Land-Use Transport Interaction: State of the Art
What Can We Learn from North America?

Michael Wegener
Institute of Spatial Planning, University of Dortmund

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 later the private automobile. 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.

1. Theories of Land-Use Transport Interaction

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). For lack of space, only the most important references can be given here; for a more comprehensive presentation see Wegener and Fürst (1999).

Technical Theories: Urban Mobility Systems

In the technical paradigm of urban development, technical conditions 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.

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.

Paper presented at the STELLA Genesis Kick-off Meeting at the Tinbergen Institute, Amsterdam, 8-9 February 2002

The relationships implied by this term can be briefly summarised as follows (Figure 1):

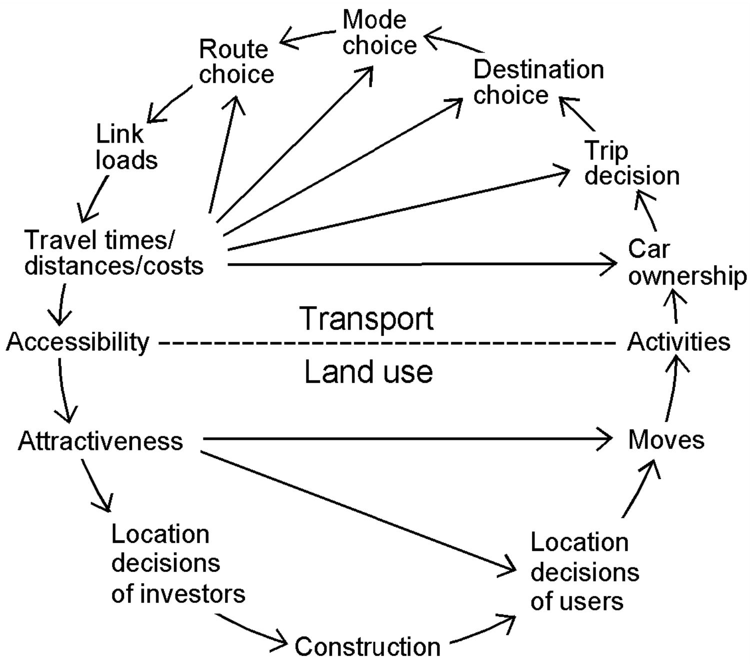

Figure 1. The land-use transport feedback cycle

- 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 interaction 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 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.

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 or information theory, yet even after these substitutions the SIA model did not provide any *explanation* for the spatial behaviour modelled. Only later did it become possible to link it via random utility theory to psychological models of human decision making.

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). Lowry's (1964) *Model of Metropolis* essentially consists of two 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.

However, location models based on the SIA paradigm suffer from two problems: 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. This, however, cannot be represented by the SIA location model. Second, the SIA location model lacks economic content. The only variable explaining location behaviour in the model is transport cost. There is no link between transport costs and other expenditures 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.

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 thirty years of refinement and generalisation, 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 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 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, and partly by the availability of new mathematical instruments such as catastrophe and bifurcation theory or the theory of nonlinear dynamic systems. Another important direction has tried to take account of the heterogeneity of travel behaviour by discrete choice analysis.

Economic Theories: Cities as Markets

A second set of theories focuses on the *economic* foundations of city growth. 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.

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 or spatial polarisation 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. 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. So it is not surprising that, say, jewellers are found in the centre, whereas trucking companies have their yards at 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. 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. 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. In more advanced variations of the model, restrictive assumptions such as perfect competition and complete information or the monocentric city have been relaxed. Other extensions include models to deal with land speculation or the behaviour of landlords in neighbourhoods undergoing gentrification or the incorporation of intersectoral and interregional factor and commodity flows into the model.

New technological developments tend to reinforce the trend to spatial polarisation observed in 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. 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 to work, smaller households, more leisure time and consequential changes 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 at 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.

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, 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. 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.

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, the stage for social interaction and self-expression, the medium for the world of daily life or the field of action of social movements. However, as a rule, these approaches remained essentially social theories and failed to deal explicitly with the spatial and temporal dimensions of urban development.

This changed when, between the wars, the Chicago school of urban sociologists looked more closely into processes of social change at 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). 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, sector, or polycentric 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.

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 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.

On the basis of Hägerstrand's action-space theory, Zahavi (1974) 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 show 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 it 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 at 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. Zahavi's theory of fixed travel budgets has since been extended by the concept of flexible time and money budgets responding to external constraints. 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.

2. Policy Conclusions

Based on the above *theoretical* considerations the expected impacts of essential factors such as urban density, employment density, neighbourhood design, location, city size, accessibility, travel cost and travel time can be summarised as follows:

- The impact of *land use* on *transport* is obvious as the spatial distribution activities is the primary cause of travel. However, the impact of high residential density in reducing average trip length is likely to be minimal in the absence of travel cost increases, whereas high density of employment should be 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 should be positively correlated with the modal share of public transport, while neighbourhood design and a mixture of work places 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 change in accessibility of locations. Higher accessibility increases the attractiveness of a location for all types of land uses and should therefore influence the direction of urban development. If, however, accessibility in the entire city is increased, it is likely to result in a more dispersed settlement structure.

- The impacts of *transport* policies on *transport* patterns are clearer and likely to be stronger compared to the interaction between land use and transport. While travel cost and travel time should have a negative impact on both trip length and trip frequency, accessibility should heave a positive impact on trip length and frequency. Mode choice depends on the relative attractiveness of modes. The fastest and cheapest mode is therefore likely to have the highest modal share.

Results from empirical studies of land-use transport interaction confirm the expectations derived from theoretical insights:

- Higher residential density and mixed land use enable individuals to choose closer destinations and hence lead to shorter trips. However, with present very low fuel prices people living in high-density and mixed-use areas take little advantage of near-by opportunities and continue to make long trips. Urban density is positively correlated with public transport; however, efficient public transport requires a minimum ridership. Urban density is negatively correlated with car ownership and car use; however, fuel cost is an equally important factor. The balance between work places and labour force in a community is significantly correlated with commuting distance; however, distance to major employment centres is a more important factor. 'Traditional' neighbourhoods have higher shares of public transport and walking than suburban neighbourhoods; however, neighbourhood design loses significance once socio-economic characteristics are taken into account.

- Land use changes much more slowly than travel behaviour but is co-determined by the distribution of accessibility provided by the transport system. Locations with better accessibility are developed more rapidly and with higher density than remote locations. However, with low fuel costs and inner-city congestion, accessibility differences become less significant. Locations near motorway exits and public transport stations have higher land prices than other locations. This leads to strip development at motorway exits but only rarely to higher densities at public transport stops. Transport infrastructure improvements increase the accessibility of the locations served. However, they also extend the range of locations suitable as places to live and work and so accelerate the trend toward spatial dispersal.

- Travel cost affects mode choice and trip length. However, as public transport costs have gone up and car travel costs gone down (in real terms), this has led to fewer public transport trips and more and longer car trips. Also travel time affects mode choice and trip length. However, time savings are not used for local activities but tend to result in more and longer trips being made.

Successful policies to achieve sustainable urban transport are policies that reduce car travel and make the remaining travel more sustainable. The results of both theoretical considerations and empirical studies suggest the following policy conclusions:

- Land-use and transport policies are only successful 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 an 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').

- 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.

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.

3. Learning from North America

There are many cities in Europe in which some or all of the above policies are being applied with the effect that Europeans travel about as half as many kilometres, consume half as much energy for transport and emit about half as much greenhouse gases than North Americans. However, some interesting policy innovations have originated in North America.

- *Transit-oriented development* (TOD) combines light-rail transit with bus feeder networks and the concentration of jobs, services and residences at transit stops.

- *Smart Growth* comprises urban growth boundaries, park and open space concepts, transit-oriented development and urban renewal and ecological protection projects. 'Highway-Dollars' are re-directed to finance walking and cycling lanes. Tax systems favouring urban sprawl are redesigned. New infrastructure is financed by user fees.

- *New Urbanism*: The new movement, often misunderstood as merely a re-creation of traditional neighbourhoods, promotes regional co-operation, polycentric articulated settlements, rural-urban linkages, infill development, new towns and villages, preservation of the historical heritage, economic and social diversity and regional revenue sharing.

Portland, Oregon, is the model region of the new movement. Its long-term Regional Growth Concept 2040 combines transit-oriented development, an urban growth boundary and protection of the countryside and a hierarchical settlement structure (Calthorpe and Fulton, 2001). In 1979 Portland Metro was given responsibility for regional land-use and transport planning in parts of three counties with 24 municipalities and 1.3 million people. The Metro Charter requires local comprehensive plans to comply with the regional framework plan and requires each city and county within the jurisdiction of Metro to make local land use decisions consistent with the regional framework. Metro operates an extensive system of light-rail transit and bus lines in three counties, with the Metropolitan Area Express (MAX) as its backbone.

Although urban development is a slow process, there are first signs of success. Portland grows in more compact form than other cities in the US. Public transport use has increased by sixty percent. Traffic congestion occurs less frequently than in other cites. In the MAX corridors housing and work places for $2.4 billion have been or are being constructed. More than a quarter of all new construction occurs on already built-up sites.

Opponents of the New Urbanism claim that urban growth boundaries increase land and house prices and distort the evolution of regional settlement hierarchies and that urban rail development distracts money which could have more effectively be spent on buses. They argue that commuting distances in US cities have declined due to decentralisation of jobs and that hence automobility is sustainable. However there is also evidence that land price increases in cities with growth management are mainly due to increases in attractiveness and that cities with growth management on average are economically more successful than other cities.

3. Research Agenda

The similarity of problems of cities in North America and Europe, such as urban sprawl, congestion, inner-city decline, social exclusion and environmental degradation, suggests that joint research projects between North American and European researchers offer great promise.

It is to be hoped that STELLA will initiate a set of co-ordinated comparative studies of policies for sustainable urban transport applied in North American and European cities as well as collaborations between North American and European researchers to exchange or jointly develop methods and models to address issues of sustainable urban transport.

References

Alonso, W. (1964): *Location and Land Use.* Cambridge, MA: Harvard University Press.

Calthorpe, P., Fulton, W. (2001): *The Regional City. Planning for the End of Sprawl*. Washington: Island Press, 2001.

Chapin, F.S., Weiss S.F. (1968): A probabilistic model for residential growth. *Transportation Research* 2, 375-390.

Forrester, J. W. (1969): *Urban Dynamics*. Cambridge, MA: MIT Press.

Hägerstrand, T. (1970): What about people in regional science? *Papers of the Regional Science Association* 24, 7-21.

Hansen, W.G. (1959): How accessibility shapes land use. *Journal of the American Institute of Planners* 25, 73-76.

Lowry, I.S. (1964): *A Model of Metropolis*. RM-4035-RC. Santa Monica, CA: Rand Corporation.

Park, R.E., Burgess, F.W., MacKenzie, R.D. (1925): *The City*. Chicago: Chicago University Press.

van den Berg, L., Drewett, R., Klaassen, L.H., Rossi, A., Vijverberg, C.H.T. (1982): *Urban Europe: A Study of Growth and Decline*. Oxford: Pergamon Press.

Wegener, M., Fürst, F. (1999): *Land-Use Transport Interaction: State of the Art*. Report to the European Commission. Berichte aus dem Institut für Raumplanung 46. Dortmund: Institut für Raumplanung. http://www.inro.tno/transland/Deliverable%202a.pdf.

Wilson, A.G. (1970): *Entropy in Urban and Regional Modelling*. London: Pion.

Zahavi, Y. (1974): *Traveltime Budgets and Mobility in Urban Areas*. Report FHW PL-8183, Washington, D: US Department of Transportation.