor	Impact on	Expected impacts
Land use ⇓ Transport	Residential density	Trip length	Higher residential density alone will not lead to shorter trips. A mixture of workplaces and residences can lead to shorter trips if travel costs are increased.
		Trip frequency	Little impact expected. If trips are shorter, more trips may be made.
		Mode choice	Minimum residential densities are a prerequisite for efficient public transport. More walking and cycling trips will be made only if trips become shorter (see above).
	Employment density	Trip length	Concentration of workplaces in few employment centres tends to increase average trip lengths. A balance of workplaces and residences in an area would lead to shorter work trips only if travel becomes more expensive.
		Trip frequency	Little impact expected. If trips are shorter, more trips may be made.
		Mode choice	Concentration of workplaces in few employment centres may reduce car use if supported by efficient public transport. More walking and cycling trips will be made only if trips become shorter (see above).
	Neighbourhood design	Trip length	Attractive public spaces and a variety of shops and services can induce more local trips.
		Trip frequency	If trips are shorter, more trips may be made.
		Mode choice	Street layout, pedestrian spaces and cycling lanes could lead to more walking and cycling.
	Location	Trip length	More peripheral locations tend to have longer trips.
		Trip frequency	No impact expected.
		Mode choice	Locations close to public transport stations should have more public transport trips.
	City size	Trip length	Trip length should be negatively correlated with city size.
		Trip frequency	No impact expected.
		Mode choice	Larger cities can support more efficient public transport systems, so more trips should be made by public transport in larger cities.

Table 2.3. Theoretically expected impacts of transport

Direction	Factor	Impact on	Expected impacts
Transport ⇓ Land use	Accessibility	Residential location	Locations with better accessibility to workplaces, shops, education and leisure facilities will be more attractive for residential development, have higher land prices and be developed faster. Improving accessibility locally will change the direction of new residential development, improving accessibility in the whole urban area will result in more dispersed residential development.
		Industrial location	Locations with better accessibility to motorways and railway freight terminals will be more attractive for industrial development and be developed faster. Improving accessibility locally will change the direction of new industrial development.
		Office location	Locations with better accessibility to airports, high-speed rail railway stations and motorways will be more attractive for office development, have higher land prices. Improving accessibility locally will change the direction of new office development.
		Retail location	Locations with better accessibility to customers and competing retail firms will be more attractive for retail development, have higher land prices and be faster developed. Improving accessibility locally will change the direction of new retail development.
Transport ⇓ Transport	Accessibility	Trip length	Locations with good accessibility to many destinations will produce longer trips.
		Trip frequency	Locations with good accessibility to many destinations will produce more trips.
		Mode choice	Locations with good accessibility by car will produce more car trips: locations with good accessibility by public transport will produce more public transport trips.
	Travel cost	Trip length	There is a strong inverse relationship between travel cost and trip length.
		Trip frequency	There is a strong inverse relationship between travel cost and trip frequency.
		Mode choice	There is a strong relationship between travel cost and choice of travel mode.
	Travel time	Trip length	There is a strong inverse relationship between travel time and trip length.
		Trip frequency	There is a strong inverse relationship between travel cost and trip frequency.
		Mode choice	There is a strong relationship between travel cost and choice of travel mode.

The impacts of transport policies on transport patterns are clearer and stronger compared to the interplay of land use and transport. While travel cost and travel time tend to have a negative impact on both trip length and trip frequency, accessibility has a positive impact on trip length and frequency. Mode choice is dependent upon the relative attractiveness of a mode compared to all other modes. The fastest and cheapest mode is likely to have the highest modal share.

In general, the theoretical considerations support the conclusion that the impact of 'pull' measures, i.e. land use measures, is much weaker than the impact of 'push' measures, i.e. increases in travel time, travel cost etc.

3. 'Ideal' Land-Use Transport Systems

The review of land-use transport interaction theory in the previous section revealed that there exist close interactions between land-use and transport systems. This section contains a brief overview of configurations of land-use and transport systems which were considered to be ideal in a given set of preconditions and objectives. The approaches presented here are comprehensive policies which attempt to influence not only mobility patterns but also social and economic processes by means of urban form. The following presentation is focused on the most important structural characteristics of 'ideal' land use transport systems in order to give an overview of the typology of possible spatial city structures. Comprehensive descriptions can be found in Benevolo (1980), Hall (1988) and Fürst et al. (1999).

3.1 Historical Proposals

'Ideal' land-use transport system as optimal solutions to urban land-use and transportation problems have been formulated since the late 19th century. During this period, the traditional European city has been reshaped by the forces of the industrialisation process. Within a few decades, the economic and social structures and along with them the settlement patterns have been fundamentally transformed from a predominantly rural society with agriculture as the most important economic sector to an industrial and urban society. The unprecedented industrialisation and urbanisation process entailed serious problems, such as excessive residential densities, unsatisfactory sanitary conditions and a high degree of industrial air pollution. Visions of ideal cities created in this period are primarily attempts of city planners to overcome these urgent problems.

One of the earliest proposals on how to respond to dynamic urbanisation processes is the linear city. The idea was initially formulated by the Spanish architect Arturo Soria y Mata who planned a ring-shaped settlement structure around the city of Madrid with a total length of 48 kilometres and a breadth of only 400 metres. The plan is characterised by a main axis with public transport and road infrastructure around which residential buildings are situated at a breadth of roughly 200 metres at each side of the axis. The ribbon of built-up areas was to be separated from agricultural land by parks and woodlands serving recreational and environmental purposes. While Soria y Matas concept remained largely unfinished, similar plans for linear cities were developed in other countries (Soria y Mata, 1882). Benôit-Lévy (1904) founded the 'Association Internationale des Cités Linéaires' in France. In Russia, the idea of linear cities was developed further by the Soviet ‘deurbanists’ Baruch, Ginsburg and Miljutin (Fehl et al., 1997). They regarded the linear city as the adequate urban form in which an egalitarian ideal of society was mirrored by an ubiquitous spatial concept of the city. The general idea behind these linear city concepts is to provide easy access to both open spaces and infrastructure facilities. However, the linear city remains problematic with regard to the allocation of higher-order central facilities which are planned to serve an entire city. One of the rare examples of an existing linear city is Brasilia, which is particular in that it is an intersection of two linear cities, one with office buildings and one with residential buildings (Hall, 1988, 216).

A different conception of the ideal urban form was created by Ebenezer Howard (1898) around the turn of the century. The rationale behind his garden city (alternatively called the 'social city' or 'town-country') was to reconcile rural and urban areas by combining the qualities of both thus ensuring balanced spatial growth patterns in the inevitable progress of the urbanisation process. Howard conceived a satellite system consisting of a central city with 58,000 inhabitants and six surrounding towns with 32,000 inhabitants each, forming an urban system of 250,000 inhabitants. Intermunicipal railway lines were to connect the satellite towns to each other and to the central city. Howard's conception was also innovative in that it defined the ideal distance of satellite towns to the central city by travel time and not by geographic distance thus leaving room for potential changes of the spatial configuration due to technological progress. Within the towns, workplaces, parks, retail and transport facilities were to be located within walking distance from the residential areas. Industrial areas, which had to be separated from the residential areas to preserve the high quality of living, were connected to the urban system. The central city was subdivided into several land-use rings by parks and avenues. Howard considered an average density of 220 inhabitants per hectare as adequate. Moreover, he deemed it essential that growth boundaries be defined for a garden city with regard to maximum density, land take and number of inhabitants. The growth boundary was to be marked by a greenbelt around each town. Elements of Howard's garden city have been adopted in a number of other concepts.

With the further evolution of the industrialisation process and ever increasing scales of production units, urban planners were faced with the problem of how to arrange land uses within the urban fabric. The French architect Tony Garnier (1932) in 1904 proposed a clear spatial separation of industrial areas from residential areas. The notion of a functional separation of land uses was developed further by Le Corbusier and other architects of the Congrès Internationaux d'Architecture Moderne (CIAM) in the Athens Charter, a document which promoted a clear separation of urban functions. Le Corbusier (1929, 178) proposed the following solution to urban problems: 'We must decongest the centres of our cities by increasing their density. In addition, we must improve circulation and increase the amount of open space.' His solution involved the obliteration of the entire built-up area of inner cities and the construction of skyscrapers on a small percentage of the total ground area. The distribution of land-uses was to follow a rigid scheme of functional and socio-economic segregation. Workers would live in modestly equipped apartments in very tall apartment towers built on a uniform gridiron of streets with 48 percent of open space on the ground space, while the upper class would live in more comfortable apartments with 85 percent of the ground space left open. In 1930 he elaborated his vision of a functional city further in the plan for the 'ville radieuse' where spatial hierarchies were largely abandoned in favour of homogeneous functional zones without any mix of land uses. According to this plan, distinct zones were to be identified for offices, hotels, housing, factories, warehouses, and heavy industries (Hilpert, 1978).

A different approach to the spatial organisation of land uses was presented by the American architect Frank Lloyd Wright (1950; 1958). Based on the assumption that the 'vertical' and 'mechanical' way of living in big cities was opposed to human nature, he envisioned a settlement pattern of small pockets of low-density development offering the inhabitants the chance to develop their individual lifestyles. Since Wright assumed that human beings were degraded to machines themselves if they had to spend their life in a high-density urban environment, he aimed at the dissolution of such structures. His plan of the so-called 'Broadacre City' is characterised by a grid raster of streets with large-sized building plots of one acre each. Detached family homes were considered to be the preferable type of building with only one building being erected on most of the plots. The aim of counteracting overcrowding in large metropolitan areas could of course only be pursued with the help of wide-spread motorisation and adequate road infrastructure. Therefore, Wright proposed large highway corridors to ensure convenient long-distance commuting. He also envisaged that cars would later be replaced by helicopters, thus enabling an even higher degree of freedom regarding the choice of locations and trip destinations.

Following the destruction of European cities during World War II, several ideas regarding the spatial organisation of the cities to be rebuilt were put forward. In Germany, Göderitz, Rainer and Hoffmann (1957) proposed a concept of hierarchically structured combinations of elements with small neighbourhoods being aggregated to larger units and corresponding higher-order central facilities on each level of aggregation. High-density structures were planned for the construction of new towns in the vicinity of London with a linear zone comprising the city centre and industrial and residential zones of various sizes and shapes surrounding this linear zone (London City Council, 1961). A similar structure, albeit on a larger scale, had been developed earlier for the entire agglomeration of London. The basic idea underlying this concept was a comb-like structure with a linear central axis and adjacent residential areas departing from the central axis. The residential areas were connected to the central axis via commuter rail lines and roads.

In the 1960s and 1970s widespread protest arose against urban structures following the guidelines of the functional city. The various alternatives to the functional city encompassed the promotion of mixed-use areas and of high-density neighbourhoods. Urbanists like Jacobs (1961) or Mitscherlich (1965) identified urbanity as a key notion for pertaining a high quality of living in metropolitan areas. Supporters of the New Urbanism movement in the United States proposed that new neighbourhoods should be designed and structured in the tradition of historic quarters. Instead of constructing new suburban satellite towns, a reinforcement of the city centre was demanded, thus also promoting the use of non-car transport modes.

A further stylised type of land-use transport system pursued to this day in various cities is the axial system. Fritz Schumacher had proposed an axial structure for Hamburg and Cologne along commuter rail lines already in the 1920s (Schumacher, 1921). Supporters of axial city systems argue that the garden city as defined by Howard was unable to solve the problems of continuously growing metropolitan areas since it did not allow for additional population and land uses to be allocated beyond the defined growth limit. The axial system is more flexible in this respect, since it can be extended beyond previous city boundaries while maintaining the quality of living in the inner areas of the city. The basic principle of this system is that when urban development is focused on axes, green wedges emerge in the interstices which connect the parks of the inner city to the rural areas surrounding the city thus ensuring rapid access to open spaces from almost any point in the metropolitan area. This type of spatial organisation was developed further in a number of cities including after World War II Copenhagen and Stockholm and more recently Portland, Oregon and various towns in the Netherlands. With the construction of new commuter rail lines, suburban business and retail centres as well as high-density residential areas were developed around the rail stations. The spaces between the nodal points of the axes were planned to remain open thus creating lateral links between the radial green wedges. In spite of the slight decentralisation of workplaces and other urban functions, the central city retains its predominant position as the major concentration of higher-order urban functions in an axial city system.

3.2 Contemporary Proposals

Presently three basic concepts of urban development rooted in the prototypes of land-use transport systems described above are concurrently being discussed.

Compact City

The compact-city policy is based on a strategy of reducing the expansion of urbanised areas thus protecting the surrounding environment and creating a distinct contrast between urban and rural areas. The compact-city model implies intensive land use patterns and a predominantly monocentric urban macrostructure. Municipalities which pursue a compact-city policy regularly promote urban regeneration and brownfield projects, take measures to enhance the quality of living in inner-city residential areas and prioritise improvements in public transport service over investments in automobile infrastructure.

As a consequence of the high density and the high accessibility of all areas in the city region, the share of non-car modes can be expected to be very high. However, compaction and land-use intensification policies require thorough analysis and sophisticated solutions regarding logistics and potential interferences of non-compatible land uses. As to energy efficiency, sources such as the Green Paper on Urban Environment (European Commission, 1990) argue that the compact-city form is likely to be the most efficient land-use transport system. Objections put forward against the compact city include doubts about the chances of reversing the current counter-urbanisation trend and concerns about a loss of open space, biodiversity and quality of living in urban areas.

Polycentric Development

Pursuing a polycentric development strategy (alternatively termed 'decentralised concentration'), involves development at a relatively high density around suburban employment and business centres. While retaining a primus-inter-pares role for inner cities, development is ideally restricted to zones adjacent to subcentres thus ensuring high accessibility of central facilities by non-car modes and preserving open spaces within the metropolitan area. Decentralised concentration is based on the assumption that compact cities above a certain size of the metropolitan region are not efficient because of high energy consumption, high levels of congestion and a critical accumulation of environmental pollution in some areas of the city. Because of its insular spatial pattern, a polycentric urban form allows for the preservation of environmentally sensitive areas within an urban system. Public transport infrastructure is likely to be more evenly used throughout the urban area in a polycentric city compared to a monocentric city. The ideal constellation of a polycentric city involves that distances between workplaces and homes are short enough to commute mainly by walking or cycling. Critics of the polycentric-development policy have argued that being a compromise between a monocentric model and urban dispersal this policy is unlikely to generate any significant effects in the face of the current preponderance for a rather dispersed spatial organisation of land uses.

Dispersed development

Due to the negative connotation of the term 'dispersed development', this option of urban development is rarely referred to as such by its advocates. Rather it is addressed as 'city in the park', 'moderate density development', 'citizen-oriented development' and the like. All these notions are rooted in the assumption that urban planning should cater to the needs and preferences of people, the majority of which prefers to live in single-family homes and dislikes mobility restrictions. The supporters of this tradition of urban development derive their argumentation from Ebenezer Howard's plea for 'town-country' and Frank Lloyd Wright's reflections on individual freedom rights in his Broadacre City vision.

More recently, the American architect and planner Peter G. Rowe (1991) described the ideal of a 'middle landscape' as an optimal mix of the qualities of both urban and rural areas. Similar ideas have been developed for the European context (Sieverts, 1997) with a particular reference to the alleged inability of the traditionally monocentric European city to cope with the requirements of contemporary societies and economies. Supporters of dispersed development emphasise the fact of urban sprawl and low-density development as the predominant mode of urbanisation in all western countries. Urban form is therefore bound to be determined by low-density development on the fringes of metropolitan areas and in adjacent rural areas with the automobile as the adequate transport mode for this type of land use pattern. Visions propagating dispersed development vary with regard to the degree of desirable settlement dispersal and automobile dependence. An intermediate concept in this respect is the so-called edge city which is characterised by a concentration of business and retail facilities around metropolitan freeway intersections (Garreau, 1991). Despite their higher density compared to a homogeneous dispersal pattern, edge cities attain a similar degree of car dependency invoked by this type of land use organisation.

3.3 A Typology of 'Ideal' Land-Use Transport Systems

A variety of 'ideal' land-use transport systems as optimal solutions to urban land-use and transportation problems have been formulated since the late 19th century. These systems vary with regard to spatial structure, residential density, distribution of land uses and predominant transport mode. Since some of these systems evolved from earlier concepts based on similar assumptions, it is useful to illustrate the interrelationships between these structural types. Figure 3.1 contains a synopsis of the previously discussed types of land-use transport systems.

Each of the multiplicity of approaches towards an 'ideal' land-use transport system can be assigned to three basic types of urban spatial structure:

- *Point structures.* These are city types oriented towards the central point of the urban system, usually the inner city, as exemplified by the compact city model.

- *Linear structures*. These are city types built along a line, usually a large transport infrastructure, as exemplified by Soria y Mata's linear city concept.

- *Area structures*. These are city types with low density development which lack a clear spatial hierarchy and central structure, as exemplified in Wright's Broadacre City.

Departing from these three basic types, various hybrid forms of land-use transport systems can be identified. The axial system, for instance, is a formation of several linear structures aligned towards an urban centre, thus being a hybrid form between a linear city and a compact city.

Attempts to determine the 'ideal' land-use transport system in contemporary cities have yielded different results. While it has almost become common wisdom that systems involving dispersed development (left corner of Figure 3.1) are much less favourable with regard to average trip length, energy consumption, greenhouse gas emissions and land take, there is no unequivocal evidence for the advantages of either compact-city or decentralised-concentration policies.

Eventually, the appropriateness of a certain land-use transport system depends on a variety of case-specific factors, such as agglomeration size and the pre-existing spatial structure.

The definition of 'ideal' land-use transport systems cannot directly help to identify policies for sustainable urban transport. However, the value of defining such 'ideal' land-use transport system is to be seen in the structured categorisation of options for urban structures to be systematically investigated by other approaches.

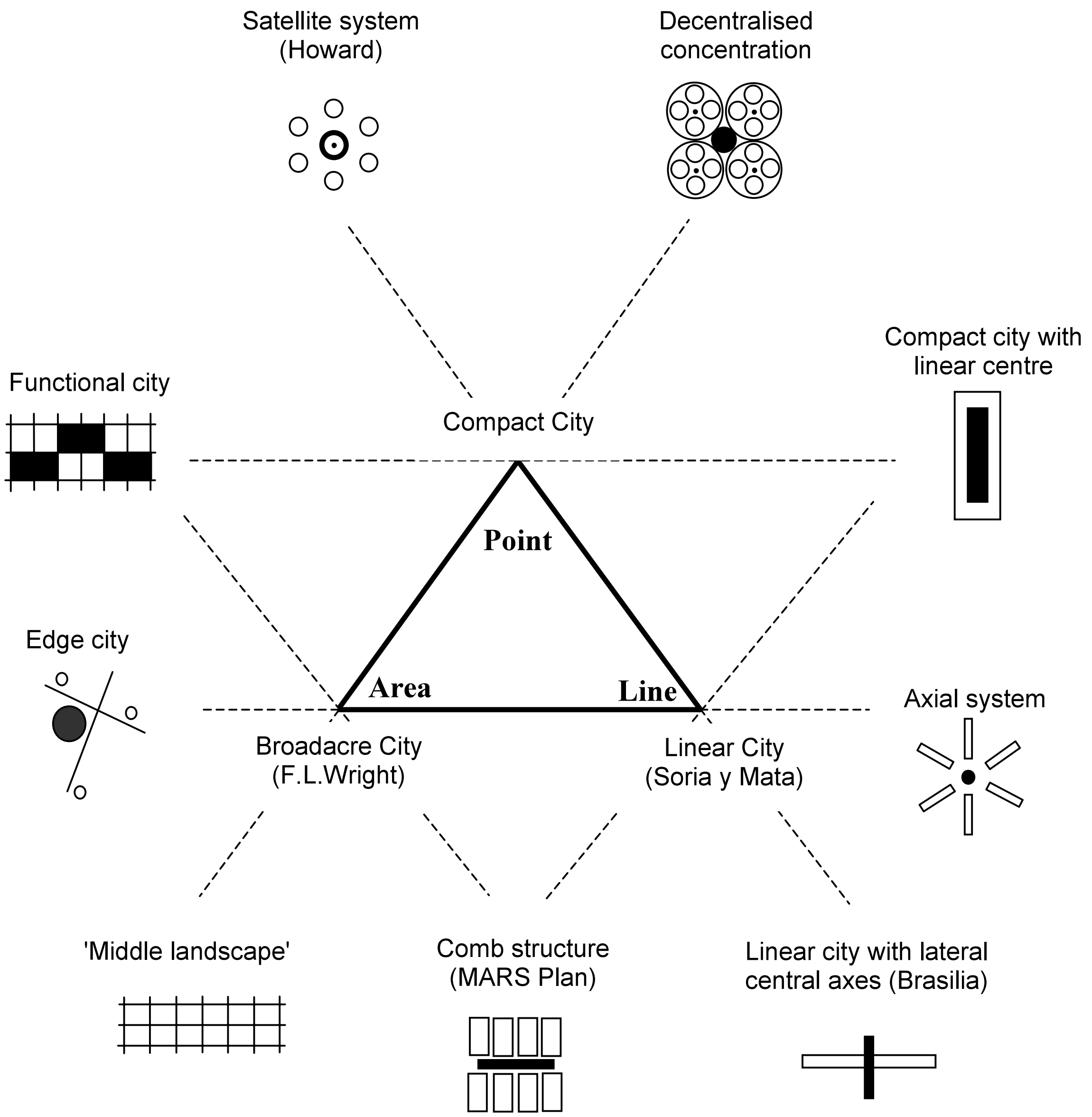


Figure 3.1. A typology of land use organisation patterns (based on Albers, 1974, 15)

4. Empirical Studies of Land-Use Transport Interaction

In this section empirical studies about the impacts of land use (residential, density, employment density, accessibility, neighbourhood design and city size) on travel and goods transport and, vice versa, impacts of transport (network structure, public transport supply, transport costs and regulations, etc.) on land use development will be summarised. The studies reviewed here consider urban areas at large, not only those in which efforts to integrate land use and transport planning have been or are being made.

4.1 Land-Use Impacts on Transport

Stimulated by the increasing awareness that present trends in urban mobility patterns are unsustainable, there is a large, and still growing, number of empirical studies on the relationship between urban form and travel patterns.

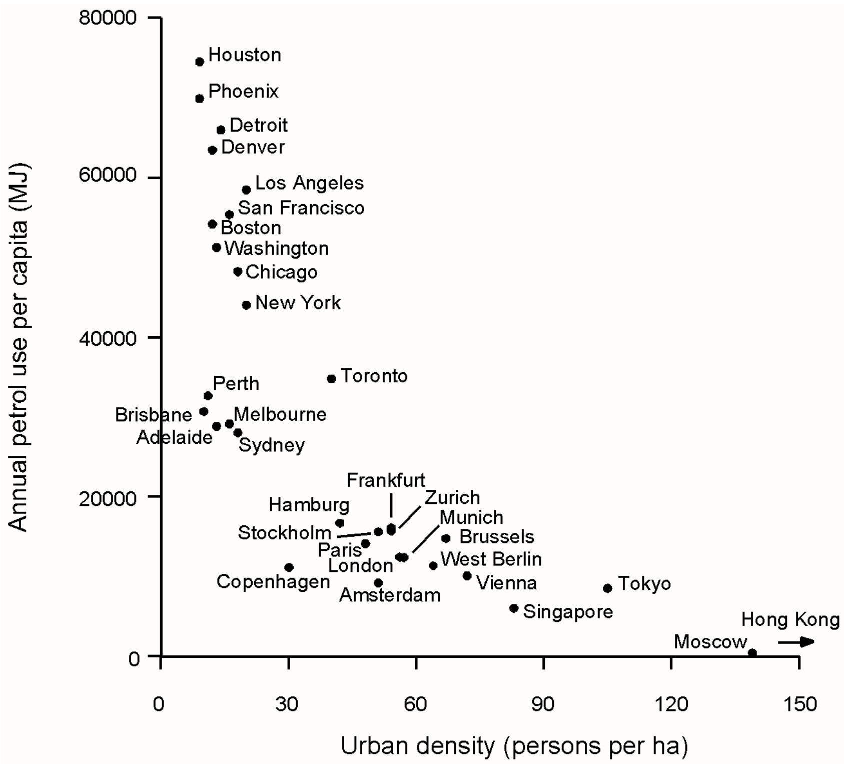
These studies usually examine one or more hypotheses about the expected effects of specific land use characteristics on trip generation, trip lengths and travel mode or about the effects of changes in these characteristics either through the course of time or through planning policies. This section will discuss the most frequently investigated hypotheses. It incorporates material from two highly informative review papers, Miller et al. (1998) and Stead and Marshall (1998).

Residential Density and Trip Frequency and Length

One major class of studies aims at testing the hypothesis that the volume of urban transport is a direct function of settlement density and that therefore a return to compact land-use patterns would result in less and shorter trips.

The most frequently quoted support of this hypothesis is the study by Newman and Kenworthy (1989), who analysed 32 cities in four continents and found a significant negative statistical correlation between residential density and transport-related energy consumption per capita (see Figure 4.1, top).

In US-American cities, Cervero (1996) and Cervero and Kockelman (1997) found that higher densities, in combination with mixed land use and neighbourhood design, reduce car ownership levels, trip rates and commuting distances and encourage non-auto travel. Similarly, Dunphy and Fisher (1996) found that areas with higher densities generate less per-capita car distances travelled. Hillman and Whalley (1983) report similar results from an analysis of travel patterns in Great Britain. According to their survey, average car distances are more than twice as high in very low-density areas as in very high-density areas. The more recent study by ECOTEC (1993) corroborates these findings in that it shows that average trip length of all modes except walking decreases with increasing residential density. However, ECOTEC could not detect a clear correlation between residential density and trip frequency, because only very little variation in average trip frequency could be found.



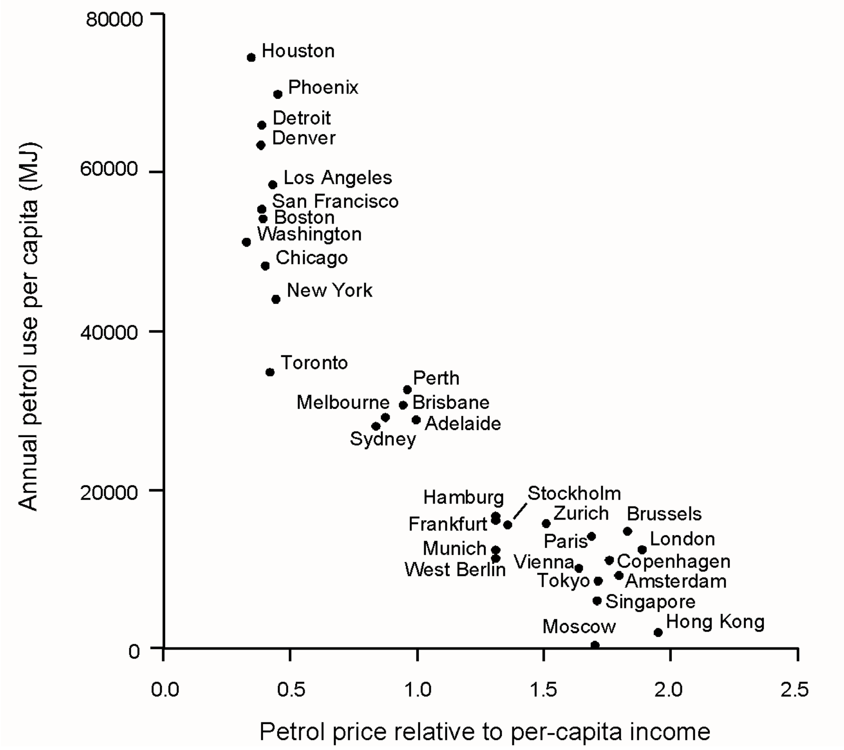


Figure 4.1. Petrol use v. urban density (top) and petrol price relative to income (bottom), 1980 (Newman and Kenworthy, 1989)

The problem with these studies is that there has been no evidence so far that under today's conditions, i.e. with an unconstrained transport market and current low travel costs, a return to higher densities would lead to a reduction of energy consumption of urban transport. In fact there have been several studies contradicting this hypothesis:

- Breheny (1992; 1995) collected various evidence that cast doubts on the Newman and Kenworthy hypothesis. He demonstrated *inter alia* that, if the population of England and Wales had *not* suburbanised between 1961 and 1991, total energy savings would have been less than three percent.

- Holz-Rau and Kutter (1995) and Holz-Rau (1997) compared urban neighbourhoods with different residential density in Stuttgart, Germany and found that per-capita distances travelled were only partly related to density. Work trip lengths were predominantly determined by distance to the city centre, where in Stuttgart most jobs are still concentrated. Shopping trip lengths could be explained by different levels of retail supply. Leisure trips differed more by social group than by neighbourhood, which, however, could be indirectly linked to density by different housing preferences and hence residential location.

- Kagermeier (1997) collected data on trips within the Munich metropolitan area and found that density has only little impact on per-capita distances travelled. Much more important were spatial scale and distances between the city centre and secondary centres.

- Miller and Ibrahim (1998) found that density does not directly affect commuting distances.

Moreover, even the data presented by Newman and Kenworthy can be interpreted in a different way which sheds doubt on the simple relationship between density and energy use. For instance, if one plots transport energy consumption not against urban density but against the petrol price data contained in the study, one finds the same, but even stronger, inverse relationship. In Figure 4.1 (bottom) annual petrol use per capita is plotted against petrol price relative to per-capita income, where 1.0 indicates the average relative petrol price of all 32 cities. Now it becomes plausible why petrol consumption in Australian cities is much lower than in cities of the United States, although Australian cities are no less dispersed than cities in the United States: because petrol is twice as expensive in Australia than in the United States.

In summary, one might hypothesise that urban density is only an intermediate variable and that the real cause behind a high level of mobility, trips lengths and transport energy consumption is the availability of cheap transport energy.

Residential Density and Public Transport Use

Efficient and frequent public transport requires a minimum ridership to at least partly recover its cost. Moreover, ridership should ideally be evenly spread across the whole day without extreme rush-hour peaks. It is clearly difficult if not impossible to maintain an acceptable level of service of public transport in areas of very low residential density. Another popular hypothesis is therefore that urban density is positively correlated with public transport use and negatively correlated with car ownership and car use.

There is ample evidence that this hypothesis is valid in a great variety of contexts:

- Several studies of US-American cities determined that urban regions with higher densities have lower car ownership, more public transport trips and less car kilometres per capita (Dunphy and Fisher, 1996; PBQD, 1996a; 1996c; Messenger and Ewing, 1996; Schimek, 1996a; 1996b; Cervero, 1996; Cervero and Kockelman, 1997). Pushkarev and Zupan (1977; 1980) found that public transport use is a function of size of downtown, distance from downtown and residential density. Kitamura et al. (1997) showed that population density is linked to the proportion of public transport trips, even though there are differences in the travel mode choice of socio-economic groups. Smith (1984) found that public transport use increases significantly when residential density increases from seven to sixteen dwellings per acre. Levison and Kumar (1990) identified a threshold for the relationship between density and mode choice at 10,000 persons per square mile.

- The results for European cities are similar. Kagermeier (1997) found for the Munich metropolitan area that density and mixed land use lead to reduced car travel. Findings of the ECOTEC study (1993) point in the same direction with the trip proportion of public transport and walking increasing and the proportion of car trips decreasing with increasing residential density. Bahrenberg (1997) demonstrated that in Bremen between 1970 and 1987 only one tenth of the increase in the number of car trips was caused by suburbanisation, whereas ninety percent were caused by shifts from public transport to car without a change in trip length due to higher car ownership.

However, there have also been studies that could not find a significant impact of urban density on public transport use, if other variables such as socio-economic factors or public transport supply are accounted for (Peat Marwick and Mitchell, 1975; Kockelman, 1997; Loutzenheiser, 1997). These studies suggest that the most important determinant of public transport use may be public transport supply - the frequency, speed, comfort and affordability of buses or trains that serve an area, and the destinations that can be reached by them.

Employment Density

One factor increasingly attracting attention is the spatial co-ordination between residential and work-place locations. It is obvious that if more people work close to their homes, the need for long commuting trips is reduced. However, as the Brotchie-Triangle (Figure 2.2) has illustrated, most people, in search for suburban yet affordable living, choose a place of residence far away from their job. Even people living in mixed-use inner-city neighbourhoods with many jobs commute to far-away work-places because of specialised job and skill requirements (Fishman, 1987). In this situation efforts to promote mixed-use neighbourhoods with a balance between households and work-places are not likely to lead to great reductions in commuting distances.

Although studies examining the relationship between travel patterns and employment density are rare, there are at least two studies underlining that household-employment balance has little impact on distance travelled (Ewing, 1995; Miller and Ibrahim, 1998). There are a few other studies, however, that demonstrate that it does matter. Cervero (1989a) reports a negative relationship between the job ratio (ratio of employment to workers resident in the area) and the share of walking and cycling in an urban area. Holz-Rau and Kutter (1995) in a study of the larger Stuttgart metropolitan region found a significant correlation between job supply (the relationship between work-places and labour force) in a community and per-capita commuting distance. The shortest distances were found in communities with as many work-places as workers, so that in theory all workers could have found a job in their own community, whereas employment centres with a predominant proportion of in-commuters (the larger cities) and surburban dormitory communities had significantly longer commuting trips.

Employment density may also affect modal share. Several studies of US-American cities observed higher public transport use to employment centres in the inner city as well as in the inner and outer suburbs and near public transport stations (Schimek, 1996a; PBQD, 1996a; Cervero, 1989). Frank and Pivo (1994) identified a threshold of 75 employees per acre for significant shifts to public transport to occur. Banister et al. (1997) detected a relationship between job ratio and energy use per trip in a case study of Oxford.

Neighbourhood Design

A lively debate exists about how much neighbourhood design encouraging walking and cycling can contribute to reducing the need for travel. In the United States the debate has been stimulated by the movement of 'transit-oriented development' (TOD) frequently associated with concepts of 'neo-traditional' urban design schemes replicating the model of the 19th century small American town. In Europe the discussion has an even longer tradition since the introduction of 'traffic-calming' and pedestrianisation in Dutch cities which have spread from Holland to many other European countries.

In the American literature there are many studies confirming that pre-war, traditional communities or new, mixed-use communities have significantly higher public transport use and walking and lower auto use than standard, post-war American suburbs (Friedman et al., 1994; Cervero, 1996; Kockelman, 1997; Cervero and Kockelman, 1997). Friedman et al. (1994) found out that the share of public transport trips is three to seven times higher in 'traditional' neighbourhoods than in suburban neighbourhoods while the share of walking is two to eight times higher in 'traditional' than in suburban neighbourhoods. Fehrs and Peers (1992) came to a similar conclusion. However, other studies find little effect of design factors (1974; PBQD, 1996a) or point out that the range of destination choices in a neighbourhood matters, not the design itself (Handy, 1995; 1996b). Winter and Farthing (1997) found that the provision of facilities in close proximity to residential areas leads to reduced average trip distances. However, they could not confirm an increased use of less energy-intensive modes, i.e. walking and cycling, in these areas. Still other studies note that neighborhood type is not significant in explaining travel behaviour once socio-economic factors are accounted for (McNally & Kulkarni, 1997).

Similar results are obtained in European studies. Holz-Rau and Kutter (1995) observed that neighbourhood design variables lose significance once socio-economic characteristics of the population are taken into account.

In summary, mixing of land uses and neighbourhood design remain relatively uncertain factors in achieving more sustainable travel patterns. The existing studies differ about the evaluation of land use mixing and especially of the role of urban design as a means to reduce travel demand and average trip length.

Location

There is reason to assume that not only the internal structure of urban neighbourhoods is relevant for the mobility behaviour of their residents but also their location within the urban region and to the regional transport networks. It can be expected that a central location within and good connection to the regional road network will be positively correlated with car ownership and number and length of car trips and negatively correlated with walking, cycling and public transport mobility. Vice versa, a central location and closeness to a public transport stop can be expected to lead to a higher proportion and greater length of public transport trips at the expense of the other modes.

It is important to note the distinction between the term location as it is used here and the term accessibility that will be used later (see Section 4.2). Location here indicates physical location without taking account of transport supply, whereas accessibility includes both, physical location and ease of travel.

Spence and Frost (1995) found that in London commuting distances increase roughly linearly with distance from the city centre while in cities like Birmingham and Manchester, commuting distances reach a peak at seven and nine kilometres respectively from the city centre and decrease thereafter. Næss et al (1995) identified by statistical analysis distance from home to urban centre as a key variable for total distance travelled and energy consumption per person by using data from Oslo.

There are several studies that confirm that location is an important determinant of distance travelled and mode choice (Frank & Pivo, 1994; Ewing, 1995; Kockelman, 1997). Kitamura et al. (1997) found that the distance from home to the nearest bus stop and railway station affects the choice of travel mode. The proportion of non-automobile trips increases and the proportion of car trips decreases the closer homes are located to a bus station. Similarly, the study found that the proportion of rail journeys decreases with increasing distance from railway stations. Cervero (1994) confirms these findings with a survey of North American cities, which indicates that residents living at a 900 metre distance from a railway station are likely to make only half the number of rail journeys than residents living within a 500 metre distance.

City Size

There is no simple relationship between city size and travel behaviour due to the interaction of several competing factors (Owens, 1986; ECOTEC, 1993). On the one hand, the number of local jobs, facilities and services that can be supported increases with the size of a settlement, thus enabling residents to access these opportunities by travelling relatively short distances. On the other hand, very large cities can cause longer travel distances, particularly when there is a large-scale spatial separation of homes from employment centres, usually the city centre and from other central facilities.

- Evidence from European cities shows that transport energy consumption and mean travel distance are lowest in large metropolitan regions. Banister (1992) and Breheny (1995) report that in British towns and cities, mean transport energy consumption decreases when urban size increases with energy consumption being one third lower than average in the largest metropolitan areas in Great Britain (excluding London) and more than one third higher than average in the smallest settlements.

- Apel (1992) and Pharoah and Apel (1995) found a strong correlation between city size and public transport use in cities in Europe, which can be easily explained by the fact that only larger cities can afford efficient and attractive public transport systems.

- Evidence from the United States, however, reports no clear relationship between population size and modal choice of urban areas. Among the metropolitan areas studied, the share of automobile trips is lowest in New York and highest in Detroit, which may, however, be more related to urban density than to city size.

Summing up, it can be stated that many studies especially from Europe confirm that the share of automobile trips decreases with city size and increases with distance of homes from the centre. None of the studies found a significant variation of trip frequency.

4.2 Transport Impacts on Land Use

Whereas there exists a great number of empirical studies investigating the impact of urban form on transport behaviour, the reverse direction of impacts, the impact of transport on urban form, has attracted much less attention of empirical researchers. One reason for this may be that land use changes occur much more slowly than changes of travel behaviour and are subject to many other influences other than transport, such as population growth, economic development changes in life styles, household formation, consumption patterns and production technology and are therefore difficult to isolate.

Nevertheless there have been a number of studies in which the effect of transport on urban land use has been analysed. The earliest of these is the seminal study by Hansen (1956) mentioned above, in which he demonstrated for Washington, DC, that locations with good accessibility had a higher chance of being developed, and at a higher density, than remote locations ("How accessibility shapes land use"). Figure 4.2 shows the correlation between accessibility to work-places and land use development in terms of residential development in percent of developable residential land.

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

Kreibich (1978) analysed suburbanisation in the Munich metropolitan area after the opening of the Munich S-Bahn system in 1972 and found increasing residential growth rates along the S-Bahn lines fanning out into the Munich hinterland (Figure 4.3).

Miller et al. (1998) reviewed studies of the impacts of commuter rail projects in North America. A common observation is that, at least in the North American context, land-use impacts of rail development tend to be small and concentrate on downtown and few suburban stations (Knight and Trygg, 1973; 1977; Guiliano, 1995; Cervero and Landis, 1997).

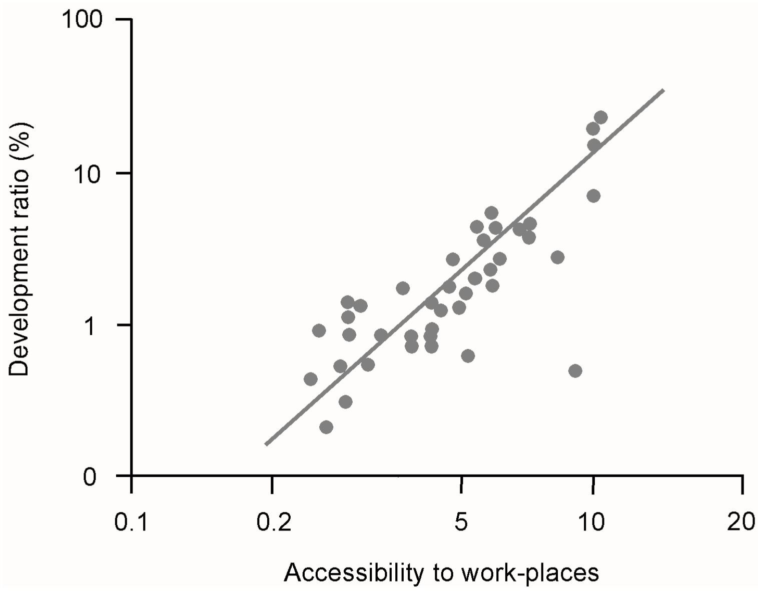


Figure 4.2. "How accessibility shapes land use" (Hansen, 1956)

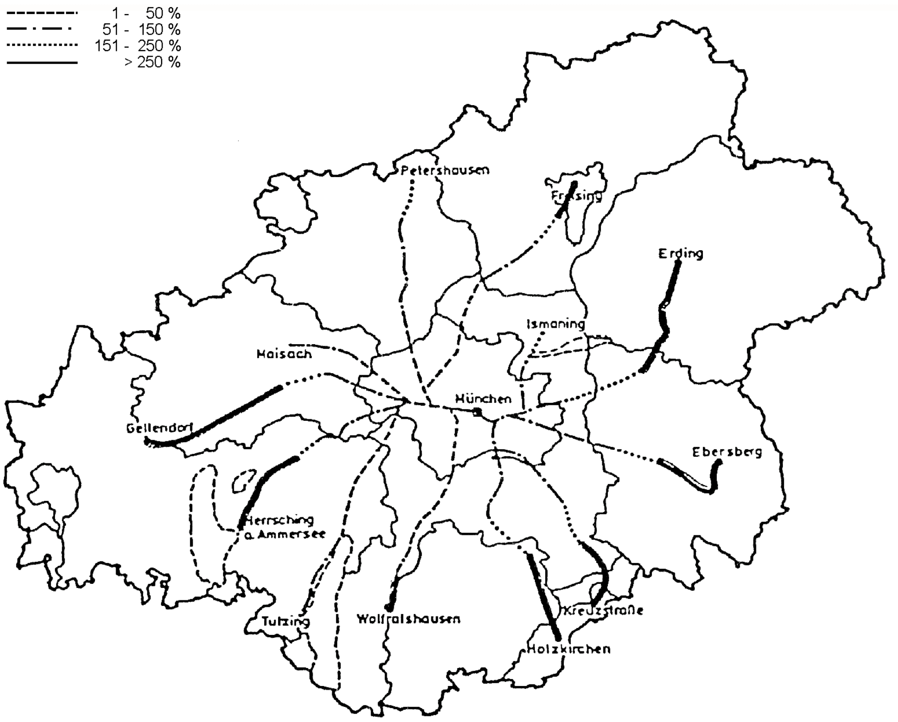


Figure 4.3. S-Bahn construction and population growth in the Munich metropolitan area (Kreibich, 1978)

Knight and Trygg (1973; 1977) reported wide differences in the strength of impacts between cities, ranging from significant in Boston, Montreal, Toronto and Philadelphia to negligible in Cleveland and Chicago. Significant concentrations of development near metro stations were found in Washington, DC (Green and James, 1993) and Portland, OR (Arrington, 1989). Nelson and Sanchez (1997) reported that in Atlanta employment around metro stations increased, whereas population decreased. According to Hunt et al. (1994) residential location preferences in Calgary are strongly influenced by distance to light-rail stations. Increasing property values near metro stations were reported from Philadelphia (Knight and Trygg, 1973; 1977) and the San Francisco Bay Area (Workman and Brod, 1997), but property value impacts were difficult to identify in Portland, OR (Al-Mosaind et al., 1993; Workman and Brod, 1997)

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

Pharoah and Apel (1995) in their comparison of transport concepts in European cities observed that policies to promote public transport over car tend to have strong positive effects on the economic development of city centres, whereas the negative effects of car restraint policies frequently feared by local businessmen have in no case been confirmed by empirical evidence. They note, however, that the causal relationship may work in the opposite direction: that city centres are not attractive because they are accessible by car but that attractive city centres can afford to be less accessible by car.

There are few systematic studies but ample common-experience evidence of the importance of accessibility for the location of firms in urban areas. Everybody knows the road-side development of manufacturing, wholesale and service establishments along major thoroughfares and suburban motorways. The Route-128 and M5 strip developments of high-tech firms near Boston and London have their counterparts in many European countries. Garreau (1991) phrased the term 'edge city' to describe car-based office and retail developments at the outer edge of metropolitan areas in the United States.

Besides the small number of studies on the impacts of transport on land use, most of them suffer from methodological problems. Miller et al. (1998) note that in virtually no case the study design provided an adequately controlled 'experiment' to properly isolate the impacts of transport investments from other evolutionary factors at work in the urban region. They make the point that this can be achieved only by integrated land-use transport models – a point that will be taken up in Section 5.

4.3 Summarised Findings of Empirical Studies

The results of empirical studies of land-use transport interaction are summarised in Tables 4.1 and 4.2 with regard to factors referred to in the above two subsections.

Table 4.1 describes the impact of land use policies on transport patterns. Residential density has been shown to be inversely related to trip length. Centralisation of employment results in longer trips, while trip lengths in areas with a balanced residents-to-workers ratio are shorter. American studies confirm that attractive neighbourhood facilities also contribute to shorter average trip lengths. The theoretical insight that distance of residential locations to employment centres is an important determinant of average trip length has been confirmed empirically. The larger a city is the shorter are mean travel distances except in some of the largest metropolises. None of the studies reported a significant impact of any factor on trip frequency. Residential and employment density as well as large agglomeration size and rapid access to public transport stops of a location were found to be positively correlated with the modal share of public transport. 'Traditional' neighbourhoods showed a higher share of non-car modes.

Table 4.2 illustrates the impact of transport policies on land use and the impact of transport policies on transport patterns. Accessibility was reported to be of varying importance for different types of land uses. It is an essential location factor for retail and office uses. Locations with high accessibility tend to be developed faster than other areas. as residential areas. The value of accessibility to manufacturing industries varies considerably depending mainly on the goods produced. In general, ubiquitous improvements in accessibility invoke a more dispersed spatial organisation of land uses.

The impacts of transport on transport patterns tend to be much stronger than those of land use on transport or of transport on land use. The causal relationships are relatively undisputed and empirical studies largely agree on the impact mechanisms. While travel cost and travel time tend to have a negative impact on trip length, high accessibility of a location generates longer work and leisure trips. Studies on changes in trip frequency are only known for travel time improvements, where time savings were found to result in more trips being made. Mode choice depends on the relative attractiveness of a mode compared to all other modes. The fastest and cheapest mode is likely to have the highest modal share. However, offering public transport free of charge will not induce a significant mode switch of car drivers, rather of walkers and cyclists.

The results of the investigated empirical studies were found to be largely in line with the conclusions from land-use transport theory in Section 2.

Table 4.1. Impacts of land use in empirical studies

Direction	Factor	Impact on	Observed impacts
Land use ⇓ Transport	Residential density	Trip length	Numerous studies support the hypothesis that higher density combined with mixed land use leads to shorter trips. However, the impact is much weaker if travel cost differences are accounted for.
		Trip frequency	Little or no impact observed.
		Mode choice	The hypothesis that residential density is correlated with public transport use and negatively with car use is widely confirmed.
	Employment density	Trip length	In several studies the hypothesis was confirmed that a balance between workers and jobs results in shorter work trips, however this could not be confirmed in other studies. Mono-functional employment centres and dormitory suburbs, however, have clearly longer trips.
		Trip frequency	No significant impact was found.
		Mode choice	Higher employment density is likely to induce more public transport use.
	Neighbourhood design	Trip length	American studies confirmed that 'traditional' neighbourhoods have shorter trips than car-oriented suburbs. Similar results are found in Europe.
		Trip frequency	No effects are reported.
		Mode choice	'Traditional' neighbourhoods have significant higher shares of public transport, walking and cycling. However, design factors lose in importance once socio-economic characteristics of the population are accounted for.
	Location	Trip length	Distance to main employment centres is an important determinant of distance travelled.
		Trip frequency	No effect observed.
		Mode choice	Distance to public transport stops strongly influences public transport use.
	City size	Trip length	Mean travel distances are lowest in large urban areas and highest in rural settlements.
		Trip frequency	No effect observed.
		Mode choice	Public transport use is highest in large cities and smallest in rural settlements.

Table 4.2. Impacts of transport in empirical studies

Direction	Factor	Impact on	Observed impacts
Transport ⇓ Land use	Accessibility	Residential location	More accessible locations are developed faster. If accessibility in the whole region grows, residential development will be more dispersed.
		Industrial location	There is little evidence of impacts of accessibility on location of manufacturing, but ample evidence of the importance of accessibility for high-tech and service firms.
		Office location	Office development occurs predominantly at highly accessible inner-city locations or in office parks or 'edge cities' at the urban periphery with good motorway access.
		Retail location	Retail development occurs either at highly accessible inner-city locations or on peripheral sites with ample parking and good road accessibility.
Transport ⇓ Transport	Accessibility	Trip length	Suburban dispersal accelerated by good accessibility to the central city generates longer work and shopping trips.
		Trip frequency	No systematic studies on the impact on trip frequency are known.
		Mode choice	Accessibility differences generate modal shifts via travel time and travel cost (see below).
	Travel cost	Trip length	Price elasticity of trip length was found to be in the range of -0.3.
		Trip frequency	No systematic studies of trip frequency as a function of travel cost are known.
		Mode choice	Travel cost differences influence modal choice; making public transport free will not induce many car drivers to switch to public transport, mainly former walkers and cyclists.
	Travel time	Trip length	Travel time savings through transport system improvements are partly spent on longer trips.
		Trip frequency	Travel time savings through transport system improvements are partly spent on more trips.
		Mode choice	Travel time improvements on one mode strongly influence modal choice.

5. Models of Land-Use Transport Interaction

The review of empirical evidence of land-use transport interaction in the previous section showed that it is difficult to empirically isolate impacts of land use on transport and vice versa because of the multitude of concurrent changes of other system variables. This poses a problem if the likely impacts of integrated land-use and transport policies to reduce the demand for travel are to be predicted.

There are principally three methods to predict those impacts. The first is to ask people how they would change their location and mobility behaviour if certain parameters, such as land use regulations or transport costs, would change ('stated preference'). The second consists of drawing conclusions from observed decision behaviour of people under different conditions on how they would be likely to behave if these parameters would change ('revealed preference'). The third method is to simulate human decision behaviour in mathematical models.

All three methods have their advantages and disadvantages. Surveys can reveal also subjective factors of location and mobility decisions, however, their respondents can only make conjectures about how they would behave in still unknown situations, and the validity of such conjectures is uncertain. Empirical studies based on observations (as the ones reviewed in the previous section) produce detailed and reliable results; these, however, are valid only for existing situations and are therefore not suited for the assessment of the impacts of novel yet untested policies. In addition it is usually not possible to associate the observed changes of behaviour unequivocally with specific causes, because in reality several determining factors change at the same time.

Mathematical models of human behaviour are also based on empirical surveys or observations. The difference is that the conclusions to be drawn from the survey and observation data are quantified. Strictly speaking, the results of mathematical models are therefore no more universally valid than those of empirical studies but are only valid for situations which are similar to those for which their parameters were estimated. Nevertheless is it possible to transfer human behaviour represented in mathematical models within certain limits to still unknown situations. In addition, mathematical models are the only method by which the effects of individual determining factors can be analysed by keeping all other determining factors fixed.

In the following section therefore recent developments in the field of operational integrated land-use transport models (starting from the work of ISGLUTI) will be reviewed with special emphasis on their ability to test both land use and transport policies and to assess their impacts in terms of the objectives of TRANSLAND.

5.1 Existing Urban Land-Use Transport Models

The models reviewed in this section are all integrated, i.e. incorporate the most essential processes of spatial development; this implies that they include urban land use, where land use denotes a range of land uses such as residential, industrial and commercial. This excludes partial models addressing only one subsystem such as housing or retail. It is essential that the links from transport to land use are considered; transport itself may be modelled either endogenously or by an exogenous transport model. The models are operational in the sense that they have been implemented, calibrated and used for policy analysis for at least one metropolitan region.

The number of real-world applications of models falling under the above definition has increased steadily over the last decade. There has been a continuous reflection of purpose, direction and theoretical basis of land-use transport modelling as witnessed by volumes edited by Hutchinson et al. (1985); Hutchinson and Batty (1986) and Webster et al. (1988) and by reviews by Harris (1985), Mackett (1985a), Wegener (1986b; 1987), Kain (1987), Boyce (1988), Berechman and Small (1988), Aoyama (1989), and Batty (1994), Harris (1994), Southworth (1995), Wilson (1997) and Wegener (1994; 1995; 1998a).

To assess the current state-of-the-art in urban modelling, in this section first a framework for the classification and evaluation of urban models is established.

Urban Change Processes

For the evaluation of operational urban models, the urban change processes to be modelled are identified. Eight types of major urban subsystem are distinguished. They are ordered by the speed by which they change, from slow to fast processes:

- *Very slow change: networks, land use*. Urban transport, communications and utility *networks* are the most permanent elements of the physical structure of cities. Large infrastructure projects require a decade or more, and once in place, are rarely abandoned. The *land use* distribution is equally stable; it changes only incrementally.

- *Slow changes: workplaces, housing.* Buildings have a life-span of up to one hundred years and take several years from planning to completion. *Workplaces* (non-residential buildings) such as factories, warehouses, shopping centres or offices, theatres or universities exist much longer than the firms or institutions that occupy them, just as *housing* exists longer than the households that live in it.

- *Fast change: employment, population*. Firms are established or closed down, expanded or relocated; this creates new jobs or makes workers redundant and so affects *employment*. Households are created, grow or decline and eventually are dissolved, and in each stage in their lifecycle adjust their housing consumption and location and motorisation to their changing needs; this determines the distribution of *population* and *car ownership*.

- *Immediate change: goods transport, travel*. The location of human activities in space gives rise to a demand for spatial interaction in the form of *goods transport* or *travel*. These interactions are the most flexible phenomena of spatial urban development; they can adjust in minutes or hours to changes in congestion or fluctuations in demand, though in reality adjustment may be retarded by habits, obligations or subscriptions.

There is a ninth subsystem, the *urban environment*. Its temporal behaviour is more complex. The direct impacts of human activities, such as transport noise and air pollution are immediate; other effects such as water or soil contamination build up incrementally over time, and still others such as long-term climate effects are so slow that they are hardly observable. All other eight subsystems affect the environment by energy and space consumption, air pollution and noise emission, whereas only locational choices of housing investors and households, firms and workers are co-determined by environmental quality, or lack of it. All nine subsystems are partly market-driven and partly subject to policy regulation.

Seventeen Urban Models

Seventeen models were selected for the comparison. The selection does not imply a judgement on the quality of the models, but was based on the availability of information. These are the seventeen models:

BOYCE	the combined models of location and travel choice developed by Boyce (Boyce et al. 1983; 1985; Boyce 1986; Boyce et al. 1992).
CUFM	the California Urban Futures Model developed at the University of California at Berkeley (Landis 1992; 1993; 1994; Landis and Zhang, 1998a; 1998b).
DELTA/ START	the new land-use modelling package DELTA by Davids Simmonds Consultancy, Cambridge, UK linked with the START transport model developed by MVA Consultants and the Institute of Transport Studies (ITS) of the University of Leeds (Simmonds and Still, 1998; Simmonds, 1999).
HUDS	the Harvard Urban Development Simulation developed by Kain and Apgar (1985).
IMREL	the Integrated Model of Residential and Employment Location by Anderstig and Mattsson (1991; 1998).
IRPUD	the model of the Dortmund region developed by Wegener (1982a; 1982b; 1985; 1986a; Wegener et al. 1991; Wegener, 1996; 1998b).
ITLUP	the Integrated Transportation and Land Use Package developed by Putman (1983; 1991; 1998).
KIM	the non-linear version of the urban equilibrium model developed by Kim (1989) and Rho and Kim (1989).
LILT	the Leeds Integrated Land-Use/Transport model developed by Mackett (1983; 1990c; 1991a; 1991b).
MEPLAN	the integrated modelling package developed by Marcial Echenique & Partners (Echenique et al., 1969; Echenique and Williams, 1980; Echenique, 1985; Echenique et al., 1990; Hunt and Echenique, 1993; Hunt and Simmonds, 1993, Echenique, 1994; Williams 1994; Hunt 1994).
METROSIM	the microeconomic land-use and transport model developed by Anas (Anas and Moses, 1978; Anas, 1982; Anas and Brown, 1985; Anas and Duann, 1986; Anas et al., 1987; Anas, 1992; Anas and Arnott, 1993; 1994; Anas, 1994; 1995; 1998).
MUSSA	the '5-Stage Land-Use Transport Model' developed by Martinez for Santiago de Chile (1991; 1992a; 1992b; Martinez and Donoso, 1995; Martinez, 1996; 1997a; 1997b).
POLIS	the Projective Optimization Land Use Information System developed by Prastacos for the Association of Bay Area Governments (Prastacos, 1986; Caindec and Prastacos, 1995).
RURBAN	the Random-Utility URBAN model developed by Miyamoto (Miyamoto et al., 1986; Miyamoto and Kitazume, 1989; Miyamoto and Udomsri, 1996).
STASA	the master equation based integrated transport and urban/regional model developed by Haag (Haag 1990). The STASA model is used in the SILUS case study of the EU EUROSIL project.

TRANUS the transport and land-use model developed by de la Barra (de la Barra, 1982; de la Barra et al. 1984; de la Barra 1989; 1998).

URBANSIM the new microeconomic model of location choice of households and firms by Waddell (1998a; 1998b; 1998c; 1998d; Waddel et al., 1998).

These seventeen models will now be compared using as criteria comprehensiveness, overall structure, theoretical foundations, modelling techniques, dynamics, data requirements, calibration and validation, operationality and applicability.

Comprehensiveness

All seventeen models are comprehensive in the sense that they address at least two of the eight subsystems identified above. Only DELTA/START, MEPLAN, STASA and TRANUS encompass all eight subsystems. IRPUD, LILT and METROSIM address all subsystems except goods transport, KIM models goods movements but not physical stock and land use, HUDS has a housing supply submodel but does not model non-residential buildings. Half of the models make no distinction between activities (population and employment) and physical stock (housing and workplaces). Four models (DELTA, CUFM, HUDS, POLIS and RURBAN and URBANSIM) do not model transport and hence rely on input from exogenous transport models. Only DELTA, HUDS, IRPUD, LILT and URBANSIM model demographic change and household formation. Table 5.1 shows the urban subsystems that can be modelled with each model.

Model Structure

With respect to overall model structure, two groups can be distinguished. One group of models searches for a unifying principle for modelling and linking all subsystems; the others see the city as a hierarchical system of interconnected but structurally autonomous subsystems; The resulting model structure is either tightly integrated, 'all of one kind', or consists of loosely coupled submodels, each of which has its own independent internal structure. The former type of model is called 'unified', the latter 'composite' (Wegener et al. 1986). Six of the seventeen models (BOYCE, MUSSA, KIM, METROSIM, RURBAN and STASA) belong to the unified category, the remaining ten are composite. The distinction between unified and composite model designs has important implications for the modelling techniques applied and for the dynamic behaviour of the models (see below).

Theory

In the last twenty years great advances in theories to explain spatial choice behaviour and in techniques for calibrating spatial choice models have been made. Today there is a broad consensus about what constitutes a state-of-the-art land use model: Except for one (CUFM), all models rely on random utility or discrete choice theory to explain and forecast the behaviour of actors such as investors, households, firms or travellers. Random utility models predict choices between alternatives as a function of attributes of the alternatives, subject to stochastic dispersion constraints that take account of unobserved attributes of the alternatives, differences in taste between the decision makers, or uncertainty or lack of information (Domencich and McFadden 1975).

Table 5.1. Urban subsystems represented in land-use transport models

Models	Speed of change							
	Very slow		Slow		Fast		Immediate	
	Networks	Land use	Work-places	Housing	Employ-ment	Popula-tion	Goods transport	Travel
BOYCE	+				+	+		+
CUFM		+	+	+	+	+		
DELTA/START	+	+	+	+	+	+	+	+
HUDS				+	+	+		
IMREL	+	+	+	+	+	+		+
IRPUD	+	+	+	+	+	+		+
ITLUP	+	+			+	+		+
KIM	+				+	+	+	+
LILT	+	+	+	+	+	+		+
MEPLAN	+	+	+	+	+	+	+	+
METROSIM	+	+	+	+	+	+		+
MUSSA	+	+			+	+		+
POLIS		+			+	+		+
RURBAN		+			+	+		+
STASA	+	+	+	+	+	+	+	+
TRANUS	+	+	+	+	+	+	+	+
URBANSIM		+	+	+	+	+		+

Anas (1983) showed that the multinomial logit model resulting from random utility maximisation is, at equal levels of aggregation, formally equivalent to the entropy-maximising model proposed by Wilson (1967; 1970); he thus laid the foundation for the convergence and general acceptance of formerly separate strands of theory. The STASA model is based on the Master equation approach and may be seen as a dynamic and decision based multi-agent system (Haag, 1990).

Underneath that uniformity, however, there are significant differences between the theoretical foundations of the models. Eight models (HUDS, IMREL, KIM, MEPLAN, METROSIM, MUSSA, RURBAN and TRANUS) represent the land (or floorspace or housing) market with endogenous prices and market clearing in each period; three (DELTA, IRPUD, URBANSIM) have endogenous land and housing prices with delayed price adjustment. These models are indebted to microeconomic theory, in particular to Alonso's (1964) theory of urban land markets or bid-rent theory. The eight models without market equilibrium rely on random utility maximisation; however, three of the microeconomic models (MUSSA, RURBAN and STASA) are hybrids between bid-rent and random utility theory. All models with transport submodels use random utility or entropy theory for modelling destination and mode choice, except the STASA model.

Only KIM and METROSIM determine a general equilibrium of transport and location with endogenous prices. The other models, except STASA are equilibrium models of transport only (IRPUD, ITLUP, START), of transport and activity location separately (IMREL, MEPLAN and TRANUS), or of transport and location combined, but without endogenous prices (BOYCE and LILT). Five models apply concepts of locational surplus (IMREL, POLIS), random utility (DELTA, IRPUD and ITLUP) or profitability (CUFM) to locate activities. ITLUP may be brought to general equilibrium, but this is not normally done; METROSIM may produce a long-run equilibrium or converge to a steady state in annual increments. Only STASA describes the short-term redistribution of population during a day due to transport events.

Several other theoretical elements are built into some models. MEPLAN and TRANUS use export base theory to link population and non-basic employment to exogenous forecasts of export industries. DELTA, HUDS, IRPUD, LILT and URBANSIM apply standard probabilistic concepts of cohort survival analysis in their demographic and household formation submodels. IRPUD also utilises ideas from time geography, such as time and money budgets, to determine action spaces of travellers in its transport submodel.

Modelling Techniques

In all seventeen models, the urban region is represented as a set of discrete subareas or zones. Time is typically subdivided into discrete periods of one to five years. This classifies all models except IMREL (which is static) as recursive simulation models. STASA uses a discrete time scale of one year for the urban/regional modelling and a one hour time scale for redistribution effects due to transport events.

In seven models (BOYCE, IMREL, KIM, LILT, MEPLAN, RURBAN and TRANUS) transport and location are simultaneously determined in spatial-interaction location models, in which activities are located as destinations of trips; in the remaining models (and in the employment location model of IMREL) transport influences location via accessibility indicators. In the ten models with network representation state-of-the-art modelling techniques are applied with network equilibrium the dominant trip assignment method despite its well-known weakness of collapsing to all-or-nothing assignment in the absence of congestion. Only ITLUP, MEPLAN, START, STASA and TRANUS have multiple-path assignment allowing for true route-choice dispersion.

For representing flows of goods, multiregional input-output methods are the standard method. KIM, MEPLAN and TRANUS use input-output coefficients or demand functions for determining intersectoral flows and random utility or entropy models for their spatial distribution. MEPLAN and TRANUS have generalised this to incorporate industries and households as consuming and producing 'factors' resulting in goods movements or travel.

With the exception of CUFM and HUDS, all models are aggregate at a meso level, i.e. all results are given for medium-sized zones and for aggregates of households and industries. CUFM and HUDS are disaggregate, i.e. apply microsimulation techniques. HUDS works on a sample of individual households in list form, whereas CUFM uses detailed land information in map form generated by a geographical information system. IRPUD starts with aggregate data but uses microsimulation techniques in its housing market submodel.

Dynamics

All but one of the seventeen models are recursive simulation models. Recursive simulation models are called quasi-dynamic because, although they model the development of a city over time, within one simulation period they are in fact cross-sectional. This is however only true for strictly unified models. Composite models consist of several interlinked submodels that are processed sequentially or iteratively once or several times during a simulation period. This makes composite models well suited for taking account of time lags or delays due to the complex superposition of slow and fast processes of urban development (cf. Wegener et al., 1986). However, this feature is insufficiently used by most models, because the typical simulation period of five years has the effect of an implicit time lag - a too long time lag in most cases.

Data Requirements

The data collection for a model of a large metropolis has remained a major effort. However, in many cases the introduction of computers in local government has generated a pool of routinely collected and updated data that can be used as the information base for a model, in particular in the fields of population, housing, land use and transport. Another factor reducing the data-dependency of urban models is the significant progress made in urban theory in the last decades. The models of today are more parsimonious, i.e. can do with less data than previous models. Examples illustrating this are the techniques to generate regional input-output matrices from national input-output matrices and regional totals through biproportional scaling methods; or techniques to create artificial microdata as samples from multivariate aggregate data.

Calibration and Validation

All seventeen models of the sample have been (or could have been) calibrated using observed data, using readily available computer programs and following well-established methods and standards. In particular, maximum-likelihood estimation of the ubiquitous logit model has become routine. Yet, while calibration has become easier, the limits to calibrating a model with data of the past have become visible. Calibration of cross-sectional models, as it is practised today, provides the illusion of precision but does little to establish the credibility of models designed to look into the far future. There has been almost no progress in the methodology required to calibrate dynamic or quasi-dynamic models.

In the face of this dilemma, the insistence of some modellers on 'estimating' every model equation appears almost an obsession. It would probably be more effective to concentrate instead on model *validation*, i.e. the comparison of model results with observed data over a longer period. In the future, the only real test of a model's performance should be its ability to forecast the essential dynamics of the modelled system over a past period at least as long as the forecasting period. There are only four models in the sample following this philosophy, IRPUD, STASA, MEPLAN and URBANSIM. IRPUD and MEPLAN are partly calibrated not by statistical estimation, but by manual fine-tuning in a long, interactive process. STASA use flow data and stock data to estimate the key-parameters of the model.

Operationality

All the models in the sample are operational in the sense that they have been applied to real cities. However, only few models are on their way to become standard software for a wider market. Among these, TRANUS stands out as a particularly advanced and well documented software with an attractive user interface in Spanish or English. The time seems not far when any planning office will be able to buy a complex and versatile urban model with full documentation, default values and test data sets for less than a thousand dollars.

Applicability

If one considers the enormous range of planning problems facing a typical metropolitan area in industrialised countries today, the spectrum of problems actually addressed with the seventeen urban models in the sample is very narrow. The majority of applications answer traditional questions such as how land use planning or housing programs would affect land use development and transport, or how transport improvements or changes in travel costs would shift the distribution of activities in an urban area. However, this makes the models especially suited to answer questions arising in the context of TRANSLAND. In Tables 5.2 and 5.3 the types of land-use and transport policy that can be studied with the models are specified.

5.2 Future Urban Land-Use Transport Models

Today there are many urban modelling projects in Europe underway. The MEPLAN model is applied in more and more cities all over the world. The European Commission has funded a number of important studies employing land use-transport models. There are some twenty urban regions in Europe where, mostly funded by the European Commission, integrated land use-transport models are now being applied. Another project is EUNET, which applies land use-transport modelling on a regional scale to Europe, including future extensions of the European Union. There are several TRANUS applications, among them the study of the Swiss Metro, a high-speed vacuum-tube underground railway proposed to cross the whole of Switzerland, which is considered one single metropolitan area. There is the DELTA/START land-use transport model by David Simmonds and Martin Vorhees Associates (Simmonds, 1995), which is applied to an increasing number of metropolitan areas. There is the SPARTACUS project which applied MEPLAN to three urban areas, Helsinki, Bilbao and Naples and connects the model with spatially disaggregate environmental submodels (see Section 6). Moreover, the European Commission is launching its 5th Framework Programme of Research and Technology Development for the years 1999-2002, which is expected to include a number of substantial projects devoted to sustainable urban and regional systems.

Remaining Challenges

Nevertheless, there are challenges still to meet. The transport submodels used in existing land use transport models do not apply state-of-the-art activity-based modeling techniques. All of them apply the traditional four-step travel demand model sequence which is not suitable to model behavioural responses to many travel demand management policies presently discussed. Moreover, the spatial resolution of existing land-use transport models is too coarse to model activity-based travel behaviour or neighbourhood-scale travel demand management policies.

Table 5.2. Land-use policies that can be studied with land-use transport models

	Land use policies											
	Investment and services			Planning		Regulation		Pricing and subsidies			Information	
Models	Facilities	Workplaces	Housing	General land-use plan	Detailed land-use plan	Building standards	Building permits	Taxes and subsidies	Development charges	Impact fees	Education	Marketing
BOYCE		+	+									
CUFM		+	+	+								
DELTA/START	+	+	+	+								
HUDS		+	+									
IMREL	+	+	+	+								
IRPUD	+	+	+	+								
ITLUP	+	+	+	+								
KIM		+	+	+								
LILT	+	+	+	+								
MEPLAN	+	+	+	+								
METROSIM	+	+	+	+								
MUSSA	+	+	+	+								
POLIS		+	+	+								
RURBAN		+	+	+								
STASA	+	+	+	+								
TRANUS	+	+	+	+								
URBANSIM	+	+	+	+								

Their insufficient spatial resolution is also one of the reasons why only very few land-use transport models are linked to advanced environmental submodels of air quality, traffic noise, land take and biotopes (Wegener, 1998b). Environmental issues are certain to play a more prominent role in the future when the manifest unsustainability of present urban lifestyles and mobility patterns will increasingly come under scrutiny (Greene and Wegener, 1997). However, most present efforts to link environmental submodels to transport or land-use transport models are content with modelling *emissions* where actually *immisions*, i.e. local impacts of emissions occurring elsewhere should be forecast.

Table 5.3. Transport policies that can be studied with land-use transport models

	Transport policies											
	Investment and services			Regulation			Pricing and subsidies			Information		
Models	Roads	Public transport	Public transport operation	Parking	Traffic regulation	Parking regulation	Road pricing	Parking fees	Fuel taxes	Public transport fares	Education	Marketing
BOYCE	+	+	+		+		+		+	+		
CUFM												
DELTA/START	+	+	+	+	+	+	+	+	+	+		
HUDS												
IMREL	+	+	+	+	+	+	+	+	+	+		
IRPUD	+	+		+	+	+	+	+	+	+		
ITLUP	+	+	+		+		+		+	+		
KIM	+	+			+		+		+	+		
LILT	+	+	+		+		+		+	+		
MEPLAN	+	+	+	+	+	+	+	+	+	+		
METROSIM	+	+	+		+		+		+	+		
MUSSA	+	+	+		+		+		+	+		
POLIS												
RURBAN												
STASA	+	+	+		+		+		+	+		
TRANUS	+	+	+	+	+	+	+	+	+	+		
URBANSIM												

This leads to issues of spatial equity. Most land-use transport models are utilitarian in that they favour solutions yielding the greatest aggregate social benefit. However, urban societies are increasingly becoming socially and spatially fragmented and polarised, which means that distributional issues, both in social and spatial terms, are becoming more prominent. Distributional issues are particularly relevant in environmental conflicts where polluters and those affected by pollution tend to come from different social groups or neighbourhoods of a city. However, most present land-use transport models are insensitive to issues of social exclusion and spatial equity.

Future Developments

The future of land-use transport modelling will largely depend on whether emerging new models will live up to these challenges.

From a technical point of view, the prospects are excellent. More powerful computers will remove former barriers to increasing the spatial, temporal and substantive resolution of models. The wealth of publicly available high-resolution spatial data will reduce aggregation error in spatial models. Geographic information systems will become the mainstream data organisation of urban models. Spatial disaggregation of land use and transport network data in raster GIS will permit the linkage between land-use transport models and dispersion (emission-immission) air quality and noise propagation models. Multiple representation of spatial data in raster and vector GIS will combine the advantages of spatial disaggregation (raster) and efficient network algorithms (vector). Aggregate probabilistic approaches (e.g. entropy maximising) will be replaced by disaggregate stochastic (microsimulation) approaches.

Microsimulation was first used in social science applications by Orcutt et al (1961), yet applications in a spatial context remained occasional experiments without deeper impact, though covering a wide range of phenomena such as spatial diffusion (Hägerstrand, 1968), urban development (Chapin and Weiss, 1968), transport behaviour (Kreibich, 1979), demographic and household dynamics (Clarke *et al*., 1980; Clarke 1981; Clarke and Holm 1987) and housing choice (Kain and Apgar, 1985; Wegener, 1985). Only recently microsimulation has found new interest because of its flexibility to model processes that cannot be modelled in the aggregate (Clarke, 1996). Today there are several microsimulation models of urban land use and transport under development (Hayashi and Tomita 1989; Mackett 1985b; 1990a; 1990b; Landis, 1992; 1993; 1994; Landis and Zhang, 1998a; 1998b; Waddell, 1998a; 1998b; 1998c; 1998d; Wegener and Spiekermann, 1996; Salomon et al., 1998).
A different approach emerged from the theory of cellular dynamics. Cellular automata (CA) are objects associated with areal units or *cells*. CA follow simple stimulus-response rules to change or not to change their *state* based on the state of adjacent or near-by cells. By adding random noise to the rules, surprisingly complex patterns that closely resemble real cities can be generated (White and Engelen, 1993; Batty and Xie, 1994; Batty, 1997). More complex stimulus-response behaviour is given to CA models in multi-reactive agents models. Multi-reactive agents are complex automata with the ability to control their interaction pattern; they can change their environment but also their own behaviour, i.e. are able to learn (Ferrand, 1999). The distinction between the behaviour of multi-reactive agents and the choice behaviour generated in microsimulation models is becoming smaller.

Probably the most advanced area of application of microsimulation in urban models is travel modelling. Aggregate travel models are unable to reproduce the complex spatial behaviour of individuals and to respond to sophisticated travel demand management measures. As a reaction, disaggregate travel models aim at a one-to-one reproduction of spatial behaviour by which individuals choose between mobility options in their pursuit of activities during a day (Axhausen and Gärling, 1992; Ben Akiva et al., 1996). Activity-based travel models start from interdependent 'activity programmes' of household members of a 'synthetic population' (Beckman et al., 1995) and translate these into home-based 'tours' consisting of one or more trips. This way interdependencies between the mobility behaviour of household members and between the trips of a tour can be modelled as well as intermodal trips that cannot be handled in aggregate multimodal travel models. Activity-based travel models do not model peak-hour or all-day travel but disaggregate travel behaviour by time of day, which permits the modelling of choice of departure time. There are also disaggregate traffic assignment models based on queueing or CA approaches, e.g. in the TRANSIMS project (Barrett et al., 1995; 1999; Nagel et al., 1999), which reproduce the movement of vehicles in the road network with a level of detail not known before.

There are presently several urban land-use transport models based on microsimulation under development in different parts of the world, but it will take some time until the first of them will be operational.

Miller et al. (1998) presented a matrix in which the past and future evolution of urban land-use transport model was charted. The following diagram is an adaption in which a sixth row L6 was added (Figure 5.1).

In Figure 5.1, the rows correspond to different levels of levels of land-use modelling capability:

Transport model Land-use model	T1 No public transport no modal split	T2 Public transport no logit 24 h	T3 Public transport logit peak hour	T4 Multi-modal activity -based
L1 None				
L2 Activity and judgement				
L3 No market-based land allocation				
L4 Logit allocation with price signals				
L5 Market-based land-use model				
L6 Activity-based land-use model				

Figure 5.1. Evolution of urban land-use transport models (adapted from Miller et al., 1998)

L1 No land use model.
L2 Activities are allocated to zones by professional judgement.
L3 Non-market-based land allocation model.
L4 Land allocation with price signals.
L5 Fully integrated market-based model
L6 Activity-based land-use model using microsimulation

Similarly, the columns in Figure 5.1 represent different levels of travel demand modelling capability:

T1 Only roads and auto travel are modelled.
T2 Public transport with simplified (non-logit) modal choice.
T3 Logit-based modal choice, peak-period assignment.
T4 Activity-based travel model using microsimulation.

Each cell in the figure therefore represents a land-use transport modelling combination. The arrows indicate incremental paths local governments can take to develop their land-use transport modelling capability.

5.3 Summary of Land-Use Transport Models

Predicting the impacts of integrated land-use transport policies is a difficult task due to the multitude of concurrent changes of pertinent system variables. In general, there are three groups of methods to predict those impacts. The first one is to ask people about their anticipated reaction to changes such as increased transport costs or land use restrictions ('stated preference'). The second possibility is to draw conclusions from empirically observed behaviour of people ('revealed preference'). The third group of methods comprises mathematical models to simulate human decision making and its consequences. While all of the three possibilities have shortcomings, mathematical models are the only method to forecast still unknown situations and to determine the effect of a single factor while keeping all other factors fixed.

Urban land-use transport models incorporate the most essential processes of spatial development including all types of land uses. Transport may be modelled either endogenously or by an exogenous transport model. Urban systems represented in land-use transport models can be divided into nine subsystems according to the speed by which they change. The urban fabric consisting of infrastructure networks and land use patterns are subject to very slow change over time. Workplaces and housing change relatively slow while the employment and residential population adjust their spatial behaviour fairly quickly to changing circumstances. Goods transport or travel destinations are the most flexible phenomena of urban spatial development. They can be modified almost instantly according to changes in congestion or fluctuations in demand. There is a ninth subsystem, the urban environment, which is more complex regarding its temporal behaviour.

A number of integrated land-use transport systems are in use today. There are significant variations among the models as concerns overall structure, comprehensiveness, theoretical foundations, modelling techniques, dynamics, data requirements and model calibration. Despite the achievements in developing these models further, there remain some challenges to be met. The transport submodels used in current land-use transport models do not apply state-of-the-art activity based modelling techniques but the traditional four-step travel demand model sequence which is inadequate for modelling behavioural responses to many currently applied travel demand management policies. The most promising technique for activity-based transport modelling is microsimulation which makes it possible to reproduce the complex spatial behaviour of individuals on a one-to-one basis.

In addition, the spatial resolution of present models is still too coarse to model neighbourhood scale policies and effects. In the future, the integration of environmental submodels for air quality, traffic noise, land take and biotopes are likely to play a prominent role. Issues of spatial equity and socio-economic distributions are expected to gain similar importance in model building.

6. Modelling Studies of Land-Use Transport Interaction

In this section selected studies using the models identified in the previous section will be reported. In addition, it will be indicated in two tables, how typical land-use and transport policies performed in these studies.

6.1 Modelling Studies: Typical Results

In this subsection selected modelling studies are reviewed and illustrated with typical results.

ISGLUTI

The International Study Group on Land-Use Transport Interaction (ISGLUTI) was a group of urban modellers who between 1981 and 1991, under the co-ordination of the British Transport and Road Research Laboratory (TRRL) conducted extensive model simulations of land-use transport scenarios for various cities in Europe, North America and Japan. In a first phase (Webster et al., 1988, Webster and Paulley, 1990), each modelling group used their own model to simulate a joint set of policy scenarios for the city (or cities) for which the model was calibrated. In a second phase a reduced set of models was used to simulate the same set of policy scenarios for selected cities, either applying the same model to several cities or several models to the same city. The results of phase 2 were published in a series of articles (Echenique et al., 1990; Mackett, 1990; Wegener et al., 1991; Mackett, 1991; 1991b; Webster and Paulley, 1991).

The ISGLUTI study was able to confirm many of the well-known effects of policy implementation, especially in relation to travel cost changes:

- It showed that the type of town and transport system play a central role in the outcome of policies, and that the longer-term effects are important.

- It appears that car trip making is not much affected by changes in public transport fares, but public transport patronage is very much affected by changes in car cost.

- The models predicted that higher costs and lower speeds lead to shorter and more expensive trips, but they did not agree on the impacts on land use. All the models assumed that the location of employment is more responsive to travel cost than is population: in fact transport policy appears to have little effect on *overall* population movement, despite its historical role. This is probably because modern cities already have well-developed transport systems so the scope for general improvements in accessibility is limited.

- It seemed also that forced changes in land use may not be sustained: the modelling showed in fact that land-use patterns tent to revert to the original background trend unless measures are taken to prevent this.

This does not mean, however, that all land-use policies necessarily have little effect over the long term. It certainly does not mean that the longer-term interactions between transport and land use and the various feedback mechanisms are not important. On the contrary, the study has shown that land-use changes in some cases reinforce the initial effects to a significant effect, while in others they completely obliterate them.

An Archetypical British Town

Rickaby and de la Barra (Rickaby, 1991; Rickaby at al., 1992) analysed land-use patterns and road networks of twenty medium-sized British towns to construct a synthetic 'archetypical British town', for which they simulated five principal development options using the TRANUS model (de la Barra, 1982; de la Barra et al. 1984; de la Barra 1989; 1998). The five development options were (see Figure 6.1):

(a) a containment option in which new development is concentrated into four of the eight suburban subcentres,

(b) a containment option in which new development is concentrated along four of the main roads leading out of the town centre,

(c) a combination of options (a) and (b) in which new development is concentrated into four of the eight existing subcentres and along the radial routes which connect them to the town centre,

(d) a peripheral expansion option in which it is assumed that all the land between the boundary of the contiguously developed urban area and the outer ring road is made available for new development,

(e) a peripheral expansion option in which new development is concentrated into eight limited areas between the radial 'arms' of the existing town at relatively high densities.

The results from the TRANUS simulations were essentially negative. No significant variations in fuel use, either in transport or domestic heating, were found between the development options. Also there was nearly no variation in model shares between the five options. This outcome contrasts sharply with that of an earlier study following a very similar methodology at the city-regional scale (Rickaby, 1987). That work made use of the same 'archetypical town' but set in the framework of an 'archetypical city region' divided into the central urban area, a surrounding 'rural hinterland', and a 'rural background' beyond that (Figure 6.2). The changes to this pattern involved relocating 25,000 people from the rural hinterland, along with their associated places of employment and services, over a twenty-five year period, into five alternative new configurations of land uses. The results were that two patterns, the concentrated city and the village dispersal showed significant savings in transport fuel use. The results of both studies seen together suggest that within towns of this size even quite radical variations in the location of new development may have only slight implications for the use of fuel in passenger transport.

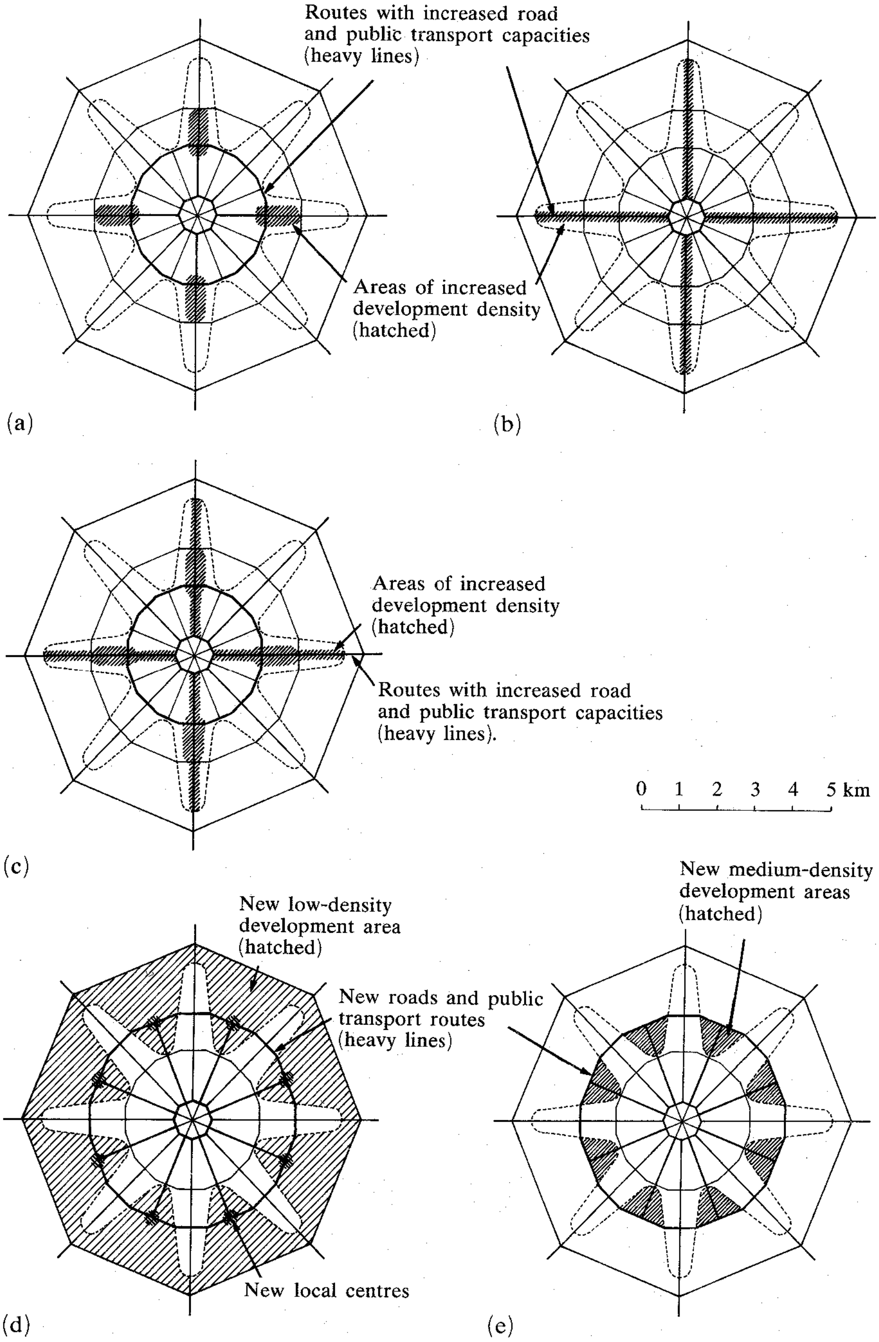


Figure 6.1. Development options for an 'archetypical British town' (Rickaby, 1992)

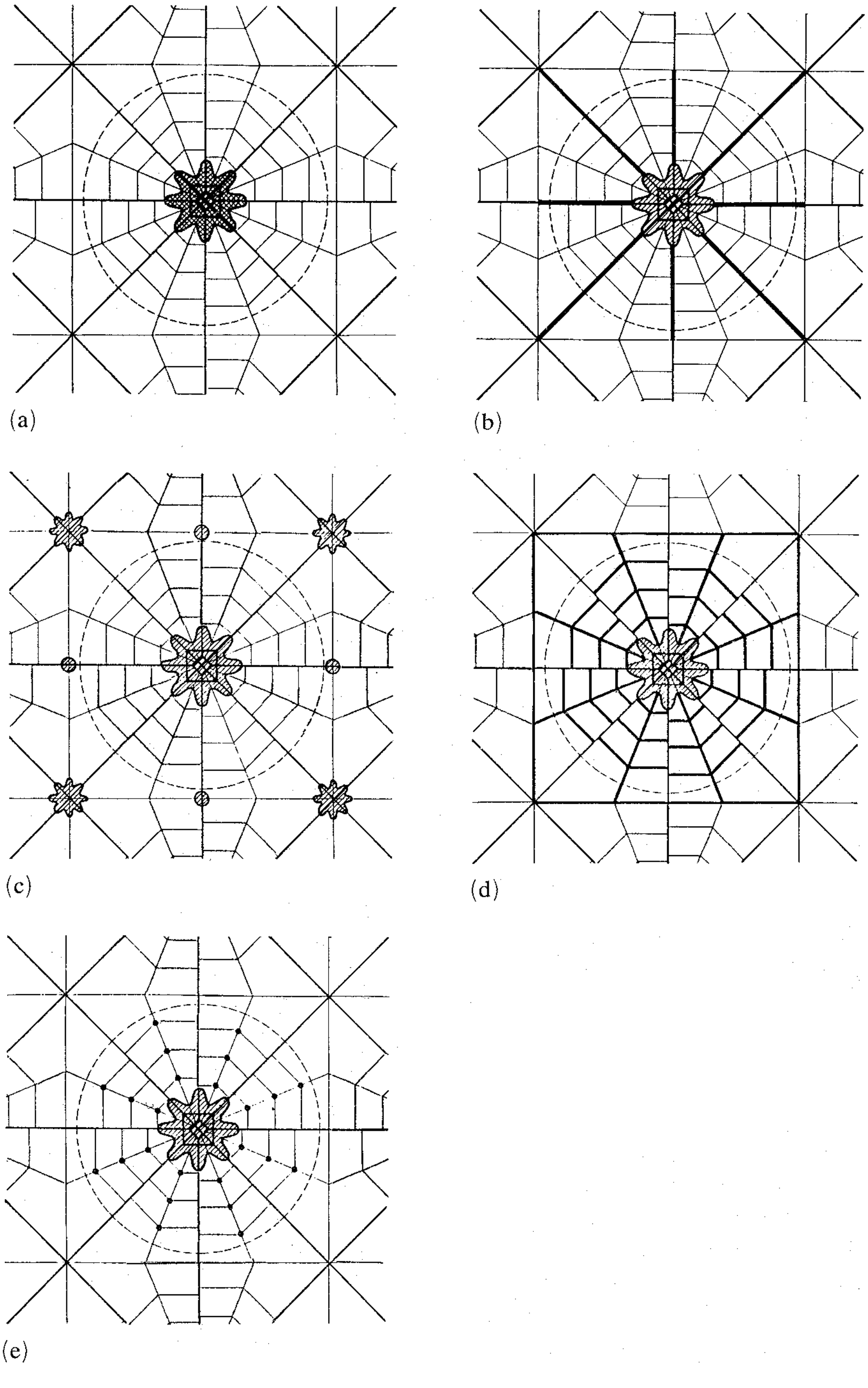


Figure 6.2. Development options for an 'archetypical British town' in a regional context (Rickaby, 1987; Rickaby et al., 1992)

Future Urbanisation Patterns of Dutch Cities

In the Netherlands, several types of possible land-use transport configurations have been investigated with regard to a future urbanisation policy. The current policy emphasises development adjacent to existing neighbourhoods with access to high-quality public transport infrastructure. Since critics argued that this policy tends to emphasise proximity instead of accessibility, a re-evaluation of the policy for the period after 2005 has been undertaken. To this end, the TNO-Institute for Infrastructure, Transport and Regional Development developed a model to set up and test various scenarios of future urbanisation patterns (Verroen and Jansen, 1990; 1991). Eight promising urbanisation options taking into account various combinations of mixing or separating land-uses in monocentric and polycentric urban areas have been tested. The scenario variations are described in Table 6.1.

Table 6.1. Dutch urbanisation scenarios tested

Clustering principle	Mixing principle	Orientation	
		Single-core	Multi-core
Clustering	Separate functions	Compact City 'separated'	New Cities (along axes) 'separated'
	Mixed functions	Compact City 'mixed'	New Cities (along axes) 'mixed'
Dispersing	Separate functions	Incremental City 'separated'	Belt Cities 'separated'
	Mixed functions	Incremental City 'mixed'	Belt Cities 'mixed'

Source: Verroen (1996)

The specific policy-relevant question related to these scenarios was where to allocate the expected future demand of roughly five per cent of the current stock for additional housing and business premises. The effects on travel behaviour of the eight scenarios were computed (Verroen, 1995). Various indicators, including mobility, accessibility, liveability, safety and affordability, were calculated. The following results were obtained:

- *Mixture of functions*. A considerable contribution to cutting trip lengths and the modal share of cars is to be expected from a mixture of population and workplaces. Especially commuter traffic decreases considerably. The share of slow transport modes walking and cycling increases.

- *Clustering of functions*. Peak loads on motorways will be less in the scenario with a clustering of urban functions than in the scenario with dispersed locations. Clustering also has a favourable impact on the accessibility of locations. Public transport was found to benefit from clustering in contrast to car use which is expected to grow slower. Predicted impacts vary with the size and urbanisation character of existing structures.

- *Urban core structure.* Single-core structures were compared to multi-core structures. Since single-core structures involve more commuter traffic than multi-core structures, public transport utilisation is lower. Moreover, investments in public transport infrastructure have a much higher effect in multi-core locations, everything else being equal. The further the extensions of the single-core urban area are located from the centre the less favourable is their positive impact on reducing traffic.

The policy recommendation derived from this modelling study is not unequivocal since some scenarios performed differently in different cities. However, patterns with mixed functions which are clustered in larger spatial units attached to existing neighbourhoods and have high public transport accessibility obtained the best values. Verroen (1996) concludes that the compact city policy which focuses on monocentric locations and function separation is generally not the best option as regards sustainable mobility patterns especially in large urban areas.

Dortmund Region

The study area was the metropolitan area of Dortmund in Germany. Dortmund (population 600,000) is the most eastern of the cities of the Ruhr Area, the largest industrial region in Germany. Four types of scenarios were simulated: land use scenarios, scenarios of travel cost changes, scenarios of travel speed changes, and scenarios in which several types of policies were combined. Here six typical scenarios are selected:

Base scenario:
- 00 Trend scenario (no new policies)

Land use scenario::
- 20 Compact city: centralisation of population and work-places (land use restrictions in the suburbs)

Travel cost scenarios:
- 30 Increase petrol price incrementally to 12 DM/l by 2015 and reduce average petrol consumption of cars incrementally to 5 l per 100 km by 2015.
- 32 Increase inner-city parking charges incrementally, after 2000 quintupled.

Travel speed scenarios:
- 40 Make public transport faster (25 %) and reduce headways (50 %) and make cars slower (40 %).

Combination scenario::
- 60 Combination of scenarios 20 (compact city), 30 (petrol price increase), 32 (parking charge increase) and 40 (public transport faster and car traffic slower)

Figure 6.3 shows the CO_2 emissions resulting from the selected scenarios. Each curve represents the development of CO_2 in a particular scenario between 1970 and 2015. The curve of each scenario is indicated by its number. Scenario 00 is the trend scenario without the policies studied in the other scenarios. Until the mid-1990s all scenarios are identical to the trend scenario as the policies are implemented from 1994 onward. This part of the diagram serves to show the development of the indicator in the past and to establish confidence in the forecasts of the model.

The diagram shows that even drastic land use changes like the ones in Scenario 20 have only little effect on mobility; the CO_2 emissions increase nearly as fast as in the trend scenario. The impacts of increases in the costs of car driving (Scenarios 30 and 32) or in travel times (Scenario 40) are by far greater then those of the land-use scenario. In the combination scenario the impacts of the individual policies reinforce each other.

The conclusions from these results are that land-use policies alone will contribute only little to the reduction of CO_2 emissions, that, however, a combination of land-use policies and policies to increase the costs of car driving and to improve the quality of public transport would lead to a significant reduction of energy consumption and CO_2 emissions of urban transport. It was possible to show that this would be possible without leading to unacceptable reductions in mobility and social disparities.

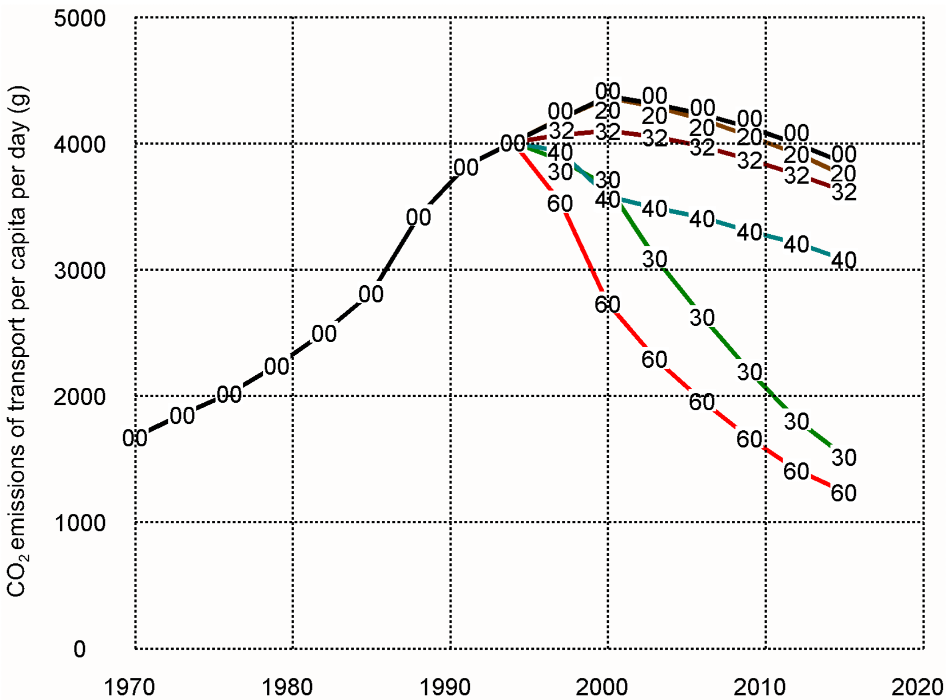


Figure 6.3. IRPUD model: CO_2 emissions of land use and transport scenarios

These results are compatible with those of the empirical studies reported in Section 4. They confirm that high density and mixed land use are only prerequisites for the reduction of travel distances, but that without accompanying transport policies they cannot bring it about. The present settlement structure of European cities with their still relatively high densities offer a great, so far not sufficiently exploited potential for the reduction of daily travel distances by car - only by more efficient spatial organisation.

SPARTACUS

SPARTACUS was a research project in the Environment and Climate programme of the 4th Framework Programme of the European Union (LT et al., 1998). The objectives of the project were to design and specify a system for analysing and forecasting the interactions between land use, transport, economy, the environment and social factors and to simulate and assess the long term effects of urban policies in a set of case study cities and to compare the results. The modelling system developed provides environmental, social and economic indicators of urban sustainability. The indicators were chosen so that they as far as possible are sensitive to urban policies, are independent from each other and follow the impact chain. The SPARTACUS sustainability indicator system consists of more than twenty indicators which are aggregated to three indices for the three major dimensions of sustainability: environmental, social and economic.

The SPARTACUS model system was based on the MEPLAN land-use transport model introduced in Section 5 which provides forecasts of the location of jobs and households and the movement of persons and goods by origin and destination and mode. Some of the sustainability indicators are calculated directly from the model outputs, while others are calculated in subsequent modules. A novelty in urban land-use transport modelling is a raster module which enhances the spatial resolution of the system by a grid representation with a cell size of 100 x 100 m (Spiekermann, 1999). The raster module calculates micro-scale indicators such as exposure to air pollution from transport or noise disturbance for different socio-economic groups. The indicator values are assessed with respect to sustainability and aggregated to the three sustainability indices using indicator-specific weights and value functions

The SPARTACUS system has been used for assessing options for urban sustainability policies in three European cities: Bilbao, Helsinki and Naples. Almost 70 land-use and transport policies and their combinations were analysed. The policy elements represent different pricing, regulatory, land use, transport planning and investment measures.

Figure 6.4 shows selected typical results of policy combinations in the form of a tableau of the three main sustainability indices for different scenarios. The results are presented relative to the base scenario (B). The study showed that many of the policies tested have positive effects from the sustainability point of view but have also negative side effects. It could be demonstrated that by combining policies it was possible to mitigate their negative effects and exploit their synergies. This was for instance the case with pricing policies which tended to concentrate population and jobs in the central cities leaving the surrounding rural areas without services. This phenomenon could be mitigated by combining the pricing policy with a scenario assuming increased levels of teleworking.

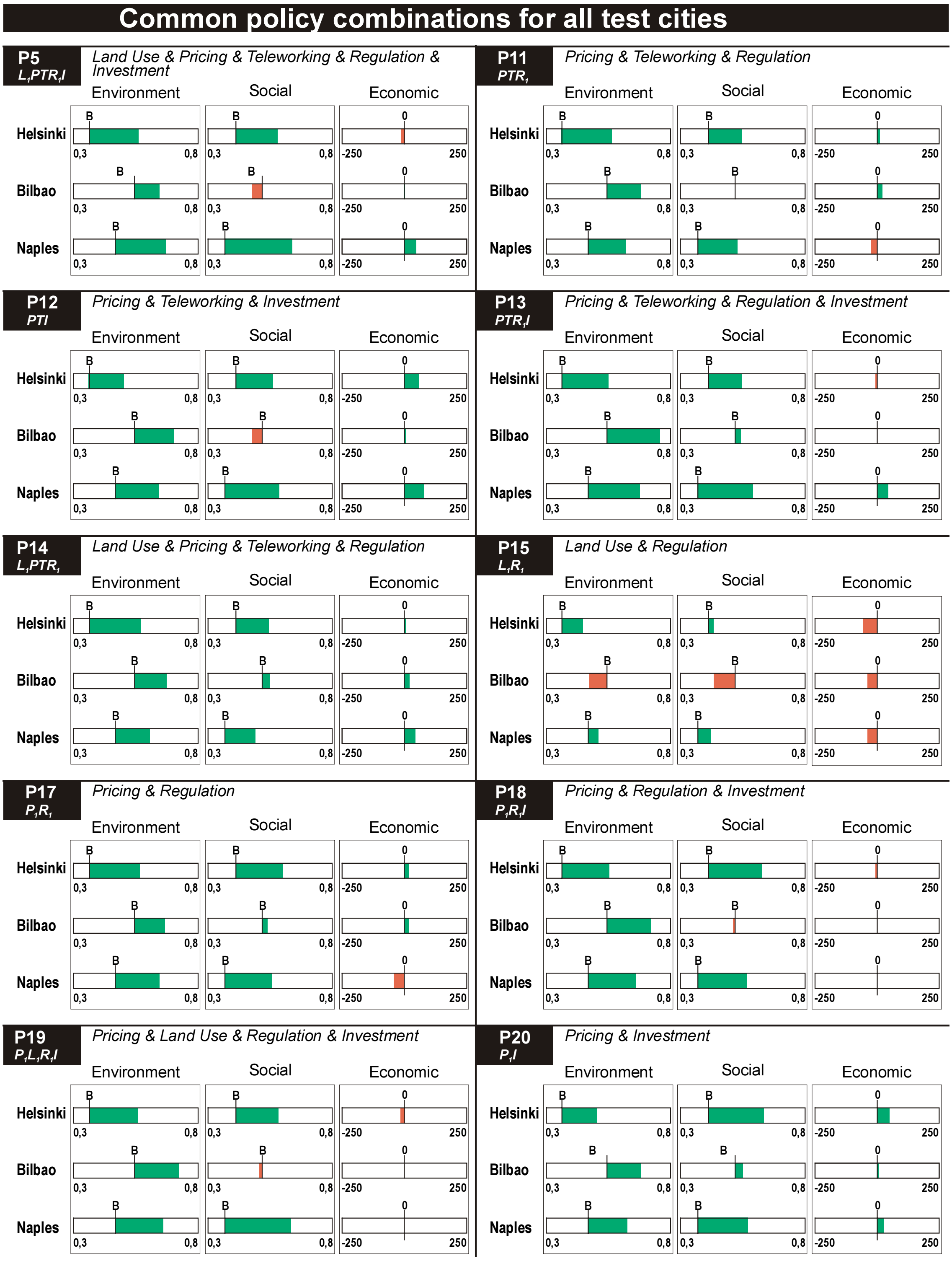


Figure 6.4. Selected results of the SPARTACUS study (LT et al., 1998, 187)

The SPARTACUS study clearly identified pricing policies as the most promising land-use and transport policies: "The most effective policies from an urban sustainability point of view are the pricing policies. Also the regulation policies, especially lowering car speeds, have significant effects. Investment programmes may have positive effects locally but their overall positive effects on urban sustainability are small if not negative. (...) The land use policy element tests show that individual measures designed to encourage either inhabitants or employment to move to other areas in order to balance the inhabitant/employment ratio in different zones do not produce any significant positive effects. However, if the policies are combined so that both inhabitants and employment are redistributed at the same time, then positive effects can be gained" (LT et al., 1998, 197-198.). The study has demonstrated that a combination of specific land use and transport policies could have synergetic effects that are larger than the sum of the impacts of the single policies.

6.2 Summarised Findings of Modelling Studies

The following Tables 6.2 and 6.3 summarise how typical land-use and transport policies performed in the above modelling studies.

Different types of policies affecting the location of workplaces were investigated including the construction of peripheral industrial estates and out-of-town shopping centres as well as an equal distribution of employment and population. It was found that decentralisation of facilities negatively affects the economy of the inner city, while trip length and mode choice depend on the specific location and spatial configuration of population and facilities in the decentralised areas. Regarding housing policies, neither the centralisation of population nor residential development in subcentres were found to have a significant impact on key transport indicators.

Land use planning policies have a major impact not only on spatial development but also on travel patterns. Development restrictions, e.g. a green belt around the city, can retard the suburbanisation of population and workplaces thus strengthening the economy of the city centre.

As concerns the impact of transport policies, a number of common examples were examined. One of them concerns the construction of an outer ring road which results in further decentralisation, relief of congestion and increasing travel distances. New public transport lines have little impact on location choices, except where new radial lines significantly improve the accessibility of suburban locations, but tend to strengthen the inner-city economy. Introducing speed limits results in shorter trips and increased use of public transport. The effect of increased fuel taxes on the number and length of car trips is particularly strong. Significant fuel tax increases curb the further dispersal of residences and workplaces. Higher downtown parking fees generate negative economic effects in the centre and make out-of-town shopping centres more attractive. Public transport use free of charge reinforces a pattern of centralised employment and decentralised residential locations. Volume and length of car trips remain by and large unaffected by this measure.

Table 6.2. Impacts of land-use policies in modelling studies (examples)

Policy area	Policy type	Policy	Examples	Model impact
Land use	Investment and services	Work places	Peripheral industrial estate	Decentralisation of non-service employment, negative economic impact on city centre, little effect on population. Travel distance may increase but also decrease if location closer to already decentralised population.
			Out-of-town shopping centre	Strong decentralisation effect on retail employment and population, negative economic impact on city centre. Distances increase or decrease depending on the location. Car use increases.
			Employment distributed as population	Travel distances and travel times decreasing. Effect on modal choice ambiguous: share of car increases in some cities as work places are more dispersed. Walk and cycle trips increase as trips become shorter.
		Housing	New residential development concentrated in subcentres	Little impact on travel distances, mode choice and energy consumption.
			Centralisation of population as employment	Only slightly reduced trip distances, share of car trips and energy use.
	Planning	General land use plan	Development restrictions (green belt)	Significant retardation of suburbanisation of population and retail, positive economic effects on city centre. Travel distances and times decrease, increase of public transport use.
			Peripheral land made available for development	Acceleration of suburbanisation, increasing travel distances and car use.

Table 6.3. Impacts of transport policies in modelling studies (examples)

Policy area	Policy type	Policy	Examples	Model impact
Transport	Investment and services	Road construction	Outer ring road	Further decentralisation of population, uncertain effect on non-service employment location. Less congestion in the city centre, positive effect on downtown retail. Travel distances increase, mainly by car.
		Public transport lines	New public transport lines	Little impact on residential location, except where new radial lines significantly improve the accessibility of suburban locations, small centralisation effect on employment. Positive economic effect on city centre. Increased public transport use at the expense of car and walking.
	Regulation	Traffic regulations	Speed limits on car travel	Significant reduction of trip length by car and increase of public transport trips. Little impact on residential location; somewhat faster decentralisation of employment.
	Pricing and subsidies	Fuel taxes	Higher fuel taxes	Strong reduction of number and length of car trips and significant shift to public transport. Retardation of decentralisation of employment and population.
		Parking fees	Higher central area parking fees	Negative economic effects on inner cities and longer shopping trips (by car) to out-of town shopping centres
		Public transport fares	Public transport free	Less decentralisation of employment and more of population. Benefits for inner-city retail. Strong increase in distance travelled but little reduction in car trips.

7. EU 4th RTD FP Studies of Land-Use Transport Interaction

The general principle of the European Commission's 4th Framework Programme of Research and Technology Development was to support applications which are user-orientated and yield tools and knowledge bases useful to decision and policy makers. Within the realm of transportation research, a scope of projects concerned with the interaction of land use and transport has been carried out. Besides the application of land-use transport models in more than twenty European regions, a variety of empirical methodological frameworks was developed, thus combining basic and applied research to assess the interaction processes.

7.1 EU 4th RTD FP Studies: Selected Results

In this section selected results of the EU 4th RTD FP studies ESTEEM, SPARTACUS, SESAME, DANTE, EUROSIL, CAPTURE, COST 332, LEDA and ECMD/OECD relevant for TRANSLAND are described.

ESTEEM

The ESTEEM (European Scenarios on Transport-Energy-Environment for Metropolitan Areas) project set out to develop a set of decision support tools to evaluate the impact of land use and transport policy decisions on energy consumption and polluting emissions within the framework of economic and technological scenarios. The overall aim was to optimise the conditions along the chain land-use, transport, energy use, emission, dispersion and environmental impact.

To this end, a variety of methodological approaches has been applied to the case study cities of Brussels, Lyon, Rome and London. With the help of a stated-preference approach, the utility functions of residential location choice and travel behaviour were derived for two case study cities. One remarkable result obtained by the stated-preference approach was that a majority of the households preferred urban residential neighbourhoods with very low traffic levels over traditional urban neighbourhoods and also over rural environments. Since this type of residential structure is currently not broadly available, this finding gives a valuable hint for urban planning with regard to reducing car travel.

The ESTEEM research consortium (1998) also found that a planning policy of abstaining from further road investments generates two antagonistic effects, the first one being an increase in traffic congestion and thus in mean fuel consumption and the second one being a shift in modal choice in favour of public transport. Calculations yielded that both effects largely cancel out each other. The overall conclusion of the study regarding further research paths is that a more detailed and thorough integration of the behavioural and activity-based aspects of urban travel is likely to yield the greatest benefits with regard to modelling the interaction patterns between land use and transportation.

SPARTACUS

A brief summary and selected results of the SPARTACUS project are contained in Section 6 of this report.

SESAME

The SESAME project developed tools to facilitate strategic and tactical policy decisions for integrated land-use and transport planning by enhancing the knowledge of the interaction between land-use, transport supply and travel demand. The information tools were designed to support decision makers in evaluating the impact of urban development policies. By comparing a large number of cities of various types, the researchers intended to corroborate their hypotheses with regard to the generalisation of their findings.

The database which was compiled during the project contains structured information on the land-use and transport characteristics of forty European cities with up to 500 datasets per city. The indicators covered various aspects of land-use, transport supply and travel demand. In order to identify causal relationships between the indicators, statistical methods, such as correlation, multiple regression and cluster analysis were applied to the data. To be both consistent with the statistical data for administrative entities and to render the case study data comparable, administrative boundaries subdivided into structural categories, such as 'central city' or 'local urban area'. The definition of the categories is based on the travel demand surveys and the spatial properties of an area.

In a further step, key indicators, such as population characteristics, urban form, transport supply, vehicle ownership, travel patterns, mode choice and activity patterns have been investigated. Based on the indicator analysis, a typology of cities was derived which relates to travel modes predominant in a certain urban area (car cities, car-and-walk cities, public-transport cities, public-transport-and-walk cities and bike cities). The analysis revealed that mode share in the investigated cities was particularly related to land-use patterns quality of public transport supply and vehicle ownership. The higher the density and the degree of mix of uses in a particular case study city, the higher was the share of non-car modes. Equivalently, the lower vehicle ownership and the higher the quality of public transport services was, the higher was the share of non-car modes.

Among the hypotheses investigated was the common-sense assumption that public transport and non-motorised modes are competitors on the transport market. The results of the empirical data analysis contradict this hypothesis. Strong substitutive competition was found between car and non-motorised modes. Particularly in the central city further evidence was collected that the car experiences substitutive competition from public transport. However, little competition was found between non motorised modes and public transport. The share of automotive travel in modal choice decreases with increasing size for cities above a threshold of over 750,000 inhabitants. For cities below the threshold, a slightly positive relationship between city size and the modal share of cars was found.

The SESAME analysis confirms the findings of other studies that urban density and the share of non-motorised travel and public transport modes are positively correlated. Not surprisingly, car ownership rate and the respective share in modal choice were found to be positively correlated. However, the assumption, that the daily time budget allocated to travel is fixed regardless of prevailing land-use and transport patterns, could not be verified. The mean total time used for daily travelling varied between 50 and 90 minutes in the case study cities and was found to be heavily dependent on the particular modal split of a city.

DANTE

The DANTE project examined ways to reduce the need for road travel. Considering that 85 percent of all journeys made in the European Union occur on roads and that motorised traffic in European cities is expected to increase by another 80 percent within the next twenty years, there is an urgent need for strategies counteracting these developments. Thus, in the DANTE project, strategies designed to reduce the need and level of demand for road travel in European cities and on inter-urban road transport corridors were assessed.

In the DANTE project, 64 of such policies were analysed, the majority of which address modal switching, destination switching and trip substitution. The measures were assessed with a list of criteria comprising movement from car to other modes (mode switching), reduction in travel at peak times (time switching), reduction in distances travelled (destination switching) and reduction in overall numbers of journeys (trip substitution/ avoidance). As regards the impact of land use planning measures, the following results were obtained:

- Urban concentration is effective for destination switching

- Mixed-use development is effective for linking trips

- Development at public transport modes is effective for mode switching and destination switching

- Design of new developments to facilitate non-motorised modes is effective for mode switching and destination switching

- Design of new developments to provide access to transport services is effective for mode switching and destination switching

Among the most effective measures of reducing car use are those which are related to modal switching, even though measures of this type were found to be already largely applied in the case study areas. Another category, though considerably smaller, regarding the number of related measures, is the switching of trip destinations and the switching of trips in the daily schedule. Relatively few measures are known to this date which facilitate actual traffic reduction by substituting the need for physical trips, for instance by exploiting the potentials of telecommuting.

EUROSIL

The EUROSIL project was dedicated to developing analytical tools for the spatial coordination of large transport networks and their elements and to assessing the impacts of transport networks on area development (EUROSIL, 1999). The elaboration of the assessment tool focused primarily on aspects of intermodality and interoperability. Two of the thirteen case studies carried out in this project, are of particular relevance regarding land-use transport interaction:

- *Brussels.* In this modelling study using the TRANUS model (see Section 5), the effects of various road pricing scenarios on population and employment distribution in the Brussels region were examined. Road pricing at the gates of the Brussels region or on trips travelled on a beltway was calculated to result in a population increase of up to 4% within the city, but to a decrease in retail and service employment of up to 8%. However, the loss of employment could be compensated with lower public transport fares. It was also found that flat fares only applied to commuters will trigger relocation of households to the urban periphery.

- *Stuttgart.* The modelling study using the STASA model (see Section 5) confirmed the importance of accessibility to household location choice. Furthermore, the model predicted that intermodal transport, such as park-and-ride support the migration of households to the periphery. The construction of a new commuter rail line alongside an existing motorway was found to have little impact on population distribution and land-use patterns but helped to alleviate traffic loads on the motorway to a significant extent.

In addition, a number of hypotheses were tested across the thirteen case study areas. The following hypotheses related to land-use transport interaction were at least partly confirmed:

- Infrastructure investments will only entail significant economic growth in areas where isolation and bottleneck situations are being resolved.

- Infrastructure investment enhances economic growth only in areas where economic basis and growth were already existing prior to the investment.

- The only driving forces to mode choice are travel/transport times and costs.

The synthesis provided a basis for determining the potential added value of projects enhancing the spatial co-ordination of transport mode with particular consideration of area development issues and the obstacles to achieving added value with these projects. In general, the case studies showed that the economic, land-use and transport impacts of intermodality investments are far more complex and difficult to evaluate than traditional transport investments which can be evaluated with standard econometric and network analysis tools. The study found that area development benefits which are apt to be major justifications for the implementation of a project are often neglected in the project design, thus leaving additional potentials of such projects unexploited.

CAPTURE

The objective of the CAPTURE project has been to evaluate the effectiveness of 11 physical transport measures designed to encourage people to walk, cycle, and use public transport for some of their journeys. The selection of case studies comprised a variety of city types. Transport-related measures were not found to have an identical effect in all the cities. Some of the measures analysed have had great success in some cities, and little in others due to differing local preconditions. The essence of the findings of the CAPTURE project is that large-scale investments and well-structured planning procedures in public-transport facilities are necessary in order to generate an impact in the modal share.

COST 332

The COST Action 332 currently under progress aims at providing public authorities with a better knowledge of the potential and conditions for successful co-ordination between transport planning and land-use policies, in order to avoid the many costly malfunctions resulting from the absence of spatial and temporal co-ordination between sectoral policies taking into account both the economic benefits arising from the availability of high-quality road infrastructure networks and the scope of environmental and social damages caused by a preponderance of motorised travel modes (European Commission, 1998).

The COST 332 research so far has yielded that coherence and co-ordination on various levels is required to achieve more sustainable land use and transport patterns:

- sectoral coherence of planning measures between technico-administrative fields.

- regional coherence of planning measures between politico-administrative levels.

- temporal coherence between the time-scales of the administrative and planning procedures.

By means of case study analyses and enquiries to local political representatives, specific innovative approaches of exploiting such coherence potentials are to be identified (see Greiving and Kemper, 1999)

LEDA

The LEDA research project studied the legal and regulatory measures to promote sustainable transport in cities. To this end, measures in the transport sector and in related sectors influencing transport demand and supply, such as environmental and land-use planning were analysed. An inventory of legal and regulatory measures concerning urban transport and related areas was compiled comprising a selection of forty European cities with the most innovative and effective measures. The analysis raster included aspects such as public response and enforcement requirements.
With the help of this analysis, 'best practices' were identified and the conditions for achieving more sustainable transport patterns were determined individually for each of the case study cities. The main result of the study regarding policy relevant research was the finding that many of the current land-use and transport problems could be solved or mitigated by a regional integration of transport planning in metropolitan areas.

ECMD/OECD

A further study conducted jointly on behalf of the Organisation for Economic Co-operation and Development (OECD) and the European Conference of Ministers of Transport (ECMT) explored the sustainability deficits of current urban travel patterns and what can be done to mitigate or solve this problem. Based on the insight that present land-use and transport planning policies in the industrialised countries encourage excessive travel by car particularly in urban agglomerations, the study attempted to classify land-use and transport policies according to their effectiveness to reduce car dependency in cities. The external costs of transport pollution and noise were evaluated as a percentage of gross domestic product. The principal conclusion of the study was that an integrated land-use transport policy approach is required to reduce automobile use and its subsequent negative consequences, such as congestion, air pollution and acid rain. Three components make up the policy package recommended in this study (OECD/ECMT, 1995):

(1) *Best practice*. Consequent implementation of best practice compilations would mean to rise the overall standards for car travel reduction to the level of those in the best-managed cities. Important though this part of the policy package is, it will not be sufficient to identify the steps necessary to reduce car travel by the required order of magnitude.

(2) *Policy innovations*. Involves land use planning policies aiming at better spatial integration of jobs and homes, congestion pricing and telecommuting. Substantial reduction of overall traffic levels and emissions is expected from these policies.

(3) *Sustainable development*. This measure consists mainly of a progressive increase in fuel tax designed to significantly reduce vehicle kilometres. An annual rise of seven percent (in real terms) over the next twenty years in the industrialised countries is expected to reduce fuel consumption to less than 50% of the forecast level of consumption and vehicle kilometres travelled to less than 66% of the forecast level.

Of the three strands of the comprehensive policy package required to reduce car dependency, only the components 2 and 3 will bring about significant reductions. It is emphasised, however, in the study that the severe measures of component 3 alone would not suffice to achieve the envisaged reduction goals. Only the combined effects of all three components will bring a decrease to 85% of present levels of vehicle kilometres and to 55% of present levels of fuel consumption by the year 2015.

7.2 Summarised Findings of EU 4th FP Studies

The European Commission's 4th Framework Programme of Research and Technology Development comprised a number of studies in the realm of land use transport interaction. Besides the application of land-use transport models in more than twenty European regions, a variety of empirical methodological frameworks was developed, thus combining basic and applied research to assess the interaction processes.

The ESTEEM (European Scenarios on Transport-Energy-Environment for Metropolitan Areas) project aimed at optimising the conditions along the chain land-use, transport, energy use, emission, dispersion and environmental impact. One of the main results of the study is that a planning policy of abstaining from further road investments generates two antagonistic effects, the first one being an increase in traffic congestion and thus in mean fuel consumption and the second one being a shift in modal choice in favour of public transport. Calculations yielded that both effects largely cancel out each other. The overall conclusion of the study regarding further research paths is that a more detailed and thorough integration of the behavioural and activity-based aspects of urban travel is likely to yield the greatest benefits with regard to modelling the interaction patterns between land use and transportation.

The SESAME project developed tools to facilitate strategic and tactical policy decisions for integrated land-use and transportation planning by enhancing the knowledge of the interaction between land-use, transport supply and travel demand. The share of automotive travel in modal choice was found to decrease with increasing size for cities above a threshold of over 750,000 inhabitants. For cities below the threshold, a slightly positive relationship between city size and the modal share of cars was reported.

The study confirms the findings of other analyses that urban density and the share of non-motorised travel and public transport modes are positively correlated. Car ownership rate and the respective share in modal choice were found to be positively related. However, the assumption that the daily time budget allocated to travel is fixed regardless of prevailing land-use and transport patterns could not be verified. The mean total time used for daily travelling varied between 50 and 90 minutes in the case study cities and was found to be heavily dependent on the particular modal split of a city.

The DANTE project examined the effectiveness of policies to reduce the need for road travel. 64 such policies were analysed, the majority of which address modal switching, destination switching and trip substitution. With regard to specific objectives, it was found that urban concentration is effective for destination switching, mixed-use development is effective for linking trips and development at public transport modes is effective for mode switching and destination switching. Moreover, the design of new developments to facilitate non-motorised modes and the design of new developments to provide access to transport services was found to be effective for both mode switching and destination switching.

The EUROSIL project was dedicated to developing analytical tools for the spatial co-ordination of large transport networks and their elements and to assessing the impacts of transport networks on area development. A modelling study of Stuttgart confirmed the importance of accessibility to household location choice. Furthermore, the model predicted that intermodal transport, such as park-and-ride support the migration of households to the periphery. The construction of a new commuter rail line alongside an existing motorway was found to have little impact on population distribution and land-use patterns but helped to alleviate traffic loads on the motorway to a significant extent. Infrastructure investments were found to induce significant economic growth only in areas where isolation and bottleneck situations are being resolved. Furthermore, infrastructure investment enhances economic growth only in areas where economic basis and growth were already existing prior to the investment. The study also found that the only factors relevant for mode choice are travel/transport times and transport costs.

The essence of the findings of the CAPTURE project is that large-scale investments and well-structured planning procedures in public-transport facilities are necessary in order to generate an impact in the modal share.

The research of COST 332 yielded that coherence and coordination is required on various levels to achieve more sustainable land use and transport patterns.

The main result of the LEDA study regarding policy relevant research was the finding that many of the current land-use and transport problems could be solved or mitigated by a regional integration of transport planning in metropolitan areas.

The OECD/ECMD study explored the sustainability deficits of current urban travel patterns and what can be done to mitigate or solve this problem. According to the study, a better spatial integration of jobs and homes, congestion pricing and telecommuting is expected to lead to a substantial reduction of overall traffic levels and emissions. Furthermore, an annual rise of seven percent (in real terms) over the next twenty years in the industrialised countries is expected to reduce fuel consumption to less than 50% of the forecast level of consumption and vehicle kilometres travelled to less than 66% of the forecast level.

8. Successful Land-Use Transport Policies

Based on the review of theoretical and modelling research in Sections 2 and 5 and the empirical and modelling studies reviewed in Sections 4, 6 and 7, this section tries to identify the most successful land-use and transport policies and policy packages.

This section is preliminary. The discussion within the TRANSLAND project about what will be the final set of criteria for judging a land-use transport policy to be successful is still ongoing. As the work is progressing, it is becoming more and more obvious that there is no simple answer to that question. Not only will different stakeholders present different answers, also their perception about what is a successful policy will change over time.

What is successful ?

What are successful land-use and transport policies? Following the objectives of TRANSLAND, successful land-use and transport policies contribute to an optimum spatial organisation of activities and a well balanced transport system linking these activities in an efficient and sustainable way by improving accessibility and the use of space, increasing the use of environment-friendly modes (public transport, cycling, walking), reducing congestion, improving safety and reducing air pollution, noise, and visual nuisance, while developing and maintaining a healthy urban economy and ensuring social equity and transport opportunities for all social groups (ISIS, 1999).

These objectives are clearly in conflict. Efficient and sustainable transport are likely to contradict each other, as efficient transport is inextricably associated with speed. Improving accessibility is not likely to reduce air pollution, noise and visual nuisance. The transport needs of the urban economy are not likely to be sustainable nor do they ensure social equity - even though it has yet to be substantiated that policies to contain the use of cars in cities have negative economic effects (Pharoah and Apel, 1995).

There is no easy way out of these goal conflicts. To put sustainability goals in first place, would be no solution. Clearly the most sustainable city would be one without all movement, but it would have no healthy economy, would be neither efficient nor equitable and would require an unacceptable amount of coercion.

One popular suggestion is that, instead of putting constraints on travel, a sustainable land use system should reduce the *need* for travel. By this criterion policies aiming at higher-density, mixed-use land uses would score high as they would enable people to find a greater number and variety of destinations in the vicinity of their homes. However, experience has shown that, in line with Zahavi's theory (see Section 2), only few people may take advantage of this potential and may instead travel to as many and as distant destinations as before. This example demonstrates that not *potential* but *actual* mobility behaviour needs to be measured. It is not sufficient to reduce the *need* for travel, but it is necessary to reduce *travel*, or, more precisely, unsustainable travel, and make the remaining travel as sustainable as possible by promoting sustainable modes of travel, such as public transport, cycling and walking (cf. Greiving and Kemper, 1999, Chapter 6).

The most straightforward measure of success of land-use and transport policies would therefore be their impact on *per-capita distance travelled by car*. This measure is highly correlated with negative environmental impacts of car travel such as energy use, CO_2 emissions, air pollution and traffic noise. Of course, direct measures of energy use, CO_2 emissions, air pollution and traffic noise would be the best indicators for the degree of unsustainability of a transport system, but as these are only rarely available, per-capita distance travelled by car can serve as a good proxy for *unsustainability*. Other measures, such as travel time, the percentage shares of car, public transport, cycling and walking trips, travel time, the share of multimodal trips or the share of peak to off-peak travel can provide useful additional information but cannot compare with per-capita distance travelled by car as indicator.

These travel-related measures deal with the environmental impacts of travel but do not take account of environmental aspects of land use. Dispersed land use patterns do not only create more traffic than compact urban forms, but they also require the conversion of more land from open space to built-up area, which is creating severe ecological problems in densely populated European countries. High-density settlement patterns, on the other hand, have other ecological disadvantages, such as low permeability for rainfall, poor ventilation ('heat islands'), fragmented green spaces and insufficient habitat conditions for most small animals. Landscape ecology has so far failed to provide clear guidelines as to what constitutes the right balance between high-density and low-density urban forms.

The plain travel-related measures also do not take account of the economic and equity effects of land-use and transport policies. However, the economic impacts of urban land-use and transport policies for the region at large, such as their impacts on employment or the attraction of new businesses, have been impossible to isolate in empirical studies and cannot be modelled in land-use transport models, unless the model is embedded in a regional development model. Development gains, i.e. the impacts of land-use and transport policies on land values or residential or office rents, have been analysed and modelled (see Sections 4 and 6) but are rarely reported in studies of travel behaviour. Equity effects have been ignored in most empirical and modelling studies, though they can be modelled if the model distinguishes between social groups.

In conclusion, most empirical and modelling studies do not provide the necessary information for a comprehensive assessment of the success or failure of land-use and transport policies. One notable exception is the SPARTACUS project, which developed a methodology for forecasting and evaluating the impacts of land-use and transport policies using a comprehensive system of environmental, economic and social indicators of urban sustainability (LT et al., 1998, see Chapter 6).

Successful Policies: Summary of Empirical and Modelling Studies

The following summary of empirical and modelling studies is therefore necessarily based on a limited range of available indicators, which in most cases are travel-related. The other indicators referred to above, such as environmental aspects of land use and economic and equity aspects of land-use transport policies, must be kept in mind when inspecting the results.

The following findings for successful land-use and transport policies based on theories, empirical and modelling studies reported in Sections 2, 4 and 6 can be summarised:

- Land-use and transport policies are only successful with respect to criteria essential for sustainable urban transport (reduction of travel distances and travel time and reduction of share of car travel) if they make car travel less attractive (i.e. more expensive or slower).

- Land-use policies to increase urban density or mixed land-use without accompanying measures to make car travel more expensive or slower have only little effect as people will continue to make long trips to maximise opportunities within their travel cost and travel time budgets. However, these policies are important in the long run as they provide the preconditions for a less car-dependent urban way of life in the future.

- Transport policies making car travel less attractive (more expensive or slower) are very effective in achieving the goals of reduction of travel distance and share of car travel. However, they depend on a spatial organisation that is not too dispersed. In addition, highly diversified labour markets and different work places of workers in multiple-worker households set limits to a optimum co-ordination of work places and residences.

- Large spatially not integrated retail and leisure facilities increase the distance travelled by car and the share of car travel. Land-use policies to *prevent* the development of such facilities (‘push’) are more effective than land-use policies aimed at *promoting* high-density, mixed-use development (‘pull’).

- Fears that land-use and transport policies designed to constrain the use of cars in city centres are detrimental to the economic viability of city centres have in no case been confirmed by reality (except in cases where at the same time massive retail developments at peripheral greenfield locations have been approved).

- Transport policies to improve the attractiveness of public transport have in general not led to a major reduction of car travel, attracted only little development at public transport stations, but contributed to further suburbanisation of population.

In summary, if land-use and transport policies are compared, transport policies are by far more direct and efficient in achieving sustainable urban transport. However, accompanying and supporting land-use policies are essential for in the long run creating less car-dependent cities.

9. Conclusions

In the conclusions the results of the reviews of the state of the art in the theory of land-use transport interaction (Section 2), of 'ideal' land-use transport systems (Section 3) and of the state of the art in operational urban land-use transport models (Section 5) and of empirical (Section 4) and modelling (Section 6) studies of land-use transport policies and of relevant EU projects (Section 7) are summarised.

Suggestions of theory

Theories of land-use transport interaction have been discussed in Section 2. Three kinds of land-use transport policy impacts can be distinguished: impacts of land use policies on transport patterns, of transport policies on land use and finally of transport policies on transport patterns.

Impacts of land use policies on transport patterns can be theoretically expected by influencing essential factors such as urban density, employment density, neighbourhood design, location and city size. The impact of high residential density in reducing average trip length is likely to be minimal in the absence of travel cost increases whereas a high density of employment is positively correlated with average trip length. Attractive neighbourhood facilities can be seen as a 'pull' factor for reducing trip length. Since more peripheral locations usually have longer trips, trip length can be expected to be negatively correlated with city size. With regard to trip frequency little or no impact is to be expected from land use policies according to Zahavi's theory of fixed travel budgets. Residential and employment density as well as large agglomeration size and good public transport accessibility of a location tend to be positively correlated with the modal share of public transport while neighbourhood design and a mixture of workplaces and residences with shorter trips are likely to have a positive impact on the share of cycling and walking.

The impact of transport on land use is mediated by a change in the accessibility of a location. Higher accessibility increases the attractiveness of a location for all types of land uses thus influencing the direction of new urban development. If, however, accessibility in an entire city is equally increased, it will eventually result in a more dispersed settlement structure.

The impacts of transport policies on transport patterns are clearer and stronger compared to the interplay of land use and transport. While travel cost and travel time tend to have a negative impact on both trip length and trip frequency, accessibility has a positive impact on trip length and frequency. Mode choice is dependent upon the relative attractiveness of a mode compared to all other modes. The fastest and cheapest mode is likely to have the highest modal share.

In general, the theoretical considerations support the conclusion that the impact of 'pull' measures, i.e. land use measures, is much weaker than the impact of 'push' measures, i.e. increases in travel time, travel cost etc.

An ideal urban structure?

A variety of 'ideal' land-use transport systems as optimal solutions to urban land-use and transportation problems have been formulated since the late 19th century (see Section 3). These systems vary with regard to spatial structure, residential density, distribution of land uses and predominant transport mode. Each of the multiplicity of approaches towards an 'ideal' land-use transport system can be assigned to three basic types of urban spatial structure:

- *Point structures*. These are city types oriented towards the central point of the urban system, usually the inner city, as exemplified by the compact city model.

- *Linear structures.* These are city types built along a line, usually a large transport infrastructure, as exemplified by Soria y Mata's linear city concept.

- *Area structures.* These are city types with low density development which lack a clear spatial hierarchy and central structure, as exemplified in Wright's Broadacre City.

Departing from these three basic types, various hybrid forms of land-use transport systems can be identified. The axial system, for instance, is a formation of several linear structures aligned towards an urban centre, thus being a hybrid form between a linear city and a compact city.

Attempts to determine the 'ideal' land-use transport system in contemporary cities have yielded different results. While it has almost become common wisdom that systems involving dispersed development are much less favourable with regard to average trip length, energy consumption, greenhouse gas emissions and land take, there is no unequivocal evidence for the advantages of either compact-city or decentralised-concentration policies. Eventually, the appropriateness of a certain land-use transport system depends on a variety of case-specific factors, such as agglomeration size and the pre-existing spatial structure.

The definition of 'ideal' land-use transport systems cannot directly help to identify policies for sustainable urban transport. However, the value of defining such 'ideal' land-use transport system is to be seen in the structured categorisation of options for urban structures to be systematically investigated by other approaches.

Empirical Studies

The results of empirical studies of land-use transport interaction can be summarised for the same impact categories as described in the subsection on theoretical considerations (see Section 4).

Residential density has been shown to be inversely related to trip length. Centralisation of employment results in longer trips, while trip lengths in areas with a balanced residents-to-workers ratio are shorter. American studies confirm that attractive neighbourhood facilities also contribute to shorter average trip lengths. The theoretical insight that distance of residential locations to employment centres is an important determinant of average trip length has been confirmed empirically. The larger a city is the shorter are mean travel distances with the exception of some of the largest metropolises. None of the studies reported a significant impact of any factor on trip frequency. Residential and employment density as well as large agglomeration size and rapid access to public transport stops of a location were found to be positively correlated with the modal share of public transport. 'Traditional' neighbourhoods showed a higher share of non-car modes.

With respect to the impact of transport policies on land use, accessibility was reported to be of varying importance for different types of land uses. It is an essential location factor for retail, office and residential uses. Locations with high accessibility tend to be developed faster than other areas. The value of accessibility to manufacturing industries varies considerably depending mainly on the goods produced. In general, ubiquitous improvements in accessibility invoke a more dispersed spatial organisation of land uses.

Regarding transport to transport impacts, causal relationships are relatively undisputed and empirical studies largely agree on the impact mechanisms. While travel cost and travel time tend to have a negative impact on trip length, high accessibility of a location generates longer work and leisure trips. Studies on changes in trip frequency are only known for travel time improvements, where time savings were found to result in more trips being made. Mode choice depends on the relative attractiveness of a mode compared to all other modes. The fastest and cheapest mode is likely to have the highest modal share. However, flat fares in public transport will not induce a significant mode switch of car drivers, rather of walkers and cyclists.

The results of the investigated empirical studies were found to be largely in line with the conclusions from land-use transport theory.

Land-Use Transport Models

Predicting the impacts of integrated land-use transport policies is difficult due to the multitude of concurrent changes of pertinent system variables. In general, there are three groups of methods to predict those impacts. The first one is to ask people about their anticipated reaction to changes such as increased transport costs or land use restrictions ('stated preference'). The second possibility is to draw conclusions from empirically observed behaviour of people ('revealed preference'). The third group of methods comprises mathematical models to simulate human decision making and its consequences. While all of the three possibilities have shortcomings, mathematical models are the only method to forecast still unknown situations and to determine the effect of a single factor while keeping all other factors fixed.

Urban land-use transport models incorporate the most essential processes of spatial development including all types of land uses. Transport may be modelled either endogenously or by an exogenous transport model. Urban systems represented in land-use transport models can be divided into nine subsystems according to the speed by which they change. The urban fabric consisting of infrastructure networks and land use patterns are subject to very slow change over time. Workplaces and housing change relatively slow while the employment and residential population adjust their spatial behaviour fairly quickly to changing circumstances. Goods transport or travel destinations are the most flexible phenomena of urban spatial development. They can be modified almost instantly according to changes in congestion or fluctuations in demand. There is a ninth subsystem, the urban environment, which is more complex regarding its temporal behaviour.

A number of integrated land-use transport systems are in use today. There are significant variations among the models as concerns overall structure, comprehensiveness, theoretical foundations, modelling techniques, dynamics, data requirements, calibration of the models. Despite the achievements in developing these models further, there remain some challenges to be met. The transport submodels used in current land-use transport models do not apply state-of-the-art activity based modelling techniques but the traditional four-step travel demand model sequence which is inadequate for modelling behavioural responses to many currently applied travel demand management policies. The most promising technique for activity-based transport modelling is microsimulation which makes it possible to reproduce the complex spatial behaviour of individuals on a one-to-one basis.

In addition, the spatial resolution of present models is still too coarse to model neighbourhood scale policies and effects. In the future, the integration of environmental submodels for air quality, traffic noise, land take and biotopes are likely to play a prominent role. Issues of spatial equity and socio-economic distributions are expected to gain similar importance in model building.

Modelling Studies

Different types of policies affecting the location of workplaces were investigated in the modelling studies considered in Section 6. The policies include the construction of peripheral industrial estate and out-of-town shopping centres as well as an equal distribution of employment and population. It was found that decentralisation of facilities negatively affects the economy of the inner city while trip length and mode choice depend on the specific location and spatial configuration of population and facilities in the decentralised areas. Regarding housing policies, neither the centralisation of population nor residential development in subcentres were found to have a significant impact on key transport indicators.

Land use planning policies have a major impact not only on spatial development but also on travel patterns. Development restrictions, e.g. a green belt around the city, can retard the suburbanisation of population and workplaces thus strengthening the economy of the city centre.

As concerns the impact of transport policies, a number of common examples were examined. One of them concerns the construction of an outer ring road which results in further decentralisation, relief of congestion and increasing travel distances. New public transport lines have little impact on location choices, except where new radial lines significantly improve the accessibility of suburban locations, but tend to strengthen the inner-city economy. Introducing speed limits results in shorter trips and increased use of public transport. The effect of increased fuel taxes on the number and length of car trips is particularly strong. Significant fuel tax increases curb the further dispersal of residences and workplaces. Higher downtown parking fees generate negative economic effects in the centre and make out-of-town shopping centres more attractive. Public transport use free of charge reinforces a pattern of centralised employment and decentralised residential locations. Volume and length of car trips remain by and large unaffected by this measure.

EU 4th RTD FP Studies

The findings of the studies carried out within the European Commission's 4th RTD Framework Programme are largely in line with other theoretical and empirical results reviewed in this report. The ESTEEM study showed that the share of automotive travel in modal choice decreases with increasing size for cities above a threshold of over 750,000 inhabitants. For cities below the threshold, a slightly positive relationship between city size and the modal share of cars was found. The SESAME study reports that urban density and the share of non-motorised travel and public transport modes are positively correlated. Car ownership rate and the car share in modal choice were found to be positively related. However, the assumption that the daily time budget allocated to travel is fixed regardless of prevailing land-use and transport patterns could not be verified. The mean total time used for daily travelling varied between 50 and 90 minutes in the case study cities and was found to be heavily dependent on the particular modal split of a city. The EUROSIL project found that infrastructure investments will only induce significant economic growth in areas where isolation and bottleneck situations are being resolved. Similarly, infrastructure investment enhances economic growth only in areas where economic basis and growth were already existing prior to the investment. The only factors relevant for mode choice are reported to be travel/transport times and transport costs.

Successful Land Use and Transport Policies

The following findings for successful land-use and transport policies based on theories, empirical and modelling studies presented in this report can be summarised.

- Land-use and transport policies are only successful with respect to criteria essential for sustainable urban transport (reduction of travel distances and travel time and reduction of share of car travel) if they make car travel less attractive (i.e. more expensive or slower).

- Land-use policies to increase urban density or mixed land-use without accompanying measures to make car travel more expensive or slower have only little effect as people will continue to make long trips to maximise opportunities within their travel cost and travel time budgets. However, these policies are important in the long run as they provide the preconditions for a less car-dependent urban way of life in the future.

- Transport policies making car travel less attractive (more expensive or slower) are very effective in achieving the goals of reduction of travel distance and share of car travel. However, they depend on a spatial organisation that is not too dispersed. In addition, highly diversified labour markets and different work places of workers in multiple-worker households set limits to a optimum co-ordination of work places and residences.

- Large spatially not integrated retail and leisure facilities increase the distance travelled by car and the share of car travel. Land-use policies to *prevent* the development of such facilities (‘push’) are more effective than land-use policies aimed at *promoting* high-density, mixed-use development (‘pull’).

- Fears that land-use and transport policies designed to constrain the use of cars in city centres are detrimental to the economic viability of city centres have in no case been confirmed by reality (except in cases where at the same time massive retail developments at peripheral greenfield locations have been approved).

- Transport policies to improve the attractiveness of public transport have in general not led to a major reduction of car travel, attracted only little development at public transport stations, but contributed to further suburbanisation of population.

In summary, if land-use and transport policies are compared, transport policies are by far more direct and efficient in achieving sustainable urban transport. However, accompanying and supporting land-use policies are essential for in the long run creating less car-dependent cities.

The identification of promising policies is one necessary precondition for achieving sustainable urban transport but this does not tackle the question of implementation of such policies. This issue is addressed in the corresponding TRANSLAND Deliverable D2b (Greiving and Kemper, 1999). In that report the 'How' questions, i.e. the institutional potential for and barriers to the co-ordination of land use and transport policies at the urban-regional level in the different institutional settings of the Member States and the potential barriers to such co-ordination are reviewed.

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