THE FUTURE OF MOBILITY IN CITIES: CHALLENGES FOR URBAN MODELLING

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ABSTRACT

Urban development in the last two centuries has been driven by an unprecedented growth in mobility made possible by abundant and cheap energy. Yet this trend will not continue forever. Despite technological innovation, finite fossil fuel reserves will in the long run lead to increasing costs of transport. Moreover, to fight global warming many governments have set ambitious greenhouse gas reduction targets, and to achieve them fossil fuels must become more expensive either through market developments or by political intervention. The paper gives an overview about the drivers, feedbacks and constraints of urban mobility and location in a possible future in which transport energy will no longer be abundant and cheap. It asks whether current urban models are able to adequately model the impacts of significantly higher transport costs and demonstrates by an example how it can be done.

Keywords: Land use, transport, environment, energy, climate, lifestyles

INTRODUCTION

The rise of the modern city is built on mobility. The evolution from the medieval city in which all movements were on foot to today's sprawling agglomerations has only been possible with first the railway and later the automobile. The Garden City movement promised a life in a healthy environment in harmony with nature and heralded the exodus to the suburbs. Employers, retail and services followed their workers and clients. With growing spatial division of labour, travel and goods transport have increased and so have their environmental impacts.

The suburban arcadia depends on abundant and cheap energy. Over two centuries people have continued to travel more but pay less. Yet this trend will not continue forever. Finite fossil fuel reserves and high costs of alternative vehicles and fuels will, despite technological innovation, lead to increasing costs of transport. Even more important is the imperative to contain global warming. In most countries greenhouse gas emissions have continued to grow, and transport is a major contributor. More and more governments have set ambitious greenhouse gas reduction targets. To achieve them will require both technological innovation and price incentives to induce changes in mobility and location behaviour.

What does this mean for cities? How will higher transport costs affect mobility and location patterns? Will distances travelled to workplaces, shops, services and leisure become shorter? Will there be a renaissance of public transport? Will goods from far-away places be substituted by deliveries from local suppliers? Will face-to-face communication be replaced by telework and videoconferences? Will suburbanisation be halted or even reversed? Will modern lifestyles based on freedom of movement be reoriented towards a new sense of neighbourhood? Will greenfield shopping centres be abandoned for local shops? Will suburban locations decline in attractiveness and value? What will be the impacts on equity? Will there be a social divide between those who can maintain their mobility and those who must give up their cars?

If urban planning is to respond to the challenges of energy scarcity and climate change, it needs to answer these questions.

Unfortunately, most transport and land use models of today have not yet responded to the new challenges. Many urban models are not prepared to model policies, such as the promotion of more energy-efficient vehicles or alternative fuels and the necessary refuelling infrastructure, redirection of transport investment to public transport, transport demand management and anti-sprawl legislation, and the resulting distributive effects and social conflicts. Many do not consider travel costs in trip generation, trip destination and mode choice. Many do not forecast induced or suppressed trips. Many use price elasticities estimated in times of cheap energy. Many do not consider household travel and housing budgets. All this means they will underestimate the response to rising transport costs.

The fundamental changes in the priorities of planning caused by energy scarcity and climate change will have significant impacts on the theory and method of urban modelling: less reliance on observed behaviour, more foundation on strong theory, less statistical calibration, more plausibility analysis, less focus on preferences, more attention to constraints.

The paper gives an overview about the drivers, feedbacks and constraints of urban mobility and location in a possible future in which transport energy will no longer be abundant and cheap. It asks whether current urban models are able to adequately model the impacts of significantly higher transport costs and demonstrates how it can be done using an example from a European Union project.

MOBILITY AND LOCATION

The term mobility indicates both the willingness and capability for movement and the movement itself. Mobility has many dimensions, such as intellectual, social, professional or spatial mobility. Spatial mobility comprises temporary relocations, such as trips, as well as permanent relocations, such as change of job or migration. Permanent relocations imply changes in the locations of activities. Location decisions create relationships between humans and space: by physical change (e.g. construction), use of space (e.g. living or working) or local attachment (e.g. identity, habit, integration).

Hence spatial mobility and location are fundamental alternatives of spatial behaviour. While spatial mobility aims at overcoming space, location aims at using it. Increasingly, physical mobility is substituted by telecommunications, but telecommunications also create desire for more personal face-to-face interaction and hence physical mobility.

Originally spatial mobility implied freedom, emancipation and opportunity. Rural-to-urban migration brought freedom from hunger and serfdom, outmigration to America freedom from religious suppression. Travel pioneers, such as Erasmus of Rotterdam or Mozart, laid the foundations for the cultural identity of Europe. Goethe, writing home from his Italian journey, described the fundamental experience of travel, which survives as a shadow even in today's mass tourism:

> *"I feel like a child that has to learn to live again. ... I cannot tell you how much I have gained in humanity. ... I have already given up many ideas I held fixed which had made me and others unhappy, and have become much freer here. Every day I am peeling off another shell and hope to return as a human being."*
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> J.W. Goethe: *Italian Voyage* (1787)

At Goethe's time, spatial mobility was a privilege of nobility and a small number of affluent citizens. Today, the railway, the car and the air plane have brought a level of mass mobility never known before in human history.

However, more and more also the negative sides of unlimited spatial mobility are becoming apparent. As it grows to perfection, it destroys not only the very preconditions for its success but also the happiness it promised:

- The end of the isolation of rural regions has its counterpart in sprawl at urban peripheries. Outmigration no longer leads to freedom from backwardness and suppression but to rejection by richer nations. International exchange promotes tolerance and knowledge of foreign cultures but goes hand in hand with mass tourism and the exploitation of nature. Participation of rural areas in metropolitan cultures reduces disparities but also endangers regional identity.

- Easy and cheap travel opportunities facilitate wide networks of friendships and social relations but at the expense of local contacts. Affordable mobility facilitates labour force participation of women but subjects them to the double burden of work and household. Spatial mobility facilitates social and job mobility but often also enforces separation of partners and fragmented families. Automobility for all is a fiction as large parts of the population (the elderly, the poor, the handicapped) remain excluded.

- Efficient transport systems are vital for the economic competitiveness of regions but also increase the disadvantage of peripheral regions not connected. Improvements of transport infrastructure stimulate the demand for more transport resulting in increasing congestion, energy consumption, greenhouse gas emission and air pollution leading to problems of sustainability and global and intergenerational equity.

Theory

There is a broad range of theoretical approaches in engineering, urban economics and geography to model changes in mobility and location behaviour in response to changes in transport cost (for more details see Wegener and Fürst, 1999):

- *Technical* theories interpret cities as mobility systems. Spatial interaction theories explain mobility as a function of size and attraction of origins and destinations and an inverse function of travel time and travel cost, or both, between them. This is the gravity or spatial interaction model underlying most travel demand models. Inversely, if it is possible to make inferences from the distribution of human activities to spatial interactions, it is also possible to identify the location of activities giving rise to a certain pattern of mobility defined as above. This is the spatial interaction location model. The first urban spatial interaction location model was the 'Model of Metropolis' by Lowry (1964).

- *Economic* theories interpret cities as markets. They assume that locations with good accessibility are more attractive and have higher market values than peripheral locations. The model of urban land markets by Alonso (1964) assumes that firms and households choose locations at which their bid rents, i.e. the land prices they are willing to pay given their production and transport costs, equal the asking rents of landlords. Firms with higher added value per unit of land will pay higher prices than firms with less intensive use of land. This explains why jewellers are found in the centre, whereas trucking companies have their yards on the periphery.

- *Social* theories interpret cities as the result of individual or collective appropriation of space. Action space theory analyses activity patterns which lead to characteristic spatio-temporal behaviour and hence locations. Hägerstrand (1970) introduced time budgets, within which individuals command action spaces of different size and duration subject to capacity, coupling and institutional constraints. Based on action-space theory, Zahavi *et al.* (1981) proposed the hypothesis that households within their time and money budgets maximise spatial opportunities (i.e. travel distances), in contrast to most travel demand models used in the planning practice which assume that trip rates are fixed and travellers minimise travel times needed to perform these trips.

All three theories of mobility and location were well suited to explain the impacts of travel becoming faster and less expensive in the past:

- If travel becomes *faster* or *less* expensive, people make *more* and *longer* trips.
- If travel becomes *faster* or less expensive, people choose *more distant* locations.
- If people get *more affluent*, they make *more* and *longer* trips and choose *more distant* locations.
- If people have to work less, they make *more* and *longer* trips and choose *more distant* locations.
- If all this happens together, people make *more* and *longer* trips and choose *more distant* locations.

Conversely all three theories can be used to predict what will happen if travel becomes slower or more expensive: People will make fewer and shorter trips and choose more nearby locations. This will affect discretionary trips, such as shopping or leisure trips, more than mandatory trips, such as work or education trips.

While all three theories predict the same direction of changes, action-space theory has a particular potential to deal with non-marginal travel cost increases because its behavioural assumptions are founded not on subjective preferences but on the options individuals have to perform their mandatory and discretionary activities in time and space subject to their time and money constraints. It can therefore be expected that the behaviour so predicted will in a consistent way reflect their likely response to significantly changed conditions.

Action-space theory is also well suited for forecasting the effects of telecommunications on mobility and location. Regular use of telecommunications, e.g. by telework or teleshopping, allows households to choose more distant locations and make fewer but longer trips without additional travel time or travel cost (Shen, 2000).

Urban Models

Integrated mathematical models of urban land use and transport appeared first in the United States in the early 1960s. The Lowry model stimulated modelling efforts in many large metropolitan areas. Many of these early efforts failed to deliver because of unexpected difficulties in data collection, calibration and computing. Moreover, the models were focused on growth allocation and transport efficiency and failed to address new problems of social and ethnic conflict. In addition, the synoptic rationalist planning paradigm the models were based on was replaced by incremental, participatory ways of planning.

In his "Requiem for large-scale models" , Douglass B. Lee (1973) accused the models of "seven sins": hypercomprehensiveness, grossness, hungriness, wrongheadedness, complicatedness, mechanicalness and expensiveness. The urban modelling community retreated into the basements of academia.

The requiem was premature (Wegener, 1994). Some of the technical problems were relieved by better data availability and faster computers. The models became more disaggregate and were based on better theory, such as bid-rent theory or discrete choice theory and user equilibrium in urban networks. Better visualisation tools made the model results more understandable by citizens and decision makers.

The 1990s brought a new interest in urban land-use transport models: In the United States the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 triggered a new wave of applications of urban land-use transport models. In Europe, the European Commission funded a number of studies employing urban land-use transport models (Marshall and Banister, 2007). Several urban land-use transport models, such as TRANUS, MEPLAN, IMREL, RURBAN, METROPILUS, UrbanSim, DELTA and PECAS, were applied to a growing number of metropolitan areas.

The early 2000s have opened a seemingly unlimited golden future for urban modelling (Wegener, 2004): Improved data availability through geographic information systems and new developments in computer science, such as parallel computing, have reduced former technical limitations. New advances in modelling theory and methodology, such as activity-based and agent-based models, have widened the range of issues that can be addressed. A global community of urban modelling experts meets at conferences, such as the World Conference on Transport Research (WCTR), the Conference on Computers in Urban Planning and Management (CUPUM) and the Annual Meeting of the Transportation Research Board (TRB).

However, not all large modelling projects have been successful. Many large modelling projects failed to deliver in the time available or had to reduce their too ambitious targets. Many applications of established models by others than their authors did not become operational. Many projects got lost in data collection and calibration and did not reach the state of policy analysis. Many projects remained in the academic environment and produced only PhD theses.

In particular the trend towards activity-based and agent-based or microsimulation models working with high-resolution parcel or grid-cell data has contributed to the problems of many projects (Wagner and Wegener, 2007; Nguyen-Luong, 2008). There are good reasons for this trend: With growing individualisation of society, urban life styles and hence location and mobility patterns and social networks are becoming more diversified, and disaggregate models are better able to capture this heterogeneity. In transport modelling, activity-based models have replaced the traditional four-step trip model and made it possible to model trip-chaining, car sharing and interdependencies between the mobility of household members. In addition, new model extensions addressing environmental issues, such as air quality, noise, landscape and water require high-resolution grid-cell models.

However, the trend towards disaggregation has also significantly increased the initial effort needed to make the models useful for practical applications. The data requirements and computing times of microsimulation models tend to be enormous. In addition, there are fundamental conceptual problems with highly disaggregate models (Wegener, 2009b): Microsimulation transport models are too slow to be executed several times in integrated land-use transport models and to allow the examination of the large number of scenarios required for the composition of integrated strategies or policy packages. Moreover, because they use random numbers to create probabilistic distributions of individual events, their results are subject to stochastic variation, i.e. may vary significantly between model runs with different random number seeds unless averaged to a level of aggregation they were designed to overcome. Many applications of microscopic activity- or agent-based models have ignored the pitfalls of stochastic variation and published results with illusionary precision.

In addition, most present urban transport and land use modelling projects to date have not yet responded to the new challenges of energy scarcity and climate change urban planning will face in the future.

NEW CHALLENGES

Twenty percent of mankind are responsible for eighty percent of the world's consumption, energy use and greenhouse gas emissions. This inequality is growing. Since the 1970s, the per-capita income of the industrialised countries has grown by a factor of ten, whereas that of the least developed countries has only tripled. But another multiplication of production, consumption and resource use of the rich countries as in the last thirty years would exceed the resources of the earth. Today it is foreseeable that if the energy consumption of the world continues to grow as in the past, the known deposits of fossil fuels will be exhausted before the end of this century. If, however, one adds the fast growing energy demands of large countries in transition, such as Brazil, China, India and Russia, they will be depleted already in a few decades. Similar constraints apply to other raw materials.

However, only few politicians and scientists are seriously taking account of this situation. Only few countries meet the target set by the United Nations to spend 0.7 percent of their national product on international development aid. Mainstream neo-liberal economic theory continues to put its stakes on further deregulation of international trade and unconstrained economic growth. Despite a long debate about zero-growth economics (e.g. Olson and Landsberg, 1973; Daly, 1977, 1996) there are virtually no theories, concepts or visions of how a sustainable economic order might work without continued material growth.

In July of 2008 the price of crude oil rose to almost 150 US $ per barrel. During the recent world-wide financial and economic crisis it went back to below 40 US $ per barrel and has since started to grow again (Figure 1). Most experts believe that because of the ultimate depletion of deposits oil will continue to become more expensive. This will have significant impacts on fuel production, fuel efficiency and mobility and location.

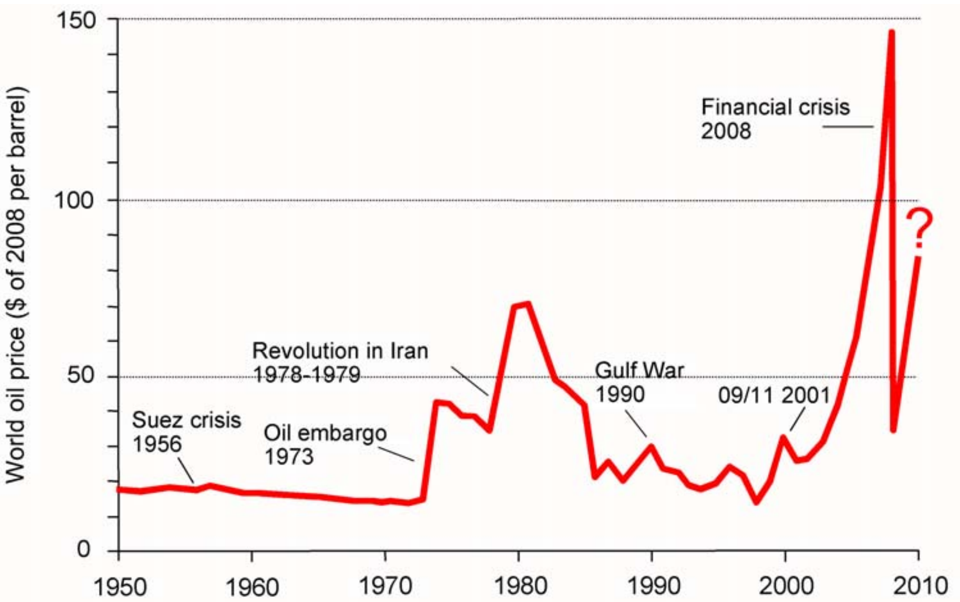

Figure 1 – World oil price 1950-2010 (WTRG Economics 2009, updated)

Closely related to this are the challenges of climate change. Climate researchers agree that anthropogenic greenhouse gas emissions contribute significantly to global warming and that to avoid its worst implications a reduction of greenhouse gas emissions by fifty percent world-wide until 2050 is necessary. The question is how this reduction is to be achieved. Figure 2 shows CO_2 emissions per capita per year of selected countries in 1990 and 2006 compared to the CO_2 emissions considered as climate-neutral (2 t per capita per year). It becomes apparent that countries like the United States or Canada need to reduce their CO_2 emissions by 90 percent, most European countries by 80 percent and China by 50 percent until 2050 in order to allow developing countries like India, Bangladesh or Rwanda to catch up in economic development.

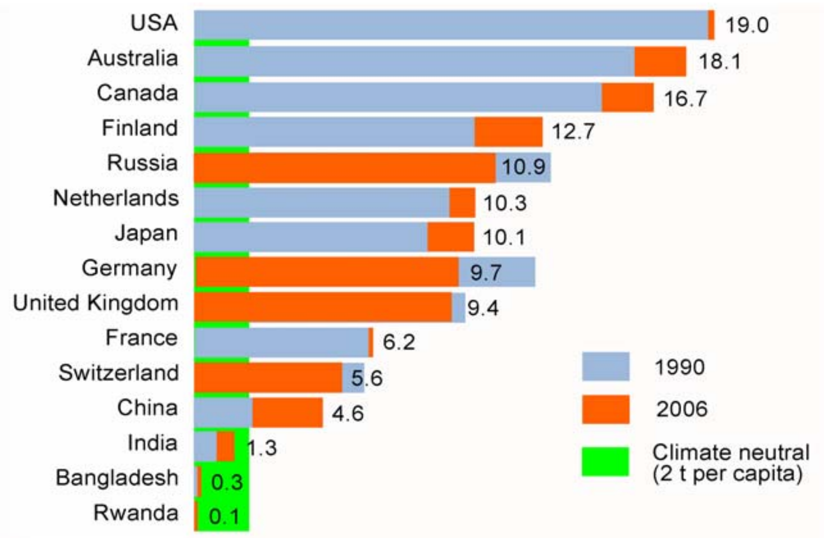

Figure 2 – CO_2 emissions per capita per year (t) 1990-2006 (CDIAC, 2009)

Under the impression of growing certainty of the threats of climate change, the heads of state of the European Union in March 2007 signed a declaration that by 2020 their countries achieve 20 percent less energy consumption, 20 percent renewable energy and 20 percent less greenhouse gas emissions compared to 1990 (and 30 percent if other developed countries co-operate). In August of the same year Germany adopted the target of reducing its greenhouse gas emissions by 40 percent until 2020. At the G8 Summit in L'Aquila in July 2009 the political leaders agreed that the developed countries reduce their greenhouse gas emissions by 80 percent until 2050 to allow developing countries to advance their economy. Despite these commitments, the United Nations Climate Conference in Copenhagen in December 2008 turned out to be a sad demonstration of the "tragedy of the commons", the unwillingness to give up the over-use of free common resources (Hardin, 1968).

Since then not very much has happened to achieve the original ambitious targets. Fuel consumption by transport, after some stabilisation during the economic crisis, has started to grow again. Technological progress in alternative fuels, electric cars or fuel cells has been slower than expected. If current trends continue, it is likely that without higher fuel prices, either by market developments or political intervention, the targets will not be achieved.

URBAN MODELS: FIT FOR THE TASK?

The policy challenges of energy scarcity and climate protection for cities are closely related. Both require the reduction of the use of carbon-intensive fossil fuels by more energy-efficient vehicles, alternative fuels and changes in mobility and location behaviour.

To achieve this will require new policies and policy packages in urban transport and land use planning, such as the promotion of more energy-efficient vehicles or alternative fuels and the necessary refuelling or charging infrastructure, redirection of transport investment to public transport, transport demand management to promote public transport, cycling and walking through higher fuel taxes, road pricing, speed limits and other restrictions of car driving, the implementation and enforcement of anti-sprawl legislation and the maintenance of minimum standards of access to basic services, such as retail, health care and education, for all groups of the population also in suburban and rural areas. These policies are likely to generate significant financial and distributive problems and still unknown social conflicts. Planners will therefore have to identify groups or communities affected by energy scarcity and greenhouse gas reduction policies and to design and test compensation policies to assist the most affected groups.

What will this mean for urban models? Will they be able to adequately forecast the impacts and effectiveness of these policies?

The answer is that, except for few empirical and modelling studies at the frontier of research (e.g. Ettema et al., 2009; Arentze et al., 2010), most transport and integrated land use and transport models applied in the planning practice have not yet responded to these new challenges. Many current urban models cannot model the impacts of significant fuel price increases as their travel models do not consider travel cost in their trip generation, trip distribution and modal split models. But even many models that consider travel costs in the form of generalised cost do not predict induced or suppressed travel demand because they work with fixed trip rates. Many land-use and transport models work with price elasticities estimated in times of cheap energy which may not be valid after significant fuel price increases. Many land use and transport models do not consider household budgets for housing, transport and other expenditures and do not model car ownership as a function of household incomes or travel budgets.

In order to adequately deal with significantly rising costs of transport, urban models have to address the basic needs of households that can be expected to stay more or less constant over time, such as shelter and security at the residence (space, recreation, health) and access to vital destinations (work, education, shops, services) considering the constraints of housing and travel costs in relation to household incomes. Action space theory taking into account time and money budgets may be a way to achieve this. To cope with much higher transport costs, models need to rely less on behaviour observed in times of cheap energy and instead pay more attention to strong theory. This implies less emphasis on preferences and choices but more emphasis on needs and constraints, less statistical calibration and more plausibility analysis, less focus on detail and more focus on basic essentials.

THE STEPs PROJECT

In this section it is demonstrated how the impacts of significant energy price increases on urban mobility and location behaviour can be modelled based on concepts of action-space theory. The example is taken from the EU 6th RTD Framework project STEPs (Scenarios for the Transport System and Energy Supply and their Potential Effects). In STEPs five urban land-use transport models were applied to forecast the long-term economic, social and environmental impacts of scenarios of fuel price increases and infrastructure, technology and demand regulation policies (Fiorello *et al.*, 2006). Here the results for the urban region of Dortmund are summarised.

The IRPUD Model

For this the IRPUD model developed at the Institute of Spatial Planning of the University of Dortmund (IRPUD) was used (Wegener, 2001). The IRPUD model is a simulation model of intraregional location and mobility decisions in a metropolitan area. It receives its spatial dimension by the subdivision of the study area into zones connected with each other by transport networks containing the most important links of the public transport and road networks coded as an integrated, multimodal network including past and future network changes. It receives its temporal dimension by the subdivision of time into periods of one or more years duration.

The IRPUD model has a modular structure and consists of six interlinked submodels operating in a recursive fashion on a common spatio-temporal database:

- The *Transport* submodel calculates work, shopping, service, and education trips for four socio-economic groups, and three modes: walking/cycling, public transport and car.
- The *Ageing* submodel computes all changes of the stock variables of the model (employment, population and households/housing) which result from demographic, technological or long-term socio-economic trends.
- The *Public Programmes* submodel processes a large variety of public programmes specified by the model user in the fields of employment, housing, health, welfare, education, recreation and transport.
- The *Private Construction* submodel considers investment and location decisions of private developers, i.e. of enterprises erecting new industrial or commercial buildings, and of residential developers who build flats or houses for sale or rent or for their own use.
- The *Labour Market* submodel models intraregional labour mobility as decisions of workers to change their job in the regional labour market.
- The *Housing Market* submodel simulates intraregional migration decisions of households as search processes in the regional housing market as stochastic microsimulation.

The top diagram in Figure 3 shows how the submodels work together.

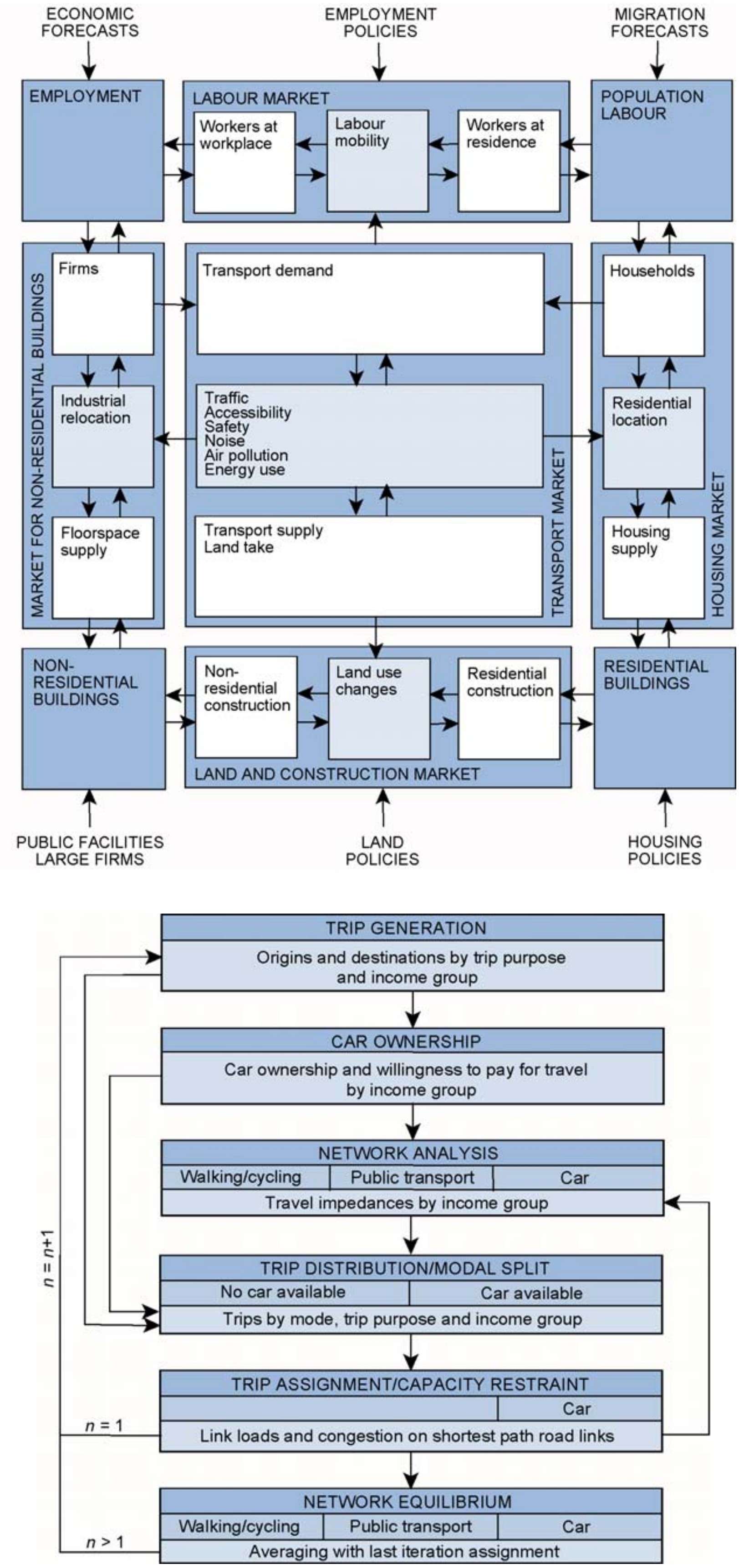

Figure 3 – The IRPUD model (top) and its transport submodel (bottom)

The two square boxes at the top corners of the diagram show the main actors of the model, employment (firms) and population (households). The two square boxes at the bottom corners show the corresponding residential and non-residential buildings. Between the four boxes there are markets: the regional labour market, the regional housing market, the regional market for non-residential buildings and the regional land market. They are linked by the transport market in the centre.

The *Transport* submodel determines a user-optimum set of flows where car ownership, trip rates and destination, mode and route choice are in equilibrium subject to congestion in the road network and household budgets for travel time and travel expenditures. These budgets change over time as a function of demographic and household formation trends, labour market dynamics and changes in household incomes due to increasing wealth or economic growth or decline. Equilibrium between budget constraints and transport expenditures is achieved by adjusting car ownership and the number of discretionary trips and destination, mode and route choice after each iteration of the assignment step. In addition, the budget constraints are modified by substitution elasticities between housing and travel budgets. Figure 3 (bottom) shows the main steps and feedbacks in the transport submodel.

Scenarios

The STEPs scenarios combined three rates of consumer fuel price increases with three sets of policies (Table 1):

Table 1 – STEPs scenarios

Policies	Fuel price increase		
	1 % p.a.	4 % p.a.	7 % p.a.
Do-nothing	A-1 *1.60 €**	B-1 *3.33 €**	C-1 *6.80 €**
Business as usual	A0 *1.81 €**	B0 *3.77 €**	C0 *6.05 €**
Technology and infrastructure	A1 *1.81 €**	B1 *3.77 €**	C1 *6.05 €**
Travel demand management	A2 *3.35 €**	B2 *6.95 €**	C2 *23.25 €**
Policy packages	A3 *3.35 €**	B3 *6.95 €**	C3 *23.25 €**

** € of 2008 per litre in 2030* A-1 *Reference Scenario*

The A scenarios assume a low price increase of 1 % p.a. resulting in a consumer fuel price at the petrol station of 1.60 € (of 2008) per litre in 2030 if no other policies are implemented. The B scenarios assume a medium rate of increase of 4 % p.a. resulting in a consumer price of 3.33 € (of 2008) in 2030. The worst-case C scenarios assume a large increase of 7 % p.a. resulting in a fuel price of 6.80 € (of 2008) in 2030.

Besides the do-nothing scenarios A-1, B-1 and C-1 and the business-as-usual scenarios A0, B0 and C0, three types of policy scenarios were simulated: Scenarios A1, B1 and C1 examine various technology and infrastructure policies, such as more energy-efficient cars, alternative vehicles and fuels and public transport improvements. The demand management scenarios A2, B2 and C2 examine taxation and pricing policies, speed limits, promotion of telework and land use planning. The combination scenarios A3, B3 and C3 examine integrated strategies combining technology, infrastructure and demand management policies. Table 1 shows the resulting consumer fuel prices in 2030 in each scenario. Scenario A-1 is used as the Reference Scenario for comparison between scenarios.

Scenario Results

Figure 4 shows selected results of the fifteen scenarios for selected transport indicators. All scenarios are identical until 2005 and then diverge due to the assumed fuel price increases or policies. The differences between the coloured lines representing the policy scenarios and the heavy black line representing the Reference Scenario A-1 indicate the effect of the fuel price increases and/or related policies. All fuel price increases and policies work in the same direction: they constrain spatial mobility – despite the fact that some policies are intended to compensate or at least mitigate the negative effects of increasing fuel prices. In no case these are strong enough to compensate the fuel price effect.

Figure 4 (top) shows the effects on mode choice. They are consistent with expectations: the higher the fuel price increase, the fewer people drive by car. In the Reference Scenario A-1 the share of car trips continues to increase due to cheap fuel and growing incomes and car ownership. As fuel prices go up, the share of car trips goes down to the levels of the 1970s and 1980s. In the two worst-case Scenarios C2 and C3 car travel is reduced to taxi and emergency trips. It can also be seen that with each rate of fuel price increase, the travel demand management policies in Scenarios A2, B2 and C2 reduce car travel more than the technology and infrastructure policies in Scenarios A1, B1 and C1, because they make car travel slower and/or more expensive.

Figure 5 (bottom) shows the impacts on CO_2 emissions of transport of trips by all modes generated or attracted by the origins and destinations in the study area, including the parts of long-distance trips lying outside the study area. In the Reference Scenario A-1, car fuel consumption and resulting CO_2 emissions continue to grow despite improvements in car energy efficiency because of growing car ownership and more and longer car trips. The reductions in fuel consumption and CO_2 emissions in the policy scenarios are more or less proportional to those in the share of car trips. The combined strategies of Scenarios A3, B3 and C3 perform better than the corresponding travel demand management policies in Scenarios A2, B2 and C2 because they use more energy-efficient cars and alternative vehicles and fuels. However, in only few scenarios the resulting reductions in CO_2 emissions meet or exceed the greenhouse gas reduction target of the German government of 40 percent by 2020. This demonstrates that only a combination of advances in fuel efficiency and alternative vehicles with price incentives to induce changes in mobility and location behaviour will achieve this target.

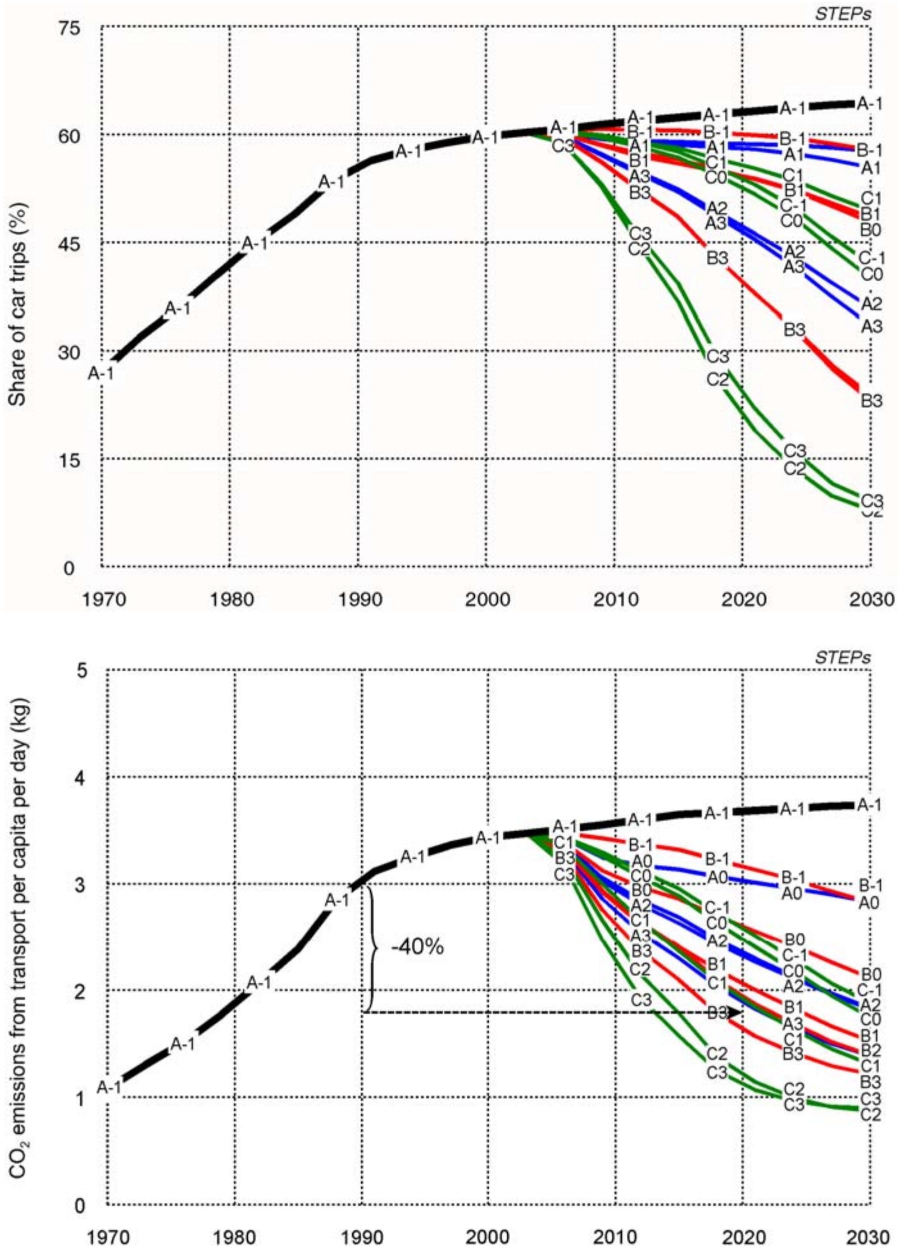

Figure 5 – Scenario results 1970-2030: Share of car trips (top) and CO_2 emissions by transport (bottom)

The simulation results suggest that if travel time budgets and income-dependent travel cost budgets are considered, the responses of mobility and location behaviour to travel cost increases are substantial.

This is in good agreement with empirically measured price elasticities of travel reported in the literature of about -0.3 for short-term and higher for long-term responses including relocation (Litman, 2010). When the results of the different urban land-use transport models applied in STEPs were compared in a meta analysis (Fiorello *et al.*, 2006, 138-147; Wegener, 2009a), the IRPUD model showed stronger responses to higher fuel costs than the other models. It will be an issue of further research to find out which models are right.

From a planning point of view, the simulations show that the ambitious greenhouse gas reduction targets of the government can be achieved, but not by technology alone but by a combination of technological and behavioural change. In all scenarios, the long-term trend towards more and longer trips and more trips by car is stopped or even reversed. Average travel distances per capita return to the levels of the 1990s, average travel distances by car to the levels of the 1980s and before. There is a renaissance of cycling and walking, and the number of trips by public transport more than doubles. The share of car trips declines to levels last experienced in the 1970s.

These changes in travel behaviour are not voluntary, but forced responses to severe constraints. By present standards they imply a loss of quality of life. As mandatory trips, such as work and school trips, cannot easily be changed, the reductions in trips and trip distances mostly affect voluntary trips, such as social or leisure trips, and every such trip not made means a friend not visited, a meeting not attended or a theatre performance or soccer match not seen. Rising costs of transport also mean financial stress for households who have to sell their cars and still have to spend more on travel than before, although their incomes grow less and housing becomes more expensive.

However, European cities contain a huge potential for long-term adjustment of mobility and location behaviour by internal reorganisation, i.e. by better spatial co-ordination of activities. When mobility becomes more expensive, accessibility becomes again an important location factor. Households move closer to their work places and firms closer to their customers, suppliers and workers. Farther-away destinations are replaced by nearer ones that can be reached by bicycle or on foot. Neighbourhood relations, often neglected in the past, become important again. Higher-density, mixed-use urban structures facilitate these adjustments.

The most positive effects of the reduction in traffic caused by rising fuel prices are its effect on the environment. Every car trip not made and every kilometre the remaining trips are shorter means less greenhouse gases, air pollution and accidents. In addition, the efforts to develop more energy-efficient cars and alternative vehicles stimulated by the fuel price increases and related policies contribute to the positive environmental balance. From the point of view of achieving the government greenhouse gas reduction targets, high fuel prices are the best possible prospect.

The policy challenge will be to make high fuel prices socially and politically acceptable. For this cities need integrated and long-term transport and land use strategies that include a combination of pricing policies directed at car users with affordable public transport fares, public transport infrastructure investments to improve public transport speed and service and regional spatial development plans supporting living near central areas, in satellite cities or along public transport corridors.

Moreover, integrated transport and land use strategies require co-operation between the core cities and suburban municipalities, a strong regional planning system and efficient mechanisms of horizontal and vertical co-ordination and a broad public debate between researchers, policy makers, stakeholders and citizens.

CONCLUSIONS

Because of the ultimate depletion of fossil fuels and the imperatives of climate protection, energy for transport will no longer be abundant and inexpensive but scarce and expensive. This will have fundamental consequences for mobility and location behaviour in cities. The changes in the priorities of planning caused by energy scarcity and climate change will have significant impacts on the philosophy and method of urban modelling.

Urban models that were calibrated on past behaviour and/or do not explicitly consider the costs of mobility and location relative to household incomes are not able to forecast these changes and will tend to underestimate the behavioural response of households and predict that they overspend their travel budgets. In order to adequately deal with significantly rising costs of transport, urban models have to address the basic needs of households that can be expected to stay more or less constant over time, such as shelter and security at the place of residence and access to necessary activities and services, and consider the constraints of housing and travel costs in relation to household income. Action space theory taking into account both time and money budgets may a way to achieve this.

There is again the danger that urban models are rejected because they fail to address the new challenges of energy scarcity and climate change and the resulting social conflicts. This time the "seven sins of large-scale models" would be:

- too much extrapolation of past trends
- too much belief in equilibrium
- too much reliance on observed behaviour
- too much attention to preferences
- too much emphasis on calibration
- too much effort spent on detail
- too much focus on incremental solutions

The fundamental changes in the problems and priorities of urban planning due to energy scarcity and climate change will require a change in the philosophy and method of urban modelling:

- less extrapolation, more fundamental change
- less equilibrium, more dynamics
- less observed behaviour, more theory
- less preferences, more constraints
- less calibration, more plausibility analysis
- less detail, more basic essentials
- less forecasting, more backcasting

Backcasting means in this context that urban modellers concentrate less on policies that are politically acceptable but more on policies that need to be implemented if the CO_2 reduction targets of governments are to be achieved (Hickman and Banister, 2007). For this nothing less than a paradigm shift in urban modelling is required.

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