

Gebhard Wulfhorst, Benjamin Büttner

(Editors)

Transportation Demand Management

Insights from the mobil.TUM 2012 International Scientific Conference on Mobility and Transport



Chair of Urban Structure and Transport Planning

Transportation Demand Management

Insights from the mobil.TUM 2012 International Scientific Conference on Mobility and Transport

Edited by Gebhard Wulfhorst Benjamin Büttner

Chair of Urban Structure and Transport Planning Institute of Transportation Technische Universität München Germany

Contents

Prefac	e
	Gebhard Wulfhorst, Benjamin Büttner1
Transp	ortation Demand Management : Win-Win Solutions to Transport Problems
	Todd Litman3
Part I: The	e revival of urban mobility by walking and cycling
Access	sibility analysis with space syntax: The pedestrian movement network in the city centre of Munich
	Christian Schwander, Stephen Law11
Incorpo	orating the Influence of Walkability into a Model of Pedestrian Accessibility
	David Jonietz, Sabine Timpf31
From i	nternational experience to French case studies PORT-VERT: a French research project investigating various possibilities of bicycle-transit intermodality
	Claude Soulas, Sylvie Abours, Francis Papon44
Part II: Pro	o-active development of transport supply
How a	nd why planners make traffic-increasing plans – and what could be done to change the situation
	Aud Tennøy61
Tramw	ay renaissance in Munich – Effects of the new Tram 23 on urban structure and mobility behavior
	Roland Priester, Benjamin Büttner84
Evalua	ting the impact of environmental constraints in networks: formulation and analysis in a simple case
	Xin Lin, Ben Immers, Francesco Viti, Chris Tampère104
Megac	ities and High Speed Rail systems: which comes first?
	Francesca Pagliara, Joao de Abreu e Silva, Joseph Sussman, Naomi Stein

Part III: Accessibility as a key to sustainable mobility

Accessibility Analysis and Dutch Transport Policy
Karst Geurs144
Interdependencies between Supply and Demand of Transport: The Evolution of Accessibility within the Lyon Metropolitan Area
Yves Crozet, Aurelié Mercier, Nicolas Ovtracht, Loïc Sapet160
Assessment of the impact of Road Pricing to Achieve a more Sustainable Development of the Transport System
Oliver Roider, Christoph Link176
Part IV: Innovative methods for land-use and travel demand modeling
Modelling the Relationsship between Urban Environment and Travel Behaviour: Policy and Indicators
Lissy La Paix, Andrés Monzón, Elisabetta Cherchi191
Meta-analysis of long-term trip generation modelling
Johannes Hartwig, André Kühn, Florian Senger, Michael Krail, Wolfgang Schade215
Part V: Modeling for sustainable mobility decisions
Modelling the impact of local policies to optimise the development of electric vehicles
Benjamin Mousseau, Anne-Sophie Fulda, Guenter Emberger233
Clean, Safe and Healthy Mobility through Non-Technical Measures – Linking Individual and Public Decision Levels
Claus Doll, Johannes Hartwig249
Conclusions
Towards sustainable mobility solutions
Gebhard Wulfhorst

PREFACE

Sustainable mobility is at the heart of our global concerns for livable cities and regions, now and for the generations to come. Major efforts are needed in research and practice on both the invention and implementation of sustainable mobility solutions.

Regarding the crucial challenges of sustainable development, we can no longer take travel demand as a given. The task is to pro-actively design, model and implement our transport supply options, to transform the spatial structure of our cities and regions and to create mobility management measures so that our individual daily mobility behavior better matches global long-term needs. Transportation Demand Management (TDM) in that sense can have an important impact on economic prosperity, social welfare and ecological viability.

We are organizing the International Scientific Conference on Mobility and Transport "mobil.TUM" at TUM's Institute of Transportation since 2008 because we intent to develop and foster a scientific, international, interdisciplinary forum for exchange about the state of the art and state of practice on a selected transportation topic. The "mobil.TUM 2012" conference was organized by the Chair of Urban Structure and Transport Planning and was a dialogue on the challenges and achievements in the field of Transportation Demand Management. One aim was to draw connections between research and practice in order to develop innovative scientific contributions as well as sound solutions for implementation.

This book contains papers on the five topics "*The revival of urban mobility by walking and cycling*", "*Pro-active development of transport supply*", "*Accessibility as a key to sustainable mobility*", "*Innovative methods for land-use and travel demand modeling*", "*Modeling for sustainable mobility decisions*" which were presented at the mobil.TUM 2012 conference on the 19th and 20th of March, 2012 in Munich.

These contributions were selected after a call for papers with more than 60 submissions. In addition, 20 posters were presented and discussed in a lively session and have been taken into account as a basis for the selected papers within this book.

The quality of the following papers has been ensured and improved by the constructive comments received from our peer reviewers Udo Becker (Technische Universität Dresden), Marco te Brömmelstroet (Universität von Amsterdam), Fritz Busch (Technische Universität München), Yves Crozet (Laboratoire d'économie des transports, Lyon), Regine Gerike (BOKU, Vienna), Karst Geurs (University of Twente, Enschede), Martin Lanzendorf (Goethe Universität, Frankfurt), Todd Litman (Victoria Transport Policy Institute) and Michael Wegener (S&W, Dortmund). We are grateful to them and highly appreciate their effort and support.

Last but not least, we would like to thank the authors for their rich contributions to the conference and especially to the book at hand.

The conference has been an exciting opportunity to meet and exchange ideas. A lot of inspiration has emerged from the presentations, discussions and informal networking. May this book capture and reflect these ideas, so that we can build upon them individually and as a community.

Gebhard Wulfhorst, Benjamin Büttner

June 2013

WIN-WIN SOLUTIONS TO TRANSPORT PROBLEMS

Todd Litman, Victoria Transport Policy Institute

Corresponding author:

Todd Litman; litman@vtpi.org

Abstract

Transportation Demand Management (TDM) includes various policies and programs that increase transport system efficiency. This can significantly reduce the need to expand roadway facilities, and provides other economic, social and environmental benefits. Current demographic and economic trends, and new community concerns, are increasing TDM benefits. Conventional transport economic evaluation tends to overlook and undervalue many of these benefits. More comprehensive and multi-modal evaluation can identify "win-win" solutions, TDM strategies that provide multiple benefits and are most cost effective overall.

Keywords: Transportation Demand Management

Introduction

A *paradigm* refers to the basic assumptions used to define problems and evaluate solutions (Kuhn 1962). A discipline's paradigm sometimes shifts, during which practitioners must reexamine their basic assumptions and analysis methods. For example, the Copernican revolution which recognized that the earth revolves around the sun, and the theory of evolution which explained biological change through natural selection, are well-known paradigm shifts. Transportation planning is undergoing a similar change (Litman).

The old paradigm developed during the period when automobile travel demand was growing rapidly and so focused primarily on expanding roadway capacity. The new paradigm is more comprehensive and multi-modal: it considers a broader range of modes, objectives, impacts and transport system improvement options. This new paradigm supports *Transportation Demand Management* (TDM, also called *mobility management*) which is the general name for various strategies that result in more efficient use of

transportation resources, including road space, parking facilities, fuel, and clean air. Table 1 summarizes major categories of TDM Strategies.

Improves Transport		Land Use	Implementation	
Options	Incentives	Management	Programs	
Carsharing Flextime Guaranteed ride home High occupancy vehicle (HOV) priority Public transit improvements Rideshare programs Taxi service improvements Telework Walking & cycling	Distance-based pricing Commuter financial incentives (parking cash out, transit subsidies, etc.) Parking pricing Parking regulations Road tolls/congestion pricing Fuel tax increases	Complete streets Smart growth/New Urbanism Transit oriented development Location-efficient development Parking management Streetscaping Traffic calming	Commute trip reduction programs Freight transport management Mobility management marketing programs School and campus transport management Tourist transport management Transport planning reforms	
improvements				

Table 1 Transportation Demand Management Strategies (VTPI 2013)

This table lists various types of TDM strategies.

Conventional transport economic evaluation (the methods used to measure the benefits and costs of a particular transportation policy, project or program) were designed primarily to evaluate roadway investments (Litman 2013). They overlook many impacts (costs and benefits) resulting from changes in total vehicle travel and mode shifts. As a result, they tend to exaggerate the benefits of automobile-oriented improvements such as roadway capacity expansions, and undervalue TDM solutions.

Transportation demand management can help acheive a variety of planning objectives:

- Congestion reduction
- Roadway cost savings
- Parking cost savings
- Consumer savings
- Transport diversity (mobility options for non-drivers)
- Road safety

- Energy conservation
- Pollution reduction
- Public health
- Efficient land use (smart growth)

Many TDM strategies directly user benefits by improving mobility options and providing financial rewards for reduced driving. In addition, consumers can benefit indirectly through reduced congestion and accident risk to road users, reduced need to chauffeur non-drivers, reduced pollution emissions, increased revenues, and economies of scale in the provision of alternative modes. Many TDM strategies reflect market principles such as efficient pricing and consumer sovereignty, and so tend to increase overall economic efficiency and equity.

More comprehensive evaluation expands the range of objectives considered in transport planning, and so can identify *win-win* solutions which provide multiple benefits. For example, it allows transport agencies to identify congestion reduction strategies that also help reduce parking problems and pollution emissions, and improve accessibility for non-drivers (Litman 2010). Table 2 illustrates this concept. Roadway expansion and increased vehicle fuel efficiency each provide few benefits. Transportation demand management strategies tend to achieve a broader range of planning objectives and so can be considered win-win solutions.

Planning	Roadway	More Fuel	Transportation	
Objective	Expansion	Efficient	Demand	
		Vehicles	Management	
Motor Vehicle Travel Impacts	Increased	Increased	Reduced	
Congestion reduction	\checkmark		✓	
Roadway cost savings			✓	
Parking cost savings			✓	
Consumer savings/affordability	\checkmark		✓	
Reduced traffic accidents			✓	
Improved accessibility for non-			✓	
drivers				
Energy conservation		✓	✓	
Pollution reduction		✓	✓	
Physical fitness and health			✓	
Land use objectives			✓	

Table 2 Comparing Strategies Including Travel Impacts

(\checkmark = Achieve objectives) Roadway expansion and increased vehicle fuel efficiency provide few benefits. Transportation demand management (TDM) strategies tend to help achieve multiple planning objectives and so can be considered win-win solutions.

Valuing Transport System Diversity

The old planning paradigm assumed that the primary planning goal was to increase travel speeds, and so favored automobile transport over other walking, cycling and public transport, leading to automobile-dependent communities where driving is convenient but access by other modes is inconvenient. For example, the old paradigm allows construction of roads that lack sidewalks, and by widening roads and traffic volumes and speeds, creates landscapes that are unfriendly for walking and cycling, and since most transit trips include walking links, are difficult for public transit access.

The new planning paradigm recognizes the unique and important roles that walking, cycling and public transport play in an efficient and equitable transport system, and so values transport system diversity. As previously described, current demographic and economic trends are increasing demands for alternative modes. Meeting these demands benefits users directly, and because walking, cycling and public transit tend to impose less external costs, they help achieve other planning objectives such as congestion reductions, increased traffic safety, energy conservation and emission reductions.

Recent experience demonstrates the latent demand for alternative modes, and the benefits that can result from meeting these demands. Communities that implement more multimodal planning have much higher walking, cycling and transit mode shares, and significantly lower rates of automobile travel, than their peers (FHWA 2012).

Redefining Efficiency

Efficiency refers to the ratio of benefits (outputs) to costs (inputs). The old paradigm evaluated roadway efficiency based primarily on motor vehicle travel time and operating costs (generalized costs). From this perspective bigger and faster roads are more efficient. More comprehensive analysis considers other benefits and costs, and so reaches very different conclusions concerning how to increase transport system efficiency.

- Traffic network analysis evaluates efficiency based on travel distances as well as speeds. This recognizes that a lower-speed but more connected road network may allow motorists to reach destinations more quickly than a higher-speed but less connected hierarchical road network that has longer trip distances.
- Multi-modal transport planning recognizes that not everybody can drive, and that walking, cycling and public transport are more efficient than driving. From this perspective transport systems are most efficient if they allow system users to select the most appropriate mode for each trip, such as walking and cycling for local errands, public transit and rideshare vehicles for travel on major corridors, and automobile travel when it is truly most resource efficient overall.
- Accessibility-based transport planning recognizes the various factors that affect accessibility including mobility, the quality of transport options, transport network connectivity and land use accessibility. From this perspective, a transport system is most efficient if it optimizes all of these factors in order to minimize the total resource costs required to access services and activities.
- Economic efficiency refers to the degree that a system maximizes the value of goods and services provided. From this perspective a transport system is most efficient if managed to favor higher-value trips and more resource-efficient modes over lowervalue trips and less efficient modes. This can justify priority for commercial vehicles (which tend to have high value) and public transit vehicles (which tend to be space

efficient), and efficient pricing of roads and parking facilities. In this way, higher value trips and more efficient modes can outbid lower-value trips and more space-intensive modes for scarce road space and parking facility use.

 Planning efficiency refers to the degree of planning process integration, so that short-term decisions support strategic, long-term goals. From this perspective transport systems are most efficient if planned and managed to support strategic objectives, for example, if transport, land use, environmental objectives, social and economic development planning are effectively integrated.

For example, if traffic is congested around a school, the old paradigm considered roadway expansion the preferred solution. However, wider roads and the increase in vehicle traffic they cause tend to create a barrier to walking and cycling. This may cause even more parents to drive their children to school, creating a self-reinforcing cycle of increased traffic congestion, wider roads and reduced walking and cycling. The new paradigm recognizes the inefficiencies that result if poor walking and cycling conditions discourage use of these modes, causing drivers to make special chauffeuring non-drivers. Such trips are particularly costly and inefficient because they often involve empty backhauls, so two vehicle-kilometers are required to provide one passenger-kilometer of useful travel.

The new paradigm applies more comprehensive and multi-modal planning. It considers other congestion reduction strategies, such as Safe Routes to Schools programs which include a combination of pedestrian and cycling improvements, and programs that encourage students to use alternative modes when possible. It recognizes that this is often more efficient and equitable overall, since it accommodates demand for these modes, reduces road and parking infrastructure costs, provides consumer savings and affordability, and supports strategic planning objectives such as reduced pollution and improved public fitness and health.

Conclusions

Motor vehicle ownership grew rapidly during the twentieth century, providing significant benefits to society. During that time it made sense to invest significant resources into expanding roads and parking facilities. However, current demographic and economic trends are changing travel demands in ways that are increasing the benefits of transportation demand management strategies that result in more efficient use of existing transportation resources. TDM strategies tend to provide a wide range of economic, social and environmental benefits, and so can be considered "win-win" solutions. More comprehensive and multimodal evaluation is needed to quantify these benefits and identify truly optimal transportation policies and program.

References

FHWA (2012), Report to the U.S. Congress on the Outcomes of the Nonmotorized Transportation Pilot Program, Federal Highway Administration (www.fhwa.dot.gov); at www.fhwa.dot.gov/environment/bicycle_pedestrian/ntpp/2012_report/final_report_april_2012.pd f.

Thomas S. Kuhn (1962), The Structure of Scientific Revolutions, University of Chicago Press.

Todd Litman (Forthcoming), The New Transportation Planning Paradigm, ITE Journal (www.ite.org); at www.vtpi.org/paradigm.pdf.

Todd Litman (2010), Win-Win Transportation Solutions: Cooperation for Economic, Social and Environmental Benefits, Victoria Transport Policy Institute (www.vtpi.org); at www.vtpi.org/winwin.pdf.

VTPI (2013), Online TDM Encyclopedia, Victoria Transport Policy Institute (www.vtpi.org/tdm).

Todd Litman (2013), Toward More Comprehensive and Multi-modal Transport Evaluation, VTPI (www.vtpi.org); at www.vtpi.org/comp_evaluation.pdf.

Part I

THE REVIVAL OF URBAN MOBILITY BY WALKING AND CYCLING

ACCESSIBILITY ANALYSIS WITH SPACE SYNTAX.

THE PEDESTRIAN MOVEMENT NETWORK IN THE CITY CENTRE OF MUNICH

Christian Schwander, Planungsverband Äußerer Wirtschaftsraum München;

Stephen Law, Space Syntax Limited, London

Corresponding author:

Schwander, Christian; christian.schwander@gmx.net

Abstract

Space syntax is an evidence based approach to urban design and planning that applies the methods of network science to study the configuration of spatial networks in architecture and urban planning. In this paper, we use the space syntax approach to study the pedestrian movement network in the city centre of Munich.

To this end we develop a pedestrian accessibility model of Munich and compute spatial accessibility measures for each individual street segment with the program UCL Depthmap. The results of this computation are compared with pedestrian movement observations on over 100 locations in the city centre. A statistical analysis shows a high correlation (R²=0.63) between pedestrian movement patterns and spatial accessibility measures.

Based on this finding, we use the spatial accessibility model to assess the potential of a new retail development in the city centre. We model different scenarios of a shopping arcade and show their impact on the accessibility of the street network and on pedestrian movement potential. The analysis is not limited to the impact on the planned arcade internally, but also on the surrounding urban area. It is used to assess the different scenarios against the planning framework of the City Council and the ambitions of the developer.

The scenario modelling shows that movement potential within the planned arcade is highly dependent from the location of the entrances. It also shows that a cautious integration of the planned development into the urban fabric could create a new circular route that would relieve the often overcrowded radial pedestrian routes in the city centre.

The model is a useful tool to assess pedestrian movement in an early stage of the planning process, because it does not depend on a large amount of data. The paper presents further potential applications of the space syntax model, both on a more global scale for modelling vehicular movement patterns and on a more local scale for an agent based pedestrian simulation. It compares the method to other transport models and discusses the strengths and limits of the space syntax approach.

Keywords: Space syntax, spatial accessibility, pedestrian movement, Munich city centre, pedestrian simulation

Introduction

Network science is a mathematical method to study the complex relationships between related components based on the graph theory. It has been used in many academic fields with specific emphasis in studying the connectivity and centrality of complex networks such as social, physical, biological and transportation networks (Wasserman, 1997). Space syntax applies the methods of network science to study the configuration of spatial networks in architecture, urban design and transport planning. It is based on research by Bill Hillier and Julienne Hanson at the University College London (Hillier, Hanson, 1984).

Within the field of transportation modelling, space syntax research has found strong relationship between the spatial configuration of the street network and vehicular and pedestrian flows (Penn, Hillier, Bannister, Xu, 1999, Chiaradia, 2007) and has identified key centrality indicators for spatial accessibility that correlate strongly with observed movement (Hillier, Iida, 2005).

In this paper, we present the application of the space syntax modelling approach in a case study of the pedestrian movement network in the city centre of Munich. The paper is structured in five parts:

- First, we introduce the methodology of a space syntax network analysis and explain the key indicators for spatial accessibility that show a correlation between the configuration of the street network and pedestrian movement patterns.
- In the second part, we introduce the case study of the city centre of Munich and explain the importance of pedestrian movement patterns for its functioning as economic centre.
- In the third part, we establish to what degree the spatial accessibility measures correlate with observed pedestrian movement in the south western city quarter Hackenviertel.
- Then, we use the space syntax model to assess the impact of a new shopping arcade on the pedestrian movement patterns in Hackenviertel.
- Finally, we discuss the application of the spatial network model to assess the impact of proposed changes to the street network in the city centre and propose next steps for the modelling approach.

Methodology

The space syntax method consists of three steps:

Network representation and analysis

- Visualisation
- Statistical analysis

Network representation and analysis

In a space syntax network model, each street is drawn to represent the longest lines of sight between all connected convex spaces, known as the axial line (Hillier, 1996). These axial lines are than segmented at each junction and are treated as a network, where each street segment represents a node in the network. The segment model can be analysed using the computer software UCL Depthmap developed by Alasdair Turner (Turner, 2001). Recent developments also use road centre lines instead of axial lines to create the spatial network model (Turner, 2007).

Two centrality indices that relate to the urban environment are most commonly computed in space syntax:

- Closeness centrality (a.k.a. Integration in space syntax literature): it measures the reciprocal of the sum of the shortest path between every origin (i) to every destination (k), i.e. the potential of movement to this street segment (Hillier, lida, 2005).
- $C_c(P_i) = (\sum_k d_{ik})^{-1}$
- Betweenness centrality (a.k.a. Choice in space syntax literature): it measures how many times paths overlap between all pairs of origins (j) and destinations (k), i.e. the potential of moving through this street segment (Hillier, Iida, 2005).
- $C_B(P_i) = \sum_j \sum_k g_{jk}(p_i) / g_{jk}(j < k)$



Fig. 1 Closeness Centrality (C_C, left) and Betweenness Centrality (C_B, right) in a notional street network

Three types of travel costs can be weighted in computing each centrality measure:

- Metric distance: the length of the trip between origin and destination in metres;
- Topological distance: the number of turns between origin and destination;
- Angular distance: the degree of direction change on the trip between origin and destination in degree.

A radius can also be applied to account for a typical trip length for different transport modes, where the analysis is limited to a certain distance between each pairs of origins and destinations. For example, a pedestrian model might limit the analysis up to a range of 400 metres to 2000 metres catchment area around each individual street segment.

Visualisation

The network model is usually visualised within a GIS package using a spectral colour range from red to blue: high spatial indicators are visualised in warm colours (red, orange), while low spatial values are shown in cold colours (green, blue).



Fig. 2 Closeness Centrality (Cc) and Betweenness centrality (C_B) calculated by UCL Depthmap and visualised in spectral colours

Statistical analysis

The most common type of statistical analysis in the field of space syntax is to relate pedestrian movement to the computed centrality measures through a regression analysis (Hillier, Iida, 2005). This analysis states to what degree the geometric properties of the street network explain observed patterns of pedestrian movement. If a high correlation is found, the indicator can be used in a next step to simulate the impact of changes to the configuration of the street network on pedestrian movement patterns (prognostic mode).

The seminal paper by Hillier and Iida (2005) conducted a comparative study of four areas in London and found the highest correlation with an angle minimising strategy (angular betweenness centrality), both for vehicular and pedestrian flows.

Numerous subsequent projects carried out by Space Syntax Limited over the following years found strong correlations between space syntax centrality indices and pedestrian movement patterns in various urban settings that support the findings of Hillier and Iida. While for each project the main parameters are individually established, these general findings can be reported:

- Angular distance regularly performs better than topological distance or metric distance, which indicates that an angle minimising way finding strategy is used by most pedestrians.
- A number of studies propose that betweenness centrality performs better in historically developed urban structures, while closeness centrality performs better in planned postwar urban developments, such as housing estates, but this is still inconclusive.
- In very localised areas with a high population density in close vicinity, small analysis radii 400m to 1200m perform best, while in areas with a larger catchment and a lower surrounding population density, larger radii correspond better with pedestrian movement observations. In a comparative study of London town centres (Chiaradia, Hillier, Schwander, Wedderburn, 2009) an analysis radius of 2000 metres was identified as most applicable.

Munich city centre

In this section, we show the application of the methodology on the pedestrian movement network in the city centre of Munich.

Pedestrian movement pattern

We conducted three observational studies of pedestrian flows between 2010 and 2011 in over 100 locations throughout the city centre. Pedestrians were counted by human observers for five minutes each hour from 10:00 hours to 20:00 hours and hourly averages were calculated and mapped. Higher pedestrian flows are shown in warm colours (red, orange), while lower pedestrian flows are shown in cold colours (green, blue). Fig.3 shows the recorded average daily pedestrian flow per hour on a weekday.



Fig. 3 Munich city centre: Top retail locations and pedestrian footfall

The highest footfall of 6,000 to 7,000 pedestrians per hour (pph) on average was recorded in Kaufingerstrasse, the main pedestrian zone of Munich leading from Karlsplatz in the west to Marienplatz, the central market square. Tal, the continuation of this main east-west axis has a footfall between 4,000 and 6,000 pph. The two parallel streets to the north (Weinstrasse and Dienerstrasse) account for 2,500 to 3,000 pph, while the pedestrian flows on Sendlinger Strasse, the main radial to the south accounts for 2,000 to 2,500 pph. The pedestrian movement on the side streets is significantly lower and accounts for only 10 to 25% of the movement rate in the main streets.

The pedestrian movement pattern is therefore highly concentrated on the four main axes, the historic trading routes that convene on Marienplatz. Although these streets do not play any role as thoroughfares as they are either pedestrianised or traffic calmed, their historic importance is still reflected in pedestrian movement rates.

The observed pedestrian movement pattern corresponds well with the top 1a retail locations (Kemper's City Profile 2009), shown in pink. They have the highest rent and turnover and are clearly dependent on sufficient footfall. Due to the importance of pedestrian movement for a successful economic centre a clear understanding of the pedestrian movement patterns and their reasons is necessary for successful planning.

Urban structure

According to the space syntax theory of natural movement, pedestrian flows can be explained to a high degree by the configuration of the street network (Hillier, 1984). To test this hypothesis, we developed a spatial network model for the city of Munich (Fig. 4). This network model is based on the axial map for the entire city (Rose, Schwander, Czerkauer, Davidel, 2008) and was manually drawn according to the methodology of Hillier and Hanson (1984).

In this model, the street network is represented by lines of sight and movement. Each street segment between two junctions is treated as a node in the network model and can therefore be attributed key centrality indicators, which are calculated in the program UCL Depthmap (Turner 2001).

The spatial accessibility map (Fig.4) highlights the main radial routes with the highly spatial accessibility (red) that correspond well with the location of top retail streets and the pedestrian movement patterns. They structure a spatially less accessible background network in the four city quarters Kreuzviertel, Graggenauviertel, Angerviertel und Hackenviertel (Schiermeier 2003). The south western quarter, Hackenviertel, will be analysed in more detail.



Fig. 4 Spatial network model of Munich city centre

Hackenviertel

Munich city centre is one of the top retail locations in Germany. As the area is already densely built-up, space for new developments on the 1a locations is highly restricted. Therefore, there is a high pressure to develop arcade systems within the blocks to provide

space for retail. Several of these arcades opened in the last 20 years, some are very successful, such as the Fünf Höfe, while some others are failing. It is evident, that in addition to the architecture and the quality of the retail offer, the location of the arcades and their integration into the urban context plays a key role for their success.

In this section, we test if the spatial accessibility model is able to explain pedestrian movement patterns in the city centre and to assess if a particular block is an appropriate location for new retail development. We focus on the Hackenviertel, to assess the correlation between observed pedestrian movement and spatial accessibility values.

Existing urban structure

A new development for retail is planned for a large building block between Färbergraben, Sendlinger Strasse, Hackenstrasse und Hottenstrasse.

Fig. 5 shows the pedestrian flows observed on a weekday in January 2010. The highest pedestrian movement were recorded on the main radial streets: the pedestrian zone (Kaufingerstrasse) to the west, Weinstrasse to the north and Sendlinger Strasse to the south west. The movement rate on the concentric streets that follow the former wall (Rindermarkt, Färbergraben) and in the side streets is significantly lower. South of Kaufinger Strasse it accounts for only 12%, from Sendlinger Strasse around 20% to 30%.



Fig. 5 Pedestrian movement in the Hackenviertel

The existing shopping arcades in the surrounding area perform very differently. While footfall on Kaufinger Tor is high at the entrance from Kaufingerstrasse (over 1,000 pph), it drops towards Färbergraben to only around 400 pph. The adjacent Rosenhof has lower

movement rates of 300 to 1,000 pph. The footfall in Asamhof ranges from 500 pph on the entrance from Sendlinger Strasse to only 150 pph on the entrance from Hackenstrasse.

Statistical analysis

In accordance to previous studies (Hillier, Iida, 2005) a statistical regression analysis between different spatial accessibility indicators and pedestrian movement is carried out. Fig.6 summarises the correlation coefficient of nine spatial centrality indicators.

Measure	Metric	Topological	Angular
Closeness Centrality 2000m radius	0.0016	0.5014	0.6039
Betweenness Centrality 2000m radius	0.2856	0.4261	0.6258
Closeness Centrality 800m radius	0.0091	0.4936	0.5368
Betweenness Centrality 800m radius	0.2220	0.4212	0.4585

Fig. 6 Adjusted r^2 values for correlations between pedestrian movement and different spatial accessibility indicators

The comparison shows that betweenness centrality correlates better with pedestrian flows than closeness centrality and that an analysis based on angular cost performs significantly better than topological and metric costs. In all cases, a radius of 2000 metres has a better correlation than a radius of 800 metres. These results are in line with findings from previous research (e.g. Hillier, lida, 2005).

The best correlation with observed pedestrian movement was found for angular betweenness centrality at a radius of 2000 metres (a.k.a. Angular Choice 2000m) with an adjusted correlation coefficient of r^2 =0.63. This spatial accessibility indicator is visualised in fig. 7.

Fig. 7 shows the best performing spatial accessibility index (Angular Betweenness Centrality 2000 metres) on the x-axis plotted against the observed pedestrian movement on the y-axis. The trend developed by the regression analysis is shown as a red line.

- A dot on the line performs to 100% according to its spatial accessibility, i.e. observed movement on this location equals expected movement.
- A dot below the trend line is under-performing, i.e. the observed pedestrian movement is lower than expected.

 A dot above the trend line is over-performing, i.e. the observed movement is higher than expected.



Fig. 7 Correlation between pedestrian movement and Angular Betweenness Centrality 2000 metres

Fig. 8 shows the pattern of over- and under-performing locations in the Hackenviertel. Six of the highly over-performing locations are on or next to the main pedestrian zone in Kaufingerstrasse. Here, the observed movement is up to twice as much as predicted by the spatial accessibility model. How can this pattern be explained?

One likely factor is the high number of retail outlets in this street (Kemper's 2008) that attracts more people than it would be expected under the same spatial conditions without this retail offer. Another likely factor is the vicinity to public transport nodes (underground station Marienplatz) that bring even more pedestrians in the area.

We can therefore conclude, that the spatial accessibility model explains pedestrian movement rates to a high degree (63% in this case) but does not account for additional non-spatial (land use) or spatial (vicinity to public transport nodes) factors. To include these factors, it is possible to develop a more sophisticated multi-variate model. This is discussed in more detail in section 6.



Fig. 8 Over- and under-performing street segments

Spatial accessibility model

We use the spatial accessibility model (Fig. 9) to understand the existing urban structure and its influence on pedestrian movement for a specific location, a retail development in Hackenviertel (shown in pink). The aim of this development is not to solely rely on the attractiveness of the retail offer but to benefit from natural movement (Hillier, Penn, Hanson, Grajewski, Xu, 1993) by linking into the surrounding urban network.

The impact of the development on pedestrian footfall matters for both, the developer and the planning authority, but in a different way: while the developer seeks to maximise footfall within the new arcade, the planning authority seeks to improve the permeability of the urban structure and strengthen access and footfall in the Hackenviertel, particularly on Hackenstrasse.

In order to assess these ambitions, we look at the movement potential in the surrounding streets, expressed by the observed pedestrian movement and the spatial accessibility.

Sendlinger Strasse to the south east shows the highest spatial accessibility (CB=320,000; red) and has a footfall of around 2,000 pedestrians per hour (pph). There is an opportunity to align the entrance to Dultstrasse that leads to Jakobsplatz, a cultural square with a museum and the synagogue. The spatial potential for an access on this side is high.

- Hackenstrasse to the south west has a low spatial accessibility (CB =37.000; green) and a footfall of around 400 pph. The spatial potential is only modest.
- Hottenstrasse to the north east has a very low spatial accessibility (CB =2,300; blue) and a footfall of only 130 pph. The spatial potential is low.
- Färbergraben to the north east has a medium spatial accessibility (CB =90,000; yellow) and a footfall of around 700 pph. There is an opportunity to align the entrance to the shopping arcade Kaufinger Tor that leads directly to the pedestrian zone and further to the cathedral. The spatial potential is high.

From this analysis of the spatial potential in the surrounding streets we can draw the following conclusions:

- In order to maximise footfall within the shopping arcade, it needs to connect to Sendlinger Strasse and F\u00e4rbergraben.
- A link to Hackenstrasse would increase permeability of this city quarter.
- The alignment of the entrances could help maximise the spatial potential on a wider scale by connecting the development to key cultural and economic attractors.



Fig. 9 Spatial accessibility model of Hackenviertel

Scenarios for a shopping arcade

Based on these findings, the spatial network model is used to assess different scenarios for a new shopping arcade. A spatial accessibility model for each scenario was developed and the indicator Angular Betweenness Centrality 2000 metres was calculated for each street segment.

Spatial accessibility

The first proposal for this block was to provide a new link from Färbergraben in the northeast to Sendlinger Strasse in the southeast as shown in **Scenario 1**. The entrance on Färbergraben is in the middle of a small square currently used as a car park and does not to connect directly to Kaufinger Tor and further to Kaufingerstrasse. The entrance on Sendlinger Strasse is aligned with a small arcade on the opposite side that provides a link to Oberanger, but not further to Jakobsplatz. As a result, the spatial accessibility in the arcade is low ($C_B=2,500$ to 5,000; blue), which is comparable to Hottenstrasse. In this scenario, we would not expect sufficient natural movement in the arcade to support retail, it would solely rely on its attractiveness.

In **Scenario 2**, we include a link to Hackenstrasse, to correspond to the City Council's ambition to increase permeability in the Hackenviertel. However, the spatial accessibility level within the arcade even decreases ($C_B = 1,000$ to 4,500) and the one in Hackenstrasse does not increase significantly. Therefore we doubt that scenario 2 can meet the ambitions.

In **Scenario 3,** the entrances to the shopping arcade are aligned to the surrounding street network. In the northeast the entrance is directly visible from Kaufinger Tor and in the southeast from Jakobsplatz. The pedestrian movement potential changes significantly: the spatial accessibility in the arcade increases (BC=20,000 to 35,000), which is comparable to Rindermarkt and Färbergraben. The surrounding streets are also positively affected, e.g. the western section of Hackenstrasse (C_B increases from 40,000 to 50,000).

In **Scenario 4**, we test an additional arm of the shopping arcade to Hottenstrasse. While this scenario increases the spatial accessibility in Hottenstrasse (C_B from 2,000 to 4,500), the internal route has a very low spatial accessibility (C_B =1,000), which makes it unfeasible for retail.



Fig.10 Spatial accessibility analysis of the four scenarios

Movement simulation

In addition to the comparison of the spatial accessibility comparison of the four scenarios, we use the statistical model to simulate pedestrian movement levels for the layouts in Scenario 1 and Scenario 3. The expected movement level is calculated from the spatial accessibility (C_B) according to the formula identified in section 4. The results are shown in figure 11.

In **Scenario 1**, the footfall within the new arcade remains very low at a level of under 250 pph. This movement rate is comparable with side entrances to Asamhöfe and is clearly not sufficient for a vibrant retail area. In the surrounding area, we would not expect significant changes in the movement rates, only Hottenstrasse and Sattlerstrasse will increase modestly.

In **Scenario 3**, by contrast, the footfall within the arcade ranges between 250 and 1,000 pph, significantly higher than in Scenario 1. Due to the new alignment to Kaufinger Tor, it would draw even more people in from the north east than from Sendlinger Strasse. It would result in increased pedestrian movement in Kaufinger Tor (+50%) and Sattlerstrasse (+90%) due to the new direct alignment. Also movement rates toward Jakobsplatz increase significantly as consequence of the direct link from Dultstrasse. A modest increase in footfall along Hackenstrasse (+18%) can also be expected. In summary, Scenario 3 would have a strong positive impact on the pedestrian movement network in the city centre. It would create a new circular route from the cathedral, through Kaufinger Tor and the new arcade to Jakobsplatz and further to Viktualienmarkt. This could benefit the urban structure of the city centre as a whole by relieving the radial streets, which often suffer from overcrowding with an attractive circular route. The urban structure would become less linear and more convex.

The analysis shows that local decisions on the location of entrances to a new arcade can have a significant impact on a much wider scale.



Fig. 11 Pedestrian movement simulation of scenario 1 and 3

Discussion

The presented approach to spatial accessibility modelling is different from most transport models.

In transport research, accessibility measures the ease of opportunities in an environment for either individuals or place as a function of attractiveness between origins and destinations and generalised travel cost as a function of journey time, frequency, reliability, comfort and economic costs (Miller 2000; Kwan, 1998). These models require a large number of data, usually for land use, demographics socio-economic factors, mode choice and route assignment. On this basis, transport models are able to predict flows between origins and destinations and measure traffic flows.

In space syntax, spatial accessibility is a measure of centrality within the street network where the travel costs are derived from the configuration of the network. Based on the geometry, the likelihood for flows on specific street segments is calculated. While the distribution of flows is predicted by the model, the movement level has to be calibrated with observational studies.

We see both models as complementary, one with a focus on the exact flows, the other one with a focus on the distribution of the movement pattern. In the following section, we assess what the presented method of spatial accessibility analysis can achieve and where its limits are.

Design and planning tool

The strength of the space syntax method is that a relatively simple model based solely on the geometry of the street network can explain pedestrian movement distribution to a high degree.

It is a useful tool for the early stage of the design process, when detailed data for a transport model are rarely available, especially not for pedestrian flows. It is geared towards architects and urban designers who are usually not familiar with sophisticated mathematical models, but play a key role in early design decisions.

The space syntax accessibility analysis tool can help in four phases of the planning process:

- It develops a spatial baseline for the design brief that helps the planners and designers understand the existing urban structure of the development area within its urban context.
- It creates spatial evidence and shows how the existing urban structure shapes pedestrian movement and land use distribution.
- It compares different design options against a previously set framework in an objective way and assesses to what degree the options meet the objectives of the design brief.
- The real time analysis helps optimise a design solution by assessing its impact on the pedestrian movement network.

Pedestrian movement simulation

To what degree can the tool be used to predict exact numbers of pedestrian movement? In the case study we presented a simulation of pedestrian movement on the basis of spatial accessibility, but there are certain prerequisites and limits:

 The tool is probabilistic, not deterministic. It needs a significant number of pedestrians and can then assess the likelihood that a certain path is chosen by a number of people, not by individuals.

- The wayfinding method is based on empiric studies and principles of cognitive science and takes into account both distance and route complexity. It therefore simulates natural unrestricted movement and cannot be used in situations where navigation depends solely on signposting.
- The tool is based on the geometric properties of the urban structure and underestimates the impact of additional factors, such as attractors, density and speed.

In our example, the space syntax model would certainly underestimate footfall at the opening day of the newly opened shopping arcade with very attractive shops. At this point, pedestrian movement would be guided by the new attractor rather than natural movement. Over time, however, the attractor factor usually decreases and the impact of natural movement increases.

This clarifies the aim of the space syntax pedestrian modelling: not to predict exact movement numbers at a certain point in time, but to give a prognosis of future movement distribution as a result of planning decisions. Rather than on short term footfall peaks, the model focuses on a sustainable urban form and its long term benefits for the city as a whole.

Next steps

The space syntax approach is not limited to the scale of pedestrian movement in a city quarter, but can be equally used in other scales:

- Chiaradia (2007) used a space syntax model to analyse vehicular movement patterns on a city wide scale in the metropolitan region of Nantes. A similar vehicular model for the Munich metropolitan region based on openstreetmap.org is currently under way and early results show promising correlations.
- A recent study (Law, Chiaradia, Schwander, 2012) developed an integrated spatial model of London that brings the public transport network in the play. It combines the street network and the underground network into an integrated model and is able to explain activity at public transport nodes to a high degree. A similar integrated model is planned for the Munich metropolitan region.
- On a more detailed scale, space syntax researchers developed agent analysis methods (Turner, Penn, 2002, Ferguson, Friedrich, Karimi 2012) based on the visual field properties of different standpoints at a very fine grain (e.g. 80 x 80 cm). This agent model is able to simulate pedestrian paths from the urban context through a new development

and assess the impact of small interventions that would not be visible in the street segment model.

While all these developments improve the statistical correlation of the model with empirical data, this is achieved at the expense of the simplicity of the model. However, this simplicity allows the approach to be used in early planning stages, as a means of communication between different professions such as transport planners, retail developers and architects and between professionals and local citizens. This is the essential strength of the space syntax approach.

References

- Chiaradia A (2007), Emergent Route Choice Behaviour, Motorway and Trunk Road Network: the Nantes conurbation, Delft: 6th International Space Syntax Symposium.
- Chiaradia A, Hillier B, Schwander C, Wedderburn M (2009), Spatial Centrality, Economic Vitality/ Viability: Compositional and Spatial Effects in Greater London, In: 7th International Space Syntax Symposium, Stockholm.
- Ferguson P, Friedrich E, Karimi K (2012), Origin-destination weighting in agent modelling for pedestrian movement forecasting. In: 8th International Space Syntax Symposium, Santiago de Chile.
- Hillier B, Hanson J (1984), The Social Logic of Space, Cambridge University Press: Cambridge.
- Hillier B , Penn A , Hanson J, Grajewski T, Xu J (1993), Natural Movement: or, configuration and attraction in urban pedestrian movement, Environment and Planning B: Planning and Design, Vol. 20, 29-66.
- Hillier B (1996), Cities as movement economies. in: Urban Design International 1 (1), p. 41-60.
- Hillier B, and Iida S (2005), Network and psychological effects in urban movement. In: Cohn AG and Mark D M , (eds.) Proceedings of Spatial Information Theory: International Conference, COSIT 2005, Ellicottsville, N.Y., p 475-490. Springer, Berlin.
- Kemper's (2008), Retail City Guide München.
- Kwan, MP (1998) Space-time and integral measures of individual accessibility: A comparative analysis using a point-based framework. Geographical Analysis 30, p.191–216.
- Law, S., Chiaradia, A., Schwander, C. (2012), Towards a multi-modal space syntax network analysis. A case study of the London street and underground network, in: 8th International Space Syntax Symposium, Santiago de Chile.
- Miller, HJ (2000) Geographic representation in spatial analysis. Journal of Geographical Systems 2, p. 55-60.
- Penn A, Hillier B, Banister D, Xu J (1999), Configurational modelling of urban movement networks. Environment and Planning B, 25 (1), p. 59 - 84.
- Rose A, Schwander C, Czerkauer C, Davidel R (2008), Regelbasiertes Entwerfen: Space matters, in: ARCH+ 189 Entwurfsmuster, S. 32-37, Berlin.

- Schiermeier F (2003), Stadtatlas München. Karten und Modelle von 1570 bis heute. München, Münchner Stadtmuseum, Stadtarchiv München.
- Turner A (2001), Depthmap: a program to perform visibility graph analysis. 3rd International Space Syntax Symposium, Georgia Institute of Technology, Atlanta, GA.
- Turner A, Penn A (2002), Encoding natural movement as an agent-based system: an investigation into human pedestrian behaviour in the built environment. Environment and Planning B: Planning and Design Vol. 29, p. 473-490.
- Turner A (2007), From axial to road-centre lines: a new representation for space syntax and a new model of route choice for transport network analysis, in: Environment and Planning B: Planning and Design 34(3) p.539 555.
- Wasserman S (1997), Social Network Analysis: Methods and Applications. Cambridge University Press.

Acknowledgment

The authors would like to thank rheform gmbh, München and Space Syntax Limited, London for their support. The figure ground maps of Munich are based on the building layer of openstreetmap.org. The scenarios are for explanation only and do not represent any planning stage of the related project.

INCORPORATING THE INFLUENCE OF WALKABILITY INTO A MODEL OF PEDESTRIAN ACCESSIBILITY

David Jonietz ; Sabine Timpf, Institute for Geography, University of Augsburg

Corresponding author:

David Jonietz; david.jonietz@geo.uni-augsburg.de

Abstract

Representing a critical factor for maintaining the economic, cultural and social functionality of city centres, accessibility has traditionally been a central concept in urban transportation planning. However, when modeling urban accessibility, approaches have generally concentrated on motorized means of transportation, neglecting the fact that non-motorized modes, especially walking, play an essential role in urban settings. Moreover, it is acknowledged that pedestrians place specific demands on their environment, which are not restricted to distance, time or financial cost. Thus, this study presents an alternative GIS-based approach to model urban walking accessibility by integrating a walkability-index as an additional cost value, using the example of pedestrians in the main shopping district in the city centre of Augsburg.

Keywords: pedestrian accessibility, walkability, network analysis, GIS-based index

Introduction

Throughout the entire history of urban development, accessibility, defined as the "capacity of a location to be reached by, or to reach different locations", has been a determining factor for the development and persistence of cities (Rodrigue, Comtois, & Slack, 2009). Today, against the background of increased centre-periphery interaction, place-based accessibility is still a critical factor for maintaining the economic, cultural and social functionality of city centres, which is why this particular concept continues to play a central part in urban transportation planning.

Traditionally, accessibility measures focused on motorized means of transport, measuring the ease in terms of distance, time or financial cost, of reaching the city centre from the periphery by car or other means of transportation (Taaffe, Gauthier, & O'Kelly, 1996). What has often been neglected, however, is the fact that primarily in urban settings, non-motorized transportation modes, especially walking, are of a critical importance. Thus, 27% of all trips in German inner cities are done on foot (Follmer et al., 2008). In addition, nearly every other trip includes walking since the way to the car park or train station and from there to the actual destination is usually covered on foot (Boesch, 1988). Furthermore, while

phenomena such as the distance, time or financial cost are certainly useful when evaluating the accessibility of a location via motorized private or public transportation modes, empirical research shows that for pedestrians, these units of measurement alone are not sufficient. Indeed, it has been suggested that pedestrians have certain needs for their walking environment, often categorized under the generic term walkability, meaning "the quality of walking environment perceived by the walkers" (Park, 2008). It can be assumed that a low-quality walking infrastructure requires more physical and cognitive effort from the pedestrian, ranging from annoyances by motorized traffic to the danger of falling due to an insufficient surface infrastructure. Ultimately, a low walkability could lead to a change of location or transportation mode, and therefore a reduction of accessibility. In fact, it has been shown that in highly walkable urban environments, pedestrians are willing to walk longer distances compared to areas with a lower walkability (Monheim & Raab 2008).

We argue, therefore, that a concept of urban accessibility must not be restricted to motorized transportation, but include walking accessibility measures which should be based on walkability indicators. The aim of this study is to integrate the concepts of walkability and accessibility by incorporating a measure of walkability as an impedance value for a cost-based network analysis. We implement our new model of urban pedestrian accessibility through a case study, the main shopping district in the city centre of Augsburg. Geographical Information Systems (GIS) are deployed to derive service areas which visualize the accumulated walkability costs for all possible routes from fixed origins, in our case car parks.

This paper is structured as follows: After providing background information on the concepts of walkability and pedestrian accessibility, our method is described. Then, the results are discussed before finally concluding in the last chapter.

Background

This chapter gives background information on the issues of walkability and pedestrian accessibility. In the first subchapter, walkability is discussed in terms of the general concept and the main findings. Examples of previous work on modeling pedestrian accessibility are presented in the second subchapter.
Walkability- Concept and Findings

One goal of sustainable transportation planning is to reduce the relative share of motorized means of transportation in favour of non-motorized modes. Although being long neglected by planners and scientists, since the 1990s, pedestrians have received much attention from several disciplines such as urban planning, traffic engineering or public health. It was recognized that pedestrians pose specific needs to their walking environment, which is due to their characteristic systemic features such as a low speed, direct contact with the environment and a lack of protection when involved in accidents. In addition, the positive effects of walking, such as reduced pollution, resource conservation, the support of the local economy, an increased sense of security, or a better health became evident. In this context, several empirical studies were conducted with the aim to identify the range of environmental qualities which make an urban area walkable for pedestrians and examine their actual correlation to the relative share of walking (Saelens, Sallis, & Frank, 2003).

Regarding the set of walkability-related characteristics of the urban surroundings, one can distinguish between macro-scale walkability indicators, assessed on the level of the city or the district, and micro-scale factors which focus on individual paths or street segments (Alfonso et al., 2008). The former, such as population or building density, land use diversity, street network connectivity and building block size were clearly in the focus of earlier studies (Cervero & Kockelman, 1997; Frank et al., 2005; Leslie et al., 2007; Boarnet, Greenwald & MacMillan, 2008). The factors, which all contribute to generally shorter trip distances to potential destinations, could be shown to correlate with higher levels of walking. Since city centres are generally marked by high scores concerning these macroscale walkability indicators, the micro-scale becomes more relevant. Recently, there has been much interest in the design of walking infrastructure and urban form, especially the dimension of foot paths, surface texture, street lighting, aesthetics and attractiveness of the surroundings, the presence of other pedestrians, the design of crossings, urban vegetation and cleanliness (Huston et. al., 2003; De Bourdeaudhuij et. al., 2005; Ewing et al., 2006; Boarnet, Greenwald, & McMillan, 2008; Gallagher et. al., 2010). Concerning the correlation between these micro-scale indicators and walking, however, the results remain limited since findings are inconsistent and further research is still needed (Agrawal, Schlossberg, & Irvin, 2008).

Apart from the mere identification of these potential walkability indicators, their evaluation is also a critical task for urban planners and scientists interested in pedestrian movement. Building on empirical evidence, a number of authors have presented methods to operationalize and evaluate these by calculating walkability indices (Park, 2008; Comerford, 2008; Clark & Davies, 2009). In contrast to macro-scale approaches which are often based on GIS-based measures of land use mix or density to calculate walkability values, most micro-scale analyses depend on expert surveyors to gather the data in the field. In the course of a field audit, a set of predetermined walkability indicators is evaluated in the study area. Afterwards, the walkability can be rated based on the separate scores for each individual characteristic.

Selected Work on Modeling Pedestrian Accessibility

In this section, selected work related to modeling pedestrian accessibility will be presented and discussed.

In an older study, the author attempted to show the connections between traffic and trade in city or district centres. Using the example of large food stores in a district of Zürich, Euclidean distance-based catchment areas for pedestrian customers were evaluated (Boesch, 1988). Straight-line distance, however, might differ to a great extent from the actual walking distance, since normally, the path network differs from the straight line between two locations. Using network distance therefore seems a more appropriate modeling approach.

A recent approach aimed to analyze the pedestrian accessibility to transit stations based on network distance. Service areas were created for various US and German cities in order to visualize differences between them, which, however, were exclusively based on the distance. Other types of cost were not included in the analysis. In the course of the study, the author compared data quality regarding pedestrian walkway networks from several sources (Zielstra & Hochmair, 2011).

A commonly used cost attribute other than distance is time. Thus, in one example, timebased service areas were created by combining the factors distance, gradient, and demographics in order to assess their effect on walking speed. Thus, it was possible to calculate realistic time values needed to cover a certain distance in a pedestrian network. Using the example of pedestrian accessibility to certain key locations in several proposed development sites in the West Northamptonshire area, the authors introduced a more practical approach since it is often not the distance that matters when planning a walking trip, but rather the time needed (Colclough & Owens, 2010). A huge step towards a more pedestrian-oriented research design was made by a team of researchers, who created a model of walking accessibility to public transport terminals in Singapore. In addition to distance or time-based restraints, they introduced a concept of walking effort as an influential factor for the probability of choosing a walking access to the destination. However, apart from the fact that the walkability indicators were restricted to the number of road crossings, ascending steps and points of potential conflict with other means of transportation, GIS was not put to use. Instead, the authors restricted themselves to the calculation of a walking accessibility index (Wibowo & Olszewski, 2005).

Method

In the third chapter, the proposed method is presented. Firstly, it is shown how the study area was defined, after which the creation of the walkability index is explained. In the last subsection, information about the GIS-based modeling procedure is provided.

Defining the Study Area

Since we focus on pedestrian movements between several multi-storey car parks and the main shopping districts in the city centre of Augsburg, the study area is restricted to the parts of the inner city's walkway network with a high probability to be used by pedestrians during a trip to the respective stores.

As a first step, the points of origin had to be identified. It is assumed that pedestrians start their trip from one of the main inner city car parks. In order to exclude smaller parking structures, which are in reality used almost exclusively by local residents and not freely accessible for non-local visitors, a minimum size of at least 100 available parking spaces was determined. The remaining 12 car parks were digitized as point features using ArcGIS 10 by ESRI.

Accordingly, the retail locations must be identified in order to serve as hypothetical destination points for the interpretation of the analysis. In this analysis, we focus on the main shopping districts and ignore smaller clusters or isolated locations of retail trade in adjacent areas. We define as main shopping district the area which had previously been defined as prime location, namely Bahnhofstraße, Bürgermeister-Fischer-Straße, Annastraße, Philippine-Welser-Straße, northern Maximilianstraße and Karolinenstraße (Heller & Monheim, 2004). During the first walking audit, which took place on the 12th of January 2010, the respective retail shops were mapped and digitalized as point features in the GIS.

In the following, a walkway network for the inner City of Augsburg was created. This was done manually on the basis of local knowledge. Finally, the fringe of the actual study area could be established using several shortest path analyses from the location of the particular car park to the outermost shops. The outermost shortest path routes determined the borders of the study area.

Developing a Walkability Index

This work is based on the assumption that low walkability increases the perceived effort of pedestrian movement. Thus, a walkability index was calculated in order to serve as a cost value for a network analysis. The set of indicators was chosen in accordance with the general findings of previous empirical studies, with regard to the particular situation in Augsburg and taking into consideration practicability.

The list of indicators include the quality of surface texture, footpath width, irritation by motorized traffic, the historical value of adjacent buildings and the design of crossings which each were evaluated and translated to standardized index values on a scale ranging from zero to one, where higher values were attributed to less appropriate surroundings.

The quality of a footpath's surface is of a particular importance for pedestrians. Inappropriate paving makes walking more difficult and may lead to injuries. In the study area, a majority of footpaths is paved with different kinds of paving stone. Accordingly, it was found that that the surface quality is the main point of complaint for pedestrians in Augsburg (Heller & Monheim, 2004). As Figure 1 shows, the three grades inappropriate, appropriate and excellent were distinguished.



Figure 1: Surface textures in the study area

The dimensions of the footpaths must also be noted. A minimum width of 2.5 meters is usually estimated for two pedestrians to meet and pass without touching each other (Forschungsgesellschaft für Straßen- und Verkehrswesen, 2002). We therefore assign the highest cost value to path segments with a width smaller than 2.5 meters, the medium value until 3.5 meters and the lowest value to even wider sidewalks.

Motorized transport poses a variety of threats and annoyances to pedestrians, even if there is no direct contact but only spatial proximity (Walter et. al., 2007). In Augsburg, pedestrian precincts, traffic calmed areas, smaller streets and high streets can be found and correspond with the ratings zero, low, medium and high for the expected level of irritations.

The next indicator, the historical value of the adjacent buildings, was introduced as a criterion to compensate for problems associated with the question of whether an urban setting is perceived as attractive by a pedestrian. Despite the fact that evaluating the aesthetics of built structures is certainly a highly subjective matter, several empirical studies have found a strong relation between what is perceived as attractive and historical value. In one study, for instance, pictures of buildings of different ages and states of maintenance were shown to test persons. It was found that in general, old buildings in a good condition were preferred to newer ones (Herzog & Shier, 2000). Similar findings were made when test persons were asked to identify the most visually attractive and unattractive place of their city, which showed that attraction correlates with a historical or recreational value (Hidalgo et al., 2006). Thus, in the context of this study, it appeared sufficient to introduce the historical value of the adjacent buildings as a substitute quality for the attractiveness of the urban environment. A high historical and touristic value was assigned to path segments within a buffer distance of 20 meters to officially recognized architectural monuments (Von Hagen & Wegener-Hüssen, 1994).

The final indicator was introduced to take into account the negative effects that arise when walking paths are cut by streets which pedestrians must cross. Although on average, crossings amount to less than 10 % of the walked distance, 74 % of all accidents with pedestrians involved take place there (Walter et. al., 2007). The design of the crossing is directly related to the potential risk. We differentiated between three types of crossings: Crossings of smaller streets with a speed limit of 30 km/h and only one or two lanes were assigned a low risk potential. Crossings of roads with more lanes were rated medium if supporting infrastructure such as traffic lights or traffic islands were provided and high if there were no supporting systems. Table 1 shows the standardized values for all criteria.

Indicator	Levels	Index Value
Quality of Surface Texture	Excellent	0
	Appropriate	0.5
	Inappropriate	1
Footpath Width	Above 3.5 m	0
	2.5 – 3.5 m	0.5
	Below 2.5 m	1
Historical Value of Adjacent	High	0
Buildings	Low	1
Irritation by Motorized Traffic	Pedestrian Precinct	0
	Traffic calmed area	0.33
	Two lane streets	0.66
	Multiple lane streets	1
Design of Crossings	No Crossing	0
	Low Risk	0.33
	Medium Risk	0.66
	High Risk	1

Table 1: Standardized Values

In the following, after developing an audit tool, most indicators except the historical value of the adjacent buildings were assessed during a walking audit and stored as attributes in the GIS. After that, single line features with homogenous values for the several indicators were created. In the case of a change of one or more indicator values along the path, a new feature was created.

Finally, a weighted additive walkability index could be calculated for each homogenous edge from the standardized values:

(SurfaceTexture + FootpathWidth + HistValue + IrritatMotor + Crossings *2)/6

As one can see, while all other values enter the index without additional weight, the indicator Design of Crossings was doubled in order to accentuate the negative effects which arise when pedestrian walkways are cut by street intersections. Using a field calculation, the index value for each edge was calculated and stored as an additional attribute.

Network Analysis

Measuring distance or cost over a geometric network is often used to model the accessibility for a certain source location. By calculating the distance or cost for each edge along the network, it is possible to identify all path segments which are accessible from the source location within a set maximum distance or cost. As has already been described, we assigned a walkability index value as an attribute to each path segment in order to serve as an impedance value for the network analysis. In order to avoid distortive effects as a result of the differing length of the segment before using it as an impedance value:

Impedance Value for Walkability = Walkability Index * Length of Path Segment

Based on this newly computed impedance value, service areas were then computed for each car park separately with ESRI's Network Analyst. For this, a maximum distance of 1.25 kilometers was defined in reference to the average walking distance of visitors of the city centre of Augsburg (Heller & Monheim, 2004). For the walkability impedance, no maximum cost was defined. The accumulated values were divided into three classes: low (0-50), medium (51-100) and high (101 and more). Finally, the number of shops being located in the low, medium and high range of impedance values could be counted.

Results

Figure 2 and 3 show the results for two selected car parks. For each car park as point of origin, the service area illustrates the area which is accessible for a pedestrian within a maximum walking distance of 1.25 kilometers. The colours represent the areas which are accessible within certain accumulated walkability cost intervals. However, the true informational value of the walkability-based model is achieved when comparing the results

for two or more car parks. Viewed in relation to each other, differences in the extent of the zones with low, medium and high accumulated walkability values as well as the number of shops located within these areas illustrate variances regarding the diverse set of difficulties, annoyances and barriers a pedestrian has to face when starting his walking trip from one or the other source location.



Figure 2: Accumulated Walkability Index for Car Park "Annahof"



Figure 3: Accumulated Walkability Index for Car Park "Schätzlerstraße"

Figure 2 shows the resulting service area for the car park "Annahof". This particular car park provides not only direct access to the pedestrian precinct, but is also located in an area which is considered very suitable for walking, with rather low cost values for most walkability indicators. The second car park, "Schätzlerstraße", which is shown on figure 4, is located only around 150 meters to the west, but set next to a multi-lane street and disconnected from the main shopping areas by a busy crossing. Although both car parks

are located almost equally central in the study area, the difference regarding the walkability is clearly visible in the differing extends of the lighter gray zones and the number of shops located within them. Thus, while traditional distance- or time-based accessibility measures would likely assign equal ratings to both car parks, with our method, it is possible to draw a more realistic picture. Visitors in the process of deciding between these two car parks before their trip could therefore be informed that in this case, "Annahof" is the option that they will likely perceive as being more accessible than "Schätzlerstraße".

Discussion

In this work, we have presented a concept for a walkability-based model of the urban pedestrian accessibility. By incorporating a measure of walkability as an impedance value into a cost-based network analysis, we integrated the concepts of walkability and accessibility in order to acknowledge that for pedestrians, traditional distance- or time-based accessibility concepts are not sufficient.

Although at this stage our work not much more than just an exploratory sketch, we believe that urban planners aiming to attract more pedestrians to their city centres as well as developers of routing applications or other services for walkers could profit from our concept of pedestrian accessibility. Our model allows a much more realistic insight into a pedestrian's perception and might serve various practical purposes, such as route planning, weakness detection or the explanation of human spatial behavior like route or modal choice.

There are, however, certain limitations. Hence, although there is evidence that pedestrians are willing to walk greater distances when walking conditions are good, so far, there is still not much insight into the effects that walkability can have on the actual accessibility of a location. Empirical research is certainly needed here. Although our model illustrates the relative differences in pedestrian accessibility of locations, the lack of empirical validation can be criticized. A possible approach would be to calibrate our model to observed or surveyed pedestrian behavior. In addition, better results can be expected when deploying a more complex walkability index, with its indicators being more numerous and individually weighted. Furthermore, the integration of a greater variety of pedestrian subgroups with different intentions and motivations as well as a greater variety of source locations and origins and destinations would further improve our model. Future research is needed to address these shortcomings.

Reference

- Agrawal, A. W., Schlossberg, M., & Irvin, K. (2008). How Far, by Which Route and Why? A Spatial Analysis of Pedestrian Preference. Journal of Urban Design, 13 (1), 81–98.
- Alayo, J. (2002). Pedestrian Accessibility and City Form. In AET, Association for European Transport (Ed.), Proceedings of the AET European Transport Conference. London: PTRC Education and Research Services LTD.
- Alfonso, M., Boarnet, M., Day, K., McMillan, T., & Anderson, C. L. (2008). The Relationship of Neighbourhood Built Environment Features and Walking. Journal of Urban Design, 13 (1), 29-51.
- Boarnet, M. G., Greenwald, M., & MacMillan, T. E. (2008). Walking, Urban Design, and Health Toward a Cost-Benefit Analysis Framework. Journal of Planning Education and Research, 27 (3), 341-358.
- Boesch, H. (1988). Der Fußgänger als Kunde Verkaufen bei veränderten Rahmenbedingungen. In: D. Kanzlerski (Ed.), Verkehrsberuhigung und Entwicklung von Handel und Gewerbe Materialien zur Diskussion (pp. 72-96). Bonn: Bundesanstalt für Straßenwesen (BASt).
- Cervero, R., & Kockelman, K. (1997). Travel Demand and the 3Ds: Density, Diversity, and Design. Transportation Research Part D 2, 2 (3), 199-219.
- Clark, S., & Davies, A. (2009). Identifying and Prioritising Walking Investment through the PERS audit tool [Text file]. http://www.walk21.com/papers/TfL%20TRL%20Walk21%20NYC%202009%20paper%20%20I dentifying%20and%20prioritizing%20walking%20investment%20through%20PERS%20audit% 20tool.pdf.
- Colclough, J. G., & Owens, E. (2010). Mapping Pedestrian Journey Times using a Network-based GIS Model. Journal of Maps, 6 (1), 230-239.
- Comerford, C. (2008). Pedestrian Environmental Quality Index (PEQI) [WWW Page]. http://www.sfphes.org/HIA_Tools_PEQI.htm.
- De Bourdeaudhuij, I., Sallis, J. F., & Saelens, B. E., (2005). Environmental Correlates of Physical Activity in a Sample of Belgian Adults. American Journal of Health Promotion,18 (1), 83-92.
- Ewing, R., Handy, S., Brownson, R. C., Clemente, O., & Winston, E. (2006). Identifying and Measuring Urban Design Qualities Related to Walkability. Journal of Physical Activity and Health, 3 (1), 223-240.
- Follmer, R., Gruschwitz, D., Jesske, B., & Quandt, S. (2010). Mobilitaet in Deutschland 2008: MiD 2008 Struktur, Aufkommen, Emissionen, Trends Ergebnisbericht. Berlin: Forschungsgesellschaft für Straßen- und Verkehrswesen (FGSV). Bundesanstalt für Straßenwesen 52, Bremerhaven: Wirtschaftsverl. NW.
- Forschungsgesellschaft für Straßen- und Verkehrswesen. (2002). Empfehlungen für Fußgängerverkehrsanlagen EFA 2002. Köln: FGSV-Verlag.
- Frank, L., Schmid, T. L., Sallis, J. F., Chapman, J., & Saelens, B. E. (2005). Linking Objectively Measured Physical Activity with Objectively Measured Urban Form. Findings from SMARTRAQ. American Journal of Preventive Medicine, 28 (2 Suppl. 2), 117-125.
- Gallagher, N. A., Gretebeck, K. A., Robinson, J. C., Torres, E. R., Murphy, S. L., & Martyn, K. K. (2010). Neighborhood Factors Relevant for Walking in Older, Urban, African American Adults. Journal of Aging and Physical Activity, 18 (1), 99-115.
- Heller, J., & Monheim, R. (2004). Die Augsburger Innenstadt im Bild von Verhalten und Einstellungen der Besucher und Bevolkerung. Leipzig und Bayreuth: Omniphon.
- Herzog, T. R., & Shier, R. L. (2000). Complexity, Age and Building Preference. Environment and Behavior, 32 (4), 557-575.
- Hidalgo, C. M., Berto, R., Galindo, M. P., & Getrevi, A. (2006). Identifying attractive and unattractive urban places: categories, restorativeness and aesthetic attributes. Medio Ambiente y Comportamiento Humano, 7 (2), 115-133.

- Huston, S. L., Evenson, K. R., Bor, P., & Gizlice, Z. (2003). Neighborhood Environment, Access to Places for Activity, and Leisure-time Physical Activity in a Diverse North Carolina Population. American Journal of Health Promotion,18 (1), 58-69.
- Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A., Hugo, G. (2007): Walkability of local communities: Using geographic information systems to objectively assess relevant environmental attributes. Health & Place, 13 (1), 111-122.
- Monheim, R., Raab, S. (2008): Parkstrategien und Aktionsräume von Parkhausnutzern in Innenstädten mit flächenhaftem Fußgängerbereich – Fallstudie Nurnberg. In: Handbuch der kommunalen Verkehrsplanung, 52, Heidelberg, 1-28.
- Park, S. (2008). Defining, Measuring, and Evaluating Path Walkability, and Testing Its Impacts on Transit Users' Mode Choice and Walking Distance to the Station. Berkeley: Dissertations, University of California Transportation Center, UC Berkeley.
- Rodrigue, J. P., Comtois, C., & Slack, B. (2009). The Geography of Transport Systems. (2nd ed.). New York: Routledge.
- Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental Correlates of Walking and Cycling: Findings From the Transportation, Urban Design, and Planning Literatures. Annals of behavioral medicine, 25 (2), 80-91.
- Taaffe, E. J., Gauthier, H. L., & O'Kelly, M. E. (1996). Geography of Transportation. New Jersey: Morton O'Kelly.
- Von Hagen, B., Wegener-Hüssen, A. (1994). Stadt Augsburg. Ensembles, Baudenkmäler, archäologische Denkmäler in Bayern. München: Karl M. Lipp Verlag.
- Walter, E., Cavegn, M., Scaramuzza, G., Niemann, S., & Allenbach, R. (2007). Fussverkehr-Unfallgeschehen, Risikofaktoren und Prävention. Bern: Bubenberg Druck- und Verlags-AG.
- Wibowo, S. S., & Olszewski, P. (2005). Using Equivalent Walking Distance to Assess Pedestrian Accessibility to Transit Stations in Singapore. Transportation Research Record: Journal of the Transportation Research Board, 2260, 38-45.
- Zielstra, D., & Hochmair, H. H. (2011). A Comparative Study of Pedestrian Accessibility to Transit Stations Using Free and Proprietary Network Data. Transit 2011, 2, 145-152.

FROM INTERNATIONAL EXPERIENCE TO FRENCH CASE STUDIES:

PORT-VERT, A FRENCH RESEARCH PROJECT INVESTIGATING VARIOUS POSSIBILITIES FOR BICYCLE-TRANSIT INTERMODALITY

Claude Soulas; Sylvie Abours; Francis Papon Université Paris-Est, IFSTTAR

Corresponding author:

Claude Soulas; claude.soulas@ifsttar.fr

Abstract

The PORT-VERT research project investigated bicycle-transit intermodality. After a review of the state of the art and an analysis of German best practices, the project explored technical and organizational aspects, socio-economic analysis and behavioural surveys, architectural aspects, ergonomics (such as on-board loading), and the involvement of multiple players. Finally, case studies in Marne-la-Vallée and Rouen were considered. The main results found that to develop bicycle-transit intermodal use, the entire transport chain must be improved: the bicycle and its use, public transport (networks, stations, rolling stock) and intermodal facilities and services such as bicycle parking near stations. There is no single solution; individual contexts and the potential for increase in use must be considered. An application study was carried out in Marne-la-Vallée for a Parisian suburban train station serving a large university which showed how estimated potential use varies with different hypotheses and different local or global supporting measures.

Keywords: bicycle; public transport; intermodality; multidisciplinary approach; best practices

General presentation

The PORT-VERT project

In 2007, the French National Research Programme PREDIT ("Programme national de REcherche et D'Innovation dans les Transports terrestres") launched a call for projects on the theme of bicycle use, including five sub-themes, among them complementarities between bicycle and public transport. In this framework, several partners¹ proposed a research project, called PORT-VERT, which was accepted in 2008:

- INRETS, the French National Institute for Transport and Safety Research (now IFSTTAR, the French institute of science and technology for transport, development and networks);

- CETE Normandie Centre, one of the seven technical centres for equipment, as part of the scientific and technical network of the French Ministry for transport;

- MOVIKEN, a small company specialised in the field of cartography;

- IFRESI Lille (now CLERSE), which is linked to CNRS, the French National Centre for Scientific Research.

Most of the participants have been working in fields other than the bicycle (a study topic which has been little developed until now, (Papon, 2002), so that it was necessary to form a wide group of partners, over 30 months.

Scope

On a theoretical point of view, the combination of bicycling and public transport is an efficient solution in order to serve large urban and suburban areas, and to reduce the need for private cars. On a practical point of view it is necessary to implement different measures simultaneously, so that an intermodal solution can become more attractive according to the context.

The following intermodality formulas should be considered:

- The parking of a bike at one or both ends of the public transport ride, using various parking contexts (with or without a warden, lockers, etc.);

- Bike rental at the main stations of the public transport network;

¹ In addition to the 3 authors the following people were involved in the project : F Héran (CLERSE-CNRS), C Richer (CETE Nord), V Stransky (IFSTTAR-LVMT), C Grange Faivre (IFSTTAR LESCOT), S Febvre and JC Poreau (CETE NC), JL Pottier (MOVIKEN)

- The use of bike fleets for public use (examples: Vélo'v in Lyon and Vélib in Paris), with stations covering the whole city, some of them being close to the public transport stations;

- The loading of a traditional bike, possible at selected time periods outside peak hours only;

- The loading of a folding bike with fewer limitations.

The potential of bike loading or public fleets (as regards intermodal use) is not as high as that of bicycle parking, but qualitative aspects (for specific uses) and synergy effects have to be taken into consideration.

Methodology

The methodology for this research consists of a three-step process:

• A review of the state of the art (current knowledge on bicycles and intermodality), analysis of international experience, (particularly "best practice" analysis in Germany);

- A multidisciplinary approach to bicycle-transit intermodality through:
 - Technical and organizational aspects,
 - -Socio-economic analysis and behavioural surveys,
 - Ergonomics (such as o-nboard loading),
 - Architectural aspects,
 - Involvement of multiple players;
- Case studies in two different contexts: Rouen and Marne-la-Vallée.

The methodology combines a multidisciplinary approach with expert knowledge of the geographical areas studied

State of the art and best practice analysis

General context of intermodality in France

Bicycle-transit intermodality is very much used in the Netherlands, where about 40% of commuters by regional train use bikes as a feeder service (Givoni, 2008). Other countries, such as Japan, are leaders in combining bicycle and public transport trip modes. In France, some local progress can be observed but there is a general lack of a global approach.

Planning engineers, in addition to researchers, most often give priority to car-transit intermodality, especially through park and ride facilities. This solution was neglected in the

past in France, but since 1990 some projects have been carried out (Margail, 1996). Park and ride facilities should not be the only type of intermodal facility, as its limitations include a large consumption of space and perverse effects on urban planning (Héran, 2003).

The state of the art of bicycle-transit intermodality in France was analyzed several years ago in a dissertation (Sebban, 2003). Among the various facilities which were implemented, it is worth mentioning the "Îlot vélo" in Neuilly Plaisance on the RER line A (200 bike and ride parking slots, 90 location bikes): while not the only bike station which was installed in France, this one is the result of a research project carried out with the help of the French National Programme PREDIT (Bérardo, 2001).

Bicycle-transit intermodality is rarely investigated by itself, although it is sometimes included in global approaches for interchange stations considering all feeder modes (Menerault *et al.* 2006).

A review of the state of the art

The review of the state of the art includes a synthesis of former knowledge in the field of bicycling and intermodality and results of research from the last fifteen years of the French National program PREDIT or other French and foreign studies. One major problem for bicycle-transit intermodality is the issue of bicycle theft. Former studies have explained in which conditions most bike thefts occur, and showed that theft probability can be significantly reduced if the bike is fastened to a rack with an anti-theft device characterized with a sufficient level of quality (lock in a U shape). This knowledge provided a basis to launch new investigations concerning more secure parking devices.²

Analysis of the German case, identification of "best practices"

Seen from France the German case is interesting for several reasons. First, bicycle-transit intermodality is until now much more developed there than in France, even if there have been some new implementations and efforts carried out over the last years. Second there are significant differences from "Land" to "Land", from agglomeration to agglomeration and from location to location. It means that from a strict technical point of view Holland could have been the best example, but it would have been less pedagogical, because there are

² According to former surveys 22 % of the stolen bicycles are not fastened, 32% of the stolen bicycles are not fastened at a fixed point, 95% of the anti-theft devices used on stolen bicycles are of a bad quality

huge differences with the cycling conditions in France. In France, the modal share of the bicycle is less than 3% in most of the cities (if we leave out Strasbourg); in the Netherlands it is about 30% in many cities. Germany is an intermediate case with an order of magnitude of 10%, but with significant variations between towns and areas considered.

In order to identify the "best practices", the investigations have relied on various means: document analysis (including recommendations), identification of implementations in several towns, and research projects.

Three types of documents can give useful information:

- Planning guides that take into account all feeder modes for the design of an interchange station and that show how the bicycle is considered among the other systems. An example is the environment-friendly station (Christ *et al* 1995);

- Specific documents focused on bicycle-transit intermodality. Two important documents are the so-called "book 50 / Direkt" (Fromberg *et al.* 1997) published by the transport ministry which includes many recommendations, and the material from the German public transport association VDV (Blöcher *et al.* 2002);

- General synthesis documents about cycling development show in which context intermodality can occur. For example the so-called "book 59" (Thiemann-Linden *et al.* 2004).

To better undertand the contexts under which bicycle-transit intermodality has been successful, investigations of bicycle-transit intermodality have occurred in seven significant German cities including Köln, Munich, Berlin, Dresden, Frankfurt, Karlsruhe, and Stuttgart... For example, from North-Rhine Westphalia we can retain the Bike and Ride concept studied already in 1995 in Köln (Rüdiger *et al.* 1995), as well as the implementation of bike stations (program "100 bike stations for North-Rhine Westphalia"). The Munich case study contributed a lot of information regarding bicycle-transit intermodality:

- The results of the MOBINET project (see later);

- The increasing trend in Bike and Ride slots (already 47,000 in 2005), which is now about twice the number of Park and Ride slots;

- The involvement of multiple players: the Committee "bicycle and public transport" contributes to bicycle-transit intermodality by gathering together several partners such as the Technical University, the public transport operators, the local authorities (City of Munich), and the car manufacturer BMW.

Concerning research projects, several aspects are worth mentioning:

- The first research project in 1995 subsidized by the Federal Ministry of Transport (Rüdiger *et al.* 1995) represents a basis for the development of bicycle-transit intermodality, with many results and recommendations;

- One of the tasks of the research project MOBINET (carried out in Munich between 1998 and 2003 as part of the big programme "Mobility in large conurbations") consisted in improvements to Bike and Ride facilities. A new covered bicycle parking station with automatic access was implemented in 2003 at a metro station. Some of the users of this facility are people who previously used to take their car to reach public transport (Mobinet 2003);

- The project "Development of an integrated concept for planning, communication and implementation of a sustainable multi-optional mobility culture" has been developed further with the example of biking and public transport in Frankfurt am Main (Deffner *et al.* 2006). It also included the Bike and Ride concept. The hypothesis is that sustainable mobility culture requires intelligent, multi-optional and intermodal systems. The addition of different measures is necessary, and communication measures have to be integrated with planning measures from the beginning, rather than being merely an add-on to fully developed mobility services and infrastructure;

- The recent project "Interdependencies of bicycle and public transport use" has been carried out by the Technical University of Dresden in a broader context: it is dealing with <u>multimodality</u> between biking and public transport, but also gives speaks to the specific theme of bicycle-transit <u>intermodality</u>.

Investigation of bike-transit intermodality by means of several approaches

Technical and organizational aspects

Technical aspects are not the most important ones, but should still not be neglected for the development of bike-transit intermodality, especially considering some technical evolutions for public transport, bikes and parking devices. Technical aspects are linked with organizational aspects.

Innovation for three domains

During the last years we can note a diversification for these three domains:

- Diversification of public transport systems with automatic mini-metros, modern tramways, interconnection trams, bus with high level of service, etc;

- Diversification of bike stocks: several concepts of public bike fleets, several types of electric bikes, several types of folding bikes;

- Diversification of parking devices.

Bicycle-transit intermodality can theoretically be applied to all types of public transport systems but some characteristics are favourable such as the level of service (frequency, regularity, commercial speed) and capacity in order to be able to attract a higher amount of passengers.

Public bike fleets have been studied in other projects which were either totally dedicated to this solution (OBIS (Büttner *et al.* 2011)) or partially (Transervelo (Boux de Cosson *et al.* 2008)), so that PORT-VERT did not focus too much on this solution. Although electric bicycles concern in most of the cases trips which are made from origin to destination by bike (without combining public transport), in some configurations they can enlarge the catchment area of intermodal bicycle-transit in terms of feeder distances and in terms of hilly itineraries. Therefore, the use of electric bikes is one element among many others that influences the evolution of parking devices.

There is a big variety of parking devices: stands (with or without shelters), bike stations, individual boxes, semi-collective parking, etc. Some attempts have been made to compare the different solutions by means of a multi-criteria analysis (with several criteria such as cost, space consumption, safety, efficiency, etc), but the utilization of this method is very difficult due to an increasing number of solutions with many variations and the hybridization of some of them.

In the framework of PORT-VERT, the bike parking facilities have been examined by means of different approaches:

- From a technical point of view: between the simple "base" solution (racks) and the multiservice bike stations (with hundreds of bikes) one can analyze the development of automatized solutions with different types of devices;

- A stated preference survey gives some results concerning the users' point of view, see §3.2.2 (Papon et al. 2011);

- The case studies include the basis of dimensioning, with different scenarios, see §4.3.

Organizational measures for bus networks

Until now, most of the best practices in term of bicycle-transit intermodality concern railguided transport (regional train, regional metros, urban metros, light rail, trams, etc). Therefore, a few investigations have been carried out in order to study the application of bicycle-transit intermodality to public transport networks where most of the lines are equipped with buses, a context which is more difficult than for rail-guided transport. The French public transport networks have been classified in five classes according to their characteristics; for each class, possible optimization of the network efficiency has been studied in relation to bicycle-transit intermodality. Recommendations have been made at a general level, as well as for the specific case of Rouen. An example of a measure which has been proposed concerns the hierarchical organization of the bus lines in terms of level of service.

Socio-economic aspects, surveys

General surveys

In countries with a high level of bicycle use, bicycle parking at railway stations represents a significant share of rail customers.

But in other countries, the intermodal use of the bicycle is not so frequent. In France, intermodal trips involving a bicycle part and a public transport part only represent 0.03% of all trips (French national travel survey 2007-2008). An intermodal trip by bicycle and public transport is mainly used for commuting to work or education, in addition to occasional recreational trips. Half of the trips are in the Paris region (where public transport supply is better). Nearly always, bicycling is combined with a rail-based mode, and rarely with a bus or a boat. The bicycle is often carried on board.

Some additional surveys were carried out for the project in Marne-La-Vallée and Rouen. Marne-La Vallée results will be discussed in section 4. In Rouen, the users of a 15 km interurban connection were surveyed to see which mode they used: car, train or bus. The analysis of their answers confirmed the importance of the public transport link quality on the

whole journey, which entails that the train is more suited than the bus. It also pointed out the importance of safe bicycle parking at stations to encourage bicycle transfer.

Stated preference survey

A stated preference survey was designed and implemented at regional railway stations to study cyclists' preferences for bicycle parking facilities in an attempt to promote the intermodal use of the bicycle. Results were analyzed with a cumulative logit model. The preferred feature is individual lockers. But, taking into account the results of technical and functional investigations, this parking type should only be recommended in specific cases and after a local cost benefit study. Not all cyclists are ready to pay for a better parking service. But according to this survey, qualitative comments, and expert knowledge, basic sheltered stands should be provided at all stations, with no fee, 24/7 opening and located less than 70 m from platforms.

Ergonomic aspects, synergy with PRM (Person with Reduced Mobility)

The objectives of the work presented here was to study the potential synergy between improvement in the public transport accessibility to PRM and the development of the use of bicycles in public transport. Until now much research has been carried out in France for PRM accessibility including disabled persons in wheelchairs (eg Heyrmann et al 2008); the objective here is to extend the analysis to the accessibility of passengers with bikes. The area of the study was located between the boarding area and the interior of the public transport vehicles. Existing solutions were reviewed, and a diagnosis was made describing several possible situations based on the contribution of different factors. This approach highlighted some potential synergy but also showed the conflicts which could arise from proposed solutions and the interrelation with other intermodality solutions. In particular, considerations of safety appeared to be a significant issue.

This approach concerns the journey by bicycle. While not as important a part of bicyletransit intermodality as bicycle parking, it is important on a qualitative point of view for some kinds of travel.

Architectural aspects, application to cycling routes

The relevance of an architectural approach is based on two ideas:

- The quality of a journey by bicycle plays a key role in promoting the use of this transport mode.

- Some cycling-friendly architectural elements concerning the routes can greatly increase this quality.

Consequently, improving the cycle routes to the station is likely to support the practice of Bike and Ride. First of all, it is necessary to make a diagnosis to identify the spatial problems impeding cycle journeys to be made in good conditions.

These good conditions can be described with five main criteria:

- Physical thrift, i.e. with the least efforts possible;

- Pleasant environment;

- Fluidity, i.e. without interruptions, without obstacles, without roundabout ways;

- Security and sense of security;

- Legibility, i.e. easily found destinations thanks to good signing.

What elements of the space have to be judged in this manner?

Four elements can be distinguished: a dimensional aspect; a geometric one, a topologic one and a non-formal one, depicting all aspects that are independent of the form (colour, light, etc.).

Each of these elements has to be appreciated in four types of spaces:

- real space;

- perceived space (what our eyes, hearing, and sense of smell indicate us),

- imagined space (that strongly depends on the individual),

- experienced space (the actual uses of the space are sometimes far away from the predicted ones).

Crossing the four elements with these four spaces we obtain 4×4 matrices that differ according to the spatial scale, from the regional one until the local one. According to the scale considered some cells of the matrix can be empty, which makes the problem somewhat easier.

Such an analysis grid at the relevant scale makes it possible to consider all elementary aspects of a space from different points of view. It is necessary to verify which of them meet the good conditions.

Based on this diagnosis, some recommendations can be made for a quality cycling network.

In addition to this architectural approach some investigations concerned the improvement of the design of feeder cycling routes. The most relevant criteria were selected to assess the actual quality of the entire road infrastructure from the cyclists' point of view (in terms of safety, safety feeling, comfort, etc.). Colours were chosen to express this *bikeability* on a five-level scale and used in an innovative tool. The interactive tool, tested on both areas studied in the PORT-VERT project (Rouen and Marne-la-Vallée), provides the cyclists with up-to-date information about the real conditions of cycling. It could contribute to an improvement in the modal split for bicycling within the area considered, in particular as a feeder mode to transit.

Involvement of multiple players

The success of intermodal bicycle-transit solutions depends largely on the involvement of multiple players. This is often a limiting factor in France, as identified in the case of Marnela-Vallée (see next paragraph) and also in other configurations. At a more general level, different strategies have been analysed. For example, intermodal bicycle-transit travel can be either a small appendix to an intermodal strategy mainly based on the private car (a few parking slots for bicycles are added inside a park and ride facility or near this facility) or can on the contrary be studied as a new mobility solution requiring the simultaneous implementation of different kinds of measures, with coherent planning.

The Case study of Marne-la-Vallée

The territory of Marne-la-Vallée represents an application of several approaches which have been discussed in section 3.

The context

Marne-la-Vallée is a new town in the eastern suburbs of Paris which was created in 1972 by regrouping 26 communities, among them Noisy-le-Grand and Champs-sur-Marne, where a high number of inhabitants are served by the RER (Réseau Express Régional = Rail Rapid Transit) line A. The station called Noisy-Champs warrants investigations for several reasons, as it is located in a place where cycling is only recently being developed:

- In the surroundings of the station, among other institutions, we can find the "Cité Descartes" with about 16 000 students, a group which is supposedly more cycling friendly than other groups; important to note is that this university is currently being expanded;

- The recent creation of the so-called "Pôle de compétitivité Advancity" has regrouped private companies and public research centres, including a part of IFSTTAR, under the theme of "town and sustainable mobility" (VMD: Ville et Mobilité Durable);

- Furthermore, due to the construction of a new ring of automated rapid transit with a stop at Noisy-Champs, an increase in the number of inhabitants is expected in the next decades which should induce increased travel demand. Part of the additional mobility forecast has likely to be satisfied by other modes than private car.

- The already mentioned "Îlot Vélo" bike sharing program is implemented in the surroundings, but concerns only one station, Neuilly-Plaisance, located a few kilometres from Noisy-Champs.

Several studies have been carried out in Marne-la-Vallée in different contexts. First, a synthesis of older studies (independent from PORT-VERT) has been made. Then, other inquiries have been achieved in relation with the PORT-VERT project: one of them a year before (as a preliminary investigation, see §4.2), the other after the official beginning of the project. In addition, cycling routes of a large part of Marne-la-Vallée were investigated by bicycle, in order to make a quality diagnosis, applying the methodology described in §3.3. The knowledge acquired in this way (concerning the structure of the neighbourhoods) helped to estimate a potential for the bike-transit intermodality at Noisy-Champs (see §4.3).

Qualitative study

A preliminary study was carried out in 2007 on the basis of a qualitative approach (Santana 2007). Intermodal users as well as car users were surveyed, by means of individual semidirected interviews, based on an interview guide including a list of soft questions. The interview duration was about one hour. It aimed to determine the pros and cons of bicycletransit intermodality, as seen by cyclists and car users. The results of this qualitative approach contributed to the preparation of the quantitative surveys described in 3.2. The final objective is to identify and investigate the factors that could hinder bicycle-transit intermodality or, on the contrary, favour it. From a qualitative point of view (as the result of analysing the responses of a few users), the importance of topics such as bicycle parking at a public transport station <u>and</u> at home, and the lack of cycling paths, was raised, but other questions have also been discussed. For example, some cyclists explain why they don't want to wear a helmet for this kind of urban trip, even if they are aware of the risk of accident (but they use a helmet when they are cycling for sport reasons). Financial aspect is a favourable argument sometimes used for cycling.

In the context of modal shift perspective (towards bicycle-transit intermodality) it is important to know how car drivers consider public transport as well as bicycling.

All the types of constraints have been analysed: material, social, temporal, or related to uncertainty (unexpected events). Among the constraints which deter car drivers to choose another solution, time appears often as a major factor, at least time as it is perceived; car drivers are not always aware of the exact travel time of the alternative solutions. On the other hand, the price of fuel did not appear as a significant factor to push car drivers to choose another solution (according to the persons interviewed during the first part of 2007). This was a general trend and was of course stronger in particular cases where car users did not pay the motor-fuel themselves. Much other knowledge has been noted: they are not considered as final results but as indications in order to prepare further investigations.

Estimation of a potential

Based on some spatial considerations (structures of the neighbourhoods, existence of cycle paths or not, direct cycling routes or numerous obstacles, existence of a closer station, etc.), expressed in terms of coefficients (P) of spatial pertinence (part of the population (aged 18-65) for which cycling to this station is a good solution), we estimated a potential of bicycle-transit intermodality for the Noisy-Champs station.

Due to the high number of students studying in an area of 2 km around the station (Cité Descartes), the need for Ride and Bike has to be considered.

The coefficients P1 and P2 relate to the possible practice of Bike and Ride at each entrance of the station, while the P3 relates to the possible practice of Ride and Bike at the entrance closest to the university.

Based on the general population census 2007, we obtain P1 = 0.41; P2 = 0.77; P3 = 0.58. Estimated potential of bicycle-transit intermodality at the Noisy-Champs station:

PORT-VERT, a French research project investigating various possibilities for bicycle-transit intermodality 57

Commune of departure or arrival	Number* of daily travellers	Potential of B + R	Potential of R + B
Noisy-le-Grand	8,370	× P1 × 80% = 2,746	× P1 × 20% = 686
Champs-sur-Marne	8,804	× P2 × 50% = 3,390	× P3 × 50% = 2,553
Gournay	244	× 80% = 195	× 20% = 49
Together		6,331	3,288

* RATP Inquiry, 2005

Low scenario: 5% of this potential is achieved.

B + R: 316 cyclists are likely to arrive and park the bicycle at the station, i.e. 1.7% of daily travellers.

R + B: 165 cyclists are likely to pick up a (private or hired) bicycle upon arrival at the station

In order to achieve this objective the following short term recommendations can be made: more bike stands at each entrance; *secured bike parking* on the side of the university; some ground kept for further enlargement needs.

Higher scenarios: 10 to 50% of the potential can be achieved if a long term and coherent bicycle-friendly policy is implemented. The following measures will be essential: better cycle routes to the station, signing, parking facilities for the bicycles at home, at work and at places of education, promoting campaigns, etc.

For all the scenarios, among the various options for bike-transit intermodality, the main solution is bicycle parking (combination of simple racks and more secure devices), with a relatively moderate percentage reserved for renting bicycles. Investigations carried out in this area showed that a public bike system is not relevant, due to the distribution of the traffic flows. The improvement of on-board loading is conceivable to a certain extent, but with measures which should be implemented at a larger scale than that of Marne-la-Vallée.

It is important to promote the shift from car-transit intermodality to Bike and Ride. There is a lot of free (no monetary cost to the user) Park and Ride spaces around the station, and illegal parking is also frequent. The intermodality with the bus is efficient only at peak hours. On the contrary, bicycle could be a relevant solution for a large range of people, trip purposes, and periods of the day.

In addition to this intermodal use, the car is also mainly used for direct journeys to the university, while more than one thousand students and teachers live at a distance of less than 4 km. Therefore, bicycle use can be promoted for direct journeys too, by means of a good cycling network and parking facilities. The reduction of car traffic (in terms of

circulation and parking) can increase the efficiency of measures in favour of bicycling, including intermodal use in combination with public transport.

Conclusions

The results of the PORT-VERT project show the complexity of applying a multidisciplinary approach to bicycling, a new form of mobility which requires several conditions to be simultaneously satisfied in order to succeed. Considering the very low modal split of current bicycle-transit intermodal travel in France, it is interesting to take into consideration different scenarios for the future as seen in the case of Marne-la-Vallée. Due to the complexity of the *actors game* (involvement of multiple players), this research project has been disconnected from operational projects, so that PORT-VERT does not establish detailed specifications for an implementation in the short term, but instead makes a list of recommendations at various levels.

Some recommendations are specifically dedicated to the cases of Marne-la-Vallée (at the East of Paris) and Rouen. At a more general level, the research led to the following conclusions. To increase bicycle-transit intermodal use (at present rather low on a national scale, although relatively significant in specific contexts, for example in some districts in combination with regional trains), the entire transport chain must be improved: the bicycle (spreading of E-bikes could help feeder practice over long distances and/or steep ascents) and its use, public transport (networks, stations, rolling stock) and intermodal facilities and services (varied bicycle parking solutions near stations, short and long term bicycle rental, on-board loading of standard bikes with time restrictions, or folding ones, without any). There is no single solution; individual contexts and potential for increasing cycling use must be considered. In any case, the improvement and monitoring of feeder cycling routes are an absolute necessity. Individual transport authorities should organize bike-transit intermodality in their areas to improve policy cohesion for all the players.

References

- Soulas C et al. (2011), Projet PREDIT PORT-VERT. Plusieurs Options de Rabattement ou Transfert Vélo et Réseaux de Transport. Approche multi-aspect des diverses formules d'intermodalité. Rapport final Prédit. Mars 2011. 712 p+annexes.
- Papon F et al. (2011), Intermodal Bicycle Parking Facilities: A Stated Preference Survey, TRB 90th annual meeting. Revised version. 14 p
- Büttner J, Mlasowsky H et al, (2011), Handbook OBIS, Optimising Bike Sharing in European Cities, European project

Heyrmann E, Marin-Lamellet C, Soulas C, Alauzet A (2008), Which factors limit or favour the implementation of the policy for accessible collective transport ? First elements from a comparative analysis between Lyon and Stuttgart policies, European Transport Conference, Noordwijkerhout, Pays Bas

- Zorn E (2008), Integrated Promotion of Bike-and-Ride Facilities in Munich and its surroundings, Proceedings Interdependency of bicycle traffic and public transport. Technische Universität Dresden
- Givoni M, Rietveld P (2008), Bicycle parking facilities at railway station, is it worth investing in ? Proceedings Interdependency of bicycle traffic and public transport. Technische Universität Dresden

Boux de Cosson F, Floissac L, Legrand R (2008) « TRANSERVELO – Les services vélo en faveur de l'intermodalité avec les transports en commun », Rapport du projet PREDIT, novembre 2008

- Böhmer T, Pitrone A (2008), First results from the research project : "Interdependancy of Bicycle and Public Transport". Proceedings Interdependency of bicycle traffic and public transport. Technische Universität Dresden
- Soulas C (2008), Intermodality between Bicycle and Urban Public Transport: some research questions (in the French context) Proceedings Interdependency of bicycle traffic and public transport. Technische Universität Dresden
- Martens K (2007), Promoting Bike-and-Ride: The Dutch Experience, Transportation Research, Vol. 41, Issue 4 (www.elsevier.com/locate/tra), May 2007, pp. 326-338.
- Santana D (2007), La mobilité des cyclistes et des automobilistes à Noisy-Champs : une analyse stratégique des freins et des motivations au changement modal, Université René Descartes-Paris 5, Paris
- Ville de Munich (2007), Beschluss der Vollversammlung des Stadrates vom 24 01 2007
- Marin Lamellet C et al. (2006), Entre demande sociétale, volonté politique, contraintes techniques et culture locale, la mise en accessibilité des réseaux de transports collectifs de Lyon et Stuttgart, Rapport PREDIT G010, INRETS, Arcueil
- Menerault et al. (2006), Les pôles d'échange en France, Etat des connaissances, enjeux et outils d'analyse, Edition CERTU, Lyon
- Deffner et al. (2006), Entwicklung eines integrierten Konzepts der Planung, Kommunikation und Implementierung einer nachhaltigen, multioptionalen Mobiltätsstruktur, ISOE, Frankfurt am Main
- Thieman-Linden J et al. (2004), Fahrradverkehr, Erfahrungen und Beispiele aus dem In-und Ausland, Heft 59, Direkt, Bundesministerium für Verkehr, Bonn
- Héran F (2003), Les effets pervers des parcs relais, Vélocité n°70, FUBicy p72-74, Strasbourg
- Sebban AC (2003), La complémentarité entre vélo et transport public, Thèse de Doctorat sous la direction du prof. A Motte, Université Aix Marseille III, Marseille
- Soulas C, Papon F (2003), Les conditions d'une mobilité alternative à l'automobile, Réalités industrielles nov. 2003, numéro spécial «La civilisation automobile face au défi du développement durable », Annales des Mines, p 84-93, Paris
- Mobinet (2003), Abschlussbericht / 5 Jahre Mobilitätsforschung im Ballungsraum München, Landeshauptstadt, München
- Blöcher P et al. (2002), Positionierung des VDV zur Frage ÖNPV und Fahrrad, VDV Mitteilungen, Köln
- Papon F (2002), La marche et le vélo : quels bilans économiques pour l'individu et la collectivité, Transports, N°412, p84-94, Paris
- Bérardo, JC (2001), RATP : un prototype de « Vélopôle », dossiers PREDIT « l'innovation au service des déplacements urbains », p24-25, édition CERTU, Lyon
- Héran F (2000), Transports en milieu urbain : les effets externes négligés, La Documentation Française / PREDIT
- Fromberg A et al. (1997), Fahrrad und ÖPNV / Bike and Ride, Empfehlungen zur Attraktivitätssteigerung des Fahrradeinsatzes für Zu- und Abbringerfahrten sowie Fahrradmitnahme im ÖNPV, Heft 50, Direkt, Bundesministerium für Verkehr, Bonn
- Margail F (1996), Les parcs relais, outils clés de politiques intermodales de déplacement, Thèse de doctorat sous la direction de G Dupuy, Paris X Nanterre Université, Paris
- Gwiasda P, Fromberg A et al. (1996), Attraktivitätssteigerung des Fahrradeinsatzes für Zu- und Abbringerfahrten zum ÖNPV, Forschugsvorhaben FE 77 384/94, Planungsbüro VIAeG, Köln
- Christ W, Boczeck B et al (1995), Planungshandbuch Umweltbahnhof Rheinland Pfalz, p 79-82, Mediastadt / Öko-Institut, Mainz, Darmstadt and Freiburg

PART II

PRO-ACTIVE DEVELOPMENT OF TRANSPORT SUPPLY

Aud Tennøy,

Institute of Transport Economics, Norwegian Centre of Transport Research

Corresponding author:

Aud Tennøy; ate@toi.no

Abstract

Land use and transport-systems are continuously being developed in ways that cause growth in traffic volumes. In order to be able to change this situation, it is necessary to know what causes it. Instead of studying politicians, the public, or the planning system, the question asked in this paper is *how and why planners make plans which, if implemented, cause growth in traffic volumes.* The explanatory factors studied are the expert knowledge, the planners and the plan-making processes. It was found that even if the expert knowledge is good enough to guide planners aiming at making traffic-reducing plans, it needs to be improved with respect to accessible and applicable descriptions of theoretical and empirical knowledge, as well as of methods. Further, the planners need to be more knowledgeable if the current situation is to be changed. Regarding the plan-making processes, the planners need to ensure that this objective is clearly stated in overall plans and emphasised in operational plans, that the politicians are made aware of traffic-increasing consequences of proposed projects and given alternative options, and that faulty and biased assessments and analyses are disclosed. There is large room for improvement for planners and for planning researchers.

Keywords: Land use and transport planning; reducing traffic volumes; expert knowledge; planners; plan-making processes

Introduction

According to IPCC (2007), GHG emissions need to be reduced by 50 to 80% by 2050 to avoid dramatic and irreversible climate changes. Transport is a large and growing source of GHG emissions, making reduction of GHG emissions from urban road transport an important issue in urban planning. In 2004, the transport sector was responsible for 23 % of energy-related CO₂ emissions worldwide (Kahn Ribeiro et al. 2007). Over the past decade, GHG emissions from the transport sector have increased at a faster rate than any other energy using sector (*ibid*). CO₂-emissions from road transport counted for 19 % of the GHG emissions in the EU in 2007 (European Environment Agency (EEA) 2010). While total GHG

emissions decreased, emissions from transport³ grew by 28 % from 1990 to 2007, and transport is described as the most problematic emitting sector (Eurostat 2007, EEA 2010).

Transport demand and traffic volumes hence need to be reduced in order to reduce GHG emissions and global warming. There are also numerous other arguments for reducing traffic volumes, such as to reduce negative local impacts on health and environment, congestion, and public spending, improve traffic safety and living conditions in cities, and more. Despite long standing objectives to curb the growth especially in *urban* traffic volumes, knowledge of how to achieve this, and public control of the most important means, urban land use and transport-systems are continuously planned and developed in ways which cause growth in road traffic demand and traffic volumes (see e.g. European Environmental Agency (EEA) 2001, 2006, Furu 2010). This is not a sustainable development (WCED 1987), understood as a development that is just in an intra- and inter-generational perspective (Parfit ([1984] 1987).

In order to be able to change this situation, it is necessary to know what causes it. There are several entry points for discussing this. The focus in this paper is mainly on planners making zoning plans under the (Norwegian) Planning and Building Act (PBA).

The intention is to contribute to answer the following questions: *How and why are planners making plans which, if implemented, cause growth in traffic volumes? What should be done in order to change this?*

Important explanatory factors are assumed to be properties of the *expert knowledge* regarding interrelations between developments of land use, transport-systems, travel behaviour and traffic volumes, properties of the *planners* and of how they relate to this expert knowledge, and properties of the *plan-making processes*.

Many are involved, but planners make the plans

Planning systems are often hierarchically organised, with PBAs clearly defining roles and processes. Plans at higher levels are supposed to function as steering frames for plans at lower levels. Planning processes governed by the PBA are, however, often not as tidy and clear as the hierarchical and defined systems may indicate. Rather, all political and administrative levels are involved, several policy areas and sectors as well as the private

³ Except international aviation and marine transport.

sector are more or less active and overlapping, and the general public is supposed to participate.

The main actors involved may be defined and grouped as:

- Private and public developers and initiators of zoning plans for developments of land use and transport-systems
- Planning authorities
- Authorities entitled to comment on plans (neighbouring municipalities, national and county public agencies, neighbours, NGOs⁴)
- Political bodies at various levels
- The public

Planners work for all these actors. The actors involved in a plan-making process may have real and fundamental conflicts of interests, values and objectives, different kinds of knowledge and understanding, and different kinds of power. The planning processes can be understood as arenas for handling such conflicts and making decisions. Some actors will gain and some actors lose, no matter which decision is made (Flyvbjerg 1991, Healey 2009). One may hence not necessarily expect planning processes to arrive at consensus or agreements.

Even though many interact in the planning processes, it is mainly the planners (working for various actors) who do the actual *plan-making*. *Plan-making* is here understood as the parts of a planning process where the plan is actually made: where the problem is set, where alternatives are considered, developed, assessed and compared, and where analyses, recommendations and plans are produced.

This work is mainly undertaken by planners and others professionally involved in the planmaking process. They hence strongly affect the proceedings and outcomes of the processes. The planners' employers as well as other actors may be understood as to interact in the *plan-making* processes mainly *through* the planners, as illustrated in figure 1.

⁴ Non-Governmental Organisations



Figure 1: Focus on planners, working for various actors, making plans within the frames of the PBA, the planning system and other institutional and organisational factors.

Theoretical approach, methodology and data

In her doctoral thesis, Tennøy (2012) developed explanations concerning how and why planners make plans that, if implemented, cause growth in traffic volumes (traffic-increasing plans for short). The explanations were developed within a critical realism approach (Bhaskar ([1975] 2008, Danermark et al. [1997] 2002). 'Classical planning theory' was the main planning theory applied, together with theory of power, knowledge and framing.

The explanatory factors (expert knowledge, planners, plan-making processes) were explored in abstract analyses, disclosing potential causal powers, the main mechanisms through which they may work, and the contingent conditions triggering the mechanisms and allowing the powers to work through them and cause planners making traffic-increasing plans.

These explanations were examined in and further developed with the help of empirical studies; a survey among planners working with land use and transport planning, for private and public employers, in the three largest cities in Norway (82 respondents) and two interview studies among planners (12 semi-structured interviews with land use and transport planners working for various employers in the Oslo-area in the first study and with 22 planners involved in zoning plan- processes for land use development and development of transport systems in the second), as well as a case study of four plan-making processes. Sources of data for the case study were planning documents and interviews with planners directly involved in the plan-making processes.

In the final analysis, more transfactual explanations were developed regarding how and why planners make traffic-increasing plans.

In this paper, a summarised version of the explanations developed in the thesis is presented, followed by a summary of the findings regarding how they manifested themselves in four cases. Based on this, recommendations are presented regarding 'what should be done' in order to make planners and planning researchers contribute to traffic-increasing plans being stopped more often, and traffic-reducing alternatives and plans being developed.

Explanations of how and why planners make traffic-increasing plans

Causal powers, mechanisms and conditions

Tennøy (2012) found that the main *causal power* why a traffic-increasing plan under the PBA is made is that somebody wants or needs to carry out a project which - as a side effect - causes growth in traffic volumes, and initiates a planning process in order to be allowed to do so.

In the following plan-making process, involving several planners working for different actors, a number of *mechanisms* may or may not be activated that may cause that a trafficincreasing plan is made:

- The objective 'reducing traffic volumes' is not introduced
- The objective is ousted by other objectives
- The expert knowledge in question is not introduced
- The expert knowledge is ousted by other kinds of knowledge
- The expert knowledge is applied wrongly

Whether and how these mechanisms are activated, and whether they are counteracted by other mechanisms or allowed to produce traffic-increasing plans, depend on a number of *contingent conditions*. The three explanatory factors studied here - properties of the expert knowledge, the planners and the plan-making processes - were found to be important conditions. They influence whether the mechanisms are activated, and whether they are counteracted or reinforced, and hence whether traffic-increasing or traffic-reducing plans are made.

Properties of the expert knowledge

Different kinds of knowledge are necessary in order for planners to make plans which are supposed to take developments of land use and transport systems in traffic-reducing directions (Rydin 2007). This includes among others: *theoretical knowledge* concerning the interrelations between development of land use, transport systems, travel behaviour and traffic volumes; *empirical knowledge* regarding the strength of these interrelations in various contexts, and; methods *for applying this knowledge*. These kinds of knowledge are termed *'expert knowledge'* in this paper. In all plan-making, several kinds of contextual knowledge are an absolute requisite, as well as *knowledge about the project or objective* the planning process is about. Planners need these kinds of knowledge in order to produce and assess analyses and plans, and to explain them to decision-makers, the public and others (Næss 2004). Planners also need process knowledge and knowledge of legislation etc. The latter kinds of knowledge are not discussed in this paper.

The state-of-the-art theoretical and empirical knowledge in this field appreciate that developments of land use, transports-systems, travel behaviour, and traffic volumes are causally interrelated and reciprocally interdependent. The system is complex, open, dynamic and iterative (Jacobs 1961, Byrne 2003, Tennøy 2009).



Figure 2: Land use, transport-systems, travel behaviour and traffic volumes are causally and reciprocally interrelate (Tennøy 2012).

The normative recommendations for traffic-reducing land use and transport development are often summed up and simplified as (see e.g. Downs 1962, Newman and Kenworthy

1989, Strømmen 2001, Owens 1987, Næss 1997, Cairns et al. 1998, Banister 2005, Næss 2006, Litman 2009, Hull 2011) to:

- impose or encourage land use development as densification rather than sprawl and as
 'car-independent' location of activities
- impose physical and fiscal restrictions on road traffic
- improve public transport services
- improve conditions for walking and bicycling

The most relevant properties of *the expert knowledge*, contributing to planners making traffic-increasing plans, were found in shortcomings of the knowledge:

- Lack of descriptions of theoretical and empirical knowledge that are accessible for planners and applicable in concrete plan-making processes
- Insufficient empirical knowledge: lacking knowledge, poor assembling and analyses of existing data, poor access to existing knowledge
- Lack of description of and possibly under-development of the method 'professional reasoning'

'Professional reasoning' refers to the method often used for planning analyses. The planner reasons, on the basis of her professional knowledge, the context, and the problem or project at hand, what are the most relevant alternatives, which kinds of effects and consequences each may cause, the strengths of the effects and their consequences. Calculations and model analyses may be parts of the reasoning.

The listed shortcomings may cause that the planners are left without good tools for making traffic-reducing plans, and for detecting, assessing and confronting traffic-increasing plans. These shortcomings make the knowledge and the analyses less transparent and understandable, contributing to that fewer understand them as valid and relevant. This can make it easier to oust this expert knowledge from the plan-making processes. This is not so in complex cases and when confronted with competing and simplified knowledge (see e.g Tennøy 2010).

Properties of the planners

The definition of *'planners'* here includes trained planners who are professionally involved in the making of plans that affect developments of land use and/or transport-systems. They work for all the main actors involved in planning processes.

Tennøy (2012) found that properties of each planner's discipline, paradigm, skilfulness and role affect whether she:

- possesses the expert knowledge in question
- finds the expert knowledge in question relevant and valid for the problem at hand
- possesses and rely on other kinds of expert knowledge that they rather want to apply
- is capable and skilful enough to apply the expert knowledge correctly
- agrees to apply this expert knowledge in the particular plan-making process

How each planner relates to the expert knowledge in question strongly affects whether they can and will contribute to making traffic-increasing or rather traffic-reducing plans. This affects whether the mechanisms above are activated, and whether they are counteracted by other mechanisms. Since plan-making processes normally involve several planners with different properties, they often also relate differently to the expert knowledge in question.

Properties of the plan-making processes

Properties of the objectives, knowledge and power of the planners involved reciprocally affect each other, and strongly affect how the planners act and how the plan-making process is carried out. This affects what become the main objectives in a plan-making process and which expert knowledge is applied, and hence which kind of plan is produced, as illustrated in figure 3.



Figure 3: The objectives, knowledge and power of the planners involved define whether the plans do or do not contribute to growth in urban road traffic volumes.
Mechanisms may be activated within different tasks in the plan-making

Plan-making processes are iterative, and they may be understood as continuous struggles regarding which objectives are more prominent and which knowledge should be applied. They involve a number of necessary tasks, which are based on Friedmann (1987) and Banfield, among others ([1959] 1973). The struggles may take place in all the tasks.

- 1. Situation analysis and problem definition
- 2. Formulation of goals and objectives
- 3. Identification and design of alternatives
- Identification, prediction and assessments of impacts and consequences for each alternative (impact assessment)
- Comparison of alternatives with respect to consequences in relation to desired objectives and other values
- 6. Recommendations (planning proposals)
- 7. Decision about action, based on knowledge produced

Figure 4: Tasks involved in planning and decision-making.

These tasks are different, and often involve different people. If the objective and expert knowledge in question have been made prominent in one task, they can still be ousted in other tasks. Since the plan-making processes often are iterative, there are many chances for ousting the objective and the knowledge before arriving at the final plan and recommendations. It was hence also mapped in which of the tasks in the plan-making processes the generative mechanisms were activated.

Actions and reactions

When planners make plans which, if implemented, cause growth in traffic volumes, this may be explained in terms of how planners working for different actors *act and react* in a planmaking process. This regards whether and how they apply their objectives, knowledge and power. See Tennøy (2012) for a thorough description and discussion.

The planners working for the municipal authorities may or may not:

 have produced a strong, clear and agreed upon overall municipal plan steering development of land use and transport-systems in traffic-reducing directions

Initiators of plans that conflict with overall plans may comply with the plan, or they may:

- pretend to comply with the plan, or
- oppose the plan

...by playing on and applying objectives, knowledge and power in many and diverse ways. This may among others include to: present the project as something else than it is; apply biased data; produce faulty analyses; interpret objectives differently than intended; introduce competing objectives; use their power to force their will through; etc.

If initiators oppose the plan or *pretend to* comply with the plan, the planning authorities may or may not respond by:

- pointing out conflicting objectives
- assessing and challenging the analyses etc. produced by the initiators
- preparing alternative solutions and analyses
- recommending that the plan is rejected

Other authorities and other bodies have, according to the Norwegian PBA large responsibilities, and may:

 deliver statements or formal complaints in planning processes, drawing attention to consequences, alternatives etc. that are not adequately handled in the analyses and plan

If an initiator is proposing a traffic-increasing plan, and if the planning authorities and other authorities fail to point out the conflicts of objectives, to require that the objective 'reducing traffic volumes' is included in the considerations, that traffic-reducing alternatives are included, that the alternatives are assessed and compared with respect to traffic volumes, and that the consequences with respect to traffic volumes are presented to the decisionmakers in clear and understandable ways, then the chances are high that a trafficincreasing plan is made.

Findings from studies of four cases

Tennøy (2012) examined the findings from the abstract analyses in studies of four concrete zoning plan processes resulting in traffic-increasing plans. Three are briefly presented here. One is left out because of text length limitations.

The focus in these descriptions are mainly on which *mechanisms* were activated in each case and on which *conditions* embedded in the properties of the expert knowledge, the

planners and the plan-making processes which triggered the mechanisms and allowed that the planners made a traffic-increasing plan.

Car-based housing developments in Skedsmo

How the traffic-increasing plans were made - the main mechanisms

In three zoning plans, various initiators proposed housing developments in car-based locations in Skedsmo. Despite overall plans and strategies stating that 'the majority' of new developments should take place as densification in central areas, the car-based locations of the new developments were never discussed in the planning processes.

The generative mechanisms activated in all three processes were hence that neither the objective 'reducing traffic volumes', the deduced 'to develop housing in car-independent locations', nor the expert knowledge in question were introduced in the plan-making process. This happened in the tasks; 'situation analysis' and 'definition of objectives'.

The main conditions allowing the traffic-increasing plans to be made

It was found that the *conditions* allowing this were embedded in all three explanatory factors. Regarding the plan-making process, the objective was not formulated very strongly in the municipal plan. There was no focus on this at the planning authorities. Rather, according to the interviewees, allowing housing (and other) developments in almost any location was the established practice.

None of the regional authorities exerted their power to point out that the car-based locations were not in accordance with municipal, regional and national steering documents.

The case-handler was not specialised in overall land use and transport planning, and she knew no accessible and applicable presentation of this expert knowledge she could have turned to.

The recently completed municipal plan process may cause substantial changes. It puts more emphasis on the objective 'reducing traffic volumes'. Further, it offers more accessible and applicable knowledge, since it describes and substantiates the interrelations between developments of land use, transport-systems and traffic volumes in a local context. This may allow the planners at the planning authorities to detect that plans conflict with this objective, to develop or call for traffic-reducing alternatives, to question assessments and analyses, and to produce argumentation for rejecting traffic-increasing proposals.

Large shopping centre at Økern

Main mechanisms

The initiators proposed a 160.000 m² zoning plans for a mixed land use project including a 60.000 m² shopping centre at Økern, about four km from the city centre of Oslo. This is not in accordance with the overall and binding sector plan for retail and services in Oslo, which does not allow shopping centres of this size. The strategy is to develop more and smaller centres rather than few and larger ones, in order to ensure short distances and good access for all to necessary retail and services, and to minimise the demand for and use of private car on journeys related to such activities.

This was clarified by the planning authorities and the regional authorities from the start, and the planning authorities eventually proposed a second alternative with a 25.000 m² shopping centre as part of the 160.000 m² project. Regional authorities warned from the start that they would file formal complaints if the large shopping centre was included in the final proposal.

Because of the conditions with respect to a strong overall plan, knowledgeable planning authorities, and public authorities who made it clear that they would exert their power, the initiators needed to oust either the objective or the expert knowledge which the overall plan was founded on in order to be able to get their plan approved.

They did so by twisting the objectives as well as the knowledge in various ways. They made biased, faulty, confusing and nontransparent analyses of the consequences of their proposal with respect to traffic, transport volumes and existing retail structure (this is all well documented in Tennøy 2012). They presented their findings as if their proposal was far more in accordance with the overall plans than the analyses actually showed. They presented objectives concerning 'to make something good happen here fast' as competing to the objectives in the overall plan, and they threatened that the whole project would be shelved if they could not build the large shopping centre.

This was going on in all the tasks in the plan-making process, since the authorities brought the objective and the expert knowledge back into the discussions in each task.

In the planning proposal presented for the City Council, the planning authorities explained that the initiators' proposal would have severe negative consequences with respect to important objectives in overall plans. The regional authorities filed formal complaints. The City Council did, however, adopt the plan.

Main conditions

Relevant conditions how and why a traffic-increasing alternative was produced were embedded in the properties of all three explanatory factors. Regarding properties of the *expert knowledge*, it was found that the complexity of the case matter, and hence of the expert knowledge, made it hard for the decision-makers to understand what was valid knowledge. This was probably reinforced by the lack of accessible, applicable and referable descriptions of this knowledge, lack of formally approved and agreed methods for applying the knowledge in such cases, and shortcomings of the empirical knowledge. The latter meant that one could not present empirical data for consequences of this kind of location and size of shopping centres. Together this allowed the initiators to twist their analyses and to cause confusion.

Conditions relating to properties of the *planners* involved mattered as well. The role of the planners working for the initiators probably was a main reason why they acted as they did. None of the initiators' planners were educated as land use and transport planners or had expertise in this topic. Some were applying other and less helpful knowledge with respect to assessment of consequences for traffic and on existing retail structure in various time perspectives. Only few of the planners from the public authorities had special expertise in land use and transport planning.

Regarding the *plan-making process*, the existence of a seemingly competing *objective* (make something good happen here fast) was an important condition how and why the initiators could win through to the politicians, despite the strong and clear municipal sector plan.

All actors exerted their *power* strongly in order to achieve their (employers') objectives. The initiators exerted their power to define the alternative, to make the assessments, to do lobbying, to bring in tempting extra benefits, and more. The public authorities exerted all their power. They filed a second alternative, pointed out faults in the initiators assessments, filed formal complaints, etc.

The intertwined conditions allowed the initiators to present their case in ways that allowed the City Council to disregard their own overall plan, recommendations from the planning authorities as well as formal complaints from two regional authorities. The municipal politicians adopted the initiators' proposal. Because the regional authorities exerted their power to file formal complaints, the plan was sent to the Ministry of Environment for final decision. The Ministry decided in 2013 on allowing the developers to build a 45.000 m² shopping centre, but reduced the maximum number of parking spaces substantially.

Increase road capacity on the urban motorway E 18

Main mechanisms

E 18 west of Oslo has five to six lanes, carries about 90.000 cars per day, is congested in long rush periods and causes noise and local pollution for those living nearby. The discussions concerning how to solve the traffic and environment problems related to the road have been going on for more than 15 years. In 2009, the Norwegian Public Roads Administration (NPRA) initiated a new planning process. It has so far only come up with alternatives involving to build tunnels and expand road capacity. Increased road capacity in pressured transport systems causes increased road traffic volumes (Downs 1962, Litman 2009). The hope is that high toll roads will be introduced when the road is built and keep the growth in traffic volumes down. Few of the planners interviewed believe that high enough tolls will be implemented.

The objective and the expert knowledge in question were introduced to the plan-making process by governmental, regional and local authorities. They were, however, both ousted in the tasks 'alternative generation' and 'impact assessments'. These are the generative mechanisms causing that traffic-reducing alternatives in reality never were introduced, assessed or compared to the traffic-increasing road expansion alternatives in this case.

Main conditions

The main objectives of the primary actors (NPRA and Bærum municipality) were to reduce GHG emissions from road traffic, reduce local environment problems and ensure sufficient transport quality for all users. This could have been approached by defining 'reduction of traffic volumes' as a main objective, and developing a plan based on the expert knowledge in question. This could have been a solution that contributed to achieving all the objectives.

Instead, the two latter objectives became competing objectives to reducing traffic volumes, while the first was given up on. The municipal politicians and authorities focused on local environment improvements through building tunnels. NPRA argued that long tunnels require increased road capacity in order to ensure safety and transport quality.

Several conditions contributed to this. One was that almost none of the interviewed planners really believed in that traffic volumes *could* be reduced. A main condition causing

or allowing *this* understanding was that nobody tried to or was able to come up with a traffic-reducing alternative.

This has much to do with conditions related to properties of the planners involved and of the expert knowledge in question. None of the planners involved were well enough educated or trained in co-ordinated land use and transport planning to be able to develop a traffic-reducing alternative based on the expert knowledge in question (or so it seems). This may be conditioned by – or at least it is reinforced by – the lack of accessible and applicable descriptions of the expert knowledge in question and methods for applying it in complex planning situations like this. The previously mentioned shortcomings with respect to empirical knowledge add to this.

Instead of applying the expert knowledge in question, transport models were applied. As it turned out, only traffic increasing (capacity increasing) alternatives were assessed. Only a few of the main traffic reducing measures were included in the calculations, since the models were not sensitive to or able to handle most of the relevant measures. Hence, the model analyses concluded that reducing traffic volumes is not a relevant or possible option.

In the still on-going plan-making process, only alternatives including increased road capacity and long tunnels are considered. This will, according to the expert knowledge in question as well as the model calculations, cause growth in traffic volumes on this road and in the entire region. The plan is to discuss measures that contribute to reduce traffic volumes after the zoning plan for the road is made and adopted.

Explaining how and why planners make traffic-increasing plans

Findings from the cases

As assumed in the abstract analyses, it was found in the four concrete cases that the main *causal power* how and why a traffic increasing plan is made is that a developer for some reason (not discussed here) initiates a zoning plan process in order to be allowed to carry out a project which, as a side-effect, is traffic-increasing.

All the five *mechanisms* described in the abstract analyses were identified as a generative mechanism in at least one of the four cases. In three of the cases more than one mechanism were activated and contributed to a traffic-increasing plan being made. In two cases (Økern, E 18), counteracting mechanisms pulling in direction of rejecting the traffic-increasing plans were activated too.

Mechanisms were activated in all the different *tasks* of the planning processes, demonstrating that the objective and the knowledge in question can be ousted throughout the plan-making process.

Properties of all three explanatory factors (the expert knowledge, the planners, the planmaking processes) were identified as *conditions* contributing to and/or allowing that the mechanisms were activated and that traffic increasing plans were made in more than one case. In all cases, more than one condition was found to be relevant and important. Properties of the planners, and of the objectives in the plan-making processes, were found to have contributed to that traffic increasing plans were made in all the cases. A main finding is that the conditions discussed are reciprocally interrelated.

One may hence expect tendencies towards traffic-increasing plans being made in planmaking processes where the expert knowledge is weak with respect to the particular issue at hand, and where none or few of the planners involved are experts of overall land use and transport planning for reduced traffic volumes. The same is the case if reducing traffic volumes is not a clearly stated objective in overall plans or not made prominent in the planmaking process, if the expert knowledge is not applied or applied in-correctly, and if those exerting their power most strongly are not aiming at arriving at a traffic-reducing plan.

Explanation

Hence, the explanations how and why planners make traffic-increasing plans are complex, as expected. It may be formulated as follows.

Because of needs or desires of the initiator, a zoning plan for an (un-intended) trafficincreasing project is proposed.

Because of conditions related to the expert knowledge, the planners and the plan-making processes, the planning authorities and others may or may not detect the traffic-increasing potential of the proposal as conflicting with the objective 'reducing traffic volumes', they may or may not apply the expert knowledge in order to clarify this potential for the decisions-makers and they may or may not oppose the plan in various ways.

If *nobody* points out and describes the traffic-increasing potential of the plan, the decisionmakers may not appreciate its traffic-increasing potential. Hence, they may adopt a plan which contributes to growth in transport demand and traffic volumes without being aware of this being a consequence. If *somebody* points out the traffic-increasing potential, the decision-makers may reject it, call for changes or alternatives, or adopt the proposal anyhow.

This demonstrates that planners and planning researchers have important roles to play if land use and transport-systems are to be developed in directions causing reduction rather than growth in transport demand and traffic volumes. We need to improve the expert knowledge in several respects, and we need to change how we act in plan-making processes. We cannot expect anybody else to come up with knowledge and solutions, or to make the necessary changes.

What, if anything, should we do about it?

Inspired by Flyvbjerg (2004), a main aspiration for this work was to figure out what planners and planning researchers can do, *within existing frames,* to contribute to traffic-reducing plans being produced rather than traffic-increasing plans.

What should we do about the expert knowledge?

Even if it was found that the expert knowledge in question is good enough in the sense that it can guide planners that aim at contributing to a traffic-reducing land use and transport development, it has shortcomings.

This regards *first* that the expert knowledge in question needs to be described in comprehensive, referable and understandable ways that are accessible for planners and applicable in concrete plan-making processes, and which can be helpful for planners explaining the interrelations for decision-makers. This regards theoretical knowledge of how and why developments of land use, transport-systems, travel behaviour and traffic volumes are interrelated, how certain developments of land use and transport-systems affect traffic volumes, and how land use and transport-systems ought to be developed in order to reduce rather than to increase car dependency and traffic volumes.

Second, it regards the empirical knowledge of the strengths of the effects on traffic volumes in various contexts and under various conditions. More empirical knowledge is necessary. Further, it needs to be gathered, analysed and organised in ways that makes it more usable in plan-making. It needs to be organised and presented in ways and through channels that are applicable and accessible for planning practitioners dealing with concrete problems in various and concrete contexts. *Third*, the method that has been termed 'professional reasoning' needs to be described, and to be empirically studied and analysed. It needs to be improved and developed into a referable and acknowledged method.

If the expert knowledge was improved with respect to these issues, it would make the expert knowledge more accessible and usable for planners, also those that have not been trained as specialists in this topic; make it easier to explain the knowledge and how it has been applied in order to arrive at particular recommendations, to make the knowledge and the methods more transparent, cause that this expert knowledge is not so easily ousted by other knowledge; reduce the opportunities to consciously apply the expert knowledge in faulty ways, and not least; it could contribute to traffic-reducing alternatives being produced, introduced and called for in planning processes. These may all cause that planners oppose and reject traffic-increasing plans, can explain effects and consequences better for decision-makers and others, and contribute to make more traffic-reducing plans.

What should we do about the planners?

Only by understanding the interrelated mechanisms between developments of land use, transport systems, travel behaviour and traffic volumes, and how they act and interact in various contexts, can planners be able to understand end explain effects and consequences of implementing concrete projects in specific contexts.

According to the survey and interviews conducted in the work of Tennøy (2012), many planners do possess at least basic knowledge regarding how land use and transportsystems ought to be developed in order to contribute to reducing traffic volumes. However, few planners know this expert knowledge well enough to be able to apply it skilfully in discussions of the transport generating potential of a plan or to develop traffic-reducing alternatives and plans. Some planners rather rely on other kinds of knowledge. This is causally related to among others their discipline, paradigm, skilfulness and role in the planmaking process.

The current development could be changed if the understanding of the expert knowledge in question were improved among planners in general. Not least would it be helpful if more planners were specialised in how land use and transport-systems ought to be developed in order for traffic volumes to actually be reduced.

Such improvements could be achieved if more *planning students* were taught overall land use and transport planning for reduced traffic volumes at advanced levels. In Norway, only

planning students at one of two universities educating planners can choose this as a topic in their master degree.

Many of those working as planners have not been educated as planners, and many of those educated as planners have not been taught overall land use and transport planning. It could hence improve the situation substantially if post-university courses in coordinated land use and transport planning for reduced traffic volumes were offered.

One may also expect that planning practitioners struggling with problems related to overall land use and transport planning, and with objectives related to reducing transport demand and traffic volumes (as many do), would make an effort to improve their own knowledge through self-studies. This would be easier if the expert knowledge in question was improved in ways discussed above.

What should we do about the plan-making processes?

When discussing what should be done in order for the plan-making processes to produce traffic-reducing plans instead of traffic-increasing plans, focusing on properties of objectives, knowledge and power of the planners involved, a number of suggestions can be extracted from the previous analyses.

Strong and clear objectives and strategies in overall plans regarding reduction of traffic volumes seem to be almost decisive if to allow public authorities to bring this topic strongly into plan-making processes. Planners make the overall plans, and play important roles by affecting whether these plans become strong tools that steer spatial development in traffic-reducing directions. This regards not least the formal concretisations in maps and purviews. A suggestion for change is hence that the planners work harder to ensure that the overall plans are good steering tools and takes developments in traffic reducing directions. Only planners may be expected to have the expert knowledge to ensure this.

The objective also needs to be made important by planners working with zoning plans in various positions. They need to call for and produce traffic-reducing alternatives and assessments with respect to traffic volumes, address this objective in recommendations, make comments, file complaints and so forth. A suggestion for change is hence that the planners work harder to make the objective 'reducing traffic volumes' more important in zoning plan processes and the expert knowledge in question more applied and influential.

The objectives can only be strong and important if politicians also act in accordance with them. Planners often affect how politicians understand a problem and the potential solutions.

There is often large space for manoeuvre with respect to how and how strongly planners in various positions exert their power. This regards whether planners working for initiators exert their many kinds of power to convince or mislead public authorities and decision-makers. It regards whether planners working for public authorities point out conflicting objectives, bring in alternatives, and assess the analyses conducted by initiators. It regards whether planners working for regional authorities warn about and file formal complaints. A suggestion for change is hence that the *planners to a larger extent exert their power* to pointing out conflicting objectives, and to explain negative consequences with respect to growth in traffic volumes, in the planning processes.

In order for planners to do all this, the planners need to possess the expert knowledge in question, and the expert knowledge in question needs to be accessible and applicable, as described above.

It is striking how much power the initiators have as developers of alternatives and as the ones making and presenting the alternatives, assessments and plans. Initiators are not always producing or presenting analyses in honest ways. In order to reduce this problem, one could call for development of *an approving-system for firms that were allowed to carry out analyses and assessments* with respect to overall land use and transport planning. Planning firms that produce and present non-honest planning analyses could lose their licence, and to be allowed to take on such work. A similar system already exists for the construction-industry in Norway.

Planners and expert knowledge matters

These recommendations for changes differ from proposals regarding collaboration and coordination often discussed under the headings of communicative or collaborative planning theory (e.g. Healey 1992, 1997). The focus here is rather on the necessity of especially planners working for public authorities to stating clearly the prioritised objectives, applying expert knowledge to pointing out and explaining how and why strategies, plans and projects contribute to growth in traffic volumes, producing traffic-reducing alternatives, and exerting power attributed to the various roles in the plan-making system in order to contribute to traffic-reducing plans being made.

Such research and discussions are called for among others by Mazza (2002) and Krizek (2009). Næss (2004:163) claims that if the planners' use of their scientific knowledge of causal interrelations and consequences of alternatives and actions is rejected, "*the planners are also deprived of their most important political resource in discussions with other players in the decision-making process*".

The findings referred to in this paper call for planners with strong and substantial expert knowledge to take a leadership role and responsibility for making planning processes produce traffic-reducing rather than traffic-increasing plans.

Conclusion

There is much work to be done - for planning researchers, for planning schools, and not least for planners in all positions. Changing the ways one thinks and acts is no small task. When we know what is at stake, however, it may be argued that it is necessary and worthwhile. This regards the climate and living conditions on Earth, as well as the local environment and quality of life in the near and distant future.

References

- Banfield, E. C. (1959/ 1973) Ends and Means in Planning. In Faludi, A. (1973) A reader in planning theory. Oxford: Pergamon Press.
- Banister, D. (2005) Unsustainable transport. City transport in the new century. London and New York: Routledge.
- Bhaskar, R. (1975/2008) A Realist Theory of Science. Hassocks: Harvester Press.
- Byrne, D. (2003) Complexity theory and planning theory: a necessary encounter. Planning Theory 2 (3), 171-178.
- Cairns, S., Hass-Klau, C. and Goodwin, P. (1998) Traffic impact of highway capacity reductions: assessments of the evidence. London: Landor publishing,
- Danermark, B., Ekström, M. Jakobsen, L. and Karlsson, J.C. (1997/2002) Explaining Society. Critical realism in the social sciences. London and New York: Routledge.
- Downs, A. (1962) The law of peak-hour expressway congestion. Traffic Quarterly, 16.
- European Environment Agency (2001) TERM 2001. Indicators tracking transport and environment integration in the European Union.
- European Environment Agency (2006) Urban sprawl in Europe. The ignored challenge, EEA Report No 10/2006.
- European Environment Agency (2010) Towards a resource-efficient transport-system. TERM 2009: indicators tracking transport and environment in the European Union. EEA Report No 2/2010. Brussels.
- Flyvbjerg, B. (2004) Phronetic Planning Research: Theoretical and Methodological Reflections. Planning Theory & Practice, 5:3, 283 – 306
- Flyvbjerg, B. (1991) Rationalitet og magt (Rationality and Power). Denmark: Akademisk forlag.
- Friedmann, J. (1987) Planning in the Public Domain: From Knowledge to Action. Princeton, New Jersey: Princeton University Press.
- Furu, L.E. (2010) Hvor kom veksten i Akershus 2000-2010? (Where did the growth in Akershus come in 2000 2010?). By Asplan Viak for Akershus County.
- Healey, P. (2009) In Search of the "Strategic" in Spatial Strategy Making. Planning Theory & Practice, 10:4, 439 457.
- Healey, P. (1997) Collaborative Planning. Shaping Places in Fragmented Societies. Houndmills/ London: Macmillan.
- Healey, P. (1992) Planning through debate. The communicative turn in planning theory. Transport Planning Review, 63 (2), 143-162.
- Hull, A. (2011) Transport Matters. Integrated approaches to planning city-regions. London and New York: Routledge.
- IPCC (2007) Climate change 2007: Synthesis report. An Assessment of the Intergovernmental Panel on Climate Change, 2007.
- Jacobs, J. (1961/1994) The Death and Life of Great American Cities. Penguin Books.
- Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D. S. Lee, Y. Muromachi, P. J. Newton, S. Plotkin, D. Sperling, R. Wit, P. J. Zhou (2007) Transport and its infrastructure. In B.

Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds.) Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

- Krizek, K., Forsyth, A. and Slotterback, C.S. (2009) Is there a Role for Evidence-Based Practice in Urban Planning and Policy? Planning Theory & Practice, Vol. 10, No. 4, 459-478.
- Litman, T. (2009) Generated Traffic and Induced Travel. Implications for Transport Planning. Version dated 3. February 2009. Victoria: Victoria Transport Policy Institute.
- Mazza, L. (2002) Technical Knowledge and Planning Actions. Planning Theory, 1 (1), 11-26.
- Næss, P. (1997) Fysisk planlegging og energibruk (Physical planning and energy consumption). Norway: Tano Aschehoug
- Næss, P. (2004) Prediction, Regressions and Critical Realism. Journal of Critical Realism, 2, 133-164.
- Næss, P. (2006) Urban structure matters. Residential location, car dependence and travel behaviour. London and New York: Routledge.
- Newman, P. and Kenworthy, J. (1989) Cities and Automobile Dependence. An International Sourcebook. Aldershot: Gower.
- Owens, S. (1986) Energy, Planning and Urban Form. London: Pion.
- Parfit, D. (1984/1987) Reasons and Persons. Oxford: Oxford University Press.
- Rydin, Y. (2007) Re-Examining the Role of Knowledge Within Planning Theory. Planning Theory, 6, 52-68.
- Strømmen, K. (2001) Rett virksomhet på rett sted om virksomheters transportskapende egenskaper (The right businesses in the right locations – about businesses' transport generating properties). Doctoral thesis 2001:14. Institute for urban and regional planning. Norwegian University of Science and Technology NTNU, Trondheim.
- Tennøy, A. (2012): How and why planners make plans which, if implemented, cause growth in traffic volumes. Explanations related to the expert knowledge, the planners and the plan-making processes. PhD thesis, Norwegian University of Life Sciences, Institute for Spatial Planning and Landscape Architecture.
- Tennøy, A. (2010) Why we fail to reduce urban road traffic volumes: Does it matter how planners frame the problem? Transport Policy 17, 216-223
- Tennøy, A. (2009) Why we fail to reduce urban road traffic volumes: The challenge of double complexity. Kart og Plan, 1, 27-36.
- World Commission on Environment and Development (1987) Our Common Future. Oxford: Oxford University Press.

TRAMWAY RENAISSANCE IN MUNICH

EFFECTS OF THE TRAM 23 ON URBAN STRUCTURE AND MOBILITY BEHAVIOR

Roland Priester; Benjamin Büttner,

Chair of Urban Structure and Transport Planning, Technische Universität München

Corresponding author:

Roland Priester, roland.priester@tum.de; Benjamin Büttner, benjamin.buettner@tum.de

Abstract

All across Europe, tramways are finding their way back into cities. Thus, not only are long-neglected transportation networks being renovated or expanded but once discontinued lines are being reactivated and entirely new systems are being built. For instance, a lot of attention has been paid to the so called "tramway renaissance" in France. But this trend towards tramways is also clearly noticeable in Munich. Since 1996 formerly abandoned routes have been put into service again. Recently the first completely new line - Tram 23 - has been opened in Munich.

The tram line 23 connects "Münchner Freiheit," the center of the district of Schwabing, with the newly developed neighborhood "Parkstadt Schwabing". This former industrial area has recently been converted into a new, mixed-use area according to the city's planning guideline "compact, urban and green" locating up to 6,000 inhabitants and about 18,000 jobs. Together with the existing neighborhoods and further urban development projects there will be about 50,000 people / jobs within the catchment area of the Tram 23. This transportation project will have significant effects on urban structure, transport demand and mobility behavior.

In order to evaluate the interactions between the new transport services and the built environment, a research and development project has been launched. This project is designed as an impact study that compares the situation before (2008-2009) and after the implementation of the new transport supply (2010). The essential result of the project is the documentation of possible changes in

- the cityscape and the road space
- the urban development and the distribution of urban functions
- the usage patterns of residents and employees as well as
- the transport demand and the mobility behavior.

The project is characterized by a mixed method research approach. Thus, the following steps are performed before and after the introduction of the new tram line:

- land use mapping
- photo documentation
- traffic counts
- expert interviews
- household and employee survey

After finishing the project in August 2011 the final results were presented at the conference in March 2012 together with conclusions and perspectives on possible further researches.

Keywords: Public transport; urban structure; transit orientated development

Introduction

All across Europe, tramways are finding their way back into cities. Thus, not only are longneglected transportation networks being renovated or expanded but once discontinued lines are being reactivated and entirely new systems are being built. For instance, a lot of attention has been paid to the so called "tramway renaissance" in France – a country where in post-war times nearly all tram-based systems have been eradicated except for three. But this trend towards tramways is also clearly noticeable in Munich, Germany's third but most densely populated city. After restoring abandoned tram lines to operation in the 1990's, the Tram 23 is the first new tram line constructed in 40 years (Körner 2011).

Tram 23 connects the station "Münchner Freiheit", the community and transit center in the Schwabing district, with the newly developed Parkstadt Schwabing neighborhood. The planning and implementation was made in coordination with targeted urban development. The project is exemplary of successful coordination between urban planning and transport planning (Bahn.Ville 2-Konsortium 2010).

Planning of Tram 23

The new Munich city district of Parkstadt Schwabing is 40 ha in size, lies just 5 km from the Munich city center, and is located in the northern part of the Schwabing district. The neighborhood is bounded on the east side by the Autobahn A9 (München – Berlin) and on the south side by the multilane, intersection-free Middle Ring. To the west, the new district includes an existing office and industrial site and to the north on the site of a former army barracks is the development area "Domagkstraße" (see Figure 1). Parkstadt Schwabing was created through the urban redevelopment of a former industrial and commercial area with the aim of better meeting the great need for additional housing and office space in Munich. Upon completion of the development work, Parkstadt Schwabing and Domagkstraße include about 6,000 inhabitants and about 18,000 jobs (LHM 2007 and MVG 2008).

In anticipation of a predicted increase in traffic as a result of the planned development, the development plan in 1997 decided that a high-quality public transport development was necessary (LHM 1997). Because the development site was located in the space between the catchment areas of existing underground lines and since a bus connection was rated negatively at the conclusion of the planning process because of its limited capacity, the choice fell on a tram. However, as a lead up to the implementation of a new tram line, a bus link was established.

While the tram route within Parkstadt Schwabing had the possibility of following abandoned freight tracks, the route was subject to discussion in the existing neighborhood. Also, a continuation from the district center "Münchner Freiheit" to the existing tram network also failed for political reasons. Finally, the chosen alignment is an almost 3 km long isolated section between Parkstadt Schwabing and the "Münchner Freiheit" subway station.

Objective of the research project

The integration of land use and transport planning, a key concept within the Munich guideline for urban development ("Perspektive München"), was taken into account while developing Parkstadt Schwabing. The completion of Parkstadt Schwabing was followed by the prompt construction of the tram line 23. From a scientific perspective, it is of particular interest that the numerous independencies and feedbacks between the key elements and the processes of land use and transport development were at least locally influenced and changed. Looking at the feedbacks, planning directly influenced the key elements "land use" (development of Parkstadt Schwabing) and transport supply" (inauguration of Tram 23) (see Figure 1).



Figure 1: Interactions of land use and transport, Source: Wulfhorst 2003

Many effects were expected as a result of the new transport service provided by the Tram 23 including changes to accessibility, the quality and quantity of the activities in the area, as well as the generated transport demand. The major objective of this research and development project was to shed more light on these changes and the complex interactions between land use and transport by comprehensive empirical research.

The project's client and primary contributor was the Munich Public Transport Authority (MVG). The study was also supported by the City of Munich - Department of Urban Planning and Building Regulation.



Figure 2: Alignment of Tram 23 and the study area (highlighted blue), Source: [4]

Methodology

The project was conceived as a three-year monitoring before-and-after study. In 2008 and 2009 before the commissioning of the new tram line the traffic situation and spatial structure were analyzed as well as the expected effects. Also, in 2010, one year after the implementation of the tramway, investigations were continued.



Figure 3: Changes of use from May 2008 to October 2010 in the northern part of the study area

The specific study area mainly covers the catchment areas of the stations along the route of the tram line 23. Since the analysis focused on the change in Parkstadt Schwabing and the surrounding development areas, the study area in the northern part of the district was correspondingly increased, and the study area was decreased in the southern part due to the smaller catchment areas competing with the subway stations (see Figure 1). The study area thus includes the existing neighborhood along Leopoldstraße as well as the newly developed Parkstadt Schwabing. Differences between these two specific sub-areas are highlighted in the study.

Due to the diversity of research interests, the research design of the project included a mix of methods. The following methods were applied both before and after the introduction of the new tram line:

- Land use mapping
- Analysis of land values
- Photo documentation
- Frequency counts of pedestrians and cyclists
- Analysis of public transport ridership
- Household and employee survey

Results

Spatial Structure Development

A methodological component of the project called for comprehensive land use mapping. Therefore, data about the existing land use of the whole study area was collected and categorized according to the standardized classification of economic activities and finally implemented in a Geographic Information System (GIS). Hence land use information could be differentiated not only between residential and commercial use, but also on a very detailed level, such as retail, catering or craft. The acquisition of utilization patterns took place every six months between May 2008 and October 2010 (see Figure 2).

During the period from May 2008 to October 2010 there were new uses, use changes as well as discontinued uses which led to the partial demolition of buildings. It is noteworthy that the residential area was expanded within Parkstadt Schwabing to some buildings in the north. The biggest change in the study area, however, was the resumption of construction activity and the addition of the commercial zone in the eastern part of the study area at the same time as the construction of Tram 23 began.

Tram 23 was also a new impetus for urban development and new land use on the site of the former barracks north of "Domagkstraße". Here the buildings are now demolished, and it is a mixed-use residential and commercial area with higher-value construction planned in 2013, the center of which should lie in the range of the current terminus of the tram. New residential uses are also planned for the area west of the tram route between stops "Anni-Albers-Straße" and "Domagkstraße" where the site of an industrial complex has already been cleared for new developments with the now improved public transport situation.

Photo documentation

Along with land use mapping, detailed photo documentation helped visualize the structural development changes within the study area. The surroundings at a distance of 100 meters

of the tram line were documented photographically and comprehensively catalogued every three months. Eight pictures according to the cardinal directions were taken for each of the 30 sites, providing a 360 degree view of each site. Figure 4 visualizes the location "Münchner Freiheit" at different dates in the time frame from 2007 until 2010. This particular example shows the transformation of the simple bus station to an architecturally imposing



tram station with the possibility to transfer from subway and bus.

Figure 4: Photo documentation of location "Münchner Freiheit"

Land Values

In order to better interpret changes observed from land use mapping, an analysis of land values was performed in the study area. Land values are the average positional values calculated from the purchase records of land transactions which take into consideration the state of development as well as the type of building use and the pre-dominant shape of the real estate market.

The development of land values in Parkstadt Schwabing shows a dynamic of increasing market values of land in this neighborhood. Most impacts were observed immediately after the city council decision in 1997 to establish the development plan for Parkstadt Schwabing with the corresponding tram and related urban planning intentions of the city. Both

residential and commercial real estate values between 1996 and 1998 jumped significantly higher in an apparent upward trend.



Figure 5: Development of land values in Parkstadt Schwabing,

Source: Gutachterausschuss für Grundstückswerte im Bereich der Landeshauptstadt München (1995 - 2011).

After a peak in 2002, the commercial property values have fallen, from mildly to severely depending on location, due to generally weak demand for commercial properties. As land prices in Munich have shown this trend for some time, this emphasizes that land price is not a sufficient indicator of the attractiveness of a location.

Unlike commercial space, residential real estate values were stable at a high level of 1,600 to \in 1,650 / m². Finally at the end of 2010 a year after the commissioning of Tram 23, a sharp increase in land values for residential properties in Parkstadt Schwabing was recorded. This may possibly be interpreted as in indication of the impact of new transport supply on the land value.

Household and employee surveys

The methodology of this study also included two quantitative surveys: a household survey of residents in the study area and an employee survey of the companies there. Both surveys were conducted over a period of three weeks in October in both 2009 and 2010 using a standardized questionnaire. The content of the questionnaire included the perception of transport supply and the site quality on the part of residents and employees, as well as the current mobility behavior and the reasons behind it.

The household survey was a paper-pencil, sample survey (5,000 households in the study area) sent by mail with a return envelope included. The response rate of the questionnaires

in survey year 2009 was 20%. With the identical survey design in an after-survey in 2010, 13% responded. The employee survey, however, was designed to reach the full set of potential respondents and thus was conducted as an online survey and in which all companies and their employees located in the study area were asked to participate. The first survey recorded 1401 responses in 2010, and the following year recorded 816 responses.

Residential Location Choice and Accessibility

The research approach is based on the interactions between public transport accessibility and spatial structure. The initial question asked how important the availability of Tram 23 was for the choice of residential location in the study area. The 2010 household survey shows that Tram 23 has played an important role in the choice of residential location in Parkstadt Schwabing for almost half of the respondents and for about a quarter of the respondents actually a very important role. Outside Parkstadt Schwabing, however, the commissioning of the tram was crucial for only a few households (7%), perhaps as this is a long-established neighborhood along Leopoldstraße (see Figure 6).



Figure 6: Importance of Tram 23 for residential location choice

It is likely that the observed importance of Tram 23, and therefore the accessibility of public transport, is associated with residential location decisions in Parkstadt Schwabing. Therefore, the key indicators based on the study targets of user satisfaction with public transport accessibility are compared before and after the tram's commissioning.





Household satisfaction with public transport accessibility at the commissioning of the Tram 23 in Parkstadt Schwabing rose from an already high value of 78%, to 91% currently. The proportion of very satisfied nearly doubled to just under half of the respondents. Other survey questions showed levels of satisfaction with other criteria such as the choice of residential location, the attractiveness of the district and the quiet location. However, no other 2010 survey questions on the living environment reached such a high level of satisfaction among the respondents as did the question on the accessibility to public transport.

The satisfaction with public transport accessibility in the Leopoldstraße neighborhood remains at a high value, however, it decreased 9 % from 2009 to 2010. The most likely reason for this decrease in satisfaction was the restructuring of the parallel bus service after the implementation of Tram 23. The direct bus service to the western part of Parkstadt Schwabing ceased to exist, and public transport users were required to change to the tram. This deficiency was corrected in 2011 with an adjustment of the bus lines, and the customer satisfaction today is likely to increase accordingly.



Figure 8: Employees'satisfaction with workplace accessibility by public transport

While the satisfaction of households with public transport accessibility in the entire study area prior to the introduction of the Tram 23 was very high, just under half of the study area's employee respondents were satisfied in 2009. This has changed considerably with the opening of the new tram line, and satisfaction levels of employees with the public transport accessibility of the workplace have increased tremendously.

The satisfaction of the employees in the Leopoldstraße neighborhood increased by 31% to 84% with the introduction of Tram 23. Of those, 35% of the employees were very satisfied. This can be illustrated by one of the largest employers in the study area, the "Munich RE". The new tram stop "Am Münchner Tor" is in front of the company location. Previously, public transport users arrived via bus connection to the nearest metro station "Nordfriedhof" and additional trips by foot. Within Parkstadt Schwabing, an even more significant increase in public transport users' satisfaction was due to the new tram. The satisfaction (including "very satisfied") was 47% before the opening of the Tram 23 and 83% after the inauguration.

To examine the implicit assumption that improving public transport accessibility is linked to the introduction of the new tram, the survey directly asked the influence of the Tram 23. Figure 7 shows the results of the 2009 pre-commissioning questionnaire expressing expectation for the new tram line 23.



Figure 9: Changes in accessibility by public transport of households' typical destinations due to implementation of Tram 23

For households in the existing neighborhood along Leopoldstraße a perceived deterioration in the availability of public transport from 2009 to 2010 is revealed. Prior to the start of Tram 23, just 10% expected deterioration in public transport accessibility and 5% expected a strong deterioration. With the new public transport service in 2010, 15% responded that public transport availability had become "worse", and 15% responded that it had become "much worse".

In contrast, the result for Parkstadt Schwabing showed that nearly half of the survey respondents (48%) in 2009 indicated that accessibility would be better with the Tram 23. After the start of Tram 23, almost two thirds of the respondents indicated an improvement in accessibility.

This result is not surprising and confirms the expert opinion that the Tram 23 is a higher quality, more comfortable, and faster connection from Parkstadt Schwabing to the community and transit center "Münchner Freiheit". For the residents of the long-established neighborhood along Leopoldstraße, however, a reduced vehicle frequency and new established transfer needs had to be taken in account.

In terms of improving workplace accessibility with Tram 23, the expectations of employees in the Leopoldstraße neighborhood correspond well with the retrospectively perceived changes in accessibility (see Figure 10). Particularly striking is that the proportion of those who consider the accessibility of 2010 as "much better" is significantly higher than initially

expected. Even among employees in Parkstadt Schwabing, the expectations were surpassed in terms of improving the accessibility of the workplace after the commissioning of Tram 23. This is shown by the two thirds (64%) of employees surveyed who described the accessibility after implementation of Tram 23 as "better" or "much better".



Figure 10: Changes in employees' workplace accessibility due to implementation of Tram 23

The survey also asked about the travel time by foot from home or workplace to the nearest Tram 23 stop. It should be noted that at least 90% of households or employees are within a maximum of 10 minutes walking time from all tram stops, and for the majority of the respondents within 5 minutes.

Mobility behavior

In order to determine the changes in mobility behavior due to the commissioning of the Tram 23, in the before-and-after study traffic counts were also carried out and available data evaluated. Bike and pedestrians counts were carried out by the project team. In addition, the project team used public transport ridership counts from the MVG to compare the previous bus operation and the newly introduced Tram 23.

Overall in 2010, both foot and bicycle traffic has increased significantly in the study area across counting locations. The increase in traffic is probably due to the development thrust

in the eastern industrial section of Parkstadt Schwabing, the construction and operation of the Tram 23, and the growing number of office buildings and workplaces. Contrary to this general trend, traffic flow coming from subway stations shows a decline in foot traffic (at one counting station, a drop of 29%) from 2009 to 2010. The following reason seems probable: the tram line 23 now is more attractive for the inhabitants of Parkstadt Schwabing than the previous bus service or the long walking distances to the subway line U6. In particular, now the entire residential area is within a few minutes walking distance from the tram stop "Anni-Albers-Straße". Employees in the northern commercial area of Parkstadt Schwabing now have shorter and more attractive walkways between the tram stops and job locations. Consequently, there has been a shift of subway users to the tram.

This interpretation of count data is supported by the quantitative survey. In 2010, 33% of the surveyed households in Parkstadt Schwabing indicated that they use Tram 23 for many routes towards the city center instead of the subway. Another 25% use the tram at least for some trips.

The introduction of Tram 23 and the end of the previous bus operation brought major changes to the route. Although Parkstadt Schwabing had been served a little more finegrained by the former bus service, Tram 23 has now made public transport service in the study area more comfortable, capacious and reliable and therefore more attractive.



Figure 11: Development of public transport ridership in the study area (Source: MVG 2011)

The development of the demand of public transport lines in the study area is shown in Figure 11. Other than the substitution of the bus 123 by Tram 23 and the diversion of the city bus lines 140/141 from "Münchner Freiheit" to "Scheidplatz" subway station due to the tram construction, no changes were made to the network between the two study years

2009 and 2010. The growth in passenger numbers on these two lines from 2009 to 2010 suggests a change in travel behavior. Further route opportunities were made possible by the route to "Scheidplatz", the intersection of the subway lines 2 and 3. Most remarkable is the increase in passengers on the segment from "Münchner Freiheit" to Parkstadt Schwabing, which has seen an increase of 87.3% in public transport users since the start of the Tram 23. Over the entire route, nearly twice as many passengers use the tram compared to the bus. Since the end of the study, the passenger numbers have risen even further. Currently there are around 11,000 trips per work day.

Transport Mode Share

The following survey results relate the mode choice of households and workers in the study area to the main transportation means of respondent for each trip purpose. Exclusively for "the way to work / education", mode choice was differentiated for a sunny or rainy day in order to reveal weather-related effects of shifting to another mode of transport.

The mode split (on a sunny day) for work trips for the residents of the study area is shown in Figure 12. In the survey year, before the opening of Tram 23, the modal split between Parkstadt Schwabing and the Leopoldstraße neighborhood varied little. After the inauguration of the new tram line, the changes in the two quarters followed the same trend but with varying degrees. Tram 23 gained more users from public transit than from other modes. Outside Parkstadt Schwabing, 5% more of the survey respondents take the bus or train than before Tram 23, and inside Parkstadt Schwabing there was an increase of 11% among all survey respondents. While the share of car traffic remains unchanged, the proportion of cycling decreased, especially in Parkstadt Schwabing. This may be surprising because in parallel to the Tram 23, new cycle paths - including a bridge over the Middle Ring Road - were established. But at the time the survey was conducted these routes were still not fully anchored in the urban cycle route network. In the future, bicycle traffic is expected to increase. The pedestrian mode share almost doubled in both the Parkstadt Schwabing and the Leopoldstraße neighborhood, albeit from a very low base of 2 and 4% respectively.



Figure 12: Mode share of households for trips to work/education (on a sunny day)

Among workers outside of Parkstadt Schwabing the public transport share rose from 49% (2009) to 54% (2010) slightly reducing the proportion of driving and cycling. Within Parkstadt Schwabing a similar increase for public transport can be observed. However the cycling share grew from 12% to 17%. In total, the share of motorized private transport dropped from one third (37%) to a quarter (26%) of all work trips (cf. Figure 13).



Figure 13: Mode share of employees for trips to work/education (on a sunny day)

Besides the mode split on work trips, the household survey also asked transportation mode choices for other trips (see Figure 14). As expected, bulk purchases by residents of both neighborhoods are mostly done by car. For small purchases, however, most respondents walk. The introduction of Tram 23 brought an increase in the public transport mode for the categories "errands" (from 29% to 38%) and "evening leisure time" (60% to 67%) throughout the study area.



Figure 14: Mode share of households for several activities in the study area

Another finding of the survey is that residents of Parkstadt Schwabing now leave their cars behind on trips to downtown in almost one out of two cases and use Tram 23.

With the increasing attractiveness of public transport services and its increased use since the commissioning of the Tram 23, the proportion of people who hold a public transport season ticket (MVV-tariff) has increased significantly. Nowadays, two out of three employees and more than half of households have a public transport season ticket (see Figure 15). Since such a public transport ticket can also be used for purposes other than work trips, the new transport service of Tram 23 benefits all.



Figure 15: Hold of a public transport season ticket (MVV-tariff)

Summary and Conclusions

The studies on the Tram 23 in Munich revealed the following significant correlations:

- Tram 23 is an important location factor: Tram 23 was a crucial residential location factor for nearly half of the households in Parkstadt Schwabing. Additionally, the construction and commissioning of the new rail-based public transport service brought positive benefits to the development of commercial sites in the study area. The land value of residential areas in Parkstadt Schwabing since the existence of the tram has increased dramatically.
- Satisfaction with public transport has increased with Tram 23: With the commissioning of the new tram line, the level of satisfaction with the accessibility to jobs increased significantly throughout the study area. No other form of transport allows for better accessibility. The residents of Parkstadt Schwabing now reach their destinations better. The decline in satisfaction of the residents of the existing neighborhood along Leopoldstraße with the implementation of the tram is due to removal of some bus services (in order to avoid parallel traffic). This unfortunate planning resulted in the dissatisfaction of the residents; however, some critical bus connections have since been reinstated. In summary, the implementation of Tram 23 has led to increases in the general satisfaction with residential location as well as workplace site.

- For many potential users, Tram 23 is close to home or work: all of the stops for Tram 23 are within 10 minutes walking distance for at least 90% of households and employees within the study area, and for most within 5 minutes.
- With the inauguration of the new tramline, public transport became the main means of transportation in the study area based on the modal split for work or education trips. Even for trip purposes such as "errands" or "evening leisure time", public transport is clearly gaining importance. The strong shift to public transport use leads to higher carbon savings over previous car use.
- The proportion of regular public transport customers is increasing in the study area's: the improvement in quality of public transport services is reflected in a significant increase in season ticket ownership.

Tram 23 can thus be considered as an example of sustainable urban transport development, becoming the model for further measures to build new tramways in Munich and to increase the attractiveness of public transport.

References

- Bahn.Ville 2-Konsortium (2010): Die Bahn als Rückgrat einer nachhaltigen Siedlungs- und Verkehrsentwicklung Synthesebericht zum Projekt Bahn.Ville 2. München
- Gutachterausschuss für Grundstückswerte im Bereich der Landeshauptstadt München (1995 2011): Bodenrichtwertekarten 1994 - 2010.
- Körner (2011): Münchens bewegte Geschichte. In: Münchner Verkehrsgesellschaft (MVG): 150 Jahre Mobilität für München. München
- Landeshauptstadt München Referat für Stadtplanung und Bauordnung (LHM) (2007): Parkstadt Schwabing. München
- Landeshauptstadt München Referat für Stadtplanung und Bauordnung (LHM) (1997): Beschluß des gemeinsamen Ausschusses für Stadtplanung und Bauordnung und des Werkausschusses vom 15.07.1997
- Münchner Verkehrsgesellschaft mbH (MVG) (2008): Die neue Tram 23 in die Parkstadt Schwabing. München.

EVALUATING THE IMPACT OF ENVIRONMENTAL CONSTRAINTS IN NETWORKS: FORMULATION AND ANALYSIS IN A SIMPLE CASE

Xin Lin; Ben Immers; Francesco Viti; Chris Tampère, CIB / Traffic & Infrastructure, KU Leuven

Corresponding author:

Xin Lin; xin.lin@cib.kuleuven.be

Abstract

Traffic management cannot only consider traffic accessibility and operations efficiency, but also traffic externalities, such as environmental aspects. Besides the total emission on the network level, an increasing number of public authorities are starting to impose emission or concentration limits at the local level as additional constraints. In general, the environmental constraints on the local level may influence the supply of traffic networks significantly. It is critical to assess the impact of such environmental constraints on the whole traffic network performance. In this paper, a framework for assessing the impact of environmental constraints is firstly established. This framework is based on a dynamic bi-level optimization problem, which is often adopted in such types of network design problems. The essential idea of this framework is primarily to find the best control strategy which can maximize the traffic accessibility as well as satisfy the given environmental constraints. The impact of environmental constraints. Secondly, the formulation of environmental constraints is discussed, and the link-based block-continuous (LBC) emission rate constraints are suggested. Thirdly, a simple case is studied in the established framework.

Keywords: Environmental Constraints, Control, Traffic Sustainability, Bi-Level Problem
Introduction

The environment, especially in urban areas, is deteriorating at an alarming rate. Traffic emissions, especially nitrogen oxides (NOx), carbon monoxide (CO), and Particulate Matter (PM), are contributing to this process in a significant way. According to European Union statistics from 2006, transport contributes 39% of total NOx emissions, 36% of total CO emissions, 18% of total non-methane volatile organic compounds (NMVOC) emissions and 18% of PM2.5 in EU-25[1]. Moreover, the sharp increase in the number of vehicles, both in developed and developing countries [2, 3], is forcing authorities to face and solve this issue. The assessment of environmental impacts is therefore becoming more and more important while planning urban traffic management strategies.

Different goals for controlling traffic pollution coexist. Primarily, the reduction of total emissions is critical for all pollutants. To some extent, this aim makes more sense for the pollutants influencing a large scale area over a long-term period, such as CO₂, CH₄ and other greenhouse gases. It is worth noting that some control measures reduce the total emissions of some pollutants but may increase the emissions in a short period or on a local level. For example, increasing the speed limit may decrease total NOx emission by decreasing total travel time, but may on the other hand increase the emissions on one link in a short time period by increasing both the emission factors and the traffic flow on that link. Therefore, the global emission control strategies possibly collide with the goals of short-term and local emission policies. The latter one makes more sense on the emissions having a short but harmful influence on human health, such as NOx, Particulate Matters (PM) and Noise. As a result, short-term and local environmental constraints have been imposed, and corresponding control strategies have been investigated and adopted by public authorities. These control measures mainly focus on the traffic level, for example, flow restriction and speed limit. However, applying these measures influences the supply level significantly, and in principle, it reduces the network supply. In that case, it is critical to assess the impact of imposing such environmental constraints under such control measures, to ensure suitable environmental constraints which would balance the environmental benefit and traffic performance.

The main implication of the above examples is a framework that enables one to assess the impact of local emission constraints on the overall network performance and on the pollutants at the global level. It will help to identify more effective management solutions, which would prevent shifting the local problem to other areas or to the whole network. In this paper we present one framework to assess the impact of such environmental constraints under dynamic control settings, in order to give policy makers a general idea about the influence of imposing certain environmental constraints. The paper is composed as follows: in Section 2, a review describes the research of internalizing environmental aspects in traffic management. In Section 3, the assessment criterion and the corresponding framework to calculate the criterion are presented, and then the bi-level optimization problem of Network Design Problem is mathematically defined based on the framework. In Section 4, the link-based block-continuous (LBC) emission rate constraint is suggested and compared to other constraints. In Section 5, a simple case based on a linear network is studied and the results are discussed. Section 6, finally, contains some conclusions and recommendations.

Literature Review

Considering environmental aspects has a long history in traffic network management. The impact of traffic on the environment has been investigated since an early stage[4]. At the traffic level, people studied the methodologies to reduce the total environmental cost of the network[5], reach the minimal environmental cost of the network[6], or seek a balance between total traffic cost and total environmental cost[7, 8]. These processes also have been switching from static and simulation approaches[9] to the dynamic and optimal control approaches[10-12]. Major research focused on reducing total environmental cost. Some researchers also considered local environmental aspects on the local or link level but these aspects were usually considered as externalities to the network[10, 13].

Recently, the goals of satisfying the global or local environmental hard constraints, such as emission budgets policy, become increasingly interesting for policy makers. Some researchers investigated the control measures which ensure these constraints can be satisfied and furthermore, the influence of imposing such constraints on the network. These problems about hard constraints have been formulated in two ways: as a bi-level optimization problem and as User Equilibrium (UE) with side constraints problem.

Many researches focused more on the network-wide level, such as optimizing the network performance under global emission constraints. Various control measures can influence the network system, reflected in users' choices. The problem of users' choices

can be formulated as a lower level optimization problem, along with the upper level network performance optimization problem. It is natural to formulate this entire problem as a bi-level problem. Feng[14] used a bi-level approach and genetic algorithm to find maximal car ownership under environmental constraints. Yang[15] used an artificial neural network algorithm to solve a similar problem with concentration constraints. They took respectively total emission constraints or total concentration constraints as the additional constraint on the upper level. In addition, both approaches were static because their interests were in long term control strategies. Sharma[16] and Wismans [17] suggested the bi-level multi-objective problems, respectively in static and dynamic approaches, to the find Pareto optimal frontier including different objectives such as total travel time and total emissions. The impact of emission constraints can be assessed from the Pareto optimal frontier. However, their approaches both focused on long term and global level.

On the local level, the problem has been typically formulated as a UE problem with side constraints. For instance, Larsson[18, 19] suggested a static side-constrained traffic equilibrium problem. This approach was developed into a UE problem with link environmental constraints. The environmental function (for example, emission function) can be linear[18] or convex[19] related to the flow. Chen [20] also suggested a generalized side constrained traffic equilibrium model in a variational inequality approach. In the dynamic traffic network approach, many aspects are different with respect to the static traffic network approach. For instance, the travel cost functions are not separated, continuous, monotonic, or convex. The Jacobian matrix of the travel cost function is not asymmetric. The traffic problem with environment constraints becomes more complex. Chen[21] used variational inequality to describe the dynamic UE with Penalty functions were employed instead of environmental side constraints. constraints. The constraints were described as the maximal flow during time interval k. Following the approach of Larsson, Zhong[22] described the UE problem with side constraints in dynamic traffic network.

Larsson, Chen and Zhong's approaches only considered the user level. The results reflected users' spontaneous route choice behaviours in the network in order to achieve the side constraints, which in most of the cases are formulated as flow constraints. To some extent, the result can be used to assess the impact of the environmental side constraint, but it has drawbacks. On the one hand, users cannot spontaneously choose the proposed routes in practice. Some control measures have to be employed by

authorities to guide the users into the proposed assignment. However, UE with side constraints primarily neglects the control measures and therefore, is under the assumption that there is an ultimate control measure to guarantee the users follows the solution. Of course, there is no ultimate control measure. If the tolling or route guidance cannot be employed, the control measure for that UE with side constraints solution may not be found, which means the solution cannot be achieved. Second, this problem minimizes the UE objective function under the additional side constraint. The UE objective function has nothing to do with the traffic performance or a desired control strategy (such as minimal total toll). There is therefore no confidence to use this result to assess the impact of environmental constraints.

To summarize, research still lacks a reasonable criterion and corresponding approach to assess the impact of imposing the environmental constraints on the network on the short-term and local level. In later sessions, we will suggest such criterion and corresponding assessment framework.

Framework

Assessment Criterion

The aim of the research is to quantify the impact of imposing local environmental constraints through a concise metric that could enable policy makers to find the best trade-off between network performance and environmental costs under certain control strategies. The assessment criterion should be suggested primarily. Three criterion characters need to be concerned. First, it reflects the impact of imposing constraints, for example, the change of network performance after imposing the environmental constraints. Second, different sets of environmental constraints in a network can be compared by the help of assessment criterion, and moreover, the impact of same environmental constraints set to different networks or demand scenarios can be also compared. Third, it has unique number for given constraints and other input data.

Based on these concerns, we suggest the assessment criterion as an index reflecting the reduced potential to the system optimum by imposing the environmental constraints. It is formulated in Equation (1)

$$AC(EC) = \frac{J_{min}^{S-EC}(\mathcal{M}) - J_{min}^{S}(\mathcal{M})}{J_{min}^{S}(\mathcal{M})}$$
(1)

Here, $J_{min}^{S}(\mathcal{M})$ is the minimal system cost by applying suitable control measures from the set \mathcal{M} , which includes all possible control measures, and $J_{min}^{S-EC}(\mathcal{M})$ is the minimal

system cost with environmental constraints by applying another (or same) suitable control measures from \mathcal{M} . The assessment criterion gives one concise non-negative quantity for a given set \mathcal{M} . If AC(EC) equals zero, the environmental constraints have no influence on the performance of network. A larger AC(EC) value informs that the environmental constraints reduce the performance of network more.

It is worth to note that, $J_{min}^{S}(\mathcal{M})$ can be replaced by another variable only if related to the network parameters. For example, the total cost of UE without any control measures $J_{UE}^{S}(\emptyset)$. In that case, AC(EC) can be negative, since $J_{UE}^{S}(\emptyset)$ can be larger than $J_{min}^{S-EC}(\mathcal{M})$. It also reflects the trend of imposing environmental constraints. In our research, $J_{min}^{S}(\mathcal{M})$ is applied because then AC(EC) means the reduced potential of a minimal system cost.

Network Design Problem

The next step in establishing the framework is finding the approach to calculate $J_{min}^{S}(\mathcal{M})$ and $J_{min}^{S-EC}(\mathcal{M})$. This problem in the research is considered as a Network Design Problem (NDP).

Generally, the term Network Design Problem (NDP) includes topological network plans, for instance expanding the network infrastructure, or the general traffic rules for the purpose of achieving some aims. In practice, an interesting alternative is offered by seeking suitable traffic control measures, which guide the users to achieve the aims of network management. It means the users will follow "their own choice" influenced by certain traffic control measures in this situation. Therefore, the users' behaviors can be described as a UE problem under certain traffic control measures such as tolling, speed limits, flow restriction, and others. This represents the lower level problem and is only influenced by the control measures and users own character. The upper level is then to achieve some "aims" set by the policy makers. Instead of primarily seeking traffic patterns in the UE with side constraints problem, NDP seeks suitable control measures which can achieve both the UE assignment and these "aims".

The issue of traffic assignment is how to assign the Origin-Destination demand onto the network[23]. According to the real world link flow characters, a traffic assignment with a single-class mode should satisfy the set of basic constraints \mathcal{B} , such as the flow conservation constraint, flow propagation constraints, the non-negativity constraint, and network topological constraints[24]. Link physical capacity constraints are not considered here. On the one side, the link physical capacity constraints were usually

internalized into the link cost function by some simplifications and assumptions, such as the physical capacity used in the BPR function[23] or critical density used in the METANET[25]. On the other side, they can be dealt with as additional constraints[18, 19, 22, 26].

The feasible set of the constraints for dynamic traffic flow patterns *F* can be defined as $\Omega_M = \{F = (f_{ipt_d}^{od}(t)|F \text{ satisfies set } \mathcal{B} \text{ and } M\}$. Here, $f_{ipk}^{od}(t)$ denotes the flow on link *i* following route *p* with Origin-Destination *od* at time *t*, which departs at time t_d . $M \subseteq \mathcal{M}$ is the set of applied control measures. Depending on *M*, the feasible set Ω_M can be empty, one element or multi-elements. In the situation of multi-elements, different assignments are defined according to different assumptions.

In order to assess the control measures, different traffic patterns of certain assignments need to be evaluated. The set of these traffic patterns is defined as $\Gamma^{A}(M) = \{F | F \text{ is traffic patterns of } A \text{ and } F \in \Omega_{M}\}$, and $\Gamma^{A} = \{\Gamma^{A}(M), \forall M \subseteq \mathcal{M}\}$. \mathcal{M} is the set of all possible measures which can be applied. A is the type of assignment, which in this paper is a UE. In other words, $\Gamma^{A}(M)$ is mapping the traffic flow patterns under assignment A with the measures set M. Because the users' behaviors can be described as a User Equilibrium problem in the assignment, $\Gamma^{UE}(M)$ is usually applied as the certain assignments. A Network Design problem can be finally defined as

Objective: $\min_{M \subseteq \mathcal{M}} J(M, F)$				
s.t. $F \in \Gamma^{\mathrm{UE}}(M)$	(3a)			
$g(M,F) = 0$ and $h(M,F) \leq 0$	(3b)			

Here J(M,F) is the objective function based on the aims, g(M,F) and h(M,F) are the additional constraints, all with respect to the design purposes.

The optimization problem (2)-(3) of NDP is a bi-level optimization problem. The problem of finding the feasible set of $\Gamma^{UE}(M)$ is usually described as a lower optimization problem. For the mathematic description of User Equilibrium in the static approach, we refer to Sheffi [23] and in the dynamic approach we refer to Chen [24].

Methodology

In our framework, we look for the minimal system cost with/without the environmental constraints $J_{min}^{S-EC}(\mathcal{M})$ and $J_{min}^{S}(\mathcal{M})$, following the Equation (1). If the network parameters and \mathcal{M} are given, due to the character of minimization, $J_{min}^{S}(\mathcal{M})$ is unique and not related

to environmental constraints (*EC*). Only $J_{min}^{S-EC}(\mathcal{M})$ is related to *EC*. It means that AC(EC) is only related to $J_{min}^{S}(\mathcal{M})$. Therefore, the problem to calculate assessment criterion AC(EC) can be transformed to the problem of calculating $J_{min}^{S-EC}(\mathcal{M})$, which can be solved by the bi-level optimization problem defined below.

Objective $J_{min}^{S-EC}(\mathcal{M})$: $\min_{M\subseteq\mathcal{M}} J \triangleq TC(F^{\text{DUE}-\text{EC}})$ (4) s.t. $F^{\text{DUE}-\text{EC}} \in \Gamma^{\text{UE}}(M)$ (5a) $EC(M, F^{\text{DUE}-\text{EC}}) \ge 0$ (5b) $D(M, F^{\text{DUE}-\text{EC}}) - D = 0$ (5c)

 $TC(F^{\text{DUE-EC}})$ is the total travel cost with the flow pattern $F^{\text{DUE-EC}}$. It is equal to the total travel time of all vehicles in the network to finish their trips. Depending on the adopted traffic flow model, this function has different expressions. Moreover, it can consider more costs besides the travel time cost. In the environmental cost, for example, total emissions are involved in the system cost. *J* can be formulated as the sum of total travel cost and total environment cost. In our research, total travel cost is primarily considered. The Constraint (5a) is the User Equilibrium constraints and acquired from the lower optimization problem with control measures M. Constraint (5b) is the environmental constraints. M in these equation implies that some control measures can also influence some elements in this equation. For example, encouraging using cleaner vehicle may reduce the emission factors for a single vehicle, but this measure has nothing to do with traffic patterns. $D(M, F^{DUE-EC})$ in Constraint (5c) also implies the demand may be influenced by the control measures. However, we do not consider the direct influence of M to the two equations but only to $F^{\text{DUE-EC}}$ in this paper. Moreover, Constraint (5c) implies that demand is fixed, because we will first investigate the assignment with fixed demands. Several methodologies, for example, the hypernetwork or iterative approach, can be applied in order to extend this fixed demand approach to a wide elastic demand approach. We refer to Cascetta[27]. $J_{min}^{s}(\mathcal{M})$ can be calculated by the same methodology without Constraint (5b). Some algorithms exist to solve this problem depending on different possible control measures set \mathcal{M} (for example, [10, 17, 28]).

Environmental Constraints

Environmental Unit

The framework is in the purpose of assessing the impact of environmental constraints, based on the bi-level optimization problem described in Section 3. First of all, it is important to select the unit of environmental constraint because of different approaches for different environmental units. The assessment is about short-term and local emission constraints and mainly based on the dynamic traffic network, so the environmental units should involve the temporal information. Besides, the research focuses on the network design approach, which needs efficient algorithms for its optimization. It is not wise to choose a complex environmental unit such as concentration, which needs lots of extra variables. These variables are often not controllable nor directly involved in traffic management applications. In the end, Emission Rates (g/km/h) will be selected as the environmental unit.

Strictly speaking, emission rate is the partial derivative of cumulative emission with respect to time and distance. In this paper, we define emission rate as the total emission produced during a short time and at a short distance in the discrete time-space models. Therefore, the emission rate here, whose exact terminology is local-wide cumulative emission rate, reflects short-term and microscopic pollution. It is reasonable to be considered as a simplification of concentration, but the calculation is less difficult. The total emission at the network level or total emission per link is the aggregate amount of emission rate. Moreover, it is possible to back-calculate the cumulative emission values from the concentration standards or from the total emission budget. Therefore, emission rate is handy in assessing or simulating the environmental impact of a dynamic traffic network.

Link-based block-continuous emission rate constraints

Besides the unit of environmental constraints, there are different types of constraints according to the spatial and temporal scale. First, the total emission constraints which have been discussed in the introduction cannot achieve the aim of guaranteeing the environment damage under certain levels at the short-term and local region. If we set a continuous constraint, that means the emission rate at any position on the link and at any time should be smaller than the constraints.

For any $ER(t, x) \triangleq q(t, x) \times EF(v(t, x)) \le EC$ (6)

Here ER(t, x) is Emission Rate, q is the traffic flow, EF is the Emission factor, v is speed and EC is Emission constraint. It satisfies the environmental goals but is overly strict because one local peak may not be acceptable. It is therefore straightforward that this constraint significantly reduces the feasible space of solutions.

Instead, in this framework, the link-based block-continuous (LBC) emission rate constraints are introduced. It means the average emission rate over the link during the time interval should satisfy the constraints.

For any time interval t_i :

 $\overline{ER}(t_i) = \frac{1}{L \times \Delta t} \int_{t_i}^{t_{i+1}} \int_0^L E(t, x) dx \, dt \le EC \qquad (7)$

where $\overline{ER}(t_i)$ is the average emission rate during time interval t_i and L is the link length. By imposing these kind of constraints, the feasible set of solutions is larger, which may cause less deterioration on traffic accessibility. Besides, it can be seen as more realistic. The emission constraints or concentration standards are normally an average value during 15 minutes or one hour. The concentration is quite sensitive about the emission rate in time but the minimum temporal scale of existing concentration models is per half hour[29]. This means that an overly short time critical period has no sense to the concentration constraints, nor to the further evaluation.

Case Study

In order to illustrate the conceptual framework presented in the previous chapters, a simple case is studied. In this case study, we are interested in the way that overall network performance is impacted by the environmental constraint, how optimal control differs with and without EC and what the impact of different formulations or approximations of the EC can be. For the analyses, a state-of-the-art traffic flow model and optimal control calculation is used. As a secondary objective of the case study, we evaluate the suitability and convenience of using these existing approaches for this simple case study and for future more elaborate case studies.

Traffic Flow Model

Because of the motivation of the case study, three points are necessary to be covered in order to select a suitable traffic flow model. First, the traffic flow model should reflect well the dynamic traffic aspects, as well as the impact of the control measures. Second, the traffic flow model must have already been widely used and well validated. Third, algorithms for solving the optimization problem based on such a traffic flow model should exist. As the preliminary study, the dynamic traffic flow model METANET is selected to illustrate the traffic flow on the network. This model is a second-order macroscopic discretized traffic flow model. It can represent the capacity drops and merging phenomena which may be influenced by some control measures. This traffic flow model has been widely applied in the traffic optimal control problems, and model predictive control research. For a further mathematic description of METANET and its optimal control approach, we refer to [25, 28, 30, 31]

Network

In this case study, a linear network with three links and one OD is analyzed. Suppose that the only available control measure is metering on nodes 1 and 2, and the emission rate constraint is imposed only on Link 2.



Figure 1. Network

The three links have the same parameters. Each link is 4 kilometers and divided into 8 METANET segments. Each segment is 0.5 kilometer. The maximal speed is 120km/h, the number of lanes is 1, the critical density is 32.5veh/h and the maximal flow based on METANET parameters and link parameters is approximately 2200veh/h.

The demand function is in Figure 2 and the temporal length of each control interval is 0.02h.



Figure 2 OD demand

Emission Rate Constraints

The LBC emission rate constraints are imposed, which has been discussed in Session 4.2. Based on the discrete temporal and spatial output from METANET, the LBC average emission rate $\overline{ER}_i(t)$ is calculated by

$$\overline{ER}_{i}(n) = \frac{1}{t_{n+1}-t_{n}} \sum_{z=t_{n}}^{t_{n+1}} \sum_{s=1}^{S_{i}} \left[EF\left(v_{i,s}(z)\right) q_{i,s}(z) L_{i,s} \right] / L_{i}$$
(8)

where EF(v) is the emission factor calculated by COPERT4[32]. They are related to road type (highway), speed (from traffic flow model) and vehicle categories (from Belgian data). $v_{i,s}(t)$ and $q_{i,s}(t)$ is the speed and flow in the segments *s* of link *i* at time *t*. S_i is the total number of segments of link *i*. $L_{i,s}$ is the length of segment *s* on link *i*. L_i denotes to the total length of the link *i*, which equals to $\sum_{s=1}^{S_i} L_{i,s}$. t_n and t_{n+1} are the respectively start time and end time of the time block. It has the same essence as Equation (4) but in the discrete approach.

The values of emission constraints, flow constraints and density constraints are set almost equivalent in a static network. In the dynamic approaches, the three variables sometimes are not equivalent[33]. In order to compare the influence of different constraints in the case study, another two LBC constraints are defined preliminarily. The LBC average density $\bar{\rho}_i(t)$ and the LBC average flow $\bar{q}_i(t)$ are described below.

$$\bar{\rho}_{i}(t) = \frac{1}{t_{n+1}-t_{n}} \sum_{z=t_{n}}^{t_{n+1}} \sum_{s=1}^{S_{i}} \left[\rho_{i,s}(z) L_{i,s} \right] / L_{i}$$
(9)
$$\bar{q}_{i}(t) = \frac{1}{t_{n+1}-t_{n}} \sum_{z=t_{n}}^{t_{n+1}} \sum_{s=1}^{S_{i}} \left[q_{i,s}(z) L_{i,s} \right] / L_{i}$$
(10)

Here $\rho_{i,s}(t)$ is the density in the segments *s* of link *i* at time *t*.



Figure 3. Density - Flow / Emission Rate

According to Figure 3, the constraints are LBC density constraint is 21.5 veh/km, LBC flow constraint is 1875 veh/km and LBC emission rate constraint is 325 veh.g/km/h. In contrast to the density, the Flow and Emission Rate can decrease when there is congestion. It means the control measures can let the network satisfy the flow or emission constraint, by causing congestion at the downstream part of constrained link.

Mathematical description

The bi-level optimization network design problem of this case study can be described below.

Objective:

$$\min_{u} J \triangleq T \sum_{k} (\sum_{i} \sum_{s} \rho_{i,s}(k) L_{i,s} + w_{o}(k))$$
(11)
Subject to:

$$\begin{aligned} x(k) &\triangleq \left(x_o(k), x_1(k), \dots, x_l(k)\right) = F(x(k-1), u(k)) & (12a) \\ &\qquad \frac{1}{m} \sum_{z=(n-1)m+1}^{nm} ER\left(x_{ic}(z)\right) \leq EC \\ for \ n = 1: N & (12b) \\ 0 \leq u(k) \leq 1 & (12c) \end{aligned}$$

Here *T* is the length of each simulation time interval (0.001hour in the case study), *k* is the time interval index, which represents the time *t* in the discrete approach. $x_i(k)$ is the vector of traffic variables in Link *i*, at time interval *k*. It includes segment density $\rho_{i,s}(k)$ in the segment *s* of link *i*, segment flow $f_{i,s}(k)$, segment speed $v_{i,s}(k)$ and the number of queuing vehicles $w_o(k)$, that are possibly waiting at their origin node *o*. x(k) is a vector of all $x_i(k)$, and it presents the traffic state of the network at time interval *k*. Minimization of

Objective *J* in Equation (11) is equivalent to minimization of the total system cost if the demand is fixed[28]. Equation (12a) reflects the METANET traffic flow model, implying the current traffic state x(k) is related to the previous traffic state x(k-1) and the control variables u(k) at current time for a given network and OD demand. Equation (12b) is the LBC Emission Rate Constraints. *n* is the constrained block index, *N* is the total number of constrained blocks and *m* is the number of time interval during each constrained block. Equation (12c) is the upper and lower boundary of the control measures variables, in this case metering rate, u(k) at time *k*.

It is worth noting that there is no route choice in this network due to only one route and one OD. The lower level problem (UE under control measures) is involved in Equation (12a). This problem is then described as a dynamic control problem. The "interior-point" algorithm from the MATLAB optimization toolbox is selected to solve the problem after a test of different algorithms.

Results

Preliminary results show the minimal cost based without environmental constraint is J = 260.88 hour, and the total emission is 3442.9 grams. With continuous environmental constraints described in Equation (6) and the same constrained value 325 grams/km/h, the minimal objective function becomes J = 329.88veh.g/h/km and total emission 3663.8 grams. For the methodology to calculate the latter results we refer to [34]. Note that with the continuous environmental constraint, the minimal travel time increases by 26.5% but the total emission also increases by 6.4% due to increasing travel time despite of decreasing emission rate. It is predictable that the total travel time increases by imposing the local environmental constraints. In this network, these constraints do not decrease the total emission because of different aims. In other words, local environmental constraints can cause negative effects to total environmental aspects. However, in our research, we only focus on the local constraints part, so the deterioration of total environmental aspects cannot be avoided.

Table 1 shows the results of different scenarios. m is the number of time interval in each block, which means the time length of the constrained block is 0.001m hour. *EC* is the constraint, with the unit of grams/km/h.

		J_{min}^{SO-EC}	AC(EC)
No constrain	nts	260.88	0.0%
Continuous	EC=325	329.88	26.4%
	LBC	constraints	
m	EC	J_{min}^{SO-EC}	AC(EC)
500	325	260.88	0.0%
250	325	285.68	9.5%
200	325	292.56	12.1%
100	325	299.34	14.7%
50	325	303.51	16.3%
500	300	262.70	0.7%
250	300	333.49	27.8%
200	300	336.28	28.9%
100	300	362.65	39.0%
50	300	368.78	41.4%

Table 1 Minimal system cost and assessment criterion in different scenarios

The framework assesses the impact of different environmental constraints scenarios. The results show that with LBC emission rate constraints, minimal travel time has less deterioration and corresponding assessment criterion is closer to zero than the scenario with continuous emission rate constraints. In addition, stricter emission rate constraints cause higher minimal travel time and assessment criterion. Both conclusions are predictable, but with the assessment criterion, different scenarios can be numerically compared and qualitatively analyzed.

Figures 4-7 show the different link density based on the different LBC emission rate constraints, LBC flow constraints and LBC density constraints, which are explained in Section 5.3. They show the vehicle density (veh/h) in color related to time and space based on different control measures and different types of constraints. Brighter color indicates more traffic congestion. For example, in Figure 5, a queue downstream of link 1 happens at around time interval 500 because of metering.



Figure 4. Density context plot without constraints



Figure 5. Density context plot with LBC emission rate constraints



Figure 6. Density context plot with LBC Flow constraints



Figure 7. Density context plot with LBC Density constraints

These three results show that in a dynamic system, the purpose of satisfying constraints by way of control measures influence not only the constrained link but also other links. In Figure 5, for instance, the metering control measures are set in both metering points. For the metering point 1, which is downstream of unconstrained Link 1, the effect of metering is to restrict the inflow of Link 2. It reduces the emission rate by reducing the flow according to Equation (6) and Equation (7). This control measure influences link 1 primarily instead of link 2. At the same time, metering point 2 is able to decrease the downstream flow of link 2 as well as the emission factors, in order to keep the average emission rate under the constraints but still give more throughput after one critical constrained period. Both control measures cooperate in order to minimize the total travel time. This proves the proposed idea discussed above: the links with the environmental constraints influence not only the constrained link, but the entire network.

Another phenomenon is that the control approaches are similar when adopting the emission rate constraints or the flow constraints, but the control approach is different for the density constraint. It may be caused by the second order traffic flow model of METANET and does not necessarily has a physical explanation, but we need to verify this with extra analysis. Meanwhile, the phenomenon shown in the second order traffic flow model give us a suggestion to distinguish different constraints. For example, the density constraints lead to different control measures, compared to flow constraints and emission rate constraints.

In addition to the simulation results, this simple case study gives rise to a critical evaluation of the suitability for our purpose of the applied state-of-the-art methodology and algorithms, more specifically of the selected traffic flow and optimization tools. It

appears (from figures 4-7 and further detailed analysis not reproduced here) that the second order traffic flow model exhibits oscillatory congestion patterns that are highly sensitive to METANET's parameter choice. The precise control signal needs to be adapted to these complex wave patterns, hereby causing a slow convergence of the optimization procedure and accordingly high calculation times (approximate 1.5 hours for each scenario in the case study). Even though calculation time can certainly be optimized by more efficient code, we anticipate that for larger networks METANET might not be the most suitable traffic flow model, the more since with route choice involved, multiple iterations are typically needed for the user equilibrium calculation in the lower level problem. In our future work, we will therefore turn to first order traffic flow models which are not expected to reveal these shortcomings. As a consequence, we will lose the smooth properties (continuous derivatives) that made METANET popular for control purposes. However, this problem can be overcome, as is shown among others by Lin[35] who proposed mixed integer linear first order traffic flow formulations and corresponding efficient optimization algorithms.

Conclusion and Future work

Local environmental constraints influence not only the constrained areas but also the whole network. It is therefore necessary to design a framework on the network level to assess the impacts of the local environment constraints. This paper presents the proposed framework based on the bi-level optimization network design problem. One important contribution of this framework is to consider the system optimum problem with additional environmental constraints as its upper level optimization problem. Therefore, the impact of imposing the local environmental constraints on the whole network can be assessed by comparing the potential minimal system cost with and without environmental constraints. In addition, based on this framework LBC emission rate constraints are assessed. These constraints give a balance between the local environment requirement and global traffic accessibility.

The case study indicates that this framework has a feasible solution and the results from the framework can be further elaborated to assess the impact of environment constraints. In addition, by imposing the link-based block-continuous emission rate constraints, the network and corresponding traffic flow achieves the purpose of imposing environmental constraints, while causing less traffic deterioration. The value of constraint and the control critical time slice influence the optimal solution, which require investigation by researchers and detailed selection by policy makers.

The Link-based Block-continuous Emission Rate constraints have a similar trend to Link-based Block-continuous flow constraints. In some traffic design problems, the Link-based Block-continuous flow constraints can be used as a simplified approach to find the corresponding control measures for an environment constraint. Meanwhile, the emission aspects can also be approximated by traffic flow aspects.

In future work, a first order model such as the Cell Transmission Model [36, 37] will be applied in this framework instead of the second order model. Moreover, a small network case including route choice will be studied.

References

- [1] European Commission, Eurostat Database available from: http://epp.eurostat.ec.europa.eu/portal/page/portal/environment/data/database.
- [2] European Commission, "Energy and Transport in figures 2009" available from: http://ec.europa.eu/transport/publications/statistics/statistics_en.htm.
- [3] National Bureau of Statistics of China, China statistical yearbook. Beijing: China Statistics Press, 2007.
- [4] R. E. Waller, et al., "Air Polltion in a City Street," British Journal of Industrial Medicine, vol. 22, pp. 128-138, 1965.
- [5] L. R. Rilett and C. M. Benedek, "Traffic Assignment under Environmental and Equaity Objectives". Transportation Research Record, pp. 92-99, 1994.
- [6] S. Sugawara, et al., "How much can vehicle emissions be reduced? Exploratory analysis of an upper boundary using an emissions-optimized trip assignment," in Energy, Air Quality, and Fuels 2002: Energy and Environment, Washington, 2002, pp. 29-37.
- [7] N. H. Gartner, et al., "Pilot study of computer-based urban traffic management," Transportation Research Part B: Methodological, vol. 14, pp. 203-217, 1980.
- [8] Y. Yin and S. Lawphongpanich, "Internalizing emission externality on road networks," Transportation Research Part D: Transport and Environment, vol. 11, pp. 292-301, 2006.
- [9] C. M. Benedek and L. R. Rilett, "Equitable traffic assignment with environmental cost functions," Journal of Transportation Engineering-Asce, vol. 124, pp. 16-22, Jan-Feb 1998.
- [10] S. K. Zegeye, et al., "Model Predictive Traffic Control to Reduce Vehicular Emissions An LPV-Based Approach," 2010 American Control Conference, pp. 2284-2289, 2010.
- [11] S. K. Zegeye, et al., "Variable Speed Limits for Area-Wide Reduction of Emissions," in The 13th International IEEE Conference on Intelligent Transportation Systems, Madeira Island, Portugal, 2010, pp. 677-682.
- [12] S. Bekhor and O. Iscovitch, "A Model to Minimize Road Traffic Noise in the Planning Phase of a New Neighborhood," in Transportation Research Board, Washington D.C, USA, 2011.

- [13] B. H. Immers and N. Oosterbaan, "Model Calculation of Environment-friendly Traffic Flows in Urban Networks", Transportation Research Record, vol. 1312, pp. 33-41, 1991.
- [14] T. Feng, et al., "An integrated model system and policy evaluation tool for maximizing mobility under environmental capacity constraints: A case study in Dalian City, China," Transportation Research Part D: Transport and Environment, vol. 15, pp. 263-274, 2010.
- [15] Z. Yang, et al., "Car ownership level for a sustainability urban environment," Transportation Research Part D: Transport and Environment, vol. 13, pp. 10-18, 2008.
- [16] S. Sharma, et al., "Pareto Optimal Multiobjective Optimization for Robust Transportation Network Design Problem," Transportation Research Record: Journal of the Transportation Research Board, vol. 2090, pp. 95-104, 2009.
- [17] L. J. J. Wismans, et al., "Comparison of evolutionary multi objective algorithms for the dynamic network design problem," in Networking, Sensing and Control (ICNSC), 2011 IEEE International Conference on, 2011, pp. 275-280.
- [18] T. Larsson and M. Patriksson, "An augmented lagrangean dual algorithm for link capacity side constrained traffic assignment problems," Transportation Research Part B: Methodological, vol. 29, pp. 433-455, 1995.
- [19] T. Larsson, et al., "A column generation procedure for the side constrained traffic equilibrium problem," Transportation Research Part B: Methodological, vol. 38, pp. 17-38, 2004.
- [20] A. T. Chen, et al., "Modeling Physical and Environmental Side Constraints in Traffic Equilibrium Problem," International Journal of Sustainable Transportation, vol. 5, pp. 172-197, 2011.
- [21] H.K. Chen and C.Y. Wang, "Dynamic Capacitated User-Optimal Route Choice Problem," Transportation Research Record: Journal of the Transportation Research Board, vol. 1667, pp. 16-24, Tuesday, January 30, 2007 1999.
- [22] R. X. Zhong, et al., "Dynamic user equilibrium with side constraints for a traffic network: Theoretical development and numerical solution algorithm," Transportation Research Part B: Methodological, vol. 45, pp. 1035-1061, 2011.
- [23] Y. Sheffi, Urban transportation networks : equilibrium analysis with mathematical programming methods. Englewood Cliffs, N.J.: Prentice-Hall, 1984.
- [24] H. K. Chen, Dynamic travel choice models : a variational inequality approach. Berlin ; New York: Springer, 1999.
- [25] A. Kotsialos, et al., "Traffic flow modeling of large-scale motorway networks using the macroscopic modeling tool METANET," Intelligent Transportation Systems, IEEE Transactions on, vol. 3, pp. 282-292, 2002.
- [26] M. H. P. Zuidgeest, "sustainable urban transport development a dynamic optimisation approach" Ph.D., Department of Civil Engineering, University of Twente, Twente, the Netherlands, 2005
- [27] E. Cascetta . Transportation systems analysis models and applications (2nd edition).2008
- [28] A. Kotsialos and M. Papageorgiou, "Efficiency and equity properties of freeway networkwide ramp metering with AMOC," Transportation research part C : emerging technologies., vol. 12, pp. 401-420, 2004.

- [29] K. E. Kakosimos, et al., "Operational Street Pollution Model (OSPM) a review of performed application and validation studies, and future prospects," Environmental Chemistry, vol. 7, pp. 485-503, 2010.
- [30] A. Kotsialos and M. Papageorgiou, "Motorway network traffic control systems," European Journal of Operational Research, vol. 152, pp. 321-333, 2004.
- [31] M. Papageorgiou, et al., "Traffic Simulation with METANET", Fundamentals of Traffic Simulation vol. 145, J. Barceló, Ed: Springer New York, 2010, pp. 399-430.
- [32] Zachariadis, et al., An integrated modeling system for the estimation of motor vehicle emissions vol. 49. Air & Waste Management Association, 1999.
- [33] H. Lieu. Revised Monograph on Traffic Flow Theory. U.S. Department of Transportation Federal Highway Administration, 2003.
- [34] X. Lin, et al., "From Environmental Constraints to Network-wide Environment-Friendly Traffic Patterns –Inverting the Planning Approach for Sustainability", in 12th World Conference on Transport Research Lisbon, Portugal, 2010.
- [35] S. Lin, et al., "Integrated urban traffic control for the reduction of travel delays and emissions," in the 13th International IEEE Conference on Intelligent Transportation Systems, Madeira Island, Portugal, 2010, pp. 677-682.
- [36] D. Carlos F, "The cell transmission model: A dynamic representation of highway traffic consistent with the hydrodynamic theory," Transportation Research Part B: Methodological, vol. 28, pp. 269-287, 1994.
- [37] J. P. Lebacque, "The godunov scheme and what it means for first order traffic flow models," presented at the International symposium on transportation and traffic theory, Lyon, 1996.

MEGACITIES AND HIGH SPEED RAIL SYSTEMS: WHICH COMES FIRST?

Francesca Pagliara, Department of Transportation Engineering – University of Naples; *Joao de Abreu e Silva*, CESUR, Instituto Superio Técnico, Lisboa; *Joseph Sussman; Naomi Stein*, Massachussets Institute of Technology

Corresponding author:

Francesca Pagliara; fpagliar@unina.it

Abstract

A megacity is usually defined as a metropolitan area with a total population in excess of 10 million people. The number of megacities is increasing worldwide: in 1950 there were 4; in 1980 there were 28, in 2002 there were 39 and by 2015 there will be 59. In most agglomerations and megacities, urban planning and public infrastructure can only partially guide urban development in order to achieve a proper sustainable structure. The extension of cities is in most cases in advance of urban development work and the provision of public facilities (Kotter, 2004).

In Europe it is rare to find megacities, apart from London and Paris, both of them megacities for reasons other then the existence of High Speed Rail (HSR). However, due to the general high density of population in Europe and the short distance between medium and large cities HSR can act as a catalyst for the emergence of groups of cities that will be linked together. Thus, with the help of HSR Europe can reap the economic benefits associated with megacities, namely economies of scale, economies of agglomeration and bigger labour markets. This is important because adequate levels of planning might help to avoid the costs of megacities in these European locations.

However, in this contribution the authors argue that in some cases, specific facilities can foster the formation of megacities; in fact, this is the case of High Speed rail systems (see for example, Europe). Specifically, High-Speed trains can be used to solve two different accessibility problems. In the first case, where a point-to-point link is dominant, each train is a potential substitute for an air connection between two cities, i.e. it connects cities (or rather central business districts (CBDs)) located far apart with a direct train connection (Blum *et al.*, 1997). The HSR links between Paris and Lyon, Paris and London and, Tokyo and Osaka, could be seen as examples of this first type of train connection. In this case the train trip together with access and egress times should be compared with the competing solution which consists of the air trip plus the trip to the airport at the trip origin and the trip from the airport at the trip destination.

In the second case, where a HSR network is dominant, the rail system links together many cities and CBDs and, hence, creates a new type of region with a high intra-regional accessibility sharing a common labour market and a common market for household and business services. In this case the HSR binds together cities in a band, where each pair of cities is at a time distance of between 20 minutes and 1 hour, i.e. a time distance that allows daily commuting. For example, in Germany and Italy a number of cities are connected in exactly this manner by HS train.

In the U.S., HSR projects are very recent and they will have the role of connecting already formed megacities. An example is the state of California, which is planning an 800-mile HSR service connecting Los Angeles and San Francisco in a two and a half hour trip.

On the other hand, Europe, together with Asia, is the leader in HSR systems; in fact, the development of HSR has been one of the central features of recent European Union transport infrastructure policy. The proposals for a European HSR network emerged in a 1990 report from the Community of European Railways and this was essentially adopted as the basis for what became the European Community's proposed Trans-European Network for HSR (Vickerman, 1997).

In this paper the case studies of Portugal, where HSR is a work in progress and Italy, in which some lines have already been built, will be described in detail from the viewpoint of the various kinds of development described above.

Keywords: High Speed Rail, Megacities

Introduction

A megacity is usually defined as a metropolitan area with a total population in excess of 10 million people. They could also be defined as large core cities linked by an industrial belt or a continuum of cities (Mory, 1997). The number of megacities is increasing worldwide: in 1950 there were 4; in 1980 there were 28, in 2002 there were 39 and by 2015 there will be 59. In most agglomerations and megacities, urban planning and public infrastructure can only partially guide urban development in order to achieve a proper sustainable structure. The extension of cities in most cases precedes urban development work and the provision of public facilities (Kotter, 2004). In addition to increasing global urbanization, a related but distinct phenomenon is also becoming more prominent: that of the megalopolis or megaregion. A megaregion is an economically integrated but still polycentric area, the formation of which is often induced by high-speed transportation, most notably High Speed Rail (HSR).

Hall (2009) defines a megacity region as a series of cities physically separated but functionally networked, clustered around one or more larger central cities, and connected with dense flows of people and information using important transport infrastructures. It is a process of concentrated deconcentration.

Nowadays our cities are facing multiple crises, including economic recession, congestion, resource scarcity, social and public health concerns, and the consequences of climate change. At the same time, billions of dollars are about to be spent on repairing and building urban infrastructure. This convergence presents us with an historic opportunity to invest these funds differently. The future is represented by designing 21st century smart, green, integrated infrastructure, constructing new models that result in a better environment, improved public health, a stronger economy, and a safer society.

The challenges are immense. What is required is a significant realignment of resources and in fact, entire systems, to achieve the long-term outcomes of health, sustainability, and prosperity.

Many countries of the world are investing in HSR systems which have many advantages compared to other alternative transport modes, since they represent an optimal solution to meet challenges of increasing mobility demand while simultaneously addressing the greater attention of citizens to sustainability issues. HSR offers performance, safety, service, high energy efficiency and environmental friendliness. Moreover, it has the potential to induce megaregional formation and thereby promote economic development at a large scale. Nevertheless this issue is also contentious. Although it is recognized that increases in accessibility like the ones due to HSR could result in positive gains due to effects of agglomeration which could reach up to 20% more than conventional benefits (Graham, 2007), it could lead to space polarization (Gutierrez et al, 1996; Abalate and Bel, 2010) instead of inter-territorial cohesion (Abalate and Bel, 2010), meaning that it is usually the biggest urban agglomerations that benefit the most (Vickerman, 1997;de la Fuente et al, 2006; Abalate and Bel, 2010).

In the U.S., HSR projects are still nascent and they will have the role of both connecting already formed megacities and, hopefully, of furthering megaregional development. An example is the state of California, which is planning an 800-mile HSR service connecting Los Angeles and San Francisco in a two and a half hour trip. The Northeast Corridor connecting Boston, New York, Philadelphia, Baltimore, and Washington, D.C. is also under much discussion. Together these megaregions account for about a third of the US economy.

On the other hand, Europe, together with Asia, is already the leader in HSR systems; in fact the development of HSR systems has been one of the central features of recent European Union transport infrastructure policy. The proposals for a European HSR network emerged in a 1990 report from the Community of European Railways and this was adopted as the basis for what became the European Community's proposed Trans-European Network for HSR (Vickerman, 1997). This "network" essentially links together a series of national plans promoting HSR improvements that emerged during the 1970s and 1980s.

In Europe three different *models* of rail systems can be identified (Campos and de Rus, 2009):

- the French HSR system, conceived only for passengers, set on new lines with peaks of speed equal to 300km/h and non-stop connections between metropolitan areas;
- the German HSR system, conceived for both passengers and freight, also serving intermediate cities with a system of trains with different speeds not superior to 250 km/h, developed on existing but renewed lines;
- the Swiss-English HSR system, consisting in speeding up the Intercity service to 200-225 km/h, combined with a train every hour for any other destination on the network and connections in all the stations, at the same time, with all the passenger trains.

HS trains can be used to solve two different accessibility problems. In the first case, where a point-to-point link is dominant, each train is a potential substitute for an air connection between two cities, i.e. it connects far apart cities (or rather CBD's) with a direct train connection (Blum et al., 1997). The HSR links between Paris and Lyon, Paris and London and, Tokyo and Osaka, could be seen as examples of this first type of train connection. In this case the train trip together with access and egress times should be compared with the competing solution, which consists of the air trip plus the trip to the airport at the trip origin and the trip from the airport at the trip destination.

In the second case, where a HS network is dominant, the train system links together many cities and CBD's (Blum et al., 1997) and, hence, creates a new type of region with a high intra-regional accessibility sharing a common labor market and a common market for household and business services. In this case the HS train binds together cities in a band, where each pair of cities is at a time distance of between 20-55 minutes, i.e. a time distance that allows daily commuting. For example, in Germany and Italy a number of cities are connected in exactly this manner by HS train. It is precisely this option that could contribute to the creation of a megalopolis, by strongly increasing the intra-regional accessibility, creating competitive advantages and even making possible the existence of long distance commuting relationships.

In this contribution the authors argue that in some cases, HSR systems can foster the formation of megacities and/or megaregions. In fact, in Europe megacity regions tend to be smaller and some of them are still in an initial state; additionally, some of them appeared more spontaneously while others are the result of planning policy e.g. South East England (Hall, 2009). However, due to the general high density of population in Europe and the short distance between medium and large cities HSR can act as a catalyst for the emergence of

groups of cities that will be linked together. Thus, with the help of HSR Europe can reap the economic benefits associated with megacities, namely economies of scale, economies of agglomeration, and bigger labour markets. This is important because adequate levels of planning might help to avoid the costs of megacities e.g. socioeconomic disparities and lack of efficient infrastructure (Kotter, 2004) in these European locations.

This paper is organized as follows. Section 2 deals with the formation of megacities and proposed HSR systems in the US. In section 3 the case study of Europe is discussed highlighting two countries, Italy and Portugal.

The case of Italy, reported in section 3.1, focuses on the Napoli-Roma HSR link and the formation of the megacity RONA. The case of Portugal is described in section 3.2. Section 4 presents conclusions and final remarks.

Megacities and HSR in US

At present, there is no High Speed Rail in the United States with the exception of some portions of the northeastern part of the country known as the Northeast Corridor (NEC) and California; even the conventional rail network significantly lags the European systems. Nevertheless, HSR is a topic of considerable debate and discussion at present within the US. Proponents see HSR as a way of moving from the auto- and aviation-oriented 20th century models of mobility towards a more sustainable model for economic growth. As connectivity becomes more important in a globalized service economy and with the continued strain on existing transportation infrastructure caused by growth, rail is seen as a way to transform transportation within the US.

Nevertheless, to successfully implement HSR in the US context means addressing a particular set of challenges. First, a history of underinvestment in rail must be overcome. Over the past fifty years, federal funding for transportation has disproportionately favored highways and aviation (Todorovich et al., 2011). Not only does this mean that HSR would be a considerable jump in rail provision in contrast to the more incremental progression from conventional to high-speed rail in Europe, it also leaves a legacy of inadequate institutional and financial structures to support HSR. The Federal Railway Administration's current responsibility for grant administration extends far beyond its traditional duties of rail regulation (Todorovich et al., 2011). No stable funding exists for rail in the US. Amtrak, the national rail corporation, relies on annual and unstable congressional appropriations, unlike

highways and transit, which receive dedicated revenue from the national gasoline tax. Since the first appropriation of funds for HSR in 2009-2010, 39 states, the District of Columbia, and Amtrak have applied for the \$10 billion made available (Federal Railroad Administration, 2011). In 2011 following the economic crisis, however, congress voted to strip the program of funding and at present the California project is the only one set to move forward (Todorovich et al., 2011).

Second, implementing high-speed rail in a country the size of the US poses considerable political challenges. The federal system means that individual states have significant political influence and this, unless more strategic planning occurs, will result in the spreading of federal funds rather than focusing on corridors with the greatest potential for megaregion formation. California and the Northeast Corridor (covering Boston, New York, Philadelphia, Baltimore, and Washington, D.C.) are the two most promising corridors (see Figure 1). Each serves both existing megacities (i.e. Los Angeles and New York) and would likely advance the emergence of a new type of region in which labor markets and economies benefit from increased regional accessibility. These corridors would aim to solve both types of accessibility problems introduced in Section 1, capturing both short-haul air travel and competing with the automobile for commuter-distance trips.



Figure 1 - Comparison of existing HSR and the US Proposals in California and the NEC (Todorovich et al., 2011)

Finally, an urban form that co-evolved with automobile dependency means that rail in the United States faces the challenge of a dispersed spatial pattern of existing development. This is, however, part of the reason why California and in particular the NEC have high potential for megaregion formation as supported by HSR. Both corridors have the existing

population density, transport network congestion—particularly at airports and on highways and projected growth to support high-quality rail. The NEC represents 20% of the nation's total GDP on just two percent of the land area with a population density approximately twelve times the national average (Amtrak 2010). Its existing rail market comprises 45% of all Amtrak demand, with many more passengers carried by commuter rail services along portions of the same routes (Amtrak Sept. 2010 and 2010). California's economy accounts for 13% of national GDP (Bureau of Economic Analysis, 2010) and its rail demand accounts for at least one fifth of national Amtrak usage (Federal Railroad Administration, 2011).

It remains to be seen whether High Speed Rail will be able to overcome the significant political and financial challenges to succeed in the United States. Questions remain about whether a more incremental approach to upgrade conventional rail would be significant enough to achieve the desired economic benefits or whether true international quality HSR is necessary to foster the formation of a new type of megaregion. The NEC and California have an existing level of density and economic interconnectivity that make these corridors the most likely location of HSR-enabled megaregional formation. However a natural political bias at the federal level toward spreading the resources over many projects across the country rather than focusing on a few substantial projects makes investment problematic.

Megacities and HSR in Europe

The development of HSR has been one of the central features of recent European Union transport infrastructure policy (Vickerman, 1997). The first HS line in Europe, designed at the beginning of the 1960s, was the Direttissima Roma–Firenze. The first HS link in France was the Paris–Lyon and it was opened in 1981. In the second half of the 1980s, the Hannover–Würzburg HSR line was opened in Germany; while in Spain the section Madrid–Cordoba–Seville of 470 km was inaugurated in 1992.

In 2000 Italy had 248 km of HSR line, i.e. around half of those of Germany and Spain and even 1/5 of that of France. In 2006 there were 562 km of new lines with the opening of the Roma–Napoli (to Gricignano) and of the Turino–Novara HSR sections. However, in the same period, Spain increased its HSR kilometres from 470 to 1225. In the following subsections the cases of Italy and Portugal will be analysed in detail.

Megacities and HSR in Italy

The development of the HS/HC network in Italy is embedded in the wider context of the Trans European corridors. Specifically, the big Trans European projects in which Italy is involved, apart from the Water Highways, are (see Fig.2):

- Priority Project n. 1: rail section Berlin Verona Milan –Bologna Naples Palermo;
- Priority Project n. 6 which, by linking Lisbon to Kiev, goes through the Po Valley; it corresponds to the V TenEuropean Corridor;
- Pan-European Corridor VIII: intermodal section Varna-Sofia-Bari;
- Priority Project n. 24: rail link between the port of Genoa and that of Rotterdam through the Gottardo tunnel.



Figure 2 - The Trans-European corridors passing through Italy

The "Direttissima" (HSR line) between Roma and Firenze was opened in 1981 and it represents the first example of a HS rail link in Italy. This was a specific response to the poor quality of the conventional rail route between these cities, which was also the main link between Roma and Northern Italy. However, Italy is currently undertaking a major expansion of HS rail (Cascetta et al., 2009). Once it is completed in 2014, most major cities will be

connected to the network. The key objective for the construction that is currently underway is to raise the Italian rail network to the best European standards and to improve its capacity. After the completion of the HS rail system there will be a reduction in travel time between the major cities connected on the order of 40-50% (see Table 1).

In addition to HS rail, High Capacity (HC) rail lines consist of speeding up and increasing the capacity of the existing rail lines. In this case, the new rail lines have lower speed values, but at the same time they allow a better service. In fact it is on these rail lines that the regional service for travelers and freight is made. An example of this type is the Regional Metro System (RMS) project of the Napoli and Campania region in Italy (Cascetta and Pagliara, 2008).

Link	Travel time on old rail lines	Travel time on new rail lines	% Reduction of travel time due to the new HS/HC rail lines
Torino-Milano	1h-30'	50'	-44%
Milano-Venezia	2h-43'	1h-25'	-48%
Milano-Bologna	1h-42'	60'	-41%
Milano-Roma	4h-30'	3h	-33%
Torino-Napoli	8h-30'	5h	-41%
Bologna-Firenze	59'	30'	-49%
Roma-Napoli	1h-45'	1h-05'	-38%
Roma-Bari	4h-30'	3h	-33%
Napoli-Bari	3h-40'	2h	-45%

Table 1: Reduction of travel times due to the new HS/HC rail lines

The national Italian network and operations are all owned by FS (State Railway) Holdings, a fully government owned company. It has three key operating subsidiaries: Trenitalia operates all freight and passenger trains, including the high-speed trains, RFI (Rete Ferroviaria Italiana) manages the infrastructure, and TAV (Treno Alta Velocità SpA) is responsible for the planning and construction of the new HS infrastructure.

The 195 km rail link from Roma to Gricignano was opened in December 2005. The line is still not completed as of yet as the 18 km rail link from Gricignano of Aversa to Napoli Afragola and the link penetrating the node of Napoli are still under construction (see Fig. 3). The completion of this stretch will bring a reduction of travel time from the current 87 minutes to a travel time between 60 and 65 minutes.



Figure 3 - The HSR link between Napoli and Roma

The new rail link connects two of the largest Italian metropolitan areas. The metropolitan area of Roma has a number of residents equal to 4,145,822 and a residential density of 473.19 inh/km² while the metropolitan area of Napoli has a number of residents equal to 3,582,900 and the highest residential density in Italy which is equal to 1900.27 inh/km². The two metropolitan areas are very different from each other. In a study of the 14 Italian metropolitan areas (de Luca *et al.*, 2007), an analysis of the intensity of total systematic relationships was carried out and the results indicate an urban polarised growth, i.e. a non-dispersed growth which gives rise to new central places. The latter were identified through some indicators, such as the total systematic relationship among municipalities and the intensity of total relationship indicators. The first one is given by:

$$Tot_syst_rel_mun_i = \sum_{j=1}^{n} Gen_{ij} + \sum_{j=1}^{n} Dest_{ij} \quad i \neq j$$
(1)

where:

n is the number of municipalities of the region to which municipality *j* belongs;
 *Gen*_{ij} are the generated systematic relationships from municipality i to municipality j;
 *Dest*_{ij} are the destinated systematic relationships to municipality j from municipality i.
 The intensity of total systematic relationships indicator is given by.

$$Intensity_Tot_syst_rel_mun_{i} = \frac{\sum_{j=1}^{n} Gen_{ij} + \sum_{j=1}^{n} Dest_{ij}}{Residents_{j}} \cdot 1000 \quad i \neq j$$
(2)

The latter has been considered fundamental for the identification of the polarisation phenomenon in large urbanised areas. Under the same number of systematic relationships, this ratio is more intense for the municipality with less demographic weight; while a municipality which falls into the attractive orbit of two municipalities is considered strictly linked to the municipality with which the intensity of total systematic relationships is greater.

The polarisation phenomenon within these 14 urban areas creates Second Level Urban Systems (SLUS), i.e. sets of neighbouring municipalities with a reference pole, all reciprocally integrated into a first level urban system. Specifically, three different urban forms can be identified: monocentric, when it is possible to identify just one prevailing pole (like the case of Roma, see Fig. 4); polycentric, when there is a main pole and SLUS with some towns exceeding 100,000 inhabitants (this is the case of the urban area of Napoli, see Fig. 5); multipole, when the system is a set of poles of the same level (Veneto urban area).

According to the classification reported in section 1, the Roma-Napoli HSR link is similar to the French one and solves the second problem of accessibility.



Fig.4 – The monocentric area of Roma



Fig. 5 – The polarized area of Napoli

In March 2008 a Revealed Preference survey was carried out on the multimodal connection Roma-Napoli and vice versa. The reference universe is made up of all the users who travel on the connection under study with HS trains, but also with the alternative modes/services of Eurostar (ES) trains, Intercity trains (IC) and by car on the motorway. The main outcome of the survey is that the use of a private car and of Intercity trains have almost remained unchanged during the few years of operation of the HS service, while the use of HS services have significantly increased. It follows that a generated demand is derived from the use of this HSR link and the modal share is increased as well in favour of train. This result is very interesting since the introduction of the new service also increases the level of interaction between the two cities. Specifically, from 2005 to 2007 the share between train and car has risen from 49% and 51% to 55% and 45% respectively (Cascetta et al., 2011).

Concerning access/egress to/from station, the most used means of transport are metro and taxi in Roma and taxi and private car in Napoli (see Table 2). Analysing the origin and destination of both train and car users (see Table 3) shows that, because of the impact of access/ egress times, train users are more likely to travel on the origin– destination (OD) pair Roma/Napoli. Moreover, this effect is larger when Roma is the final destination of the trip, as a consequence of the already mentioned monocentric structure of its metropolitan area (values circled in Table 3).

	Roma Napoli				Napoli Roma			
Access/egress mean	access (nr. of user)	%	egress (nr. of user)	%	access (nr. of user)	%	egress (nr. of user)	%
walking/bycicle	146	16.7	104	11.9	143	18.7	111	14.5
car/motorbike	142	16.2	216	24.7	184	24.0	118	15.4
taxi	206	23.6	177	20.3	239	31.2	173	22.6
bus/tram	134	134 15.3 113 12.9			79	10.3	103	13.4
metro/funicular 237 27.1		145	16.6	116	15.1	210	27.4	
train	5	0.6	111	12.7	2	0.3	50	6.5

Table 2 – Access/egress means of transport for HS users

Table 3: Trips from Napoli and Roma

		NAPLES	PROV. OF NAPLES	ROME	PROV. OF ROME	OTHER	
	NAPLES ROME	0 53	0 33	86 0	10 0	3 14	Weekday
R	NAPLES ROME	0 55	0 38	91 0	8 0	1 7	Saturday
Ö	NAPLES ROME	0 61	0 26	81 0	10 0	9 13	Sunday
	NAPLES ROME	0 57	0 32	85 0	10 0	5 11	Total

	ORIG	NAPLES	PROV. OF NAPLES	ROME	PROV. OF ROME	OTHER	
S	NAPLES ROME	0 68	0 24	96 0	2 0	2 8	Weekday
	NAPLES ROME	0 62	0 29	91 0	1 0	8 9	Saturday
T	NAPLES ROME	0 66	0 27	82 0	6 0	12 6	Sunday
	NAPLES ROME	0 66	0 26	92	2 0	5 8	Total

	DEST	NAPLES	PROV. OF NAPLES	ROME	PROV. OF ROME	OTHER	
IC	NAPLES ROME	0 62	0 32	88	7 0	5 6	Weekday
	NAPLES ROME	0 70	0 28	86	7 0	8 2	Saturday
	NAPLES ROME	0 70	0 25	87	4 0	9 5	Sunday
	NAPLES ROME	0 68	0 28	87	6 0	7 4	Total

	DEST	NAPLES	PROV. OF NAPLES	ROME	PROV. OF ROME	OTHER	
ES	NAPLES ROME	0 85	0 15	92	3 0	5 0	Weekday
	NAPLES ROME	0 73	0 22	91	2 0	7 5	Saturday
	NAPLES ROME	0 80	0 20	88	3 0	9 0	Sunday
	NAPLES ROME	0 78	0 19	90) 3 0	7 3	Total

The HSR project in Portugal as a tool to help the creation of a Megacity

The Portuguese HSR project includes three priority links - Lisbon-Madrid, Lisbon-Oporto, and Oporto-Vigo corridors - with a total length of about 650 km and an investment of around € 8 billion. It also includes some significant and costly civil structures such as the Tagus Crossing in Lisbon (see Fig. 6). The corridor Lisbon – Madrid had as its main objective to link these two capital cities with no intention of creating a Megapolis.

The other two main corridors were planned with the objective of reinforcing intra and interregional links either betwen the two main Portuguese cities (Lisbon and Oporto) and between the north of Portugal and the Galiza region in Spain.



Fig. 6 – The Portuguese HSR network (RAVE)

A quite significant proportion of the Portuguese population lives in the stretch between Braga (around 50 km north of Oporto) and Setubal (in the Lisbon Metropolitan Area, around 30 km south of Lisbon). Between Lisbon and Oporto cities like, Leiria, Coimbra and Aveiro are ranked in the higher positions of the Portuguese urban hierarchy. Although the population density of Portugal is relatively high around 115-120 inhab./km2 (higher than France), in general its cities tend to be of spatially smaller.

The rationale behind this project is included in several policy documents published by the Portuguese Government, namely the PNPOT, the National Program for the Policy of Territorial Planning. The document focused on all aspects related to planning and spatial development, several of them focusing on issues directly linked to the orgnization of the urban structure and the transportation sector. The main lines of this diagnosis are the following (MAOTDR, 2007):

- The more dynamic and polarizing areas in the country are located along the coast between the metropolitan areas of Lisbon and Oporto;
- Both metropolitan areas (Lisbon and Oporto) are quite strong when considering the national population but are still fragile in its international functional projection. Between them exists a large area with diffuse urbanization and several polynucleated urban areas puntuacted by some cities of regional importance. These major cities, although considered as large medium cities in the Portuguese context, don't have the demographic dimension to be considered as medium cities in the European context.
- Two main tendencies have appeared in the last decades. The first one is the depopulation of the rural areas and the urbanization of the country's population. In the decade of the 1990's there was a stabilization of the demographic weight of the two metropolitan areas (Lisbon and Oporto), as well as the reinforcement of several medium cities, particularly in the coastal areas. This was achieved through a more diffuse urbanization or sprawl. This pattern is also associated with a rise in car ownership and motorization rates, which also helped to increase the intensity of interurban relations, contributing to the rise of regional and subregional urban systems;
- In the last decades there was a strong investment in road infrastructures that were mainly concentrated along the coast and linking the two metropolitan areas as well as some important medium cities in the interior. As a result, the road density is quite high. The rail sector also experienced important changes with the investment concentrated in more important rail corridors and with several low demand lines deactivated. Nevertheless, this rationalization was not enough to stop the decline of rail market share in interurban trips.

Thus as a result of these dynamics the PNPOT indicates that the main problems are associated with:

- A strongly carbon-energy intensive transportation sector due to the heavy reliance on road based transportation, leading to a strong dependency on external energy sources;
- A strong geographical dispersion in economic infrastructures and facilities leading to their weak international presence which leads to losses of scale and atrophy of the more developed economic functions;
- An insufficient international presence of urban functions in the main urban agglomerations, which creates difficulties in the country's participation in the international investment and economic flows.

Thus the introduction of HSR in Portugal was seen in this document as a strategic tool to help reshape the regions served by this mode. Therefore, HSR would contribute to organize the cities in the northwest of the Iberian Peninsula (Line between Oporto and Vigo), to reinforce the urban centers of Leiria, Coimbra and Aveiro (Line between Lisbon and Oporto), since these are served by the HSR, and to insert Lisbon in the HSR transeuropean networks and thus increase its role in the context of the great European regions (Line between Lisbon and Madrid). Besides these objectives the line between Lisbon and Oporto would help the creation of a Megalopolis, since travel time between both cities would be around 1h15m (SDG/VTM, 2009). This corridor encompasses 63% of the total number of companies, 70% of the total GDP, 61% of the total population, and 37% of the total number of tourists in Portugal (AtKearney, 2003).

Several studies undertaken since 2000 have stressed the potential benefits of HSR in Portugal and its capability to help the formation of a megalopolis in the region between Lisbon and Oporto (with a population of around 6 million inhabitants):

- HSR could be thought of as both an instrument of economic policy by reducing regional asymmetries and territorial management (SOCINOVA, 2003),
- The Lisbon Porto line considered the existence of both direct services and others with intermediate stops which contributed to the existence of a bundle of services (contribute to the internal cohesion in the corridor and reinforcing connections between all of the cities located inside of it). At the same time one of the objectives of the project was to reinforce the competitiveness of those intermediate cities by increasing their accessibility in order to transcend their spatial limitations (SDG/VTM, 2009).
- The indirect economic benefits envisioned for the project encompassed economies

of agglomeration (due to the increase in accessibility and reduction in travel times), and impacts on the labor market. The benefits due to the economies of agglomeration were estimated at 64 million euros. The impacts for the labor market was significantly inferior, only 350 thousand euros. This was due to the low number of commuting trips, since the demand studies didn't explicitly consider the possibility of induced traffic due to the effects of super commuting. The impact on imperfect competition is again on the magnitude of the agglomeration economies, around 26.5 million euros (SDG/VTM, 2009).

Although the HSR project in Portugal has lost its momentum due to the international crisis of 2008 and subsequent sovereign debt crisis of 2011, it results at least partly from a voluntary approach from the Portuguese authorities to create a megaregion between Lisbon and Oporto that could transcend the small demographic limitations of Portuguese cities and put them in a paradigm of networked cities in order to dissociate the relations between dimension and urban functions (Capelllo and Camagni, 2000).

Conclusions

In this paper, the authors elaborated on the phenomenon of HSR-induced creation of megacities or megaregions. The detailed investigation of the Roma-Napoli case reveals generated demand as a result of the HS service. Similarly, HSR in Portugal was planned in order to explicitly contribute to a creation of a megacity region between Lisbon and Oporto by strongly increasing the intra-regional accessibility, creating competitive advantages and even allowing for the existence of long distance commuting relationships. In general, indicators of HSR-induced megaregion formation include an increase in one-day round trips, high levels of induced demand (particularly for business trips), an increase in the number of daily commuters, and a decrease in overnight stays (Melibaeva, 2010).

HSR investment is usually promoted not only as a means to increase capacity, improve service, and reduce greenhouse gas emissions, but also as a way to promote regional economic development. The formation of new types of regions, aided by the provision of both air- and auto- competitive accessibility, is a key piece of the economic development argument. Less easy to predict, however, is whether induced growth is truly new. That is, does HSR play a catalytic role by enabling travel that would not occur otherwise, or are HSR's regional effects more redistributive, resulting in zero-sum growth with "winners" and "losers"? In studies of the Tokyo-Osaka line in Japan, the Paris-Lyon link in France, and the Cologne-Frankfurt connection in Germany, Melibaeva (2010) finds no evidence for *net*
growth caused by HSR at the national scale. However in these cases and others such as the NEC in the U.S., an argument can be made that improving mobility in regions that are the "economic engines" of various nations are good strategic investments over the long run. And the environmental advantages should not be overlooked.

From this we see that HSR alone is not enough to achieve the economic benefits of megaregional formation, but instead requires concerted policy efforts. Available policy tools to maximize economic benefits and regional growth while minimizing negative distributional effects include providing adequate frequency of service to smaller intermediate cities, and providing intermodal linkages (both to the conventional rail and urban transit networks) to extend the benefits of HSR to areas not directly served. Coordinating such policies requires planning at a new spatial scale. For example, the trade-off between dominant O-D pair travel times (and thus HSR competitiveness) and adequate frequency to smaller cities necessitates optimization at the regional level, which in turn implies governance at that level. This type of institutional challenge is one of the primary barriers at present to HSR in the US. In the NEC of the U.S., numerous US states are involved along with the Federal government and regional organizations such as the I-95 Coalition. The institutional constraints are indeed daunting. Also, on a national scale in the U.S., political imperatives to spread HSR investments around the nation are counter to the need for focused funding on corridors in which HSR makes sense. In Italy, on the other hand, regional coordination was more readily achieved due to the existence of one unified rail company.

References

- Albalate, Daniel and Bel, Germá (2010), High Speed Rail: Lessons for Policy Makers from Experiences Abroad, Institut de Recerca en Economia Aplicada Regional i Pública, Working Paper 2010/03.
- Amtrak (2010). National Fact Sheet: FY 2010, pp. 1.
- Amtrak (September 2010). A Vision for High-Speed Rail in the Northeast Corridor.
- ATKearney (2003), Visão estratégica para a rede ferroviária de Alta Velocidade em Portugal, Relatório Final, http://www.refer.pt/MenuPrincipal/TransporteFerroviario/AltaVelocidade/Estudos.aspx, accessed in January 2012.
- Bureau of Economic Analysis (2010). Regional Data, GDP & Personal Income, GDP by State (current dollars): %of U.S. http://www.bea.gov/iTable/index_nipa.cfm
- Blum, U., Haynes, K.E. and Karlsson, C. (1997) The regional and urban effects of high-speed trains, The Annals of Regional Science, 31, 1 – 20.
- Campos, Javier and de Rus, Ginés (2009), Some stylized facts about high-speed rail: A review of HSR experiences around the world, Transport Policy, 14, pp 19-28.

- Capello, Roberta and Camagni, Roberto (2000), Beyond Optimal City Size: An Evaluation of Alternative Urban Growth Patterns, Urban Studies, Vol. 37, No 9, pp 1479-1496.
- Cascetta E. and Pagliara F. (2008): Integrated Railways-based Policies: The Regional Metro System project of Naples and Campania, Transport Policy, Vol. 15, N.2, pp. 81-93.
- Cascetta, E., Papola, A., Pagliara, F., Marzano, V. and Gentile, D. (2009): Analisi degli impatti sulle scelte di mobilità e di localizzazione della linea AV Roma-Napoli, Ingegneria Ferroviaria, 7/8, pp 649-665.
- Cascetta, E., Papola, A., Pagliara, F. and Marzano, V. (2011): Analysis of mobility impacts of the high speed Rome–Naples rail link using withinday dynamic mode service choice models, Journal of Transport Geography, 19, pp. 635-643.
- de la Fuente, Raul Serrano, Antín, Maddi, Capdepón, Félix, Francès, José María and Tordesillas, José María (2006), Análisis de las consecuencias territoriales del AVE en ciudades pequeñas: Ciudad Real y Puertollano, Estudios Geográficos, LXVII, 260, Enero-Junio, pp 199-229.
- Federal Railroad Administration (2011). High-Speed Intercity Passenger Rail Program. http://www.fra.dot.gov/rpd/passenger/2243.shtml
- de Luca M., Pagliara F. and Crisci L. (2007): Aree metropolitane in Italia e prospettive per il trasporto ferroviario. In La ferrovia nelle aree metropolitane italiane, Marino de Luca and Francesca Pagliata (eds), Aracne, pp. 39-65.
- Graham, Daniel (2007), Agglomeration Economies and Transport Investment, Discussion Paper 2007-11, International Transport Forum, OECD.
- Gutierrez, Javier, Gonzaléz, Rafael and Gómez, Gabriel (1996), The European High Speed Train network. Predicted effects on accessibility patterns, Journal of Transport Geography, Vol. 4, No 4, pp 227-238.
- Hall, Peter (2009), Looking Backward, Looking Forward: The City Region of the Mid-21st Century, Regional Studies, Vol. 43.6, pp. 803–817.
- Kotter, T. (2004): Risks and Opportunities of Urbanisation and Megacities, paper presented at FIG Working Week 2004, Athens, Greece, May 22-27.
- Melibaeva, Sevara. (2010): Development Impacts of High-Speed Rail: Megalopolis Formation and Implications for Portugal's Lisbon-Porto High-Speed Rail Link (Master's thesis), pp. 159, 161, 168, 181-182.
- Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional (MAOTDR) (2007), Programa Nacional da Política de Ordenamento do Território, http://www.territorioportugal.pt/pnpot/, accessed in January 2012.
- Mori, Tomoya (2001), Modeling of Megalopolis Formation: The Maturing of City Systems, Journal of Urban Economics, 42, pp 133-157.
- SOCINOVA (2003), Análise Demográfica e socio-económica dos corredores ferroviários portugueses e a rede de alta velocidade, http://www.refer.pt/MenuPrincipal/TransporteFerroviario/AltaVelocidade/Estudos.aspx, accessed in January 2012.
- Steer Davies Gleave and VTM (SDG/VTM) (2009), Análise Custo Benefício da Ligação em Alta Velocidade Ferroviária da Ligação Lisboa – Porto, http://www.refer.pt/MenuPrincipal/TransporteFerroviario/AltaVelocidade/Estudos.aspx, accessed in January 2012.
- Todorovich, P., Schned, D., and Lane, R. (2011) High-Speed Rail: International Lessons for U.S. Policy Makers, Lincoln Institute of Land Policy, pp. 2, 3, 6, 12.
- Vickerman, R. (1997) High-speed rail in Europe: experience and issues for future development, The Annals of Regional Science, 31, 21-38.

PART III

ACCESSIBILITY AS A KEY TO SUSTAINABLE MOBILITY

ACCESSIBILITY ANALYSIS AND DUTCH TRANSPORT POLICY

Karst Geurs, University of Twente, Enschede

Corresponding author:

Karst Geurs; K.T.Geurs@utwente.nl

Introduction

A principal goal of transport policy is to improve accessibility: the transport system should allow people to travel and participate in activities, and firms to transport goods between locations. Accessibility is a concept that has become central to physical planning during the last fifty years; improving accessibility is an aim which has now made its way into mainstream transport planning and policy-making throughout the world. Batty (2009) traces the origins of the concept back to the 1920s. It was used in location theory and regional economic planning, becoming important once transport planning began, mainly in North America where it was associated with transport networks and trip distribution patterns. Its conceptual basis dates back further. Hansen (1959), in his classic and much cited expose, 'How accessibility shapes land use' rolled out our first real definition: the potential for interaction (based on the notion of potential traced back to the social physics school in the 19th century).

However, despite the crucial role of accessibility in transport policy-making throughout the world, accessibility is often a misunderstood, poorly defined and poorly measured construct. Accessibility is defined and operationalised in several ways, and thus has taken on a variety of meanings. Gould (1969) noted that "one of the problems with accessibility is that "accessibility is a slippery notion... one of those common terms that everyone uses until faced with the problem of defining and measuring it". Indeed, defining and operationalising accessibility can be rather complex. This is problematic, because the choice and operationalisation of an accessibility measure may strongly affect the conclusions on accessibility. For example, Linneker and Spence (1992) illustrated that inner

London has the highest access costs (in terms of time and vehicle operation costs) in the UK, but the highest level of potential accessibility to jobs, despite the high travel cost.

In this paper, we examine if the progress in accessibility analysis is matched with advances in the use of accessibility measures in national transport policy in the Netherlands. Handy and Niemeier (1997) highlighted the gap between academic and practical applications of accessibility; asserting, "It is important that accessibility measures used in practice are theoretically and behaviourally sound and that innovative approaches to measuring accessibility are made practical" (Handy and Niemeier, 1997, page 1192). Here, we examines if researchers and practitioners working with these accessibility concepts in the Netherlands have heeded this advice.

Section 2 gives a brief review of accessibility measures and directions in which accessibility analysis and modelling has progressed. Section 3 reviews the accessibility measures used in Dutch Transport Policy and Planning from the 1970s. Section 4 gives conclusions and discusses the results.

Literature review

Defining accessibility

Several authors have written review articles on accessibility measures, often focussing on a particular category of accessibility, like location-based accessibility (Martín and Reggiani, 2007; Reggiani 1998), person-based accessibility (e.g., Kwan, 1998; Pirie, 1979) or utility-based accessibility (e.g., Koenig, 1980; Niemeier, 1997). Here we use the review of Geurs and Van Wee (2004), as a point of departure to look at accessibility measures from different perspectives.

As already noted, accessibility is defined and operationalised in several ways, and thus has taken on a variety of meanings. These include such well-known definitions as 'the potential of opportunities for interaction' (Hansen, 1959) 'the ease with which any land-use activity can be reached from a location using a particular transport system' (Dalvi and Martin, 1976), 'the freedom of individuals to decide whether or not to participate in different activities' (Burns, 1979) and 'the benefits provided by a transportation/land-use system' (Ben-Akiva and Lerman, 1979).

Here, accessibility measures are interpreted as indicators for the impact of land-use and transport developments and policy plans on the functioning of the society in general. This means that accessibility should relate to the role of the land-use and transport systems in society, which will give individuals or groups of individuals the opportunity to participate in activities in different locations. Subsequently, accessibility is defined as: "the extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s) at various times of the day (perspective of persons), and the extent to which land-use and transport systems enables companies, facilities and other activity places to receive people, goods and information at various times of the day" (perspective of locations of activities).

Components of accessibility

Four components of accessibility can be distinguished: a land-use, transportation, temporal and individual component (Geurs and Van Wee, 2004):

- The land-use component reflects the land-use system, consisting of (a) the amount, quality and spatial distribution opportunities supplied at each destination (jobs, shops, health, social and recreational facilities, etc.), and (b) the demand for these opportunities at origin locations (e.g. where inhabitants live), (c) the confrontation of supply of and demand for opportunities, which may result in competition for activities with restricted capacity such as job and school vacancies and hospital beds (see Van Wee et al., 2001).
- 2. The transportation component describes the transport system, expressed as the disutility for an individual to cover the distance between an origin and a destination using a specific transport mode; included are the amount of time (travel, waiting and parking), costs (fixed and variable) and effort (including reliability, level of comfort, accident risk, etc.). This disutility results from the confrontation between supply and demand. The supply of infrastructure includes its location and characteristics (e.g. maximum travel speed, number of lanes, public transport timetables, travel costs). The demand relates to both passenger and freight travel.
- The temporal component reflects the temporal constraints, i.e. the availability of opportunities at different times of the day, and the time available for individuals to participate in certain activities (e.g. work, recreation).
- 4. The individual component reflects the needs (depending on age, income, educational level, household situation, etc.), abilities (depending on people's physical

condition, availability of travel modes, etc.) and opportunities (depending on people's income, travel budget, educational level, etc.) of individuals. These characteristics influence a person's level of access to transport modes (e.g. being able to drive and borrow/use a car) and spatially distributed opportunities (e.g. have the skills or education to qualify for jobs near their residential area), and may strongly influence the total aggregate accessibility result. Several studies (e.g., Cervero et al., 1997; Geurs and Ritsema van Eck, 2003; Shen, 1998) have shown that in the case of job accessibility, inclusion of occupational matching strongly affects the resulting accessibility indicators.

The different components have a direct influence on accessibility, but also indirectly through interactions between the components. For example, the land-use component (distribution of activities) is an important factor determining travel demand (transport component) and may also introduce time restrictions (temporal component) and influence people's opportunities (individual component). The individual component interacts with all other components: a person's needs and abilities that influence the (valuation of) time, cost and effort of movement, types of relevant activities and the times in which one engages in specific activities.

Following our definition of accessibility, an accessibility measure should ideally take all components and elements within these components into account. In practice, applied accessibility measures focus on one or more components of accessibility, depending on the perspective taken. There are four basic types of accessibility measures generally used:

- Infrastructure-based accessibility measures, analysing the (observed or simulated) performance or service level of transport infrastructure, such as the length of infrastructure networks, the density of those networks (e.g., kilometre road length per square km), level of congestion, and average travel speed on the road network. This type of accessibility measure is typically used in transport planning. Some of these measures focus only on the supply of infrastructure, while others also use demand factors.
- 2. Location-based accessibility measures, analysing accessibility at locations, typically on a macro level. The measures describe the level of accessibility to spatially distributed activities, such as 'the number of jobs within 30 minutes travel time from origin locations'. More complex location-based measures explicitly incorporate capacity restrictions of supplied activity characteristics to include competition effects.

147

- 3. Person-based accessibility measures, analysing accessibility at the individual level, such as 'the activities in which an individual can participate at a given time'. This type of measure is founded in the space-time geography (Hägerstrand, 1970) that measures limitations on an individual's freedom of action in the environment, i.e. the location and duration of mandatory activities, the time budgets for flexible activities and travel speed allowed by the transport system.
- 4. Utility-based accessibility measures, analysing the (economic) benefits that people derive from access to the spatially distributed activities. This type of measure has its origin in economic studies and is increasingly receiving attention in accessibility studies (e.g, de Jong et al., 2007; Geurs et al., 2010).

Trends in accessibility analysis

In recent decades, the term accessibility has marshalled renewed interest from civil engineering, geography, spatial economics and other academic fields due to its potential when delivering policies requiring cross sector action. We have witnessed considerable progress in accessibility analysis and modelling. First, within the land use planning perspective, there is trend towards increased spatial resolution of accessibility measurements, using transport models with detailed transport networks and increasing use of Geographic Information Systems (GIS) platform to extract and assemble data from multiple spatial databases at fine levels of spatial resolution (e.g., see Chen et al., 2011; Kwan, 2000).

A second trend is towards disaggregated accessibility measures, largely recognizes that aggregate measures fail to account for wide variation in individual behaviour and population groups at different spatial scales. Person-based accessibility, analysing accessibility at the individual level - as opposed to a zonal levels - gains traction by further understanding human activities and travel possibilities in space and time (e.g., see Ashiru et al., 2003; Dong et al., 2006; Kwan, 2000; Neutens, 2010; Schwanen and Kwan, 2008). In a fast changing world, the travel behaviour responses are highly uncertain since new media, networks, new challenges and new ways of working mean that past trends are a poor guide to the future, so Halden highlights the benefits of a more disaggregate treatment to help manage uncertainty when making policy choices (Halden 1996).

A third trend gives increasing attention to measuring the social dimension of transport using accessibility concepts, linking accessibility concepts to social exclusion, social equity,

and/or social justice (Burdack et al., 2005; Farrington and Farrington, 2005; Scott and Horner, 2008; Zhang et al., 1998). A related trend is to focus on non-motorised accessibility and related individuals' perceptions of residential environments (lacono et al., 2010; Krizek, 2010).

Finally, in academic accessibility studies, increasing attention is paid to measuring the spatial-economic impacts accruing from accessibility changes, ranging from analysis of utility-based accessibility measures (de Jong et al., 2007; Geurs et al., 2010; Geurs et al., 2006) to spatial spillover effects (e.g., see Condeço-Melhorado et al., 2011; Gutiérrez et al., 2011; Gutiérrez et al., 2010).

Accessibility in Dutch Transport Policy and Planning

History of transport policy concepts and goals

Since the start of national transport policy there have been four major national transport policy documents. Here, we briefly describe the main policy concepts used in these documents. Table 1 summarizes the main concepts.

Policy document	Indicator
First Transport Structure Plan (1979)	level-of-service (motorways)
Second Transport Structure Plan (1990)	Congestion probability (motorways)
	Detour factor (motorways)
	Distance to access road (motorways)
	Capacity (motorways)
	Relative travel time (car/public transport)
	Speed (rail)
	Number of delayed trains (rail)
Mobility Report (2004)	Relative travel time between peak/off peak hours
	(motorways)
	Travel time reliability (motorways)
	Vehicle-hours lost (motorways)
	Punctuality (rail)
National Policy Strategy for	Relative travel time between peak/off peak hours
Infrastructure and Environment	(motorways)

Table 1 Transport performance based concepts used in the main Dutch National Transport Policy documents (passenger transport)

Generalised transport cost

The First Transport Structure Plan, 1979

The central concept of the first transport structure plan (abbreviated as 'SVV1') (Ministry of Transport Public Works and Water Management, 1990b) was the level of service indicator as defined in the US Highway Capacity Manual published by the Transportation Research Board. Flow level A refers to uninterrupted flows and level F to heavy congested flows. The transport performance goal was to achieve a C-level of service (80-90 km/hour) for motorways in rural areas on working days and D/E level (50-70 km/hour) for motorways in metropolitan and urban areas. The latter implied that a certain level of structural congestion was accepted. It was recognized that congestion cannot be completely solved by increasing road capacities: "the demand for mobility will be met in so far as the contribution to the welfare of the community has a positive balance." Although many transport policies were targeted at improving rail and regional public transport, accessibility objectives for these modalities were only described in qualitative terms.

The Second Transport Structure Plan, 1990

Transport planning, modelling and cost-benefit analyses were decisive factors in setting the transport performance based accessibility targets in the second transport structure plan ('SVV2') (Ministry of Transport Public Works and Water Management, 1990a). The national transport model system (LMS), developed in the 1980s (Bovy et al., 1992), was used to examine the desired structure and transport performance of the motorway network for the year 2010. The national transport model still is the main transport demand model used to underpin Dutch national transport policy. The starting point of designing the future motorway network structure was the aim to directly connect the main 40 economic centres in the country. A detour factor of 1.2 was considered good, a detour factor between 1.2 and 1.4 was considered reasonable and 1.4 and higher was considered poor. The second requirement was that car drivers were to access the motorway network within 15 minutes travel time (about 10 kilometres distance) from centres of economic activities. Finally, the concept of 'congestion probability' was used to indicate the probability of structural congestion on motorway road segments during working days. The national transport model was used to forecast these probabilities for transport network alternatives, and a (relatively simple) partial cost-benefit was used to determine the 'optimal' congestion probability. The smaller the accepted congestion probability, the higher the road capacity increase and

(2012)

investment costs. The CBA included travel time losses, traffic safety and the construction and maintenance costs. Environmental costs were not included in the study. The 'optimal' congestion probability was found to lie between 1% and 3%. o account for environmental impacts and avoid infrastructure construction in natural areas, SVV2 finally set a 2% congestion probability as the main transport performance goal for motorways that connect Rotterdam and Schiphol airport to the hinterland, and 5% probability for other motorways. The SVV2 was also quite unique in setting quantified targets for reducing car use ('halving the growth in car traffic') and providing transport performance based accessibility for other modes, for example in terms of rail speed, number of delayed trains, and travel time ratios between trains and cars.

Mobility Policy Document, 2004

The key objective of the Mobility Policy Document ('Nota Mobiliteit') (Ministry of Transport Public Works and Water Management, 2006) was to improve economic competitiveness of economic centres in the Netherlands by improving accessibility, while at the same time reducing environmental damage. The key concept of the policy document was to achieve a "reliable and predictable door to door travel times". Three types of transport performance based accessibility targets were set:

- A travel time reliability target: by 2020, with travellers should reach their destination on time in 95% of cases. This target was operationalised as follows: over longer distances (above 50 kilometres), a maximum of 20% of the journey times are shorter or longer than the expected journey time and, over shorter distances, the journeys are a maximum of 10 minutes shorter or longer than the expected journey time. The expected journey time was defined as the median of the travel time.
- A travel time target. Rush-hour travel time were not to exceed 1,5 times the off-peak journey time on motorways or 2 times the off-peak journey time on urban orbital roads and non-motorway roads managed by the state. This would make the average motorway rush-hour journey time over a distance of 50 kilometres 45 minutes at maximum (maximum delay 15 minutes). On urban (orbital) roads and non-motorway roads, the average rush-hour journey time over a distance of 10 kilometres will be a maximum of 12 minutes (maximum delay 6 minutes).
- Thirdly, and finally, an accessibility target was defined in terms of vehicle-hours lost; the number of hours lost in 2020 should be reduced to the level of 1992. In addition,

to a limited extent quantitative accessibility objectives were also formulated for other modalities; for example, in terms of arrival reliability of trains.

The national transport model system (LMS) was again used for transport analysis and a number of cost-benefit analysis were conducted to examine the economic efficiency of road investments combined with road pricing alternatives (Besseling et al., 2005). The cost benefit analysis followed new national standards for social cost benefit analysis (Eijgenraam et al., 2000) and include monetary values of external costs (transport safety, air pollution etc.). As in the previous policy documents, the performance based accessibility targets used reflect that some structural levels of congestion and unreliability are accepted because of economic efficiency reasons. The cost-benefit analysis shows decreasing returns at a certain point of additional road investments.

The National Policy Strategy for Infrastructure and Environment, 2012

The National Policy Strategy for Infrastructure and Environment (abbreviated as 'SVIR') (Ministry of Infrastructure and Environment, 2011) is the first national policy document in which spatial planning and transport policy are fully integrated. This is the result of the merger of the former Ministry of Transport and Water Management and the Ministry of Housing and Physical Planning into the Ministry of Infrastructure and Environment in 2011.

The travel time target from the Mobility Policy document is kept in the SVIR as a performance based accessibility indicator. The transport performance indicators 'travel time reliability' and 'vehicle hours lost' from the Mobility Policy document are abolished. The quantitative travel time reliability is replaced by a qualitative aim to achieve 'a robust and coherent mobility system'. A robust system 'provides reliable performance both in normal circumstances and in the event of accidents, extreme weather events and other disruptions'. A coherent transport system will be achieved by 'reinforcing each mode of transport (road, public transport, waterways) in response to demand, ensuring better connections between them, improving coordination with other spatial developments and influencing the demand for mobility'.

In the SVIR the Ministry wanted a new accessibility indicator which would give a more complete picture of accessibility of different transport modes and national, regional and local transport networks. The policy focus was on door to door travel times rather than congestion on road segments. The performance indicator 'vehicle hours lost' was replaced by a new accessibility indicator: a multimodal generalised transport cost. This indicator

expresses the transport resistance from areas to overcome the distance to particular destinations with different transport modes. The indicator was announced in the SVIR and a preliminary version of the indicator was shown in the policy document (figure 1). Figure 1 shows the generalised travel cost for car, public transport and road freight transport at the spatial scale of municipalities. The colour of the circle indicates the average accessibility of a municipality compared to all other municipalities in the Netherlands, while the size of the circle reveals the total number of journeys to this municipality. If a municipality is coloured 'red', this means that the average transport costs per kilometre to the municipality are high. At the moment of publication of the SVIR, a further development process was announced, which is not yet finished at the time of writing this chapter. The research project conducted after publication of the SVIR found several difficulties with operationalising the indicator. As a result, the accessibility indicator has been redefined into the average straight line speed of all journeys to a destination area in km/h. The redefined indicator now includes only travel time and excludes out of pocket costs (parking, fuel, tickets, etc.) and comfort/quality aspect which proved to be difficult to monitor and forecast. In addition, there were difficulties with estimating multimodal transport costs. For example, urban regions with a high share of non-motorised transport would have lower average travel times and result in a lower accessibility score. Therefore, when calculating the integral accessibility of an area for all modalities, the differences in travel speeds between modalities must be taken into account. How exactly this should be done is the subject of further research. At the moment, the new indicator is estimated for each mode separately, and also different operationalisations are used for passenger and freight transport.



Figure 1: Generalised travel times as the new Dutch transport performance based accessibility indicator, projection for 2030, high economic growth scenario

Accessibility concepts in Dutch transport policy: a discussion

Dutch national transport policy to date focused on transport performance based indicators and targets. However, in each new policy document, new transport performance based accessibility standards were developed for the main road network, ranging from levels-ofservice and congestion probabilities to travel time reliability. Quantitative transport performance targets are mainly formulated for road networks and not for public transport or freight networks, with some exceptions such as punctuality targets for trains. Since SVV2 the development of accessibility indicators and targets heavily relied on the outcomes of the projections from (different versions of) the Dutch transport model system and cost-benefit analysis.

The main change in transport policy was the move from the transport provider perspective focusing on the transport performance of single motorway road segments to a 'transport user' perspective focusing on door to door travel time (using different transport networks and modes) and travel time reliability. Although operationalisation of the accessibility goals was often difficult, it does provides a better link between accessibility policy targets and economic appraisal (CBA). In a CBA, travel time savings are estimated between OD-zones in the transport model. However, the 'transport user' perspective in Dutch transport policy

making is a rather aggregate one; it does not distinguish between different types of users with different accessibility needs, such as young people, elderly, low or high income groups. In the next decade, differentiating between the accessibility needs of different population groups will become more and more important, with an ageing population and population decline in several regions in the Netherlands. Keeping the current level of access to social and economic opportunities will be a major task in regions with ageing and declining populations. The social dimension has not received much attention, if any, in the development of accessibility concepts in Dutch national transport policy making.

Although the National Policy Strategy for Infrastructure and Environment is the first national policy document in which spatial planning and transport policy are fully integrated, this did not affect the perspective on accessibility. The main policy concepts used are still transport performance based accessibility measures. This perspective lacks attention for individual and land-use components of accessibility which are relevant for accessibility planning. A transport performance indicator such as generalised travel cost is quite problematic within the context of integration of transport and land use policies and sustainability. This was already illustrated by Linneker and Spence (Linneker and Spence, 1992) who illustrated that inner London has the highest access costs (in terms of time and vehicle operation costs) in the UK, but also the highest level of potential accessibility to jobs, despite the high travel cost. This is also valid for the major cities in in the Netherlands where job accessibility also highest despite higher congestion levels on the main motorways (Geurs and Ritsema van Eck, 2003). Location-based accessibility perspective did however not match the current accessibility paradigm of established administrative structures within the Ministry of Infrastructure and Environment. One fear was that location-based accessibility would not help in prioritizing road investments towards the most congested locations in the Randstad area.

The relative importance of differences in proximity to spatially distributed activities (land use component) compared to travel speed (transport component) is also illustrated in figure 2.



Figure 2: Components of potential job accessibility (PBL, 2011)

The figure shows that potential accessibility to jobs by car mainly depends on the spatial distribution of jobs. Differences in travel speed are not very substantial, even in the most urbanised areas in the country. In addition, this new indicator would show that land use policies aiming at intensifying land use in urban areas result in slower travel speeds and increase travel time, and thus negatively affect the accessibility index. This contradicts the aim in the policy document to better integrate land use and transport planning. The new indicator, generalised transport costs, might thus be a barrier towards a better integration of transport and land use policies and development of more sustainable transport policies. In the UK, this was a major argument for adding potential accessibility as an objective in the appraisal toolkit.

Conclusions

This chapter shows that accessibility planning research and practice in the Netherlands remain ambiguous about indicators and measurement. The choice of an accessibility measure (and the manner it is operationalized) strongly affects related results and, consequently, the forecast effects of accessibility changes on the spatial economy and social inequalities.

Dutch transport policy in the past decades focused on transport performance based accessibility concepts. The main change in transport policy was the move from the transport provider perspective focusing on the transport performance of single motorway road segments to a 'transport user' perspective focusing on door to door travel time (using different transport networks and modes). A broader accessibility perspective so far does however not match established administrative structures within the Ministry of Infrastructure and Environment. This presents a barrier to developing cross-sector policy strategies necessary for sustainable land-use and transport systems.

The theory of accessibility planning would suggest that it is necessary to bring together different dimensions of accessibility (e.g., economic, social, cognitive and psychological) and incorporate all transport modes, user groups and travel generating opportunities, and ensure that all providers and sectors work effectively together. These comprehensive approaches also require strong cooperation between accessibility researchers and public and private planning practitioners; enabling them to test and implement innovative practices that can be complemented by comprehensive frameworks for economic appraisal and equity impact analysis. However, closing the gap between theoretical and practical applications of accessibility concepts in the Dutch arena requires a clarity of accountability for access that will not be achieved quickly, involving administrative and perhaps legislative change. A first step to improve to bridge the gap would be to include the Hansen-based potential accessibility measure (for relevant population segments and opportunities) as an additional indicator in transport appraisal. These indicators can then be used to audit decision making, as in much of the current accessibility planning practice. This will ensure that all future land use and transport change demonstrates that all modes are included and that they are integrated into the wider economy and society.

References

- Ashiru, O., Polak, J.W., Noland, R.B., 2003. Space-Time User Benefit and Utility Accessibility Measures for Individual Activity Schedules, TRB2003, Washington.
- Batty, M., 2009. Accessibility: in search of a unified theory. Environment and Planning B: Planning and Design 36), 191-194.
- Ben-Akiva, M., Lerman, S.R., 1979. Disaggregate travel and mobility choice models and measures of accessibility, In: Hensher, D.A., Sopher, P.R. (Eds.), Behavioural Travel Modelling. Croom Helm, Andover, Hants, pp. 654-679.
- Besseling, P., Groot, W., Lebouille, R., 2005. Economische analyse van verschillende vormen van prijsbeleid voor het wegverkeer [An economic assessment of various methods of road pricing]. Netherlands Bureau for Economic Policy Analysis, The Hague.
- Bovy, P.H.L., Jager, J., Gunn, H., 1992. The Dutch National and Regional Model Systems: Principles, Scope and Applications, Selected Proceedings of the Sixth WCTR: Demand Traffic and Network Modelling. Pergamon, 1992, WCTR (2), pp. pp. 1197-1208.

- Burdack, J., Herfert, G., Rudolph, R., 2005. Europäische Metropolitane Peripherien, In: Burdack, J., Herfert, G., Rudolph, R. (Eds.), Beiträge zur Regionalen Geographie. Leibniz-Institut für Länderkunde, Leipzig.
- Burns, L.D., 1979. Transportation, Temporal and Spatial Components of Accessibility. LexingtonBooks, Lexington/Toronto.
- Cervero, R., Rood, T., Appleyard, B., 1997. Job accessibility as a performance indicator: An analysis of trends and their social policy implications in the San Fransisco Bay Area. University of California, Institute of Urban and Regional Development, Berkeley.
- Chen, Y., Ravulaparthy, S., Dalal, P., Yoon, S.Y., Lei, T., Goulias, K.G., Pendyala, R.M., Bhat, C.R., Hu, H.H., 2011. Development of opportunity-based accessibility indicators, Paper for the 90th Annual meeting of the Transportation Research Board.
- Condeço-Melhorado, A., Martín, J. C., Gutiérrez, J., 2011. Regional spillovers of transport infrastructure investment: A territorial cohesion analysis. European Journal of Transport and Infrastructure Research 11 (4), 389-404.
- Dalvi, M.Q., Martin, K.M., 1976. The measurement of accessibility: some preliminary results. Transportation 5 (1976)), pp. 17-42.
- de Jong, G., Daly, A., Pieters, M., van der Hoorn, T., 2007. The logsum as an evaluation measure: Review of the literature and new results. Transportation Research Part A: Policy and Practice 41 (9), 874-889.
- Dong, X., Ben-Akiva, M.E., Bowman, J.L., Walker, J.L., 2006. Moving from trip-based to activitybased measures of accessibility. Transportation Research Part A: Policy and Practice 40 (2), 163-180.
- Eijgenraam, C.J.J., Koopmans, C.C., Tang, P.J.G., Verster, A.C.P., 2000. Evaluation of infrastructural projects. Guide for cost-benefit analysis. Part I (Main report) and Part II (Capita Selecta). CPB Netherlands Bureau for Economic Policy Analysis/ Netherlands Economic Institute, The Hague/Rotterdam.
- Farrington, John, Farrington, Conor, 2005. Rural accessibility, social inclusion and social justice: towards conceptualisation. Journal of Transport Geography 13 (1), 1-12.
- Geurs, K., Zondag, B., De Jong, G., Bok, M. de, 2010. Accessibility appraisal of integrated landuse/transport policy strategies: more than just adding up travel time savings. Transportation Research Part D 15), 382-393.
- Geurs, K.T., Ritsema van Eck, J.R., 2003. Accessibility evaluation of land-use scenarios: the impact of job competition, land-use and infrastructure developments for the Netherlands. Environment and Planning B: Planning & design 30 (1), 69 87.
- Geurs, K.T., Van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. Journal of Transport geography 12), 127-140.
- Geurs, K.T., Van Wee, B., Rietveld, P., 2006. Accessibility appraisal of integrated land-use/transport strategies: methodology and case study for the Netherlands Randstad area. Environment and Planning B: Planning and Design 33 (5), 639-660.
- Gould, P., 1969. Spatial Diffusion. Resource paper no. 17. Commission on College Geography, Association of American Geographers (cited by Morris et al., 1979, Accessibility indicators for transportation planning. Transportation Research A Vol. 13, pp. 91-109), Washington DC.
- Gutiérrez, J., Condeço-Melhorado, A., López, E., Monzón, A., 2011. Evaluating the European added value of TEN-T projects: a methodological proposal based on spatial spillovers, accessibility and GIS. Journal of Transport Geography 19 (4), 840-850.
- Gutiérrez, J., Condeço-Melhorado, A., Martín, J. C., 2010. Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment. Journal of Transport Geography 18 (1), 141-152.

- Hägerstrand, T., 1970. What about people in regional science? Papers of the Regional Science Association 24), 7-21.
- Handy, S.L., Niemeier, D.A., 1997. Measuring accessibility: an exploration of issues and alternatives. Environment and Planning A 29), 1175-1194.
- Hansen, W.G., 1959. How accessibility shapes land use. Journal of American Institute of Planners 25 (1), pp. 73-76.
- Iacono, M., Krizek, K. J., El-Geneidy, A., 2010. Measuring non-motorized accessibility: issues, alternatives, and execution. Journal of Transport Geography 18 (1), 133-140.
- Koenig, J.G., 1980. Indicators of Urban Accessibility: Theory and Applications. Transportation 9), pp. 145-172.
- Krizek, K. J., 2010. Measuring accessibility: Prescriptions for performance measures of the creative and sustainable city. International Journal of Sustainable Development 13 (1-2), 149-160.
- Kwan, M-P., 1998. Space-time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-based Framework. Geographical Analysis 30 (3), 191-216.
- Kwan, M-P., 2000. Interactive geovisualisation of activity-travel patterns using three-dimensional geographical information systems: a methodological exploration with a large data set. Transportation research part C 8 (4), 185-203.
- Linneker, B.J., Spence, N.A., 1992. Accessibility measures compared in an analysis of the impact of the M25 London Orbital Motorway on Britain. Environment and Planning A 24), 1137-1154.
- Ministry of Infrastructure and Environment, 2011. Summary Draft National Policy Strategy for Infrastructure and Spatial Planning, The Hague.
- Ministry of Transport Public Works and Water Management, 1990a. Second transport structure plan. Ministry of Transport, Public Works and Watermanagement, The Hague.
- Ministry of Transport Public Works and Water Management, 1990b. Tweede Structuurschema Verkeer en Vervoer. Deel D: regeringsbeslissing (Second transport structure plan. Part D: government decision). Ministry of Transport, Public Works and Watermanagement, The Hague.
- Ministry of Transport Public Works and Water Management, 2006. Mobility Policy Document. Towards reliable and predictable accessibility. Part IV. Summary, The Hague.
- Neutens, T., 2010. Space, time and accessibility Analyzing human activities and travel possibilities from a time-geographic perspective. Department of Geography, University of Gent, Gent.
- Niemeier, D.A., 1997. Accessibility: an evaluation using consumer welfare. Transportation 24), pp. 377-396.
- PBL, 2011. Ex ante evaluatie Structuurvisie Infrastructuur en Ruime. Planbureau voor de Leefomgeving, Den Haag.
- Pirie, G.H., 1979. Measuring accessibility: a review and proposal. Environment and Planning A 11), 299-312.
- Schwanen, T., Kwan, M-P., 2008. The internet, mobile phone and space-time constraints. GeoForum 39 (3), 1362-1377.
- Scott, D.M., Horner, M.W., 2008. Examining The Role of Urban Form In Shaping People's Accessibility to Opportunities: An Exploratory Spatial Data Analysis. Journal of Transport and Land Use 1 (2), 89-119.
- Shen, Q., 1998. Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. Environment and Planning B: Planning & design 25 (3), 345-365.
- Zhang, M., Shen, Q., Sussman, J., 1998. Job accessibility in the San Juan metropolitan region: implications for rail transit benefit analysis. Transportation Research Record. 1998. (1618)), pp22-31.

INTERDEPENDENCIES BETWEEN SUPPLY AND DEMAND OF TRANSPORT: THE EVOLUTION OF ACCESSIBILITY WITHIN THE LYON METROPOLITAN AREA

Yves Crozet; Aurélie Mercier; Nicolas Ovtracht; Loïc Sapet,

LET-ISH, Transport Economics Laboratory, University of Lyon

Corresponding author:

Yves Crozet; yves.crozet@let.ish-lyon.cnrs.fr

Abstract

More and more metropolitan areas are confronted with the contradiction between urban sprawl and sustainable development expectations. To solve those kinds of problems, municipalities and regional government are implementing various projects like BRT, metro or tramway lines, regional trains etc. As a result, strategies for sustainable accessibility emphasize the key role of public transit (PT) to ensure mobility for the future. But these strategies are generally focused on the central part of cities especially through the development of strong radial PT lines. At the same time, more often in a more discrete manner, a lot of improvements are happening on the road network, namely in suburban areas.

Putting the focus on the case study of the Lyon metropolitan area (about 3 000 km² and more than 1.7 million inhabitants), the second largest metropolitan area in France, the objective of our paper is to illustrate the expected and unexpected effects of road transport supply improvements on transport demand. Using "MOSART" (MOdelling and Simulation of Accessibility to netwoRks and Territories), a digital platform joining a GIS and a transport model, we will present the changes in transport demand for road traffic in relation to a new ring road section in the western part of Lyon.

We will start by a presentation of MOSART (section 1), followed by some comments about the concept of accessibility, the key role of speed, and the fact that the relationship between speed and density is non-symmetrical (Section 2). Due to this asymmetry, a new ring road project in the western part of Lyon will instantly change the demand on the whole road network and the job accessibility. Therefore, accessibility maps become a useful tool for "territorial intelligence" (section 3).

Keywords : accessibility measure, sustainable mobility, transport modeling, GIS, spatial analysis, web mapping

MOSART: a modelling platform for planning sustainable mobility in the Lyon Metropolitan area

The Lyon Metropolitan area, located in the south-east of France, is the second largest metropolitan area (behind Paris) with more than 3 356 km². A brief division of the metropolitan area is as follows: the "communes" of Lyon and Villeurbanne are in the center and form the Central Business District (CBD), the neighboring "communes" are included in the Grand Lyon perimeter, and then the surrounding "communes" are classified as suburban. The whole area has a population of 1.7 millions metropolitan people (INSEE, 1999 Census), and a population density of 508 inhabitants per km².

Population growth is important (0.8% per year for 1999 – 2005, INSEE) and higher than in any other French Metropolitan region (Paris, Marseille, Lille). The population tends to be concentrated in central zones (in Lyon and Villeurbanne) and on their outlying "communes" in the Grand Lyon with densities greater than 750 inhabitants per km². Outside the Grand Lyon boundary are some dense areas close to motorway infrastructures. The Lyon Metropolitan Area offers more than 800,000 jobs (in 1999) for 765,000 workers living in the area. In Lyon as well as in most European cities, the spatial pattern of population and jobs is quite similar: employment density is the highest in the city centre, with more than 10,000 jobs per km² in some CBD divisions. Indeed, 42% and 82% of jobs compared with 75% and 34% of inhabitants are respectively located in the CBD and in Grand Lyon.

MOSART has been implemented as a Geographical Information System in Transportation to conduct accessibility analysis. It has been moved to a modelling platform for planning sustainable mobility and introduces gravity-based analysis in a second version. Many databases, spatial or not, are integrated in the GIS-T. Integration of a four-step urban transportation model system associated with updated land-use data at a very detailed zonal division (more than 4,000 zones) make it easier to do dynamic analysis of different transport/land-use policy scenarios. Land-use is determined with various databases like Navteq land use layer, or the National Geographical Institute with the BD Carto's. An innovative aspect of MOSART refers to an analysis on both urban speed issues and land-use patterns. Combining these two interrelated aspects, MOSART is well adapted to assess past and future transport and land-use policies. The MOSART platform is a decision making tool in terms of mobility for public and private authorities. This accessibility-based project defines three main final objectives:

- To model and simulate transport policies for various networks (road, urban or interurban public transports networks...),
- To compare different transport policy and urban planning scenarios. A long-term objective (not achieved in this paper) is to analyse the impacts of urban transport policy on residential location choices. Given that job location is one of the household's residential location choice factors (Cho and al., 2008), policy impacts on commuting have to be integrated. Increases in job mobility, the prevalence of two worker households, and the decentralization of urban areas suggest that accessibility to potential employment or activity centres may be a dominant determinant in explaining location choices.
- To present cartographic results and map-based tools.

An important methodological issue is the geographical study area and the spatial division. As mentioned by Kwan and Weber (2008), a regional scale reflects urban structure evolution with polycentric centres while the local scale focuses on neighbourhood mobility and modal competition to access retail stores or local jobs. After considering land–use methodological principles, the French case study was conducted in the Lyon Metropolitan area. Thus, the platform can be used both for regional analysis considering different polycentric job centres and local analysis on accessibility focusing on the city centre.

MOSART as a Geographical Information System

In a first version, MOSART has been implemented as a GIS. A number of databases, from screen digitalization or importation, have been integrated: transport networks and socioeconomic data are the two main types.

The road network, obtained from the database NAVTEQ, is composed by more than 90,000 nodes and 220,000 links. In a first time, a road section typology into 15 types has been implemented to characterize each link by length, capacity, a maximum speed, and a driving direction.

The urban public transport network, created using topological methods from a GIS Public transport attribute database, has been integrated: each line is characterized by its different stations, a certain speed, and a frequency. Each connection zone has been modeled and a walking time based on a 4 km/h speed is considered between two stations. This first public transport database is composed of 100 bus lines, 4 subway lines, and 3 tram lines. Public transport timetables have been integrated according to frequencies and the following periods of the day: peak-hour periods from 6 to 9 AM and from 4 to 7PM, and off peak

hours from 9 to 12 AM and from 7 to 10 PM. A system of self-service bicycles called Velo'V has also been integrated with 340 Velo'V stations primarily spread over the cities of Lyon and Villeurbanne.

Socio-economic data have been integrated according to various spatial divisions in order to perform spatial analysis. The population and main socio-economic data were obtained from the 2006 Census (INSEE). For socio-economic data not in the public domain (number of shops and other facilities) or not available at the IRIS level (number and structure of jobs), other sources such as the national institute of statistic (INSEE) have also been used.

MOSART as a modelling tool for transport and urban simulation

In this second version, MOSART is longer a GIS-T but also an innovative modelling platform for transport and urban policy simulations. While the first version uses static modelling to simulate isochronal accessibility impacts of a transport policy considering a "ceteris paribus" hypothesis, the second version highlights the relationship between transport demand and a static land-use model using gravity-based accessibility. MOSART "version 2", with an integrated GIS approach, aims to combine three innovative aspects.

A semi-dynamic analysis on transport modeling

A transport model (4-stage model), entirely executed in VISUM software, integrates road transport demand (and road congestion level) and travel time and accessibility (see Mercier and Stoiber, 2010 for a detailed presentation of the transport model). The core of this urban model is that traffic predictions and assignment varies according to different periods of the day. Two main periods are specified: a peak period presents traffic between 7 and 10 AM and an off-peak period corresponding to an average traffic level. While peak traffic is simulated according to traffic gathered between 7 to 10 AM by the French survey "Enquête Ménages Déplacements" in 2006, off-peak congestion is inferred using daily traffic. Semi-dynamic transport system modelling is coupled to a static land-use model. Spatial distribution of population, opportunities and transport infrastructures are assumed to be constant. In spite of this restrictive hypothesis, creating a transport land use model requires an extensive range of data related to spatial units, land use, spatial interactions and the transportation network (Rodrigue and al., 2009).

An introduction to the detailed spatial analysis based on precise land-use data and transport networks

The study area has been divided into 4,344 zones with their respective centroids. Zone size varies according to location in the Lyon Metropolitan area owing to technical limits (number of zones should be inferior to 5,000 to use VISUM software) and easy reading. The Central Business District is divided into 1,272 squares of 250 meters per side. Suburbs are divided into 2,291 squares of 500 meters per side and then the suburban part is divided into 781 squares of 2 kilometres per side. Such a detailed spatial division minimizes impacts of internal opportunities on accessibility results (Gutierrez et al., 2010 and, Frost and Spence, 1995). A distinctive feature of MOSART "Version 2" is that the very detailed urban public transport network is linked to precise timetables. For each line, public transport timetables have been integrated according to frequencies and two different periods of the day: peakhour periods and off-peak hour periods. A timetable-based assignment is then implemented in VISUM. The interurban public transport network, created in "Version 2", refers to a regional rail network with 10 railway lines. Similar to the bus network, it was generated from the NAVTEQ database. For each line, a timetable considering a typical weekday schedule has been included. It is important to note that railway stations located in Lyon are connected to the urban public transport network.

In some previous papers, we used MOSART to assess the impacts of PT accessibility improvements. But what are the effects of road improvements? Due to the fact that on road there is a direct link between supply and demand between network extension and congestion, we can use MOSART to model the potential effects of the new ring road planned in the western part of Lyon. To do that, we have to recall some basic characteristics of accessibility.

Accessibility: increasing returns of speed and asymmetry between speed and density

Since Hansen's seminal paper (1959), accessibility has been defined as the ease with which an individual can reach a location to perform an activity (Morris 1978). The concept thus already incorporates two different but complementary aspects: the opportunity or possibility of interaction between two (economic) agents and the (geographic) distance that has to be covered in order for this interaction to take place. Consequently, accessibility can also be seen as an interface between the urban economy and transport geography. Land-use and transport are linked together in a dynamic, non-linear system. Location quality is a fundamental factor in long-term mobility decisions, and is mainly influenced by accessibility in terms of transport supply, transport quality and urban structure. The time needed for urban growth to occur depends on these location qualities as addition to the urban potential and planning and construction processes. At the level of short-term mobility decisions, the local and regional spatial structures as well as transport options exert a strong influence on daily activities and travel behaviour, defining activity programmes and the choice of destination, mode and route. Travel demand leads to trips which, due to a counteracting feedback mechanism, negatively impact the quality of the transport supply because of congestion, stabilizing the overall system of interactions.

However, there is no direct, linear, and automatic link between the different elements in this structure. Change in the structure is always due to collective processes and the decisions of various actors. These dynamic interactions are often inadequately represented in land-use and transport planning processes due to a lack of empirical knowledge and methodological instruments (Wulfhorst 2007).

In this context, accessibility has been identified as a key driver of change in the overall landuse and transport system. The potential for accessibility is therefore at the heart of the interactions between geographical structure and transport planning. On the one hand, accessibility issues have a strong impact on long-term mobility due to decisions with regard to residential location, the location of business development, or car ownership. On the other hand, accessibility has a major influence on short-term mobility by altering trip destinations, mode choice and trip distances. From historical times to the present we can observe the creation of towns and the development of urban facilities at locations with good accessibility. If we want to design a sustainable mobility system and manage transportation demand, we have to develop strategies for accessibility. But, interestingly, accessibility cannot be addressed directly by planning or policy decisions as it depends on transport supply and land-use, so the implementation of accessibility strategies depends on changes in transport supply options (investment in infrastructure and services for the various transport modes) and spatial structure (opportunities for activities). Let us now consider the different accessibility metrics.

Although it is a familiar concept, the definition of accessibility can vary from one discipline to another (Geurs & Ritsema Van Eck 2001). It depends on whether the approach focuses on the accessibility of a place or an individual, relative accessibility (to different areas) or integral accessibility (to all parts of an area), or whether it views accessibility as a tool for

assessing individual utility or a transport system (Ben-Akiva & Lermann 1979). Geurs & van Wee (2004) have described four basic approaches:

- The location-based approach targets urban planning objectives that include the distribution of inhabitants and activities. Here, the main component of the access index is the number of opportunities that can be reached within a transport time constraint.
- The infrastructure-based approach takes transportation systems into account, assessing performance or level of service with travel time or cost.
- The person-based approach considers individual constraints and behaviours. Individual accessibility can be limited by the duration of mandatory activities, the time budget for flexible activities and the travel speed provided by the transport system.
- Utility-based measures refer to the benefits people derive from access to activities.

This basic definition allows us to identify different accessibility measures, such as isochrone-based measures or gravity-based measures. In this paper we will focus on the second one, aiming to transform the multiple dimensions of mobility patterns into a onedimensional indicator which becomes the new metric for policy makers. Within this metric, speed plays a key role.

Accessibility and the increasing returns of speed

Let us return to the most basic description of gravity-based accessibility, given by Hansen in 1959 (p. 74 ff): "Accessibility at point 1 to a particular type of activity at point 2 is directly proportional to the size of the activity at point 2 and inversely proportional to a function of the distance separating the two points. The total accessibility at point 1 to the activity is the summation of the accessibility to each of the points around point 1."

We can thus describe accessibility as a function of geographical structure and transport supply:

$$A_i = \sum_j D_j f(c_{ij})$$

Where,

Ai is the accessibility to destinations D from point I,

Dj are the activity destinations at points j

cij are the generalized costs (trip time, price and comfort)

After this original definition, gravity-based accessibility was redefined some years later (Ingram 1971, Koenig1972, Weibull 1976, Pirie 1979, Koenig 1980) by defining the decay function f.

The accessibility (A) between a zone i and the entire set of opportunities (D) of a group of areas j obviously depends on this set , which is weighted by the resistance factor represented by the generalised costs of transport (cij). The function can be expressed as a power function or – more commonly – an exponential function which is weighted by a 2-coefficient that takes into account the qualitative elements which increase or reduce satisfaction with regard to transport cost. This means that the more transport costs grow, the worse accessibility becomes and, symmetrically, higher speeds or lower costs improve accessibility. We can represent this as follows:

$$A_i = \sum_j D_j \exp(-\beta c_{ij})$$

This equation explains why public policies were and still are attracted by the potential speed increases provided by new transport infrastructures or services, especially in the case of road transport that potentially offers 360° mobility.

From a policy makers' viewpoint, in the past, a highway project used to critically increase accessibility, which it still does under certain circumstances. As soon as fast transportation systems are available, the accessible zone and hence the number of potential housing and job opportunities are significantly increased. The fact that transport cost affects accessibility exponentially means that a large weight is assigned to any increase in speed. This same dynamic partially explains the tremendous success of cars in industrialised countries (Vickerman R. & alii 1999). Thanks to private cars, the average distance covered each day per person has skyrocketed without a major increase in individual travel time budgets (Zahavi & Talvitie 1980). Accessibility is central to these feedback processes. High performance transportation systems have enabled people to reach a vast number of destinations in what is, at the urban region level, a dispersed low density settlement structure. But these user benefits might turn out to be a heavy burden on society.

This omnipresence of cars has tended to turn the "solution" into a problem. The difficulties are due to the fact that, contrary to common sense, high road speeds do not guarantee urban performance. The attempt to achieve high road speeds in dense areas is to some extent a mistaken goal since it simultaneously encourages road congestion and dedensification. Cities consequently tend to sprawl, as can be seen in North America where, in spite of higher average speeds, accessibility is lower than in European cities, even though the money (in % of per capita GDP) and time budgets allocated to daily commuting are higher (Crozet & Joly 2006).

Accessibility and the asymmetry between speed and density

In view of the negative impacts of road speed on urban sprawl, to achieve sustainable mobility we will need to define a new metric for the accessibility indicator (Curtis 2008; Gutiérrez et al., 2010). But this new metric cannot use density as a perfect substitute for speed (Newman and Kenworthy 1998; Litman 2008). For instance, a 100% increase in transport costs would reduce the catchment area by 75%. In order to maintain the same level of accessibility, the number of opportunities within the restricted catchment area would have to be multiplied by four. Due to this asymmetry between speed and density with regard to accessibility, it would be mistaken to suggest increasing density as the main solution. The new metric has to address accessibility not in a simple way (speed versus density) but in a comprehensive way that takes account of all the dimensions of the accessibility term.

First, with regard to the dimension of generalised travel costs in addition to speed, we have to take account of monetary travel costs. It has been shown that energy consumption by transport (distances travelled, vehicle mileages) is highest with low fuel costs and results in low density (Wegener 1999). While it is necessary to create effective and efficient spatial patterns, travel costs must not be ignored.

Second, as far as the dimension of opportunities is concerned, urban density is not the only factor at work as diversity also matters. For a given level of urban density, a change from mono-functional use (e.g. residential) to multi-functional use (residential + jobs + services/shopping + leisure) increases the number of opportunities within the distance limit (Krug, 2006). It has been shown that in urban areas with a higher density and functional mix, there is a much higher share of non-motorised trips (up to 50% of all trips, e.g. Munich surveys that are part of the German national travel survey MiD, 2008), lower mileages by private car (50% fewer vkm driven in areas with a high functional mix and good public transport than in areas with low functional mix and poor public transport in the Hamburg region, Gutsche 2001), and even a greater number of trips; therefore, higher mobility.

Diversity in the sense of options for activity destinations and trip modes also contributes greatly to sustainability. The resilience of a multi-functional system to shocks (e.g. fuel price increase due to energy scarcity or greenhouse gas emission budgets) will be much higher

than for a mono-functional system that is dependent on a given set of conditions (e.g. suburban single-family housing relying on low private car costs).

From map-based tools to "territorial intelligence"

Sustainability issues are driving the need to increase accessibility by improving the urban functions within the catchment areas of pedestrian, cycling and transit trips rather than by increasing the catchment area by higher car speeds. This is the paradoxical conclusion one reaches when accessibility is considered on the basis of a number of collective priorities about land use (Calthorpe & Fulton 2001).

The lower performance of cars in urban areas and growing social and environmental constraints with regard to increasing mobility in large urban zones mean that private and public stakeholders need appropriate tools for urban planning and achieving sustainable development. These tools should not be limited to transport. One such tool consists of a map showing gravitational accessibility indicators. By giving precise and contextualized measures of accessibility, such maps foster critical public and private choices in terms not only of the location, but also the organization, of daily activities. The issues of time and speed should not be considered on their own. By considering the accessibility of jobs, housing, shops, and the other urban amenities, public and private decision-makers can move from a rationale based on speed and individual interests to a strategy that targets the general interest and the nature of the urban space, in particular the diversity of amenities. Therefore, the question of whether the accessibility improvements will lead to some adverse effects should be considered. The case study of the Lyon agglomeration illustrates just that.

The potential impacts of contructing the missing segment of the Lyon Ring road

The highway network of the Lyon metropolitan area does not currently have a full highway ring road. For obscure reasons, the highway which connects the north and the south of France, built at the end of the sixties, passes through the downtown area of Lyon. The "Fourvière tunnel" thus attracts local, regional, national, and international traffic with 100,000 vehicles which pass each day through the tunnel. The downtown area, and in particular the new business district called "Junction" is thus obstructed in its development because of highway roadway systems which encircle it.

To rectify this situation, a road bypass project of (called TOP, western section of the ring road) is envisioned by 2020-2025 in the western part of Lyon. Charts 1 and 2 show how this project arises. Chart 1 indicates the overall vision of the urban area.



Chart 1: Lyon Metropolitan area: Highway network and TOP project

Chart 2 zooms to the project area, which will in great part be carried out in a tunnel.



Chart 2: Lyon Metropolitan area: zooming to the TOP project

Using Mosart, we simulated what the evolution of the road traffic after the opening of this new axis could be. Charts 3 and 4 show how the traffic, which still remains very congested in the downtown area at rush hour (chart 3), is transferred massively to the ring road after project completion. It is exactly what was observed in Paris 40 years ago when the Parisian ring road was finished. Thus, if the objective of the TOP is to reduce traffic in the downtown

area, the goal is achieved. The expected effects are observed. But what could be the unexpected effects of this project?



Chart 3: Lyon Metropolitan area: the present road congestion during morning peak hours



Chart 4: Lyon Metropolitan area: Road congestion with TOP project during morning peak hours We can estimate them by presenting charts of the variation of gravitational accessibility with the TOP project.



We observe an improvement of accessibility, especially in the south of the urban area (green). It is thus extremely probable that these zones will see development of new residences. We are surprised to find a weak improvement of accessibility for the western part of Lyon. This is explained by the phenomena of congestion. The access to the centre of town is not improved by the TOP because of congestion appearing locally on the access to the new road infrastructure.

On the other hand, as chart n°6 shows, the improvement of accessibility is strong for the western part of Lyon for the jobs located out of the CBD. We also observe perverse effects on the congestion to the east and the northeast of the urban area. The new infrastructure causes an increase in traffic across the network. Thus, the eastern part of the network will not show any improvement and in fact will suffer from greater road congestion.



Confronted with such scenarios, the public decision makers cannot think only in terms of new infrastructure, they must include the regulation of traffic, even through urban tolls, to avoid the rebound effects of traffic on the new infrastructure.

Conclusion

In this context, accessibility maps become a crucial part of the decision-making process. The role of the decision-maker is no longer to increase accessibility whatever the impacts on land use, but to express an explicit preference for improving (or worsening) accessibility in certain ways. More generally, urban sprawl is often only the other name of the urban growth. The challenge is thus less to fight strictly speaking against spreading out rather than to organize this growth. For that, it is necessary to develop a multidimensional "Territorial Intelligence" and multi-scale approach in order to clarify the public decision. Which tools can be developed to evaluate not only the environmental effects of mobility, but also the local impacts on mobility, such as the type of housing?

The assumption is that urban policies are always overwhelmed by their own success. Indeed, except if housing locations and trips are strictly controlled, individual choices transform the successes linked to the growing accessibility of cities into a problem. This social issue is one of the most challenging. Addressing social issues is complex in terms of accessibility. The improvement in accessibility leads to a change in the social characteristics of people living along public transit lines. Mainly because of higher land prices, poor people are pushed away. It is a negative side effect to accessibility improvements that appears when the objective function of urban planners is only defined as the ability of public transport systems to improve accessibility.

References

Banister D., 2008, 'The sustainable mobility paradigm', Transport Policy 15, pp. 73-80.

- Ben-Akiva, M., Lerman, S., 1979, Disagregate travel and mobility choice models and measures of accessibility In: Hensher, D. A., Stopher, P. R., (Eds), Behavioural travel modelling, London: Croom Helm, pp. 698-710.
- Bertolini L., le Clercq F., Kapoen L., 2005, 'Sustainable accessibility: a conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward', Transport Policy 12, pp. 207-220.
- Calthorpe P.& Fulton W. 2001. 'The Regional City: Planning for the End of Sprawl'. Washington, DC: Island Press.
- City of Munich, 2005: PERSPECTIVE MUNICH Strategies, Principles, Projects, Shaping the future of Munich, Development Report 2005
- Crozet Y & Joly I., 2006, 'La « loi de Zahavi » : quelle pertinence pour comprendre la construction et la dilatation des espaces-temps de la ville ?', PUCA collection « Recherches » n°163, Certu, Lyon, 89p.
- Crozet Y., 2009, 'Economic Development and the Role of Travel Time: the Key Concept of accessibility', Commissioned paper for the 2009 VREF (Volvo research and education foundation) Conference on Future of Urban Transport, Gothenburg, April 20-21, 2009, 23 pages.
- Curtis C., 2008, 'Planning for sustainable accessibility: The implementation challenge', Transport Policy 15, pp. 104–112.
- Geurs K. T., Ritsema Van Eck J.R., 2001. 'Accessibility measures: review and applications. Evaluation of accessibility impacts of land-use transport scenarios, and related social and economics impacts'. Rivm, Utrecht University.
- Geurs K.T., van Wee, B. (2004): 'Accessibility evaluation of land-use and transport strategies : review and research directions', Journal of Transport Geography, vol.12, p127-140
- Gutiérrez J., Condeço-Melhorado A., Martin J. C., 2010. 'Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment', Journal of Transport Geography 18, pp. 141-152.
- Gutsche, M. (2001): 'Verkehrseffekte des Wohnungsneubaus im Großraum Hamburg'. ECTL Working Paper 6, Hamburg
- Halden, D. (2008): 'Making the connections the UK experience of accessibility planning'. Paper presented at mobil.TUM 2008, International Conference on Mobility and Transport, Munich
- Hansen W.G., 'How accessibility shapes land use', Journal of the American Institute of Planners, 25, 1959, p. 73-76.
- Holz-Rau, Ch.; Kutter, E. (1995): 'Verkehrsvermeidung. Siedlungsstruk-turelle und organisatorische Konzepte'. Bundesforschungsanstalt für Landeskunde und Raumordnung (Hrsg.): Materialien zur Raumentwicklung. Heft 73, Bonn
- Ingram D. R., 1971. 'The concept of accessibility: a search for an operational form', Regional Studies 5, pp. 101-107.
- Koenig J. G., 1972. 'Indicators of urban accessibility: theory and application'. Transportation 9, pp. 145-172.

- Krug, Henning (2006): Räumliche Wahlmöglichkeiten als Effizienzkriterium für Siedlung und Verkehr; Szenarien – Modellrechnung – Vergleichende Bewertung. Kasseler Dissertation
- 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. Berichte aus dem Institut für Raumplanung Nr. 46, Universität Dortmund, November 1999
- Litman T., 2008. 'Use impacts of Transport, How Land Use Factors Affect Travel Behaviour'. Victoria Transport Policy Institute, Victoria, B.C.
- Mercier A., Stoiber T., 2010. 'Improving accessibility measurement combining transport modelling and GIS analysis: two examples from France and Germany', Selected Proceedings of the 12th WCTR in J. M. Viegas et R. Macario Ed. ISBN 978-989-96986-1-1.
- Morris J.M., Dumble P.L., Wigan M.R. (1978). 'Accessibility indicators for transport planning', Transportation research A, pp. 91-109.
- Newman P.W.G., Kenworthy J.R., 1998, Sustainability and cities. Overcoming automobile dependence, Washington; Island press.
- Pirie G.H., 1979. 'Measuring accessibility : a review and proposal', Environment and Planning A 11, pp. 299-312.
- Preston J., Rajé F., 2007. Accessibility, mobility and transport-related social exclusion, Journal of Transport Geography 15, 151-160.
- Reggiani A., et al., 2010. 'Regional labour markets and job accessibility in City Network systems in Germany', Journal of Transport Geography, doi:10.1016/j.jtrangeo.2010.05.008.
- Social Exclusion Unit (2003): Making the Connections: Final Report on Transport and Social Exclusion
- Straatemeier T, 2008. 'How to plan for regional accessibility?' Transport Policy 15, pp. 127–137.
- Vickerman R. W., Spiekermann K., Wegener M., 1999. 'Accessibility and Economic Development in Europe', Regional Studies 33(1), pp. 1-15.
- Wegener M., 2004, Transport Geography and Spatial Systems. Handbook 5 of the Handbook in Transport. Chapter 9 in David A. Hensher and Kenneth Button (Eds.)Pergamon/Elsevier Science, Kidlington, UK, pp. 127-146.
- Wegener, M. (2004): 'Overview of land-use transport models'. In: Hensher, D.A., Button, K.J. (Hg.): Transport Geography and Spatial Systems. Handbook in Transport Vol. 5. Kidlington: Pergamon/Elsevier Science, 127-146.
- Weibull J. W., 1976. 'An axiomatic approach to the measurement of accessibility', Regional Science and Urban Economics 6, pp. 357-379.
- Wulfhorst, G. (2003): 'Flächennutzung und Verkehrsverknüpfung an Personenbahnhöfen Wirkungsabschätzung mit systemdynamischen Modellen'. Bericht 49 des Instituts für Stadtbauwesen und Stadtverkehr. RWTH Aachen
- Wulfhorst, G. (2007): 'Systems Thinking approaches for the integration of land-use and transport From railway station development to accessibility planning in urban regions'. Conference Paper presented at the World Conference on Transport Research, University of California, Berkeley, June 2007
- Wulfhorst, G.; Büttner, B,; Keller, J. (2010): 'Ein Erreichbarkeitsatlas für die Europäische Metropolregion München'. Schlussbericht, München 2010 (www.metropolregion-muenchen.eu)
- Wulfhorst, G.; Stoiber, T. (2009): 'Accessibility planning in a railway corridor in Frankfurt/Rhein-Main region'; Contribution to the NECTAR workshop cluster 6 "accessibility"; Pula-Cagliari
- Zahavi Y. & A.Talvitie, 1980, 'Regularities in Travel Time and Money', Transportation Research Record 750, p.13-19.

ASSESSMENT OF THE IMPACT OF ROAD PRICING TO ACHIEVE A MORE SUSTAINABLE DEVELOPMENT OF THE TRANSPORT SYSTEM

Oliver Roider; Christoph Link,

Institute for Transport Studies, University of Natural Resources and Life Sciences (BOKU)

Corresponding author:

Oliver Roider; oliver.roider@boku.ac.at

Abstract

A road pricing scheme is often considered to be a promising contribution to a more sustainable transport system. Transport models are used to assess its impacts. Since road pricing schemes fundamentally affect route choice, model parameters (of the impedance function used) have to be calibrated in a valid way. This paper explains the adaptation of the impedance function of the Austrian transport model allowing accurate assessment of the impact of a road pricing scheme on the Austrian high-performance road network. For this purpose, a discrete choice analysis was conducted aiming at developing utility functions of route choice. A basic utility function including travel time, trip length, toll fare and length of the highway section used results in a time value of \in 15 per hour. This is in line with findings from comparable research projects. The length of the highway section used does not significantly improve the explanatory value of the function. However, for reasons of plausibility it makes sense to include this variable. The calibrated utility function was transformed into an impedance function and integrated into the Austrian transport model which permits the calculation of the impact of a road pricing scheme on road users' route choices at different toll levels. A road toll of \in 0.05 per km on high-performance roads produces a significant amount of diverted traffic as the distance traveled on highways decreases by up to 12 percent.

Keywords: transport modeling; route choice; road pricing, traffic diversion
Introduction

The transport sector is the largest source of greenhouse gas (GHG) emissions in Austria and in the entire European Union. In contrast to other sectors its share increased in absolute and relative terms during the last decade. Road transport is mainly responsible for this development (Umweltbundesamt 2011). Moreover, road transport causes other externalities, such as harmful emissions, noise, accidents, or congestion.

Increasing the price of car use seems to be a promising strategy to reduce traffic and its external costs. Due to the negative price elasticity of travel demand (Graham & Glaister, 2002; Goodwin & Dargay, 2003), higher prices cause a more sustainable travel behavior by affecting the individual mode choice, the number of car trips or the average trip length (Brons et al., 2008).

The costs of private car traffic can be influenced by taxing car purchase, fuel consumption, or distance traveled:

- Emission-based taxation of the car purchase supports the market penetration of low emission cars. However, the effectiveness of this approach is limited as it does not influence travel behavior and thus provides no incentive to avoid using the car.
- The taxation of fuel sold impacts all traffic relevant decisions: to possess a car (car ownership), to buy a new car (car purchase), and to use a car (travel behavior). Thus, transport users can maximize their individual utility by adapting their individual abatement costs in regard to these three aspects (Jansen & Denis, 1999; Wadud, 2010).
- A distance-based road pricing scheme influences car use, but since in most cases the toll is not dependent on the emission class or the fuel consumption of the vehicle - it does not affect car purchase decisions and does not encourage the market launch of environmental friendly cars. More advanced approaches take the emission level of vehicles into account by suggesting a progressive toll rate (Rapp, 2007).

In order to meet environmental targets with regard to a reduction of GHG-emissions or other external effects of road traffic, a fuel tax seems to be more appropriate than a traditional road pricing scheme. However, two aspects make the taxation of the distance traveled attractive: (i) the spatial reference can help – in combination with flexible toll levels - to avoid traffic congestions in particular areas or at selected day times, and (ii) people pay for using public goods following the "user pays principle".

Road pricing schemes have already been implemented in several European countries. These schemes differ by the amount charged but also by (Balmer et al., 2004)

- the mode considered; i.e. limitation to freight transport (e.g. Germany) or levied on all road users (e.g. Austria, France, Italy), and
- the basis for the road toll; i.e. distance-, section- or time-based.

Three types of road pricing schemes are currently used in Austria: (i) a time-based road toll on highways or expressways for vehicles under 3.5 metric tons PMW (permissible maximum weight) allows the unlimited use of the high-performance road network as long as the toll sticker is valid; (ii) a section-based road toll for particular Alpine transport routes; (iii) a distance-based road toll on highways and expressways for vehicles over 3.5 metric tons PMW depending on the number of axles and the EURO emission class (Asfinag, 2011).

The implementation of the "user pays principle" is frequently requested in the Austrian debate about transport policy. There are demands to replace the current time-based road pricing scheme with a distance-based system; this could contribute to achieving more transparency of the transport system costs and to reduce the external costs to the transport system.

The research project "RoSana" (*Influencing route choice by a flexible road charge in order to reach sustainable mobility*) assessed the impacts to be expected due to a hypothetical distance-based road pricing scheme in Austria. One main objective of the project was to answer the question of whether a road pricing scheme can contribute to a more sustainable transport system. RoSana was commissioned by the Federal Ministry for Transport, Innovation and Technology. The project was managed by the Institute for Transport Studies of the University of Natural Resources and Life Science, Vienna and conducted together with Herry Consult GmbH and ASFINAG (the organization responsible for planning, financing, and maintaining the Austrian highways).

Empirical findings from other countries cannot be applied to the situation of Austria because of the difference of the transport systems and the spatial structure. Thus, the assessment of a road pricing scheme on travel behavior and the environment was based on transport models. For this purpose, the impedance function of route choice used was re-calibrated. The impedance functions applied for route choice modeling in Austria includes a timerelated variable and distance-based vehicle operating costs. However, further variables may affect the route choice, such as traffic safety, the risk of congestion or the comfort of using a highway instead of a minor road (De Dios Ortuzar & Willumsen, 2011). To present the status quo in a realistic way and to assess the impact of a road pricing scheme, these variables were analyzed with respect to their relevance for route choice decisions and integrated into the impedance function, where appropriate. Impacts of a road pricing scheme, and in particular effects on diverted traffic caused by road pricing schemes for only parts of the network (e.g. on highways only) could be analyzed using this impedance function.

Data collection

In RoSana, the development of the impedance function for route choice was based on a two-stage survey. The target group consists of people who made car trips on a reference day using an Austrian highway or a route parallel to a highway. People who did not meet the criteria were asked if they had a car trip over a distance of more than 75 kilometers within the last three months. Stratified random sampling was used to select the target people, covering different types of settlements (big city, central districts, and peripheral districts).

The first stage of the survey (screening phase) was conducted by phone; information about recent car trips (revealed-preference) was collected. The second stage of the survey was designed as face-to-face interviews. Both survey stages were designed as computer-assisted interviews.

Hypothetical stated-preference experiments regarding route choice were the main part of the second stage. Two kinds of experiments were applied. The first one was based on the assumption of an extension of the road network combined with an increase in traffic volume. The second one assumed a distance-based road pricing scheme on Austrian high-performance roads.

In each experiment the respondents selected their preferred alternative out of a set of four alternatives: The observed route given the new circumstances, two alternative routes and a "none"-alternative: for this, respondents had to state their most likely decision (e.g. omit the trip). Each alternative was clearly defined by six specific attributes: total trip length, trip length on high-performance roads, trip duration, travel expenses, required time buffer indicating the reliability of the route, and accident rate (Fig. 1).

Annahme: Veränderung der Verke Verkehrs-infrastruktur. (Straßena	hrssituation durcl usbau)	h erhöhtes Verkehrsa	ufkommen und Verbe	esserungen der
				Szenario 1 errechnen
Verbrauch des benutzten PKW:	8 [Liter	r/km]		
Gewählte Route Situation am Stic	htag	Gewählte Route - neue Situation	Alternative Route 1	Alternative Route 2
Länge:	10 [km]	10 [km]	10,5 [km]	9,5 [km]
davon Autobahn od. Schnellstr.:	0 [km]	0 [km]	0 [km]	0 [km]
Tür-zu-Tür-Fahrzeit:	15 [min]	23 [min]	21 [min]	24 [min]
Fahrtkosten:	€ 2,00 [€]	€ 2,00 [€]	€ 2,42 [€]	€ 2,57 [€]
Zeitpuffer:	10 [min]	5 [min]	5 [min]	0 [min]
Verkehrssicherheit:		4,97 [Unfälle	4,97 [Unfälle	4,97 [Unfälle
		pro 10 Mio. km]	pro 10 Mio. km]	pro 10 Mio. km]
Wie würden Sie sich in diesem Fal	ll entscheiden?	Neue Situation	C Alternative 1	Alternative 2
		🗆 sonstiger, und zwar:		

Fig. 1. Example of a questionnaire used for the face-to-face interview

The stated-preference experiments were based on the information about car trips recorded in the telephone survey. The reported attributes of the reference trip were changed to represent the conditions of the experiment; the values of the attributes of each alternative were calculated by multiplying the characteristics of the reference trip with randomly chosen factors. This approach guarantees that the respondents are familiar with the choice situation.

In the first survey stage 3,500 households were contacted. The number of "neutral losses" such as households not reached or households without car trips was 1,996. Among the remaining households a response rate of 15 percent could be achieved. A specific non-response survey has not been launched; however, it can be assumed that the sample is representative since the distribution of socio-demographic characteristics is similar to those of the population. In total, 245 people representing 239 households completed a face-to-face interview and 483 car trips were selected for the stated preference experiments. All data were checked for plausibility and weighted according to gender, age, and employment status.

The theory of discrete choice models

A discrete choice analysis with multinomial specification was used to calibrate the utility functions. Such an analysis is based on individual choices; it is assumed that people intend to maximize their utility; each respondent opts for the alternative offering maximum personal

benefit. The resulting utility function U_{ni} includes a deterministic component V_{ni} and a stochastic component ϵ_{ni} :

$$U_{ni} = V_{ni} + \epsilon_{ni}$$

The deterministic utility function is the sum of the products of all decision-relevant variables with their specific coefficients. These variables either refer to a route (alternative-specific), to the decision maker or the decision situation (not alternative-specific).

If the stochastic component is type I extreme value distributed (Gumbel distributed), the probability p_{ni} of choosing a route can be calculated as (Hess, 2005):

$$p_{\rm ni} = \frac{e^{V_{ni}}}{\sum_{i} e^{V_{nj}}}$$

The Austrian transport model (VMÖ)

The Austrian transport model (Verkehrsmodell Österreich, VMÖ) is the Austrian tool for transport planning purposes and for assessing the impact of transport measures. It is a VISUM application (PTV-AG, 2011). The impedance function of passenger transport route choice is implemented as follows (Trafico, 2007):

$$W_{Car} = 0,145 * t_{Cur} + 0,005 * I + 100 * toll_{x} + Z$$

with t_{cur} being the trip duration in the loaded network, I the trip length, toll_x the toll for certain Alpine transit routes, and Z a correction factor. This factor considers specific features of routes, e.g. their profile. The Z-Value is calculated in regard to the VMÖ only and cannot be transferred to other impedance functions.

The value of time (VOT) and the average car operating costs can be derived from the impedance function given above. The VOT is \in 5.23 per hour, the car operating costs \in 0.05 per kilometer. Both figures are small compared to values mentioned in literature where the car operating costs are reported to vary between \in 0.12 and \in 0.18 per kilometer (Basler, 2005; Sammer et al., 2006; FSV, 2010). The VOT varies between 8.00 and 30.00 euros per hour depending on the trip purpose (FSV, 2010).

Additionally, the accuracy level of the confidence intervals of the forecasted travel demand resulting from VMÖ assignments is unsatisfactory. However, these results influence decisions about transport measures like infrastructure investments. The research project RoSana had the objective to provide a more accurate mapping of the Austrian traffic

situation by improving the VMÖ impedance function as a basis for the integration of the impact of pricing measures into the VMÖ.

RoSana utility functions

The utility functions calibrated in RoSana are based on a data set considering both revealed and stated preferences. Different kinds of utility functions were developed. They can be distinguished by the fact of whether the implementation into the current version of the VISUM software is possible or not: utility functions to be implemented in VISUM can only consist of variables of routes that are neither transformed (e.g. logarithm or squarefunctions) nor a function of other attributes (such as the reliability value which depends on traffic volume). The extended utility functions take all other characteristics into account, thus allowing a deeper understanding of route choice behavior.

The basic utility function

The basic utility function includes variables which are already used or which can be implemented in the Austrian transport model:

$$U = 1,130^{*}A1 - 0,026^{*}I - 0,047^{*}t_{Cur} - 0,187^{*}toII_{all} + 0,005^{*}I_{MW}$$

In contrast to the impedance function of the VMÖ, here a dummy variable for the reference route under the changed framework conditions is taken into account (A1). Its inclusion is necessary to account for a surplus benefit due to the familiarity of the respondents with this route. The variable toll_{all} indicates the toll costs for the chosen route and replaces the toll for the Alpine transit routes of the current VMÖ impedance function. Furthermore, a variable for the distance travelled on highways or expressways is included (I_{MW}).

With the help of the basic utility function, 68 percent of the observed choices can be predicted correctly. Rho-square (ρ^2) equals 0.086. The influence of all variables is statistically significant at a level of one percent.

The value of time can be calculated as \in 15.08 per hour which is plausible compared to those values mentioned in literature (see paragraph 3). The average vehicle operating costs of \notin 0.14 per kilometer are also plausible.

Distinguishing trips according to trip purpose shows significant impacts of a distance-based road pricing scheme. Business trips are affected eight times less than non-business trips; shopping trips are particularly influenced. Driver's characteristics affect the response on a

road pricing scheme. For example, full-time employees or persons with a high educational level are less influenced by a road pricing scheme.

The length of the highway section used has a significant impact but does not noticeably improve the explanatory power of the utility function. However, for plausibility reasons this variable is included. The integration of this function into the VMÖ improves the prediction of route choice compared to the currently used impedance function.

The extended utility function

The basic function is further developed by testing the influence of transforming the variables included. For this purpose all variables that could be integrated into the utility function were transformed by root extraction, the calculation of logarithms or squaring. The best model is achieved by calculating logarithms for the trip length and the toll costs as well as using a root extraction for the trip duration. The ρ^2 increases from 0.086 to 0.129; the quality of the model increases significantly.

Simulation settings

The basic utility function is transferred into an impedance function and integrated into the VMÖ. This allows the prediction of the impact of a road pricing scheme on car users' route choice. Three scenarios are considered: \in 0.05, \in 0.08 and \in 0.14 per kilometer for every kilometer traveled on a high-performance road.

All assignment procedures are conducted using the VISUM software. It is important to note that the consideration of car driver's characteristics or other attribute of the car trips such as the trip purpose in the Austrian transport demand model is impossible, since no origin-destination matrices regarding these aspects are available.

The quality of the status quo assignment is assessed by the comparison of the car traffic volume modeled and the amount of vehicles recorded at the 1,836 permanent counting stations (Trafico, 2007). The quality of the forecast is measured by the Percentage-Root-Mean-Square Error, PRMSE (Roider, Raser, Sammer, 2007). The lower the PRMSE, the better the modeled and counted values fit together:

$$\sqrt{\frac{1}{T} * (\sum_{t=1}^{T} \frac{\hat{y_t} - y_t}{y_t})^2} \text{RMSE} = \sqrt{\frac{1}{T} * (\sum_{t=1}^{T} \frac{\hat{y_t} - y_t}{y_t})^2} * 100\%$$

- $\hat{y_t}$: Modeled traffic volume at counting station t
- yt: measured traffic volume at counting station t

Mapping the status quo

An assignment procedure of the VMÖ results in a PRMSE of 52.8 percent when taking the Z-Value into account (see paragraph 4). An assignment without the Z-Value leads to a value of 66.2 percent. The quality of the assignment results largely depends on the Z-Value.

Without the Z-Value, a RoSana impedance function achieves a PRMSE of 55.5 percent. This is better than the VMÖ impedance function without the Z-Value and comparable to the goodness of fit of the VMÖ including the Z-Value. Figure 2 shows the comparison of modeled traffic volume using the basic RoSana impedance function and the measured value at the respective counting stations.



Fig. 2. Modeled and measured traffic volume at 1,836 counting stations for the status quo

Road pricing scenarios

The RoSana impedance function is applied to three scenarios, describing a toll level of 5, 8 and 14 cents per kilometer on high-performance roads. To achieve realistic cost levels, the price for the existing time-based road charge is subtracted from the toll. For this purpose, the costs incurred by car users were converted to costs per highway kilometer, taking the annual average driving performance on high-performance roads into account. Including value-added tax, the effective toll levels for the scenarios are 4.2, 7.8 and 15.0 cents per kilometer on high-performance roads. The following statements refer to the effects on an average working day.

A two-step analysis procedure is applied. In the first step, the current origin-destination matrix of car traffic volume is assigned; in the second step the traffic-reducing impact of a road-pricing scheme is considered by limiting the transport volume by a distance-based factor.

Impacts on route choice

The traffic-reducing effect of a toll for the use of highways and expressways is not taken into account in the first step of the analysis. Only the effect of the toll upon the route choice is analyzed; the origin-destination matrix of travel volume remains unchanged.

Distance traveled

Road pricing on high-performance roads affects the distribution of the transport volume to the different road categories. Even a nominal toll of just \in 0.05 per kilometer would reduce the distance traveled on highways and expressways by up to 11.5 percent (Tab. 1). The distance traveled on highways is reduced by more than 50 percent if the toll reaches a level of \in 0.14 per kilometer. It is important to note that the out-of-pocket toll costs of the last scenario are \in 0.15 per kilometer on highways, which are added to the average vehicle operating costs of \in 0.14 per kilometer. Thus, running costs per kilometer are more than doubled, with a corresponding impact on distance traveled.

Toll level	Entire road network	Highways, expressways	Other roads
Status Quo	163.5	62.2	101.3
€0.05 km	160.6 (-1.7%)	55.1 (-11.5%)	105.6 (4.3%)
€0.08 km	158.2 (-3.2%)	46.2 (-25.8%)	112.1 (10.7%)
€0.14 km	155.8 (-4.7%)	27.3 (-56.1%)	128.5 (26.9%)

Tab. 1. Distance traveled [million car kilometers per day]

The distance traveled on minor roads increases; however, the increase is smaller than the decrease on high-performance roads in absolute figures. Therefore, the distance traveled on the entire network decreases as well. Since the traffic volume remains constant, this decrease is caused by using direct routes more often.

Travel Speed

The average speed per car changes if a road pricing scheme is implemented on highways since the travel speed mainly depends on the traffic volume. From the status quo of 108.0

kilometers per hour on high-performance roads, the traffic speed increases up to 110.0 kilometers per hour in case of a toll level of \in 0.14 per kilometer. The corresponding individual travel time savings when using a highway are comparatively small and cannot contradict the impact of the road-pricing scheme.

The speed per car on low-performance roads decreases from 59.2 to 58.4 kilometers per hour, a decrease of 1.5 percent (\notin 0.14 per kilometer). The travel speed per car in the entire road network decreases by 13.3 percent in case of the \notin 0.14 scenario.

CO₂-emissions

 CO_2 -emissions caused by road traffic depend on the transport volume and the average speed. The expected values are shown in Table 2. Thus, the CO_2 -emissions on high-performance roads and in the entire road system decrease somewhat slower than the corresponding distance travelled (Tab. 1), because of the increases in the average speed.

Tab. 2. CO₂-emissions [1,000 tones per day]

Toll level	Entire road network	Highways, expressways	Other roads
Status Quo	24.2	9.7	14.5
€0.05 km	23.7 (-1.9%)	8.6 (-11.0%)	15.1 (4.3%)
€0.08 km	23.3 (-3.8%)	7.3 (-25.1%)	16.0 (10.6%)
€0.14 km	22.7 (-6.2%)	4.3 (-55.8%)	18.4 (27.0%)

Only CO₂-emissions were analyzed. However an increase in other harmful pollutants can be assumed for minor roads as well; they would have a negative impact on the living conditions in these areas.

Considering omitted car trips

It was the main goal of RoSana to recalibrate the impedance function of the Austrian transport model and to calculate the impacts of a route shift due to the implementation of a road pricing scheme on highways. However, road pricing schemes also influence mode or destination choice. In RoSana this change in car use is derived from the "none"-alternative answers in the face-to-face survey (see paragraph 2). Answers were classified in "another destination", "another mode", or "to omit the trip". Depending on the toll level and the length of the highway section used, a reduction of trips by up to 11 percent can be

observed (€ 0.14 per kilometer, use of the highway section for more than 50 km). These numbers were used to adapt the origin-destination matrix of traffic volume.

Distance traveled

Considering omitted car trips as described above, the distances traveled by car on the entire road network decrease by -2.3 to -7.2 percent depending on the toll level (Tab. 3). As expected, the higher the toll, the higher the decrease of distances traveled. The biggest decrease can be observed on high-performance roads. In the \in 0.05 cents scenario, the overall decrease amounts to 1.0 million car kilometers per day, 0.7 million on high-performance roads.

Toll level	Entire road network	Highways, expressways	Other roads
Status Quo	163.5	62.2	101.3
€0.05 km	159.6 (-2.3%)	54.4 (-12.6%)	105.3 (4.0%)
€0.08 km	154.4 (-5.5%)	44.0 (-29.3%)	110.4 (9.1%)
€0.14 km	151.7 (-7.2%)	25.2 (-59.4%)	126.5 (24.9%)

Tab. 3. Distances traveled, taking omitted trips into account [million car kilometers per day]

Travel Speed

The average travel speed increases up to 110.8 kilometers per hour (2.7 percent against status quo) on highways, but stays nearly unchanged on low-performance roads (58.7 kilometers per hour, -0.9 percent) assuming a road toll of $\in 0.14$ per kilometer.

CO₂-emissions

 CO_2 -emissions decrease even further. Assuming a toll level of \in 0.14 per kilometer, a reduction of CO_2 -emissions by 9.2 percent can be achieved (compared to 6.2 percent without considering omitted trips), however emissions on low-performance roads increase, but not as much as the emissions on high-performance roads decrease.

Toll level	Entire road network	Highways, expressways	Other roads
Status Quo	24.2	9.7	14.5
€0.05 km	23.6 (-2.5%)	8.6 (-12.1%)	15.0 (3.9%)
€0.08 km	22.7 (-6.2%)	7.0 (-28.5%)	15.7 (8.7%)
€0.14 km	22.0 (-9.1%)	4.0 (-59.0%)	18.0 (24.5%)

Tab. 4. CO₂-emissions, taking omitted trips into account [1,000 tones per day]

Conclusions

The impedance function currently used in the Austrian transport model leads to a value of time of \in 5.23 per hour and car operating costs of \in 0.05 per kilometer. Both values are low compared to those mentioned in literature. Based on the results of a two stage survey, the research project RoSana recalibrated this function using a discrete choice analysis (multinomial specification) for route choice decisions. The basic utility function shows a more plausible value of time of \in 15.08 per hour as well as car operating costs of \in 0.14 per kilometer. Using the RoSana impedance function, the impacts of a road pricing scheme on the high-performance road network in Austria can be assessed.

It was shown that even a small increase in the toll level has a considerable effect on the distribution of the transport volume within the road network; the distance traveled by car decreases by 11.5 percent ($\in 0.05$ per kilometer) to up to 56.1 percent ($\in 0.14$ per kilometer). Many car users shift to low-performance roads and opt for a more direct route. Therefore, diverted traffic is the utterly negative effect of a road pricing scheme which is only implemented on high-performance roads. This scheme counteracts one of the major goals of the high-performance road network: to attract traffic and thus draw it away from roads located close to residential areas. As a consequence, the implementation of this kind of road pricing scheme has to be accompanied by measures to protect the quality of life of the resident population.

References

Asfinag (2011). Mautsystem. www.asfinag.at/maut/mautsystem; accessed April, 14, 2011

Balmer, U., Lanz, A., Bachmann, A. (2007). Einführung eines Road Pricing. Bericht des Bundesrates zur möglichen Einführung von Road Pricing in der Schweiz in Erfüllung des Postulats 04.3619 KVF Nationalrat vom 16.11.2004. Bundesamt für Raumentwicklung (ARE)(Hrsg.), Zürich.

- Basler & Partner (2005). Einfluss von Road Pricing auf die Raumentwicklung, Schlussbericht. Schweiz.
- Brons, M., Nijkamp, P., Pels, E., & Rietveld, P. (2008). A meta-analysis of the price elasticity of gasoline demand. A SUR approach. Energy Economics, 30, p. 2105–2122.
- De Dios Ortuzar, J., & Willumsen, L. G. (2011). Modelling Transport, 4th. Edition. Chichester: John Wiley & Sons Ltd.
- FSV (2010). RVS 2.01.22, Entscheidungshilfen; Nutzen-Kosten-Untersuchungen im Verkehrswesen. Wien.
- Goodwin, P. & Dargay, J. (2003). Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review. Transport Reviews Vol. 24, No. 3, p. 275–292.
- Graham, D. & Glaister, S. (2002). Review of income and price elasticities of demand for road traffic. London.
- Hess, S. (2005). Advanced discrete choice models with applications to transport demand. London: Centre for Transport Studies, Imperial College London.
- Jansen, H. & Denis, C. (1999). A welfare cost assessment of various policy measures to reduce pollutant emissions from passenger road vehicles. Transportation Research Part D, 4, p. 379-396.
- PTV-AG (2011). Benutzerhandbuch für Visum 12. Karlsruhe.
- Rapp, M. (2007). Mobility Pricing Anders Bezahlen für Mobilität. Bern.
- Roider, O., Raser, E. & Sammer, G. (2007). Qualitätsmanagement bei der Anwendung von Verkehrsmodellen. DVWG - Workshop, Verkehrsmodell im Überblick (B313). Deutsche Verkehrswissenschaftliche Gesellschaft e.V.
- Sammer, G., Röschel, G., Tischler, G., Raderbauer, H. & Griesser, B. (2006). Leitfaden zur Erstellung des Umweltberichts im Rahmen der strategischen Prüfung Verkehr für Netzveränderungen hochrangiger Infrastruktur. Wien.
- Trafico (2007). Verkehrsprognose Österreich 2025+ Endbericht Rohfassung, Verkehrsmodell Personenverkehr + Güterverkehr. Wien.
- Umweltbundesamt (2011). Klimaschutzbericht 2011. Wien: Umweltbundesamt GmbH.
- Wadud, Z. (2010). Personal tradable carbon permits for road transport: Why, why not and who wins? Transportation Research Part A, doi:10.1016/j.tra.2010.03.002.

PART IV

INNOVATIVE METHODS FOR LAND-USE AND TRAVEL DEMAND MODELING

MODELLING THE RELATIONSSHIP BETWEEN URBAN ENVIRONMENT AND TRAVEL BEHAVIOUR: POLICY AND INDICATORS

Lissy La Paix; Andrés Monzón, TRANSyT, Universidad Politécnica de Madrid;

Elisabetta Cherchi, DTU Transport, Technical University of Denmark

Corresponding author:

Lissy La Paix, I.c.lapaixpuello@utwente.nl

Abstract

Due to the necessity to undertake activities, every year people increase their standards of travelling (distance and time). Urban sprawl development plays an important role in these "enlargements". Thus, governments invest money in an exhaustive search for solutions to high levels of congestion and car-trips. The complex relationship between urban environment and travel behaviour has been studied in a number of cases. Thus, the objective of this paper is to answer the important question of which land-use attributes influence which dimensions of travel behaviour, and to verify to what extent specific urban planning measures affect the individual decision process, by exhaustive statistical and systematic tests. This paper found that a crucial issue in the analysis of the relationship between the built environment and travel behaviour is the definition of indicators. As such, we recommend a feasible list of indicators to analyze this relationship.

Keywords: Land-use, forecasting, indicators, policy.

Introduction

The phenomenon called *Urban Sprawl* is produced by the movement of population from the city centre to low density urban areas, with poorer accessibility and facilities, and as a consequence, high car-dependency. City structures are changing from mono-centric to polycentric cities (Gordon, 1986; Small and Song, 1992; Clark, 1994; McDonald, 1994; Cervero, 1997). This controversial term has received a lot of attention in recent years due to its association with the environment, health, transport and public investments, and to improve our understanding of the relationship between travel behaviour and urban structure (Giuliano, 1993; Handy, 1996). This phenomenon includes low density developments which are more difficult and expensive to serve by more efficient transport modes. Urban Sprawl is also called the "development trap" that leads to further congestion and a higher proportion of our time spent in slow moving cars (Ortuzar and Willumsen, 2011).

According to the Action Plan of Urban Mobility, (European Commission 2009) urban mobility is an issue of growing concern to citizens. Nine out of ten EU citizens believe that the traffic situation in their area should be improved (European Commission (EC) 2007a). The choices that people make in the way they travel will affect not only future urban development but also the economic well-being of citizens and companies. It will also be essential for the success of the EU's overall strategy to fight against climate change, achieve the 20-20-20 objective and to promote cohesion.

Urban mobility is also a central component of long-distance transport. Most transport, both passenger and freight, starts and ends in urban areas and passes through several urban areas on its way. Urban areas should provide efficient interconnection points for the trans-European transport network and offer efficient 'last mile' transport for both freight and passengers. They are thus vital to the competitiveness and sustainability of our future European transport system.

In the report "Green Paper of Urban Transport" the European Commission considers urban sprawl an important indicator of urban mobility in Europe. Urban sprawl and other factors, such as demography, congestion, the environment, employment, etc., form the diagnostic of urban and non-urban areas at an EU level. As stated in the report, "Urban sprawl is commonly used to describe physically expanding urban areas". The European Environmental Agency (EEA) has described sprawl as the physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas. A sprawling city involves drawbacks related to urban growth and planning control of land subdivision. Development is separated, land-use is anything but mixed, and there is a tendency for discontinuity in urban structure. In other words, "Sprawling cities are the opposite of compact cities – full of empty spaces that indicate the inefficiencies in development and highlight the consequences of uncontrolled growth" (European Environment Agency EEA 2006).

There is a clear sign that the urban sprawl phenomenon is increasing in European cities. Since the mid-1950s historical trends show that European cities have expanded on average by 78% while population has grown by only 33% (European Commission (EC) 2007b). And this phenomenon is mostly accompanied by negative connotations:

• Negative environmental, social and economic impacts which seriously undermine efforts to meet the global challenge of climate change.

• Major adverse impacts in terms of increased use of land, increased energy consumption and increased soil erosion threaten the natural and rural environment, increasing GHG emissions and elevating air and noise pollution to levels that often exceed human safety limits.

• A direct effect on the quality of life for city dwellers.

The extended geographical scope of urban sprawl makes this a timely research area. The Green Paper report examined urban sprawl characteristics in cities at a European level, finding that sprawl is equally evident in the vast majority of the cities examined. It seems that the key issue is to develop sprawled cities in harmony with compact forms of urban extension. In order to achieve this objective, researchers and planners need to understand the magnitude and direction of the relationship between the built environment (BE) and travel behaviour (TB).

There are at least three elements characterizing the complex relationship between the BE and travel behaviour, as discussed below:

- 1. Multidimensional in nature
- 2. Selectivity
- 3. Methods

Multidimensional in nature

Both BE and TB are multidimensional in nature. They are influenced by many factors, many of which depend on the considered dimension of travel demand and the specific definition of land use. That is, there are many aspects to BE, including accessibility to transit stops, presence and connectivity of walk and bike paths, land-use mix, street network density (such as average length of links and number of intersections per unit area), block sizes, and proportion of street frontage with buildings. Similarly, there are many dimensions of travel, including car ownership, number of trips, time-of-day, route choice, travel mode choice, purpose of trips, and chaining of trips.

Many different factors influence the relationship between travel demand and the BE. There is no clear consensus on which feasible measures of the BE really play a role in explaining individual mobility (Brownstone, 2008). There is also little background information to compare the influence of land use and socio-economic characteristics on different travel demand dimensions. Recent research focus on: vehicles miles driven or VMD (Handy *et al.*, 2005), tour-frequency (Limanond & Niemeier, 2004), shopping tour (Agyemang-Duah *et al.*, 1995), type of activity (Naess, 2006); modal choice or modal changes (Bento *et al.*, 2005).

Other studies (La Paix *et al.*, 2010; La Paix, 2010; La Paix, 2012) have contributed to answering the above two questions.

Selectivity

Many authors show that higher-density neighbourhoods reduce motorized trips. However, whether land-use configuration itself affects travel pattern or whether people with different travel behaviour preferences select different types of neighbourhoods in which to live is an issue open to discussion. This effect is called self-selectivity, which some authors describe as: "the tendency of people to choose locations based on their travel abilities, needs and preferences", see Litman (2005). The importance of analyzing residential self-selection is because it may confound the association between BE-TB relationship and, as a consequence, it could produce invalid results. Most studies have employed multivariate analysis and accounted for the sorting effect of socio-economic characteristics (Abreu e Silva *et al.*, 1977; Kitamura *et al.*, 2001; Van Acker, 2007); while others focus on the issue of attitude induced self-selection (Cao, 2008).

Methods and techniques

Studies from the last 15 years have used many different estimation techniques, units of analysis, empirical contexts, travel behaviour dimensions, and BE characteristics and scales, as stated in Bhat and Guo (2007). Similarly, one of the major problems is the lack of consistency of results due to multicollinearity. Correlated indicators may confound the results and lead to spurious conclusions. And, multicollinearity also constrains the number of explanatory variables predicting travel demand, which make comparison difficult.

Due to the complexity, it is crucial to carefully analyze which dimension has influence over which dimension of TB. Thus, the objective of this paper is to select a set of best indicators for modelling trip frequency. Thus, an exhaustive research has been carried out, based on statistical and systematic tests. This descriptive analysis produces a set of statistical measures for modelling trip frequency; while the model is estimated and analyzed in a later work.

The rest of this paper is organized as follows: section 2 presents the data collection process and case study, section 3 describes 3 kinds of indicators: mobility (MOB), the socioeconomic (SE) and built environment (BE); section 4 presents a discussion about the best indicators and policy implementation. And finally, section 5 concludes the paper.

Survey process and case study

This paper uses a database from a survey conducted in 2006-2007 in Madrid, a suitable case study for analyzing urban sprawl due to new urban development and substantial changes in mobility patterns in the last years. The sample included 345 households, for a total of 943 individuals, distributed as follows: 288 from the central business district (CBD), 372 from urban areas and 283 from suburban areas.

As can be seen in Figure 1, the metropolitan area of Madrid is divided into four regions: the CBD, Madrid City, Metropolitan Ring and Regional. These four regions are partitioned into eight areas around the radial highways that go from the city centre to the periphery. The population of Madrid is 3.3 million inhabitants (INE-National Institute of Statistics), while the population of Metropolitan Ring is calculated to be 2.3 million. The demographic density varies considerably. Its inner core (i.e. Madrid City) has 51 inhabitants per hectare whereas in its metropolitan ring the density is only 10.3. However, the Metropolitan Ring is growing and gaining population from Madrid municipality.

Madrid is divided into 179 municipalities and each municipality is divided into several districts, the number of which varies among municipalities from a minimum of one and a maximum of 21.



Figure 5 Location Map of Madrid

A total of 943 individuals were interviewed from 3 selected neighbourhoods: one in CBD; and 2 municipalities in the Metropolitan Ring (called urban and suburban).

Survey and data

Data come from a survey conducted with the aim to analyse the influence of the type of questionnaire on mobility patterns (Monzón de Cáceres & Madrigal Díez, 2007). The two diaries used were arranged in two parts. The first part, common to both diaries, consisted of a socio-economic questionnaire aimed at gathering data related to both the household and all its members. One member of the participating household was asked to provide information about the household and each of its members. The information collected was socio-economic and related to trips.

We combined the survey data with a GIS database and administrative data to construct three spatial levels. An exhaustive research of important indicators for measuring the relationship between land-use and travel behaviour was carried out.

Case study

As introduced in this section, the case study is composed of 2 municipalities and 1 neighbourhood. The objective of choosing 3 different residence areas is to capture the *neighbourhood type effect*. In this context, this effect occurs when a specific mobility pattern is exhibited by citizens that live in the same neighbourhood.

The CBD is located in the neighbourhood of Chamberí, which corresponds to one of the 22 neighbourhoods of the Central Business District of Madrid. It is a traditional neighbourhood where several historical buildings are located and where people live mainly in apartments. The area is characterised by good transit (bus and metro) and rail services and by a gross income level that ranks 4th out of the 22 neighbourhoods of Madrid City. In 2004 the income of Chamberí was also 40% higher than the mean of the Region of Madrid.

"Urban" is part of the municipality of Pozuelo de Alarcón, located 15 km west of the Madrid CBD but still inside Madrid City. This is a car-oriented municipality, where public transport service is limited. Urban residents tend to live in single family houses or detached houses. Pozuelo's average income level ranks the highest among the municipalities of the Region of Madrid. It was 66% higher than the mean of the Region of Madrid in 2004.

"Suburban" is a district of the municipality of Algete, that is located 30 km north-east to the Madrid CBD, in the Metropolitan Ring. This municipality has lower available gross income and fewer transit services than the other two selected areas. Algete's average income level ranks 15th among the 179 municipalities of the Region of Madrid. It was 17% higher than the mean of the Region of Madrid in 2004.

Results

Mobility indicators (MOB)

Number of Trips

The number of trips were analysed in two ways: as the total number of trips made during the survey day by each individual, and as the number of trips by mode.

Table 1 shows the descriptive statistics for trip rates grouped by residence area. Unexpectedly, the highest trip rate corresponds to the suburban area, while the lowest corresponds to the CBD. A possible explanation could be the age of respondent, because, as reported below in the descriptive analysis of socio-economic characteristics, Chamberí has the largest elderly population among the 3 neighbourhoods. Additionally, trips shorter than 5 minutes, which are frequent in the CBD, were not registered in the questionnaire. Finally, it is important to mention that the statistics below are computed based on the whole sample (943 respondents), i.e. including also the non-travellers, i.e. people who declared no trips during the study day.

We can note in Table 1 variations between 0 (minimum) and 10 (maximum) in total trips which may indicate at least one individual with 10 trips. The range is a descriptive statistic that indicates the scattering of the sample. In this case, both CBD and Suburban residents have the maximum range. Kurtosis is larger than 2 for both CBD and Suburban neighbourhoods, which means that those observations do not follow a normal distribution. As can be seen in the table, there are 1959 trips, 567 (28.94%) from the CBD, 768 (39.20%) from urban and 624 for suburban (31.85%).

The box and whisker plot for total trips is presented in Figure , the stars in the plot indicates the outliers. As can be seen, the mean is equal to 2 trips, and the 25 and 75 percentile are also equal to 2, therefore, the box is barely visible. The number beside the stars is the number of the observation. On average the three zones present similar patterns, but a higher level of dispersion is observed in the CBD and suburban neighbourhood as the mean of higher trip frequency values.

Table 1: Descriptive Statistics for Total Trips

Residence Area	CBD	Urban	Suburban	Total
Mean	1.97	2.06	2.2	2.08
Median	2	2	2	2
Sum	567	768	624	1959
Minimum	0	0	0	0
Maximum	10	8	10	10
Range	10	8	10	10
Standard Deviation	1.51	1.46	1.59	1.52
Variance	2.28	2.13	2.53	2.3
Kurtosis	2.64	0.91	2.53	2.03
Skewness	0.93	0.52	1.02	0.82
% of total	28.94	39.2	31.85	100





Public transport trips

Table 1 shows the descriptive statistics for public transport trips rates grouped by residence area. As expected, the highest trip rate corresponds to the CBD. This is consistent with the transport service measured and displayed afterwards in the table.

.

The global range was between 0 and 5, which means that there was at least one individual with 5 trips. In this case, CBD takes the maximum range. Similarly, Table 1 shows 526 trips, 242 (46.01%) from CBD, 180 (34.22%) from urban, and 104 for suburban (19.77%). The box and whisker plot for public transport trips is presented in **Fehler! Verweisquelle konnte nicht gefunden werden.** As can be seen the mean is close to zero in the three neighbourhoods. However, in the CBD 50% of the individuals carried out between zero or two trips by public transport. Similarly, the highest number of public transport trips is observed in CBD (5 trips), while Urban and Suburban areas also present zero trips on average.

			an	
Residence Area	CBD	Urban	Suburb	Total
Mean	0.84	0.48	0.37	0.56
Median	0.00	0.00	0.00	0.00
Sum	242	18	104	526
Minimum	0.00	0.00	0.00	0.00
Maximum	5.00	4.00	4.00	5.00
Range	5.00	4.00	4.00	5.00
Standard Deviation	1.10	0.93	0.88	0.99
Variance	1.21	0.86	0.77	0.98
Kurtosis	0.10	1.94	4.75	1.54
Skewness	0.94	1.71	2.34	1.55
% of total	46.01	34.22	19.77	100

Table 2: Descriptive Statistics for Public Transport trips.



Figure 3 Box and Whisker Plot or Public Transport trips

Car trips

Table 2 shows the descriptive statistics for car-trips grouped by residence area. The table shows that the highest car-trip rate corresponds to the suburban area, which is exactly the opposite situation we found in the public transport analysis by residence area.

Similar to total trips, the global range is between 0 and 10, which means that there is at least one individual that carried out 10 trips, with Algete exhibiting the maximum range.

As can be seen in Table 2 there are 1009 trips, 136 (13.48%) from CBD, 469 (46.48%) from urban and 404 (40.04%) from suburban areas. The box and whisker plot for total trips is presented in Figure 3. The stars in the plot indicate the outliers, and there are more outliers in the CBD than in the other 2 neighbourhoods. As can be seen the mean for car-trips for the CBD is close to zero, and the 25 and 75 percentile are also close to zero, therefore, the box for the CBD area is barely visible. The number next to the stars is the number of the observation. In the case of urban and suburban, the box indicates that 50% of individuals are between 0 and 2 car-trips.

Table 3: Descriptive Statistics for Car-Trips

Residence Area	CBD	Urban	Suburban	Total	
Sample Size	288	372	283	943	
Mean	0.47	1.26	1.43	1.07	
Median	0	1	2	0	
Sum	136	469	404	1009	
Minimum	0	0	0	0	
Maximum	5	8	10	10	
Range	5	8	10	10	
Standard Deviation	0.96	1.47	1.6	1.44	
Variance	0.93	2.17	2.55	2.06	
Kurtosis	3.57	1.83	3.11	3.1	
Skewness	2	1.17	1.33	1.48	
% of total	13.48	46.48	40.04	100	



Figure 4: Box and Whisker lot for Car-Trips

Tour complexity

In our context tours are defined as a sequence of trip segments in the full day activity pattern. According to this definition, stops at home during the day are considered as intermediate stops inside the tour, instead of being considered as the end of the tour. A stop is considered as an intermediate (secondary) activity undertaken between the primary activity and home, or vice versa, between home and the primary activity.

In this paper we define a tour as the sequence of trips made during the whole day and identify a classification of the tours (called tour complexity) based on the primary activity in the tour and the number of stops.

A tour track was defined for each individual, and the number of stops during the tour accounted for. A hierarchy of activities was established in order to construct the tour track. The hierarchy of activities was created and used to identify primary activity during the day, in the case of several trips and/or stops. According to this hierarchy, the primary activity is used to classify the tour into five categories that compose the alternatives:

- 1. Home
- 2. Work or study
- 3. Work or study with intermediate stops
- 4. Non-work or non-study
- 5. Non-work or non-study with intermediate stops

Table 4 illustrates statistics for the frequency of each type of tour, classified according to the hierarchy and list of 5 tours explained before.

Residence Area	CBD	Urban	Suburban	Total
HOME	24.31	22.04	21.85	19.08
Work or study	44.79	45.43	46.34	49.12
Work or study with stops	14.24	15.86	15.48	16.25
Non-work or non-study	11.46	8.06	9.01	7.77
Non-work or non-study with stops	5.21	8.60	7.32	7.77
Total	100	100	100	100

Table 4: Descriptive Statistics for Type of Tour (values in percentages)

Table 4 reports the descriptive statistics for number of stops grouped by residence area. The number of stops is the sum of all the intermediate stops made in tours. As can be seen (line "Sum"), there are in total 127 stops, of which 31 (24.41%) are from the CBD, 52 (40.94%) are from urban, and 44 (34.65%) are from the suburban area. Additionally, the highest mean corresponds to the suburban area. This means that people living in the outskirts are likely to be conducting multistage tours. A possible reason for this is that in the same trip people carry out many activities before returning back home. Thus, multistage tours act as a way tocompensate local deficiencies.

The sample size is the number of individuals interviewed in each neighbourhood. The mean represents the average number of intermediate stops done by individuals residing in a neighbourhood. The table shows that residents from Algete carried out more stops than residents from the CBD. This is unexpected because the CBD is endowed with more commercial retail outlets and facilities; a possible explanation for this is that the survey only considered trips longer than 5 minutes. The skewness is positive in all of the 3 areas, which indicates that in all 3 neighbourhoods tours are mainly characterised by few or zero stops, or that there are many individuals who did not travel during the survey day.

Residence Area	CBD	Urban	Suburban	Total
Sample Size	288	372	283	943
Mean	0.11	0.14	0.16	0.13
Median	0	0	0	0
Sum	31	52	44	127
Minimum	0	0	0	0
Maximum	3	3	4	4
Range	3	3	4	4
Standard Deviation	0.44	0.44	0.56	0.48
Variance	0.19	0.19	0.31	0.23
Kurtosis	23.62	14.71	21.89	21.49
Skewness	4.71	3.62	4.41	4.33
% of total	24.41	40.94	34.65	100

Table 5: Descriptive Statistics for Number of Stops

Table 6 shows the percentages of trips grouped into four categories: 3 municipalities of case studies and otherwise. The municipality called the CBD includes 21 districts of Madrid. Urban and suburban refers to the study cases, and otherwise means all other municipalities.

Internal or *urban trips* are those trips undertaken within the municipality of residence. *Interurban trips* are those undertaken between two different municipalities.

As we can observe in the table, 85% of trips from the CBD are carried out within the Madrid CBD; while suburban dwellers undertake 37% of their trips to the CBD and 38% of their trips are undertaken within the Suburban area (municipality of residence) and only 24% to other municipalities as destinations. By contrast, urban dwellers frequently come to city centre with 53% of trips, and similar to suburban dwellers, around 35% of their trips are carried out inside the municipality of residence. This may be due to public transport service in the urban area, which is better than the Suburban one, i.e. endowed by Rail service (Cercanias). The percentage of interurban trips (both to the CBD and to other destinations) is really high. Thus, it must be carefully analyzed, (i.e. by trip purpose and mode) as a way to compensate for local deficiencies.

Table 6: Urban and Interurban Trips (values in percentages)

Residence Area	CBD	Urban	Suburba n	Others	Total
CBD	85			15	100
Urban	53	36%		12	100
Suburban	38		38	24	100

Socioeconomic Indicators (SE): the effect of the BE and life-style

The average age does not vary among neighbourhoods. However, a more disaggregated analysis reveals that the age distribution is instead quite different. Table 7 shows that individuals between 22-29 years old and between 50-64 years old are mainly located in the Urban area and in the CBD rather than in the Suburban area, while individuals aged 30-49 and 14-21 mainly live in the Suburban area. However, empirical analysis on the joint decision between number of trips and residential location have shown that age does not have an effect on the residential location choice.

The results in Table 7 might be related to the fact that families with children prefer to live in the Suburban and Urban areas. In fact, there are some differences in the household size among the three zones. Table 7 shows that households with 4 members are much more frequent in urban and suburban areas than in the CBD. According to the Census data, the

municipality of Algete has an average of 3.29 members per household and Pozuelo de Alarcón 3.38; both are higher than the Madrid Community average, of 2.88 and higher that the average for Metropolitan-North (3.20). Thus, despite the outliers observed in the CBD, on average, larger household sizes are observed for the urban and suburban areas.

Household size seems to be related to the neighbourhood selection. And of course the structure of the family and the status of the individuals are also related to the type of neighbourhood they live. Usually families with children prefer a bigger house which results in a lower density area. In fact, the Suburban area shows the highest percentage of married people (Table 7) and similarly the highest percentage of households with children.

Residence Area	CBD	Urban	Suburban
Gender			
Male	48	49	54
Female	52	51	46
Total	100	100	100
Age			
4-13 years	5	5	8
14-21 years	12	11	18
22-29 years	11	15	8
30-49 years	25	23	37
50-64 years	30	37	19
Greater than 65 years	17	9	10
Total	100	100	100
Household size			
1	8	1	2
2	24	15	18
3	27	26	25
4	26	42	45
5	9	13	10
6	2	3	
7	2		
Total	100	100	100
Marital Status			
Single	43	38	31
Married	51	57	64
Widow	4	3	1
Divorced	2	1	3

Table 7: SE indicators (values in percentages)

Total	100	100	100
Presence of child			
No Child	80	73	63
One or more	20	27	37
Total	100	100	100
Employment Status			
Worker	51	51	55
Work/study	2	2	1
Student	20	21	19
Retired/ Unemployed	20	16	18
Other Occupation	7	10	7
Total	100	100	100

Built Environment Indicators (BE)

The set of built environment (BE) variables includes all variables that are able to describe the characteristics of the neighbourhoods. One of the variables most used in the earlier literature is a simple dummy variable associated with each type of neighbourhood considered (in this case CBD, Urban and Suburban). However, one problem with this variable is that it represents too many characteristics, whose effect cannot be disentangled.

Several variables are measured and/or computed in this paper to try to specify and differentiate the BE characteristics. These include the typical measures such as residential and employment density, but also measures less frequently used such as transport accessibility, jobs, other opportunity activity, and also characteristics of the streets. Depending on their availability, these variables were measured at the residential zone, which usually corresponds to the origin of the first trip, and/or at origin and/or destination of each individual trip. Computing BE variables at both origin and destination zones made it possible to build composite variables (such as ratios between the same variable measured at origin and destination) to capture the relative effect of each characteristic between origin and destination. Similarly, the dimension (in squared kilometres) of each zone was computed in order to normalize those variables whose values were strictly correlated with the dimension of the zone. The normalized measures enable a correct comparison among the different spatial dimensions considered in this paper.

BE variables were measured at three different zone levels: by municipalities, by district and in a radius of 600 meters around the household location (called *"residential level"*).

The residential level, instead, was defined as the area in the 600 meters radio around the residence of each person interviewed.

Variables at municipal and district levels were computed using the National Institute of Statistics – INE (Spanish acronym) database. Table 8 shows the BE indicators. We discuss indicators by group in the following sections.

Table 8: BE Indicators

Description	CBD	Urban	Suburban
Land-Use Indicators			
Area of Commercial Land-use			
At origin (<i>in ha</i>)	205.59	109.77	24.53
At destination (in ha)	187.56	143.13	84.23
Percentage of Commercial Land-use			
At origin	0.05	0.04	0.01
At destination	0.03	0.03	0.01
Ratio of Commercial Land -use			
% Origin / % Destination	2.55	1.89	1.02
Area of Residential Land			
At origin (in ha)	9.390.04	1.626.96	422.39
At destination (in ha)	8.321.72	4.680.51	3.130.76
Percentage of Residential Land			
At origin	0.44	0.68	0.66
At destination	0.44	0.57	0.55
Ratio of Percentage Residential Land			
% Origin / % Destination	1.02	1.26	1.28
Area of Area of Industrial Land			
At origin (in ha)	1.468.89	6.18	96.92
At destination (in ha)	1.310.29	610.71	517.94
Percentage of Industrial Land			
At origin	0.07	0	0.15
At destination	0.08	0.04	0.13
Ratio of Industrial Land-use Percentage			
% Origin / % Destination	1.43	1.73	0.53
Employment Density Indicators			
Quantity of workers			
At origin	1,278,968	31,343	7,609
At destination	1,134,765	540,802	395,831
Percentage of workers			
At origin	0.41	0.39	0.4
At Destination	0.41	0.4	0.4

Ratio of workers						
% Origin / % Destination	0.99	0.97	0.99			
Gross Domestic Product (GDP) (in Euros)						
At origin	38,603	51,895	34,103			
At destination	37,678	43,847	36,339			
Ratio						
Origin / Destination	1.06	1.25	0.98			
Difference GDP and Madrid's GDP						
At origin (in %)	121.86	163.34	107.82			
At destination (in %)	119.32	138.86	115.08			
Ratio of Percentages						
% Origin / % Destination	1.6	1.25	0.98			
Commercial retails Indicators						
Number of places within 1.2km of the dwelling. (Average)						
Eat out places	9.54	1.03	0			
Medical	2.6	0.46	0			
Parking	1.39	0	0			
Schools and universities	17.74	10.58	6.95			
Service oriented places	18.19	2.84	0.24			
Dwelling type						
Single family	2%	32%	29%			
Terraced House	0%	48%	33%			
Detached	0%	4%	7%			
Apartment	93%	14%	23%			
Condominium	5%	2%	4%			
Street density. Average number of intersect	ions within 1.2km of t	he dwelling				
3-way	47.46	127.46	76.12			
4-way	65.67	34.18	17.74			
5-way	2.08	5.31	0.87			
Public transport supply (Average number within 1.2 km of the dwelling, average)						
Metro stations	18.51	0	0			
Bus stops	33.83	1.35	20.14			
Rail stations	0	0.58	0			

Land-use

The land-use (LU) variables that were possible to measure only at the municipal level at both the origin and the destination of each trip reported in the survey are:

- o Urban land-use
- Area in hectares of urban land-use
- Percentage of urban land-use

- Ratio of Urban Land-use
- o Commercial land-use
- Area in hectares of Commercial land-use
- Percentage of Commercial Land.
- Ratio of Commercial Land-use between origin and destination
- o Residential land-use
- Area in hectares of residential land-use
- Percentage of Residential Land
- Ratio of residential land-use between origin and destination
- o Industrial land-use
- Area in hectares of industrial land-use
- Percentage of Industrial Land
- Ratio of Industrial land-use between origin and destination

The main problem with measuring land-use at the municipal level is the lack of variability among observations. Moreover, in the case of large municipalities, such as Madrid, most of the trips start and end in the same municipality. Hence, it is impossible to distinguish the effect in the transport mobility due to differences in the land-use characteristics at origin and destination. Of course, large municipalities are not perfectly homogenous, i.e, some areas have higher concentration of commercial activities than others. However, to some extent, the ratio captures better the variability at the municipal level.

Public transport

A set of six variables was analyzed, with the aim of describing the accessibility level of destination zones regarding three different public transport modes: bus, Metro and rail (Cercanías). The number of bus stops, Metro and rail stations operating in 2008 by district and municipality are included here. The variables were calculated for both the number of units and ratio per squared kilometre. The main conclusion that emerges from this is the huge gap among destination zones; see for example in the number of bus stops by municipality.

Table 8 also shows the statistics for public transport supply by neighbourhood type. These measures are calculated at the Residence Area level, i.e. a 600m buffer around the residence. The average values show that dwellings in Pozuelo are situated close to an urban rail station; while most of the dwellers in the CBD are located close to Metro stations; there

are 18 Metro stations on average around each CBD dwelling. Similarly, we can observe that availability of bus stops is really low in Pozuelo.

Commercial retails at Residence area

The number of places to eat out can be associated with the location of Residence Area and the proximity to downtown. The number of monuments and recreational places can, to a higher extent, be explained by the location of the residence relative to downtown. Residents of the outer of the two zones (Algete and Pozuelo) live further away from medical facilities than from the CBD (Chamberí). The average number of medical facilities within 1.2km is 2.6 in CBD are (Chamberí), 0.4 in the Urban area (Pozuelo) and zero in the Suburban area (Algete), respectively. The average number of service-oriented places decreases with the distance from the residence to downtown. The high standard deviation indicates that almost all dwellings in the area have a service-oriented place, but only residents of some parts of the neighbourhood have the opportunity to choose among several service-oriented places. The number of primary schools or universities is somewhat lower in the CBD (Chamberí) it is equal to 17.

Street density

Figure indicates the number of trips by car related to the number of cul-de-sacs by residential area. It seems that the number of car-trips increases with a greater number of cul-de-sacs. Categories of 1 or 2 car-trips tend to be higher while categories of no trips tend to decrease.



Figure 5 Car-Trips and Cul-de-Sacs by Residential Area

Distance to CBD

The distance to the CBD was calculated as the distance in kilometres between the residence of each household and the city centre. It was calculated from the household location to Madrid City centre (Km zero at Sol) through a Google Earth Application Plus (5.1 version).

Figure shows the average distance from the CBD calculated for each household, and grouped by category of car trips and public transport trips by individuals, respectively. Car and public transport categories of trips are grouped in four categories as follows:

- 1. Zero trips
- 2. 1 or 2 trips
- 3. 3 or 4 trips
- 4. 5 or more.

Figure shows that the farther the household location is from the CBD, the greater the propensity to undertake more trips by car. The fourth category (5 trips or more) shows the highest average distance of household from the CBD. It shows that the relationship between trips by public transport and distance to the CBD is less clear, demonstrating the importance of analyzing different travel dimensions regarding urban environment attributes.



Figure 6 Car-trips and Public Transport Trips compared with distance to the CBD

Conclusions and Policy recommendations

This paper analyzed the existing literature and concluded that a crucial issue in the analysis of the relationship between the BE and TB is the definition of indicators. This multidimensional relationship needs to be carefully analyzed in order to avoid multicollinearity and biased results.

In that sense, this paper has shown a set of relevant and feasible indicators to be included in a demand model and more specifically, a demand model for estimating trip frequency from BE, SE and MOB indicators.

Through the selection of 3 neighbourhoods, the results show that neighbourhood effect is relevant for analyzing travel behaviour. Consistent with other studies in this field, one of the main findings has been that people living in outskirt areas are likely to multistage tours out of the residence area. A possible explanation for this is the desire to compensate for local deficiencies. Since must of interurban trips are carried out to Madrid CBD, commercial facilities at origin must be considered.

Particular to the case study of Madrid, it is important to point on the high percentage of interurban trips from the analyzed residence areas. In that sense, as policy makers try to harmonize sprawling cities with compact forms of urban extension, they must improve public transport between interurban origin and destinations. It is clear that trips from Urban to *CBD* are higher than Suburban to *CBD* and which is related to public transport accessibility. Thus, improvement in that sense is strongly necessary for *Suburban* areas.
The descriptive statistics of street density have shown that future urban development must consider high street density, because it decreases car-trips.

As a policy recommendation, it is important to highlight that transport demand models must incorporate more BE attributes. Similarly, transport policy measures must differentiate between the municipality and district scale for policy measures, because it is clear that we are dealing with different situations. Further research is ongoing about geographical scales for built environment attributes.

Finally, the importance of ratio measures (origin and destination of the first trip during a tour) indicates the relationship between local deficiencies and facilities at the destination. Further research is also forthcoming on this relationship by the authors of this paper.

References

- Abreu e Silva, J.; Golob, T. & Goulias, KG. (1977). The effects of land use characteristics on residence and employment location and travel behaviour of urban adult workers. Transportation Research Record, 121-131.
- Agyemang-Duah, K.; Anderson & Hall, WP. (1995). Trip generation for shopping travel. Transportation Research Record, (1493), 12-20.
- Bento, AM; Cropper, ML; Mobarak, AM & Vinha, K. (2005). The effects of urban spatial structure on travel demand in the united states. Review of Economics and Statistics, 87(3), 466-478.
- Bhat, C. & Guo, J. (2007). A comprehensive analysis of built environment characteristics on household residential choice and auto ownership levels. Transportation Research Part B: Methodological, 41(5), 506-526.
- Bowman, D. & Ben-Akiva, M. (2001). Activity-based disaggregate travel demand model system with activity schedules. Transportation Research Part A: Policy and Practice, 35(1), 1-28.
- Brownstone, D., (2008). Key relationships between the built environment and VMT. Transportation Research Board, , 7.
- Cao, X. (2008). Exploring causal effects of neighborhood design on travel behavior using stratification on the propensity score. Paper 09-0155 on the Transportation Research Board 88th Annual Meeting CD-ROM. Washington, DC.,
- Cervero, R. (1997). Polycentrism, commuting, and residential location in the san francisco bay area. Environment and Planning.C, Government Policy, 29, 865.
- Clark, W. (1994). Commuting in restructuring urban regions. Urban Studies, 31(3), 465.
- European Commission (EC). (2007a). Attitudes on issues related to EU transport policy. flash eurobarometer No. 206b)
- European Commission (EC). (2007b). Preparation of a green paper on urban transport: Report on urban transport in europe
- European Environment Agency EEA. (2006). Progress towards halting the loss of biodiversity by 2010. No. Report 5/2006). Copenhagen, the Netherlands:
- Giuliano, G. (1993). Is the journey to work explained by urban structure? Urban Studies, 30(9), 1485.
- Gordon, P. (1986). The distribution of population and employment in a polycentric city: The case of los angeles. Environment and Planning.C, Government Policy, 18(2), 161.

- Handy, S. (1996). Methodologies for exploring the link between urban form and travel behavior. Transportation Research Part D, 1(2), 151-165.
- Handy, S., Cao, X. and Mokhtarian, P. (2005). Correlation or causality between the built environment and travel behavior? Evidence from northern California. Transportation Research Part D, 10(6), 427-444
- Kitamura, R.; Akiyama, T.; Yamamoto, T & Golob, T. (2001). Accessibility in a metropolis: Toward a better understanding of land use and travel. Transportation Research Record, 1780, 64-75.
- La Paix, L. (2010). Relación entre la generación de viajes y la densidad urbana: Caracterización de la movilidad con modelos probit ordenados. IX Congreso Ingeniería del Transporte CIT. 5 -7 July, 2010. Madrid, Spain
- La Paix, L., Monzón, A. and Cherchi. E. (2010). Trip generation and location effects: case study of Madrid Metropolitan Area. 12th World Conference on Transport Research, 11 -15. Lisbon, Portugal, July 2010.
- La Paix, L. (2012). Modelling the impact of built environment, geographical scales and latent constructs on individual travel behaviour. Doctoral Thesis, Universidad Politécnica de Madrid.
- Limanond, T. and Niemeier, D.A. (2003). Accessibility and mode-destination choice decisions: Exploring travel in three neighborhoods in puget sound, WA. Environment and Planning B, 30(2), 219-238.
- Litman, T. (2005). Land use impacts on transport: How land use factors affect travel behavior.Victoria Transport Institute.
- McDonald, JF. (1994). Suburban employment centres: The case of Chicago. Urban Studies, 31(2), 201.
- Monzón & Madrigal (2007). Mejora metodológica de encuestas de movilidad de viajeros para el análisis de la demanda de transportes en españa. Estudios De Construcción y Transportes, (106), 93.
- Naess, P. (2006). Accessibility, activity participation and location of activities: Exploring the links between residential location and travel behaviour. Urban Studies, 43(3), 627.
- Ortuzar, J. D., & Willumsen, L. G.,(2011). In Modeling transport. John Wiley & Sons (Ed.), Chichester, UK.
- Small, K. and Song, S. (1992). "Wasteful" commuting: A resolution. Journal of Political Economy, 100(4), 888.
- Van Acker, V. (2007). The effects of the land use system on travel behavior: A structural equation modeling approach. Transportation Planning and Technology, 30(4), 331.

META-ANALYSIS OF LONG-TERM TRIP GENERATION MODELLING

Johannes Hartwig; André Kühn; Florian Senger; Michael Krail; Wolfgang Schade, Fraunhofer Institute for Systems and Innovation Research ISI

Corresponding author:

Johannes Hartwig; johannes.hartwig@isi.fraunhofer.de

Abstract

This paper investigates the current state-of-the-art in trip generation, or trip production modelling. As the first step in the classical four-step model defines the "mass" that is distributed, it is of high importance to examine changes that may be induced by altered mobility behaviour. Such changes should be driven by changing the techno-cultural framework, e.g., a new level of mobile communication technology used by younger generations or a common awareness of the climate change problem. In the discussion of sustainable transport systems it is important to consider soft factors in mathematical model endeavours. This is certainly the case in modal choice, but the impact on trip generation has to be considered as well.

We used the guidelines of the EPPI in order to conduct a near-comprehensive literature review on this topic. By using this methodology it is possible to reproduce the search process of other authors and to refine it where it may be required. We did not find that our research question is adequately addressed in the community.

"Keywords: long-term forecasting; trip generation; behavioural change; modelling"

Introduction

Despite the well-known critique of the standard four-step model, the use of activity-based modelling for long-term forecasting seems to be currently not feasible. On the one hand, this is caused by lacking a homogenous theory and on the other hand by major problems concerning long-term forecasting of the underlying factors yielding the derived demand for transport. As a consequence, the standard transport model is apparently still the state-of-the-art for aggregated demand projections with a time horizon of 20 years or longer.

The standard transport model is a four step model (see also figure 2) consisting of trip generation, distribution, modal split choice and assignment (Ortúzar, Willumsen 2001). The first three steps can be classified as the demand side of the model; step four allocates the demand to the network. Trip generation is supposed to remain fairly stable or attributed with growth factors, usually derived via regression analysis. Tendencies in mobility behaviour over the past decades for Western industrialised countries have shown only small degrees of variation and thus the assumption of a near-constant trip generation for a highly aggregated projection may seem reasonable.

However, qualitative studies envisioning future mobility trends are partly assuming a cultural change in mobility behaviour. This has implications on the core of the four step model: for a behavioural change to happen trip generation cannot be assumed to remain stable. The first step is, according to those studies, more dependent on changing socio-cultural parameters than it has apparently been in the past.

A shift in mobility behaviour may mean that the amount of trips will decline; a change in trip destinations towards near-by destinations will shorten trip distances. As the total amount of trips is defined at the first step and only spatially distributed and assigned in the later steps, behavioural change affecting trip generation and distribution are probably the biggest leverage points in the system. Though modal choice is often considered being relevant as a leverage for finding pathways for a sustainable transportation system, policies for effectively influencing the distribution are dependent on the mass that is to be distributed.

It should be noted that a shift towards a more sustainable mobility behaviour does not automatically mean a reduction in trip generation if one considers all kinds of trips produced and not only motorised trips. However, most authors do indeed consider only motorised trips in their modelling endeavour. Qualitative studies often lack some rigour in the scope of the impact of this assumed behaviour modification. For infrastructural planning or political instrument assessment it is necessary to estimate the effects of this behavioural change, despite the many problems related with it.

For enhancing the discussion about including "soft factors" into trip generation (sub-) models it is important to ascertain the state of the art in current practice. While a change in mobility behaviour influences trip distribution and mode choice as well, the focus on trip generation is justified as it seems to be underrepresented in the current discussion.

This paper presents the results of a systematic literature review on modelling trip generation. The following section describes the applied method of the systematic literature review, section 3 briefly presents the theory of the four step model, section 4 classifies the findings of the literature and section 5 discusses the consequences derived from this analysis.

Material and methods

A systematic review tries to cover the whole field of published literature on a specific topic. It has a rich tradition in the field of evidence-based medicine and is a basis for a metaanalysis of different studies. The Cochrane Group has published a handbook providing guidelines how to conduct systematic reviews (Higgins 2011).

Though applied in some cases, in the social sciences this methodology is not widespread. The Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre) seems to be the current leader in establishing this methodology in the field of social sciences. The authors have chosen to follow their methods (EPPI-Centre 2007) as they are well applicable on the research topic.

According to the EPPI-Centre one has first to decide on the kind of systematic review he wants to conduct. The research question of this paper is rather narrow, so we conducted an in-depth review, though bearing in mind that the outcome of relevant studies might be quite limited in quantity.

The first decision was to set the scope of the review. We constrained our search to trip generation (and here to trip production) because we found it most relevant for judging future mobility behaviour. We did not consider explicitly trip attraction, as it becomes more relevant for trip distribution, though formally being a part of the first step. As proposed by

the EPPI-Centre we set up a team with different expertise and sought appraisal of our approach by external experts.

Our criteria for including studies were: application of soft factors in the first stage of the four step model, qualitative descriptions of factors that may have an influence on trip generation, or descriptions of long-term effects on mobility behaviour. Excluding criteria were: applications or enhancements of one of the other three steps, methods for combining two or more of the steps, or the use of alternative approaches like activity-based modelling.

Search item	Refinements*	Initial search (Web of Knowledge/ Google Scholar**)	Title screening	Abstract screening	Final
behavioural change	Subject Area: Transportation	600 (420/180)	38 (32/6)	5 (1/4)	1 (/1)
four step model	Subject Area: Transportation	102 (90/12)	5 (5/)	4 (4/)	3 (3/)
mobility behaviour		170 (143/27)	7 (7/)	1 (1/)	
traffic demand	SubjectArea:Transportation,Psychology,Sciences, Urban Studies	777 (562/215)	80 (57/23)	14 (6/8)	3 (1/2)
transport demand modelling		111 (9/102)	40 (8/32)	14 (9/5)	3 (3/)
travel demand	SubjectArea:Transportation,SocialSciences, Urban Studies	832 (268/564)	107 (66/41)	39 (20/19)	11 (4/7)
trip generation		478 (342/136)	60 (43/17)	16 (8/8)	11 (8/3)
trip production		66 (47/19)	39 (39/17)	33 (22/11)	11 (8/3)

Table 1: Overview of the systematic review search process

*solely used for Web of Knowledge search

**Covered time span: 2006 to 2012; key words must be contained in the title

Source: Fraunhofer-ISI

As proposed by the EPPI, a protocol of our decisions was the starting point for our search activities, comprising the review question, underlying assumptions and the conceptual framework and method that formed the basis for this study. We defined a number of key words as well as search refinements and subject areas for the search engines as listed in Table 1.

Having set up the frame we followed the sequence for the systematic review (see also figure 1):

- screening the title of the search results
- screening the abstracts
- screening the whole paper
- applying formal comparisons on the results

However, we did not exactly follow the guidelines as we left out screening only the introductions and conclusions of the papers as the number at this stage was already low enough. Table 1 provides an overview of the number of papers at each stage in the process.

As expected, the number of relevant papers was, compared to the initial search output, rather low. This is due to the quite narrow research question we raised. We could draw several conclusions out of this:

There seems to be low research efforts to improving existing standards; papers published recently indicate that a further development of current practice and successful implementation of diverse kinds of agent-based simulation techniques is more in the focus of current research endeavours.



Figure 1: Flow diagram of the systematic review

Source: Fraunhofer-ISI

However, the limitations or restrictions of these approaches may lie in data issues or difficulties in sensitivity analysis. Applicability on a narrow spatial field and computational restrictions hinder long-term aggregated forecasting, especially on a national level.

Apparently, using the standard four step model for this purpose seems to be currently unchallenged. There are improvements on some aspects of trip production, often focusing on the behaviour of some subgroups of the population.

Hardly any paper looked at longer time horizons in order to gain insights into altered trip generation behaviour. It is thus quite difficult to draw conclusions about possible long-term consequences of a shift in mobility behaviour.

Theory

The four step transport model aims to estimate the demand per mode in origin/destination matrices. It consists of trip generation, trip distribution, modal split choice and assignment (figure 2).

Each step builds upon the input of the step before. The trip generation estimates the number of trips done per person and day as the row sum of the traffic demand matrix. To distribute the row sum on the single relations in the matrix step two performs a trip distribution, resulting in an overall traffic demand matrix for all modes. Step three splits the demand matrix in several matrices for each mode so that each chosen mode can be assigned to its specific network within the final step.

Within each step different methodologies are used: the assignment applies a wide range of algorithms dealing with system and user equilibrium (Gentile 2009). The state of the art modal split calculation is the logit model (Urban 1993) based on discrete choice theory with utility functions (McFadden 1974) for each mode. The second step (trip distribution) is founded on gravity theory of physics, (or entropy, see e.g. Wang et al. (2006) handling the level of attraction of different places and distances in the form of resistance between these places.



Figure 2: four step transport model

Source: Fraunhofer-ISI

The output of the first step - trip generation - is the number of trips per person. The most frequently used approach for determining the quantity of trips is a regression model, taking into account different key parameters. In many cases, these parameters are the number of inhabitants and the number of jobs in a defined area. Hence, this approach allows forecasts of the number of trips based on population development and structural changes of the regional economy. The weakness of these regression models is the fact that they are not able to account for behavioural changes. It is eminent that there is no feedback neither from trip distribution nor from mode choice back to trip generation. Arguably, time budgets in industrialised societies have changed quite a lot in the past decades and leisure time activities have gained - due to reduction of working time – a higher importance. Thus some approaches try to consider trip generation based on trip purposes (leisure, work, shopping and others) to address the higher influence of leisure trips on the total number of trips.

However, all approaches are based on the assumption of existing homogeneous sociodemographic groups not changing their behaviour over time. Therefore, all changes leading to a different number of trips are a result of demographic changes.

The described four step model above is a state-of-the-art modelling approach for forecasting transport demand of different modes and its assignment on the existing networks. It is used for most questions concerning transport planning, especially assessing the effects of strategic decisions (de Jong et al. 2007). We tried to ascertain our perceptions

that there has not been much advancement in the theory of trip generation. Therefore we conducted a systematic literature review in order challenge our mental model. The results of this review are presented in the subsequent section.

Results

A total amount of 43 articles survived the screening. Most papers that were not considered at the last stage of the process were mainly dealing with alternative approaches or integrating two or more steps and were therefore not eligible for integration into existing four step models.

The papers considered relevant after the search process fall roughly into five categories and are discussed briefly below.

Those five categories are:

- extensions of existing production functions
- considerations of time budgets
- inclusion of feedback from subsequent steps
- inclusion of accessibility
- bridging to agent-based modelling

It is difficult to make a clear distinction between category one and five, as refining the production function in smaller subgroups makes an agent-based approach more evident.

Papers expanding existent production functions

Fellendorf and Vortisch (2000) describe a production of trips based on typical activity chains (e.g. living – working – living). For achieving this they divided the population into homogeneous groups with specific mobility behaviour.

Taking internal and external influences on trip production into account, Li et al. (2008) combine classic influences like economic factors and population development with supply factors like the level of transport service.

Lin and Hsiao (2006) enlarge the production function consisting of the variables number of employees and number of residents by adding the two variables area of floor space and area of road space. This model was used in and calibrated on a case study of Taipei City and they conclude that intensity in mixed land use increases trip generation.

Guevara and Thomas (2007) state that Multiple Classification Analyses (MCA) may lead to an overestimation of the number of trips, produced on the basis of motorization rate and number of residents. The paper compares different MCA methods by using real data from Santiago de Chile. The aim was to draw quantitative conclusions regarding precision and robustness of different MCA approaches.

Ford and Fricker (2009) apply cross-classification techniques to determine the number of trips generated. The performance on a more disaggregated level can be a highly resource-intense process. Hence it is not always an option for planners.

Khaki et al. (2009) combine an extended trip production function with a Poisson distribution in order to achieve a better fit.

Yao et al. (2008) include destination attractiveness, based on several hard and soft variables like travel advantage index and its impact on trip generation.

Broadstock et al. (2010) find a sophisticated consideration of diverse dwelling types and residential data as explanatory variables for improving the accuracy of the trip production function, whereas Kermanshah (1997) focuses on a detailed clustering of different household sizes. Strambi and van de Bilt (1998) use household size, income and employment status as explanatory variables.

Badoe (2007) compares several trip production methods and concludes that the linear model is superior to more advanced approaches like Poisson or ordered logit.

Roorda et al. (2008) add an interesting comparison to the discussion: they looked at 15-year time series from Toronto and Montreal and identified diametrical trends in travel behaviour for both cities. Variation in gender roles, suburbanisation, motorisation and different behaviour on the individual household's side are, among others, causal factors for diverging trip generation rates in two cities where homogeneous behaviour could have been assumed beforehand, due to the strong cultural bondage of both cities.

Some qualitative aspects are discussed by Mokhtarian and Salomon (2001). They report evidence for challenging the wide-used assumption that travel is only a means to an end, a derived demand based upon the desire to perform activities at geographically dispersed places. Some trips are made independently from an assumed travel need. Nevertheless, this implies identifying a small group of people for which the production function ought to be broadened. Contrino and McGuckin (2009) observe that people with different ethnological backgrounds in the US differ also in their travel behaviour (in the amount of total trips made).

Current analysis techniques include the usage of genetic algorithms and neural networks, as done by Zhenghong et al. (2010).

Thus extensions of the production function can roughly be made either person-based or household-based. Further refinements of the division into heterogeneous groups with homogeneous mobility behaviour may eventually lead to single agents; however, for our research question this refinement does not yield additional insights.

Papers describing time and/or cost budgets as adaptive modules in addition to the classical production function

According to Zumkeller et al. (2004) time and cost budgets restrain the number of trips. These budgets seem to be stable over the past decades. Average speed has altered over time, but this has no effect on trip generation. Influences like rising (energy) costs and shrinking disposable income due to inflation and tax decreases are limiting demand growth. The classic trip production function with growth rates in number of residents and employees could not fully explain the stagnant travel demand of the past years. Hence the budget calculation should be considered.

The time budget theory plays also a dominant role in the paper of Goulias et al. (2007) which discovers changes in mobility behaviour of the baby boomer generation due to a shift from work time to leisure time. Changes in level of transportation service as well as a higher motorisation rate combined with better health conditions lead to a higher share of time spent with leisure trips.

A similar extension is made by Kitamura and Susilo (2003) who focus their observations on the greater Osaka region.

A shift in time budgets of distinct activities may lead to an increase of trips with that purpose to the cost of other trip purposes and an increase in mobility costs may lead to a stagnant travel demand; there are different tendencies and it is not clear whether they cancel each other out.

Papers including feedback from other steps back into trip generation

Zhou et al. (2009) as well as Feng et al. (2009b) discover methods for extending the existing four step demand model with feedback loops. Besides feedback loops between modal split and assignment, iterative algorithms to influence trip generation are presented as well. The major aim of both papers is to improve the results of the four step demand model and attenuate the effects caused by the claimed unrealistic division of the decision process.

Lohse et al. (2006) illustrate the integrated demand, distribution and modal choice model EVA. In this case study trip generation is calculated by splitting the population in origin-destination-groups. Taking accessibility into account the model operates with stochastic route choice procedures.

The inclusion of feedbacks is supposed to attenuate the effects of the claimed artificial division of the decision process, an often articulated critique of the four step model, which led to the development of activity-based modelling. Apparently the decision-making process is not understood well enough.

Papers using accessibility as a concept

The impact of accessibility on trip production is discussed by Leake and Huzayyin (1980a; 1980b; 1979). These papers reflect three main features of the transport system (depending on the mode): resistance, network structure and level of service. Different measures to improve the accessibility are explored.

Daly (1997) gives an overview of trip generation methods; he points strongly to accessibility as a concept to incorporate into the first step and lists also the history and the strengths and weaknesses of this attempt.

An accessibility measure based on random utility theory is proposed by Yang and He (2010).

A generic model for testing inequalities in distribution justices based on differences in transportation accessibility for different household types is tested and discussed in Martens and Hurvitz (2011).

Induced travel is defined as the additional demand that stems from infrastructural improvements and can therefore be regarded as relevant in the context of accessibility. Cervero (2002) provides an overview of this topic, comparing various studies dealing with

induced travel. Some of the studies find evidence for the occurrence of this phenomenon, but most authors of these studies have difficulties in quantifying the effects. Cervero does not try to link the results to the four step modelling approach. In view of the high uncertainty in quantifying induced travel demand it is unclear how this can lead to a significant improvement of current modelling practice.

In a case study on a high speed rail project Yao and Morikawa (2005) present a way to estimate induced travel resulting from long-term changes.

Accessibility was the category with the strongest focus on long-term forecasting, as infrastructure projects often have an impact over several decades. On the other hand studies in this context are often locally restricted and effects on a highly aggregated level are often unclear.

Papers building bridges to activity-based or agent-based modelling

The disaggregation of the trip production function towards a trip generation based on households is described by Hayfield and Stoker (1978). The main challenge in this approach lies in dividing all households into homogeneous groups based on key figures like income or car availability.

A more detailed look at one subgroup of the population is made by Pettersson and Schmoecker (2010) and Berry (2011) in focusing on the group of older people. This can also be seen as an extension of one part of the production function.

One step further towards activity- or agent-based modelling is disaggregating the trip production function in discrete decisions. Munshi (1993) explains the dependency between utility maximisation of households and number of trips. The general idea which is also discussed by Pas (1985) is applying a discrete choice model based on utility functions of different alternatives (e.g., staying at home or making a trip). In bringing activity-based modelling together with the classic four step demand model, Recker (2001) describes the idea of building a link between these two approaches.

Pinjari and Bhat (2011) present an overview of different activity-based model approaches. The paper stresses the decision process of the individuals and households which sum up to the total transport demand. Besides a lack of knowledge in complex decision processes, missing detailed data seem to be an ongoing challenge. Pendyala and Bhat (2006) try to compare the classic four step demand model with activitybased approaches to clarify the quality of such models.

As mentioned already in point a) the refinements of the trip production function in smaller and smaller subgroups eventually lead to an agent-based model, a tendency that can also be observed in point c).

Discussion

Though the sheer amount of papers was relatively high before the first screening process (3,136 in total), the numbers of papers actually relevant for the research question was rather small. This is astonishing as one would expect a higher publishing rate for an established methodology than for new methods, which is especially true for non-activity-based transport modelling since the four step model has been criticised for its artificial division of the decision process since the 70's.

One could claim that this is caused by our narrow research question; on the other hand we also used quite specific search terms or key words which should have been reflected in a high rate of relevant papers. It is remarkable that the intersection in between the search results was not too high. We expected to find a large part of the papers we searched for using more specific key words already included in the search results using wider search terms. This was only true for a small number.

Another reason for our low search results could be the time-wise restriction; yet this applies solely for the Google Scholar search. We decided on this restriction as we believe that working papers with substantial methodological improvements would eventually lead to published reviewed papers and ought therefore to be found with a search performed with the Web of Knowledge search-engine.

However, as our findings indicate, especially for long-term and aggregated forecasting the four step model is still unchallenged. Horowitz (2008) gives an overview of state-wide travel models for the US federal states and shows that they are all based on the standard methodology.

There are only few publications trying to incorporate a long-term observation of mobility trends (see, e.g., Froehlich (2008) or Litman (2006)), but few draw conclusions on further developments and none tries to quantify them.

Some authors also consider spatial correlations (Kwigizile, Teng 2009) and implementation of a step before trip production (Feng et al. 2009a), though it is unclear how this adds up to improving the standard model or how this might have an effect on long-term forecasting.

It is easy to imagine describing behavioural change by some soft variables influencing destination attractiveness and then proceed as Yao et al. (2008) propose, but its impact on trip production should be elaborated more.

Tendencies show a shift towards publications in the realm of new approaches. For longterm forecasting some kind of agent-based modelling seems to be too computer intense, leaving aside the issues of data requirements, especially for a statistically valid distribution of psychological factors affecting mobility behaviour choices among larger population groups. A compromise incorporating elements of existing trip production methods, of feedbacks to trip production, and of agent-based modelling is described by Krail (2009, pp. 112-127). He developed a System Dynamics approach applying the classical methods of Cross Classification and Multiple Classification Analysis. The approach is combined with a dynamic modelling of socio-economic attributes like income distribution, household structure, employment, and age, and considering feedback loops from the final output of the transport model and implemented within the ASTRA model.

Conclusions

It seems as the topic is viewed as being already treated exhaustively by a large part of the scientific community. Publications focusing on trip generation are at the utmost merely case applications or extensions of some subgroups of the population. To our knowledge there is no ongoing discussion on a shift in mobility behaviour in current trip production modelling. If one considers a "green" movement or more sustainable travel behaviour to occur in future Western societies then it is eminent that some modelling endeavour should reflect this in one way or another. The research question is not solely an academic one, but it becomes also highly relevant for performing an effective sensitivity analysis of already existing models or long-term forecasts.

The issue of a time shift in mobility behaviour will apparently not be resolved by implementing some form of agent-based approach. For this to happen there ought to be a way to effectively apply some decision rules for the agents which are representative for a given cordon, something that is not on the way, at least to the knowledge of the authors of this paper.

The conclusion that agent-based modelling will not be the solution to current modelling problems is not held by all researchers in the field. Chunyana and Jun (2009) for example argue for the opposite: "The former [aggregate models] uses area as a unit and reflects its average variation, but it can't reflect individual characters' changes". This statement might be valid to some extent, however, both authors do not offer good solutions to the aforementioned problems related to agent-based transport modelling.

It would be highly welcome to receive some contributions which add to the actual discussion of sustainable mobility behaviour from a modeller's point of view, but apparently the interest does not lie in the first step of the classic four-step transportation forecasting model. Though it is clear to us that forecasting a substantial shift in mobility behaviour would be highly speculative, it would be of high interest to assess the impact of these assumed changes quantitatively and make this knowledge available for policy makers.

References

- Badoe, D.A. (2007): Forecasting travel demand with alternatively structured models of trip frequency. In: Transportation Planning and Technology, 30 (5), pp. 455-475.
- Berry, C. (2011): Older drivers and behavioural change. An ILC-UK policy brief.
- Broadstock, D.C.; Collins, A.; Hunt, L.C. (2010): Modelling car trip generations for UK residential developments using data from TRICS. In: Transportation Planning and Technology, 33 (8), pp. 671-678.
- Cervero, R. (2002): Induced travel demand: Research design, empirical evidence, and normative policies. In: Journal of Planning Literature, 17 (1), pp. 3-20.
- Chunyan, L.; Jun, C. (2009): An improvement of the binary logit model for trip generation forecasting. In: 2009 International Conference on Measuring Technology and Mechatronics Automation (ICMTMA).
- Contrino, H.; McGuckin, N. (2009): Travel Demand in the Context of Growing Diversity: Considerations for Policy, Planning, and Forecasting.
- Daly, A. (1997): Improved methods for trip generation, P415: Transportation planning methods Volume 11. Proceedings of seminar F held at PTRC European Transport Forum, Brunel University, England.
- de Jong, G.; Daly, A.; Pieters, M.; Miller, S.; Plasmeijer, R.; Hofman, F. (2007): Uncertainty in traffic forecasts: literature review and new results for The Netherlands. In: Transportation, 34 (4), pp. 375-395.
- EPPI-Centre (2007): EPPI-Centre methods for conducting systematic reviews., Institute of Education, University of London: EPPI-Centre, Social Science Research Unit.
- Fellendorf, M.; Vortisch, P. (2000): Integrated Modeling of Transport Demand, Route Choice, Traffic Flow and Traffic Emissions: Transportation Research Board.
- Feng, X.; Zhang, J.; Fujiwara, A. (2009a): Adding a new step with spatial autocorrelation to improve the four-step travel demand model with feedback for a developing city. In: IATSS Research, 33 (1).
- Feng, X.; Zhang, J.; Fujiwara, A. (2009b): Analysis of feedback to obtain steady-state solutions in four-step modelling. In: Transportmetrica, 5 (3), pp. 215-227.

- Ford, KM.; Fricker, JD. (2009): Resource-Efficient Approach to Trip Generation by Crossclassification, TRB 89th Annual Meeting: Transportation Research Board.
- Froehlich, P. (2008): Changes in Travel Behavior of Commuters Between 1970 and 2000. In: Transportation Research Record (2082), pp. 35-42.
- Gentile, G. (2009): Linear User Cost Equilibrium: a new algorithm for traffic assignment, Wien, Austria.
- Goulias, K.G.; Blain, L.; Kilgren, N.; Michalowski, T.; Murakami, E. (2007): Catching the next big wave
 Do observed behavioral dynamics of baby boomers force rethinking of regional travel demand models? In: Transportation Research Record (2014), pp. 67-75.
- Guevara, C.A.; Thomas, A. (2007): Multiple classification analysis in trip production models. In: Transport Policy, 14 (6), pp. 514-522.
- Hayfield, C.P.; Stoker, R.B. (1978): Geographical Stability of A Typical Trip Production-Model Applications of National and Local Data in 4 Urban Areas. In: Transportation, 7 (2), pp. 211-224.
- Higgins, J.G.S.e. (2011): Cochrane Handbook for Systematic Reviews of Interventions, Version 5.1.0: The Cochrane Collaboration.
- Horowitz, AJ. (2008): White Paper: Statewide Travel Demand Forecasting: American Association of State Highway and Transportation Officials (AASHTO), Standing Committee on Planning.
- Kermanshah, M. (1997): Life cycle concept: Application to trip generation procedures. In: Iranian Journal of Science and Technology, 21 (1), pp. 47-67.
- Khaki, A.M.; Afandizadeh, S.; Moayedfar, R. (2009): Developing the Composed Probability Model to Predict Household Trip Production (A Case Study of Isfahan City). In: Transport, 24 (1), pp. 30-36.
- Kitamura, R.; Susilo, Y.O. (2003): Trends in Travel: A Study of Changes in Structural Relationships Underlying Travel. In: Transportation and Logistics, pp. 14-23.
- Krail, M. (2009): System-based analysis of income distribution impacts on mobility behaviour., Baden-Baden: Nomos-Verlag.
- Kwigizile, V.; Teng, H. (2009): Comparison of Methods for Defining Geographical Connectivity for Variables of Trip Generation Models. In: Journal of Transportation Engineering-Asce, 135 (7), pp. 454-466.
- Leake, G.; Huzayyin, A. (1980a): Importance of accessibility measures in trip production models. In: Transport Planning and Technology, 6 (1).
- Leake, G.; Huzayyin, A. (1980b): The impact of accessibility on trip production and trip attraction models. In: Traffic Engineering & Control, 21 (10).
- Leake, G.R.; Huzayyin, A.S. (1979): Accessibility Measures and Their Suitability for Use in Trip Generation Models. In: Traffic Engineering & Control, 20 (12), pp. 566-572.
- Li, Y.; Yuan, Z.; Cao, S.; Ding, Y.; Hu, P. (2008): Application of Combined Traffic Demand Forecasting for Comprehensive Transport Corridor. In: Ncm 2008 : 4Th International Conference on Networked Computing and Advanced Information Management, Vol 1, Proceedings, pp. 205-210.
- Lin, J.J.; Hsiao, P.C. (2006): Strategy development for restraining trip generation in Taipei city, Taiwan. In: Energy and Environmental Concerns 2006: Including 2006 Thomas B.Deen Distinguished Lecture (1983), pp. 167-174.
- Litman, T. (2006): Changing travel demand: Implications for transport planning. In: Ite Journal-Institute of Transportation Engineers, 76 (9), pp. 27-33.
- Lohse, D.; Schiller, C.; Teichert, H. (2006): Das Verkehrsnachfragemodell EVA Simultane Verkehrserzeugung, Verkehrsverteilung und Verkehrsaufteilung. In: Straßenverkehrstechnik, 50 (4), pp. 181-192.
- Martens, K.; Hurvitz, E. (2011): Distributive impacts of demand-based modelling. In: Transportmetrica, 7 (3), pp. 181-200.

- McFadden, D. (1974): The measurement of urban travel demand. In: Journal of Public Economics, 3, pp. 303-328.
- Mokhtarian, P.L.; Salomon, I. (2001): How derived is the demand for travel? Some conceptual and measurement considerations. In: Transportation Research Part A-Policy and Practice, 35 (8), pp. 695-719.
- Munshi, K. (1993): Urban Passenger Travel Demand Estimation A Household Activity Approach. In: Transportation Research Part A-Policy and Practice, 27 (6), pp. 423-432.
- Ortúzar, JD.; Willumsen, LG. (2001): Modelling Transport, 3, West Sussex, England: Wiley & Sons Ltd.
- Pas, E.I. (1985): State of the Art and Research Opportunities in Travel Demand Another Perspective. In: Transportation Research Part A-Policy and Practice, 19 (5-6), pp. 460-464.
- Pendyala, R.M.; Bhat, CR. (2006): Validation and Assessment of Activity-Based Travel Demand Modeling Systems, Innovations in Travel Demand Modeling: Transportation Research Board.
- Pettersson, P.; Schmoecker, J.D. (2010): Active ageing in developing countries? trip generation and tour complexity of older people in Metro Manila. In: Journal of Transport Geography, 18 (5), pp. 613-623.
- Pinjari, AR.; Bhat, CR. (2011): Activity-based travel demand analysis. In: de Palma, A.; Lindsey, R.; Quinet, E.; Vickerman, R. (eds.): Handbook in Transport Economics. Edward Elgar.
- Project Assessment (HEATCO), Deliverable D5: Proposal for Har-monised Guidelines. IER, University of Stuttgart
- Recker, W.W. (2001): A bridge between travel demand modeling and activity-based travel analysis. In: Transportation Research Part B: Methodological, 35 (5), pp. 481-506.
- Roorda, M.J.; Morency, C.; Woo, K. (2008): Two Cities, Two Realities? A Closer Look at the Evolution of Trip Rates in Toronto and Montreal, Canada. In: Transportation Research Record (2082), pp. 156-167.
- Strambi, O.; van de Bilt, K.A. (1998): Trip generation modeling using CHAID, a criterion-based segmentation modeling tool. In: Forecasting, Travel Behavior, and Network Modeling (1645), pp. 24-31.
- Urban, D. (1993): Logit-Analyse, Stuttgart: Gustav Fischer Verlag.
- Wang, D.H.; Yao, R.H.; Jing, C. (2006): Entropy models of trip distribution. In: Journal of Urban Planning and Development-Asce, 132 (1), pp. 29-35.
- Yang, C.; He, S. (2010): An accessibility measure for the combined travel demand model. In: Science China-Information Sciences, 53 (2), pp. 299-306.
- Yao, E.J.; Morikawa, T. (2005): A study of an integrated intercity travel demand model. In: Transportation Research Part A-Policy and Practice, 39 (4), pp. 367-381.
- Yao, L.; Guan, H.; Yan, H. (2008): Trip generation model based on destination attractiveness. In: Tsinghua Science and Technology, 13 (5).
- Zhenghong, P.; Wenting, D.; Junfeng, X. (2010): Research on trip-generation forecasting model based on neural networks and genetic algorithms. In: 2010 International Conference on Mechanic Automation and Control Engineering (MACE).
- Zhou, Z.; Chen, A.; Wong, S. (2009): Alternative formulations of a combined trip generation, trip distribution, modal split, and trip assignment model. In: European Journal of Operational Research, 198 (1), pp. 129-138.
- Zumkeller, D.; Chlond, B.; Manz, W. (2004): Infrastructure development in Germany under stagnating demand conditions A new paradigm?, pp. 121-128.

PART V

MODELING FOR SUSTAINABLE MOBILITY DECISIONS

MODELLING THE IMPACT OF LOCAL POLICIES TO OPTIMISE THE DEVELOPMENT OF ELECTRIC VEHICLES

Benjamin Mousseau; Anne-Sophie Fulda, EIFER - European Institute for Energy Research;

Guenter Emberger, Institute of Transportation - Center for Transport Planning and Traffic Engineering, University of Technology Vienna

Corresponding author:

Benjamin Mousseau mousseau@eifer.org

Abstract

In this project, scenarios for urban transport policies are simulated using the Land Use Transport Interaction (LUTI) "MARS" (Metropolitan Activity Relocation Simulator) model. This model had been used in the previous project "MARS-VE" to evaluate the impact of the policies and the effects of electric vehicles (EVs) on modal split, traffic volume, energy consumed and CO2 emissions.

Three scenarios make it possible to analyse different penetration rates of EVs and the impact of local policies on promoting the use of EVs. The application in Mulhouse shows some first results. The integration of EVs should be carried out within a framework of local policy in order to limit total traffic volume. The implementation of these local policies should be different in city centres and than in the outskirts of cities.

Keywords: Transport; Land Use; Urban Area; Electric Mobility; Simulation; Energy; CO2 Emissions; Impact; Local Policy; Forecast.

Introduction

In cities, people move through transportation flows which are supported by local infrastructure. This urban mobility impacts the development of land use and quality of life. Mobility has a particular impact on noise, emissions, and the time that people spend in transit. It is possible to reach a balance between mobility and quality of life through both technological development and political action. Various European governments are currently promoting electrical mobility on a national scale. EV technology is thought to be a way to reduce local emissions and noise. However, this promotion, focused on individual mobility, is not yet implemented at the local scale.

On a local scale, cities are creating policies to limit car traffic, especially in city centres, because of traffic jams and lack of public space. There is a need to analyse the effect of the

penetration of electric vehicles (EVs) on the local scale of mobility and urban systems in order to anticipate their impact and to integrate local policies to support them. Do EVs have any effects on the local transport system? Will EVs lead to a behavioural change in the use of cars? Is it possible to reduce local energy consumption and local emissions through EVs? How is it best to optimise technological development and movement within a city?

The aim of this study is to analyse the impact of electric mobility in a metropolitan area, and the optimisation of local personal mobility as well as energy consumption and local emissions. The project takes into account the complexity of urban systems by considering technological changes, city developments and local transport policies. The integration of EVs into an urban system was evaluated in terms of energy and greenhouse gases (GHG) (amount of kWh and CO2 eq. emissions) and on transportation (modal split and amount of km per year and use of parking spaces). The method chosen was the LUTI theory (Land Use Transport Interaction), in order to simulate different technologies in the transport system as well as different transport policies. The impact has been simulated for the next 30 years (2005-2035). MARS software was identified as particularly appropriate for the study because it takes into account the localisation of activities and population, as well as the transport system (different modes and parking situations) and allows for the simulation of new technologies (fuel cell, electric vehicles, etc.).

The study area chosen was the agglomeration of Mulhouse, a mid-sized French city (population 250,000). Mulhouse is characterized by a dense network of public transportation, due to its tram system and regional train network. An adaptation of MARS to new modes of electric transport and to the French context was carried out in the MARS-EVs project.

The first part of this paper describes the method of simulation as well as the assumptions used to implement EVs as a new technology. In a second part, the scenarios are applied and results are described.

MARS, a LUTI model

MARS is an integrated, strategic, and dynamic land-use and transport (LUTI) model. The underlying hypothesis of MARS is that settlements and the activities within them are self-organising systems. Therefore, it is sensible to use the principles of synergy to describe collective behaviour (Haken 1983a; Haken 1983b).

MARS assumes that land-use is not a constant but is rather part of a dynamic system that is influenced by the transport infrastructure. Therefore at the highest level of aggregation

MARS can be divided into two main sub-models: the land-use model and the transport model. The interaction process is implemented through time-lagged feedback loops between the transport and land-use sub-models over a period of 30 years.

In the European version of MARS, two person groups, one with and one without access to a private car, are considered in the "transport module". This model is broken down into commuting and non-commuting trips, to include travel by car, public transport and slow modes. Car speed in the MARS transport sub-model is volume and capacity dependent and hence not constant. The land-use model considers residential and workplace location preferences based on accessibility, available land, average rents and amount of green space available. Decisions in the land-use sub-model are based on random utility theory. Due to its strategic characteristic, a rather high level of spatial aggregation is used in MARS. In most case studies this means that the municipal districts are chosen as travel analysis zones. The outputs of the transport model are accessibility measures by mode for each zone while the land-use model yields workplace and residential location preferences per zone.

MARS is able to estimate the effects of several demand and supply-side instruments, the results of which can be measured against sustainability targets. These instruments range from demand-side measures, such as public transport fares (increases or decreases), parking or road pricing charges to supply-side measures, such as increased transit service or capacity changes for road or non-motorised transport. These measures, furthermore, could be applied to various spatial levels and/or to time-of-day periods (peak or off-peak).

To date, the MARS model has been applied to a series of European and international case studies (for example: Edinburgh, Helsinki, Leeds, Madrid, Oslo, Stockholm, Vienna, Chiang Mai, Ho Chi Minh City, etc.). In the new project MARS-EVs, (EIFER-TU Vienna) MARS software was adapted to the French context (specific mobility and land use parameters). The city of Mulhouse was chosen because the local authority has an innovative transport policy and showed great interest in applying EVs as an instrument of policy. Furthermore, the city had an important collection of data and had recently carried out a local transport survey (Enquète Ménages et Déplacements) (Certu, 2008) (AURM, 2009b).

To evaluate the integration of EVs on the urban district scale, Mulhouse was divided into 32 zones. The city centre was represented by five zones and the outskirts by 27 zones in the simulation.

Referencing an EVs module

The main aim of the study was to develop MARS by integrating new EV technology into the model. Some simulations had already been run in Vienna and these were the basis for the work on the EV module developed for MARS-EVs. It was decided to identify the electric car in the model MARS as a new mode of transport, referenced by different parameters which can be brought out in the outputs: identifying the influence of EVs in terms of energy consumption, emissions, and in terms of significance in the transport system.

There are many parameters with which to define the use of EVs: average speed per trip, cost per km, time spent to walk to the car and find a parking space, percentage of EVs in the fleet, etc. The aim of the simulation is to evaluate behaviour change resulting from the societal adoption of EVs. Referencing those parameters is not a matter of absolute values, but the comparison of EVs with other modes is relevant (other private vehicles (PV), public transport (PT), and cycling and walking).

Technical aspects of EVs

In order to reference EVs in the context of all private vehicles, most of the technical references were taken from research performed at TU Vienna, especially in the Altankra project and its successor, Elektra (Haas, et al., 2009) and Kloess's resulting PhD (Kloess, et al., 2011). Kloess evaluates the diffusion of EVs in the entire fleet, the price of EVs, and the emission factor, based on the same use of private vehicle (15 000 km/year over 10 years). This reference ensures the coherence of hypotheses between price diffusion and consumption. This database is comprehensive because it references the whole fleet to every identified fuel type, and has a long term, 40 year approach.

The penetration of EVs throughout the private vehicle fleet is on a national scale and takes into account other innovative technologies (hybrids, gas and bio fuel). It presents scenarios dependent on price, technological improvement and national taxation over 40 years. The "business as usual" scenario indicates up to 5% EV penetration of the fleet by 2035; and the "high EV development" scenario assumes 31% penetration by 2035.

Today, electric vehicle technology is almost mature. Initial models are on the market and have been used in some test projects. Even if the way of driving is smoother than the one with other PVs, the average speed and the acceleration in urban driving is not different. In order to compare EV and PV trips, energy consumption and emission-factors should be

quantified with the driving cycle ADCA ARTEMIS. The calculation of energy consumption factors (kWh/km) is based on an EV engine efficiency of 87% in 2010 and of 95% in 2035. These are Well to Wheel factors, which include Life Cycle Analyses of both the car and its related energy consumption. In the model, the energy consumption factors were referenced with 0,48 kWh/km in 2010 and 0,43 kWh/km in 2035 (Kloess, 2011).

The balance of CO2 eq. is calculated on the basis of the Austrian energy mix (200 gCO2 eq. pro kWh). The Well to Wheel factor is 89 eq. gCO2/ km in 2010 for a middle-sized car; it decrease to 68 eq. gCO2/ km in 2035 (Kloess, 2011). These emission factors correspond to the national energy mix, so that this reference is temporary and new emissions are being recalculated to fit to the French context. Nevertheless, in terms of CO_2 emissions, the Austrian and French mix both have low average factors per kWh and are therefore relatively comparable.

Using EVs in a local context

In order to evaluate EV user behaviour, it is necessary to formulate hypotheses on specific local circumstances.

The first hypothesis is that the reduced driving range of EVs will not change user behaviour in terms of daily mobility, in a mid-sized city like Mulhouse. The daily distances driven are far below the EV 120 km battery capacity. This is irrespective of type of employment, familial status, age, and place of residence. Weekly driven distances will exceed battery capacity so that charging must take place during the week. (Commissariat général au développement durable, 2011). EV performance caters to daily mobility; thus the reference to the daily transport time budget used in MARS is the same for all PVs.

The second hypothesis is that the EV penetration will not be homogenous within the agglomeration but may be more important in peripheral areas (Slater, et al., 2009). This phenomenon is also observed in the penetration of diesel vehicles, which are used more in the outskirts. In fact, EVs are attractive to users:

- with high incomes and who drive a lot in order to ensure the cost-effectiveness of their high investment,
- who have the opportunity to recharge at home (private garage),
- who own a second vehicle that they use for additional long distance mobility,
- who are sensitive to environmental issues and are open to new technology.

Some of these parameters (the option to charge at home, second vehicle ownership) are much more representative of the population living in the outskirts (Wirges, et al., 2010). Consequently, there will be 25% more EVs in the periphery than in the centre.

Electric Vehicle mode choice

It was necessary to make some assumptions on cost and the time spent using an EV, because those parameters help to determine modal choice and thus the use of EVs.

In terms of cost, the initial investment of purchasing an EV is high, but the cost of use is lower than for other PVs. Perceived cost determines user behaviour in daily trips, so that investment cost is not directly and fully taken into account when calculating modal choice. In order to define the perceived cost of using EVs (ℓ /km), a number of possibilities were analysed.

- Infrastructure costs: some pilot projects indicate that the use of public charging stations is relatively marginal, so the cost of public infrastructure is not passed on to the user (Mendrisio, 2010).
- Battery cost: the high cost of batteries is an impediment to EV penetration. Although various business models have been developed (e.g. battery leasing, vehicle leasing, and mobility services). These models are not sufficiently quantified to permit a simulation (Borgmann, 2010).
- Electricity price: the main hypothesis is that electricity prices should follow the same growth rate as other fuel types (excluding taxes). The assumed increase in fuel price is based on the European hypotheses of fuel price development (IEA, 2009) and depends on several parameters including offer/demand, economic development, and taxes. These parameters are used to provide different scenarios for the simulation.

Consequently, EV costs per km have been referenced to cost of electricity (over 30 years) charged at home on a wall box and, for the first scenario (S-1), without taxes on electricity.

The MARS model is particularly well suited to the simulation because it considers not only the price of energy in the modal split, but also the price of parking. In Mulhouse, parking costs are generally high in the city centre. Parking price is identified as one way to control the number of private vehicles per zone. This parameter is important for EV integration, and many cities (Paris, Copenhagen, Oslo) already offer free parking and free charging to EVs. Consequently, the simulation of local policies promoting EVs is based on parking prices (Helmich, 2009).

Time is an important factor in the selection of a transportation mode. Users value "time spent" on a trip even more than cost (this includes walking and waiting time to, from and at a public transportation (PT) station, as well as walking and searching time for parking spaces) (Pezzoli, 2001). Driving time remains constant for both EVs and PVs, but the time spent in reaching the car, finding a parking space and then reaching the destination will depend on the density of re-charging stations for EVs and the way in which it is managed. As charging is expected to mainly take place at home during the night, the total time spent may stay the same. This assumption will be used in MARS for the base run scenario where the time in transit both to, from, and in finding a parking space remains the same for EVs and PVs.

However, the time factor provides the opportunity to promote the use of EVs. The availability of public charging points and the option to reserve the parking space may influence the amount of time spent in transit (Vullien, 2010). Accordingly, this parameter "parking management" supports the promotion of EV use.

Actually, electric vehicles are identified as a separate individual mode in the simulation even though they have almost the same parameters as the other PVs in terms of daily urban mobility. The reference data are also the same in the base run. Nevertheless, parking fees and the possibility to reserve the parking space may induce a change in the behaviour of EV users. Consequently, different policies to promote and to organise the local use of EVs are implemented in scenario S-3.

Scenarios

In order to compare the effect of technological development and different local policies, three scenarios have been implemented. They suggest three different ways to balance transport in Mulhouse over the next 30 years. Each scenario is compared with the base run.

Three topics are identified to differentiate between the scenarios:

- Evolution of the fleet composition to include the penetration of EVs.
- The transport policies implemented by the local authorities.
- The policies promoting local use of EVs.

Fleet composition

Two different levels of EV fleet penetration are used in this study. The first is characterized by a low EV share: 5% in 2035. This is based on a trend where neither large scale nor local EV incentives are planned. It also supposes that the price of this technology will remain high until 2030. In this fleet scenario, energy prices increase moderately (crude oil prices double from 2010 to 2050). This assumption is based on the "PRIMES-high" energy price scenario (Kapros et al. 2008). The second fleet composition scenario results in greater fleet penetration. This scenario assumes a significant increase in oil price (crude oil prices triple from 2010 to 2050) and multiple improvements in efficiency, especially battery efficiency. This scenario is also characterized by high taxes on fossil fuel powered engines. It leads to a 31% EV fleet share in 2035.

The low penetration of EVs is implemented in the base run and in scenario S-1. In the two remaining scenarios (S-2 and S-3), the EV share reaches up to 31% of the whole fleet in 2035.

Local transport policies

Scenarios S-1 and S-3 are further characterized by specific local policies. The policy base comes from the urban master plans of Mulhouse (Plan de Déplacement Urbain- PDU) (AURM, 2005). These are transport policies identified by the city of Mulhouse to be implemented in the agglomeration. It has to be noted that not all of the policies can be simulated, because of the boundary conditions of the MARS model. However, an incentive package of local transport policies has been integrated into scenario S-1 and some have been adapted or added to S-3 in order to fit into the context of high EV penetration. They are listed in the table below.

Mode	Policy area	Policy implemented in MARS	Details of the corresponding city policy	Implementation scheme
Public transportation (PT)	Bus	Increase of average bus speed to 2 km.h ⁻	One of the objectives is to increase the speed of public transportation to 2 km.h-1 corresponding to high change in comparison with the actual trend (AURM, 2009a).	Continuous
	Tram	Bus speed replaced by	Some tramway lines are to be extended (with tramway	From 2015

Table 1. Description of the transport policies implemented as the policy base.

		Tramway speed for concerned zones	or with Bus Rapid Transit).	
	Price of public transportation	Reduction of PT fares during peak periods	It is envisioned to propose a special reduced PT fare during the air pollution peaks. This policy has been extended to daily traffic peak periods.	Continuous
Private car	Road capacity	Reduction of road capacity for private cars in the city centre	This policy has led to a reduction in the mean speed (about 5km.h ⁻¹) for private cars in the city centre.	Continuous
	Parking price	Charged parking for all zones in the city centre	This policy aims to limit the use of private cars in the city centre	From 2015
	Car occupancy	Increased occupancy rates	This represents the possible impact of carpooling incentive policies.	Continuous
Bicycle	Bicycle speed	Increased average Bicycle speed up to 3 km.h ⁻¹ in some zones, in which the support infrastructure will be developed.	Mulhouse has launched a Bicycle Action Plan to develop the use of bikes, especially in certain dedicated zones (Mulhouse, 2010).	Continuous

Local EVs policies

In scenario S-3, a package of local policies has been implemented to promote the local use of electric vehicles, especially in the peripheral zones. Parking policies (fees and reservations) are the most appropriate way to promote EVs as well as through the implemention of some all-inclusive Park & Charge offers.

The goal of these policies is to reduce the use of private cars in general and to develop the use of EVs in the outskirts, where the pressure on public space is lower and where it is not possible to have a cost-effective public transportation infrastructure due to low density of population. "Increased parking fees for PVs" has been set up partly in the outskirts. Parking EVs in the outskirts is free of charge, as is long term parking in the city centre. In order to simulate specific reservable EV parking spaces in the city centre, a share of the parking lots has been identified for EV use. The long term development of parking in Mulhouse is mainly planned around multi-storey car parks (Mulhouse Grand Centre, 2010). Thus, the walking time spent from the parking space to the destination has been increased. The table below

details the different parking policies implemented, planned to begin in 2015 when electric vehicles start to be a relevant part of the fleet (in the second scenario).

Mode	Policy area	Policy implemented in MARS	Details of the corresponding city policy	Time scheme
Private Car	Parking fees	Increase in city centre parking fees of up to 25 %	In the city centre, parking fees will increase for the cars parked in public spaces, resulting in additional public space available.	From 2015
	Parking in outskirts	Introduction of parking fees for 60% of available parking spaces in the city outskirts	Until now, there was no charge for parking in the outskirts. Policy aims to put pressure on the use of private cars in the secondary centre.	From 2015
	Time from parking space	Walking time from parking space to the destination increased.	This aims to increase the use of multi-storey car parks. Indeed, in comparison with off-street parking, it is often not possible to park very close to the destination.	From 2015
Electric Car	Parking EVs outskirts	Free parking for EVs in outskirts	This intends to promote the use of EVs in the outskirts.	From 2015
	Parking EVs city centre	Free long term parking/ charged short term parking	The purpose of this policy is to allow the charging of EVs in the city centre in dedicated multi- storey car parks but to prevent the use of EVs for short trips, which could be accomplished with slow modes and PT.	From 2015
	Dedicated parking spaces for EVs	Reduction of the number of parking spaces for other PVs by 30%	Some parking spaces will be dedicated to EVs to park and/or charge.	From 2015

Table 2. Description of the local EV policies (S-3).

The 3 scenarios show the different effects of local transport policies and of a high penetration of EVs, with or without dedicated local policies. The composition of the different scenarios by the penetration of EVs and policies are detailed in the table below:

Table 3. Overview of the scenarios.

Name	EVs penetration	Local	Local
of the		transpor	EVs
scenari		t	policies

0		policies	
Base run	Low (5% in 2035)	No	No
S-1	Low (5% in 2035)	Yes	No
S-2	High (31% in 2035)	No	No
S-3	High (31% in 2035)	Yes	Yes

Outputs and analysis

The outputs of the different scenarios are compared in terms of kilometres driven, modal split, energy consumed (GWh) and GHG emissions (CO₂ equivalent).

Total Kilometres driven and modal split (km)

Mobility is represented in terms of vehicle kilometres because this is the indicator that leads to emissions and energy consumption, and because it also represents the problems of the use of public space and an overloaded infrastructure. Different fuel types have been separated to show the evolution of hybrid and electric vehicles in comparison to fossil fuels used in private cars.





The first result shown by this graph is the kilometre total. The trend (base run) is characterized by a continued increase in total kilometres driven. This finding underlines the need to implement transport policies to limit or reverse this increase.

With a low development of EVs (base run and S-1), local transport policies have a limiting effect: a reduction of 43 millions of driven kilometres annually from private cars can be observed. This is from incentive policies promoting the use of public transport. Indeed, this scenario shows an increase of modal split per trip for PT of up to 11%, in comparison with the base run. Modal shift from cars to PT permits a significant reduction in vehicle kilometres.

Scenario S-2 shows the effect of a high penetration of EVs without a supportive framework of local policy. The increase in kilometres travelled can be explained by the modal shift from PT and slow modes to EVs. An increase in EV use is due to the low perceived cost.

The modal shift can also result in the extension of short trips to longer journeys over the same amount of time.

Local EV policies put pressure on EVs in the city centre and lead to a reduction in vehicle kilometres (scenario S-3) to a level close to that of the base run. The difference between parking policies in the city centre and the outskirts has played an important role as has the

difference in parking fees and search time between EVs and other PVs. Indeed, the use of private cars (including EVs) per trip has been reduced up to 19 % in the five zones of Mulhouse city, between S-2 and S-3, while this reduction amounts to 5 % in the outskirts.

The difference between these two urban typologies (centre and outskirts) allows pressure to be put on all private cars in the city centre and to promote the use of EVs in the outskirts. It emphasises the role of parking policies in promoting EVs in the desired urban area (low density area) without increasing the negative effects associated with the use of private cars (including EVs) in the dense city centre.



Energy balance



The energy balance for transportation in the three different scenarios shows that the overall deviation remains small, despite the difference in total kilometres driven. This is mostly due to the evolution in efficiency of PV motors. The increase of electric vehicles throughout the fleet in the two last scenarios (S-2 and S-3) leads to a move from fossil fuels towards electricity (around 20%). There are also gains in the energy balance, especially in scenarios S-1 and S-3 (-4% in S-1 and -8% in S-3 when compared with the base run scenario). This

is due to the reduction of kilometres driven and also, in scenario S-3, because of the low energy consumption of the EVs compared to other fuel types (49% compared to Diesel, 74% to Petrol and 91% to CNG in 2035). The energy outputs in the scenarios with high EV use indicate electricity consumption in future decades.



CHG emissions (CO2 equivalent)

Fig. 3. Total yearly GHG emissions from transport in Mulhouse for the different scenarios (10³ tCO₂ eq.).

The GHG balance decreases in each scenario. Despite the varying degree of increases in kilometres driven compared to the base year, emissions decrease in each scenario. This has three causes: technological evolution, the modal shift to EVs, and a reduction in kilometres driven.

In terms of emissions, the reduction in kilometres driven with private cars which is brought by local policies (scenario S-1) does not lead to a huge reduction in GHG emissions (3% compared with the base run).

Widespread EVs in scenario S-2 has a positive effect on the GHG balance that compensates for the increase in kilometres driven. This shows how important it is to look both at the GHG balance and at mobility behaviour, in order to make a statement on the benefits of EVs. By only looking at GHGs, scenario S-2 could be a better solution than the ones with local policies.

In fact, the S-3 scenario shows that it is possible to combine a reduction of kilometres and a better GHG balance.

Conclusions

The first base run simulation reveals that mobility (numbers of trips and distances travelled) has a tendency to increase over time. By applying pressure to private car use and by increasing the attractiveness of the slow modes and PT, the total amount of kilometres driven could be reduced (S-1). The policies implemented in the simulation (out of the PDU of Mulhouse) are mostly oriented to improve the infrastructure for slow modes and PT, and to put pricing pressure on cars. In terms of energy and GHG emissions, the impact of a reduction in kilometres driven has a positive effect (a reduction in overall energy consumption and GHG emissions from transport) but the improvement in technology efficiency also strongly influences the benefit in terms of energy use. Also, the hybridizing of most private vehicles leads to an improvement in the GHG emission balance.

The high EV penetration scenario (S-2) can lead to an evolution in mobility by a significant increase in kilometres driven. Short distance trips are shifted from slow modes to EVs due to the low price of electricity. This low price also leads to an increase in the length of some trips. This means that EVs can have a negative impact for cities, particularly in terms of lack of public space due to parking pressure and the frequency of traffic jams in a dense city centre. These existing conditions could be worsened by the development of electric vehicles. Yet an increase in use of EVs also has positive effects, in terms of local GHG emissions and on mobility in the outskirts. As described above, the outskirts seem to be the urban environment well suited to EV use and EVs are more likely to be bought and used by people living in the outskirts. Indeed, the outskirts are characterized by a high use of private cars and a difficulty in reducing this use through transportation policies because of low population density. In general, the PT infrastructure in the outskirts has high costs. The development of EVs could, in part, respond to this problem by supplying a low emission mode of transport.

Scenario S-3 shows that the implementation of differentiated policies between outskirts and city centre could be beneficial. The pressure on private cars (including EVs) is high in the city centre while the use of EVs is promoted in the outskirts. The overall emission balance is reduced and we observe that the reduction of private car use is high in the city centre. In the outskirts, the use of private cars remains high but with a better emission balance.

The overall conclusion that we can draw from this study is that the introduction of EVs should be carried out within a framework of local policy initiatives in order to limit the increase in total traffic volume of private cars. The implementation of these local policies should be different in the city centre and the outskirts.

In order to implement these policies to benefit mobility and the environment, local authorities and organizations in charge of charging infrastructure must work together.

References

- AURM (2009a). "Observatoire du Plan de Déplacements Urbains de l'agglomération mulhousienne." Mulhouse, 96p.
- AURM (2005). "Plan de déplacements urbains de l'agglomération mulhousienne Première révision." Mulhouse, 49p.
- AURM (2009b). "Tableau de bord de la région mulhousienne." Mulhouse, 60p.
- Borgmann, M. (2010). "Finanzierungsstrategien für eine elektromobileZukunft." Berlin, 13p.
- Certu, I., Sitram (2008). "Enquete ménage déplacement urbains et moyens de communication." Mulhouse, 31p.
- Commissariat général au développement durable (2011). "La mobilité des Français Panorama issu de l'enquête nationale transports et déplacements 2008." Paris, 228p.
- Haas, R. and Kloess, M. (2009). "Entwicklung von Szenarien der Verbreitung von PKW mit teil und voll-elektrifiziertem Antriebsstrang unter verschiedenen politischen Rahmenbedingungen, ELEKTRA" Wien, 5p.
- Helmich, H. (2009). "Elektromobilität Städte und Kommunen als Partner der ergieversorger." Köln, 28p.
- IEA (2009). "Technology Roadmap Electric and Plug-In Hybrid Electric Vehicles." Bruxelle, 52p.
- Kloess, M. (2011). "Potentials of hybrid and electric cars to reduce energy consumption and greenhouse gas emissions in passenger car transport Techno-economic assessment and model-based scenarios." Wien, 210p.
- Kloess, M. and Müller, A. (2011). "Simulating the impact of policy, energy prices and technological progress on the passenger car fleet in Austria—A model based analysis 2010–2050." Wien, 18p.
- Mendrisio (2010). "Elektromobilität in Gemeinden: lessons learned aus Mendrisio." Mendrisio, 29p.
- Pezzoli, F. (2001). "Processus d'évaluation dans le stationnement automobile à domicile, formalisation floue du niveau d'acceptation des automobilites devant une politique de stationnement contraingnante." Paris, 11p.
- Slater, S., Dolman, M., Taylor, P., Trichakis, P. and Shine, J. (2009). "Strategies for the Uptake of Electric Vehicles and Associated Infrastructure Implications (for the Commitee on Climate Change)." Cambridge, 108p.
- Ville de Mulhouse (2010). "Mulhouse ville cyclable Plan d'actions 2010/2015." Mulhouse, 31p.
- Ville de Mulhouse (2010). "Mulhouse Grand Centre: Une nouvelle ambition au centre de notre-ville." Mulhouse, 9p.
- Vullien, M. (2010). "Pour une politique de stationnement intégrée, volontariste et pédagogique." Paris, 36p.
- Wirges, J. and Linder, S. (2010). "Räumliche Diffusion von Elektroautos in der Region Stuttgart bis 2020." Karlsruhe, 49p.
CLEAN, SAFE AND HEALTHY MOBILITY THROUGH NON-TECHNICAL MEASURES – LINKING INDIVIDUAL AND PUBLIC DECISION LEVELS

Claus Doll; Johannes Hartwig,

Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe

Corresponding author:

Doll, C.; claus.doll@isi.fraunhofer.de

Abstract

The project "Economic aspects of non-technical measures to reduce traffic emissions", funded by the German Environmental Agency, had as an objective to assess measures, i.e. non-technical options to reduce the emissions of motorized road traffic. The focus of the study is on the effect of measures to reduce emissions and the associated consequences for the private sector and the economy as a whole. This study aims to provide an objective basis for the debate about the commercial and social consequences of more sustainable traffic behavior on the part of both individuals and companies. The assessment was performed using two tools, one focusing on an individual-based level whereas the other (ASTRA-D) is a macro-economic model.

"Keywords: economic assessment; traffic emissions; health benefits"

Introduction

The EC Transport White Paper 2011 (EC 2011) envisions cutting transport-related CO2 emissions by 60 % and zero fatality rates by 2050, although it states that curbing mobility is not an option. Similar goals put forward by rail and automotive associations exist, focusing mainly on technical solutions. While technical progress in particular with respect to air emissions and accident rates has brought about major advantages in the past two decades, other areas such as reducing greenhouse gas emissions and noise pollution has still not been solved.

Better technology thus has to be accompanied by strengthening measures related to the mobility behaviour of people and freight. Changing daily travel patterns, however, will not only affect the sustainability of the transport sector, but will also impact individual variables,

such as time availability, costs and health. Further activities by the public sector, e.g. investments in infrastructures and information provision will be necessary.

This trade-off between personal and public implications of more sustainable mobility patterns and appropriate instruments to achieve given targets of less car and truck use are investigated by the on-going study "Economic Aspects of Non-Technical Measures for Emission Reduction in Transport" commissioned by the German Environment Agency (UBA) and carried out by Fraunhofer ISI (Karlsruhe), INFRAS (Zurich) and IFEU (Heidelberg) between November 2009 and February 2013. The results are published in Doll et al. (2013) and can be downloaded together with further supplemental material from http://www.isi-projekt.de/wissprojekt-de/ntm/.

Material and methods

The study is designed to give advice on how to approach sustainability goals for affected travellers (individual level) as well as for transport policy and planning (public level). The major thesis to be explored by the study is that sustainable transport policy can be made more acceptable to the public and could be more efficient when bringing both levels together and by respecting the needs, preferences, boundary conditions, and decision frameworks of individuals in day-to-day mobility.

The final outputs of the study are fact sheets on the performance of various measures both for policy makers and interested individuals. These advertise a less car based mobility style by referring both to the personal benefits and positive economic impacts.

The study terminology distinguishes between measures, i.e. changes in the transport sector to be made in order to achieve the final emission reduction goals, and instruments required to implement the measures. Both the individual (micro) and public (macro) levels explore five measures, four passenger and one freight market objectives. Their principal design and the relevant local environment are presented by Table 1.

Measure	Change 2030	Related variable	Spatial context
Modal split walking & cycling	+10 % points against BAU	Number of trips	local mobility
Modal split public transport	+10 % points against BAU	Number of trips	local mobility
Journey lengths passenger cars	-10 % against BAU	km / trip	all distance bands
Energy efficiency passenger car	-10 % against BAU	l fuel per car- km	All distance classes
Modal split rail freight	+10 % points against BAU	Ton-km	Long distance shipments

Table 1: Definition of the measures for emission reduction

Source: Fraunhofer-ISI

The given percentage changes can of course not be achieved on the individual level. Here we rather face an all or nothing situation, e.g. when providing users with alternative proposals for their daily trip to work. In the macro-economic analysis the effects of the measures by themselves, such as if as people or companies autonomously change their mobility behaviour, are analysed next to a number of instruments. In most cases these are pricing (road or fuel charges), regulation (access control to sensitive areas) and incentives (e.g. by infrastructure investments).

The macro-economic analyses of the study reach out until 2030 by comparing scenario developments to a given base case. But particularly in the current times of economic crises and market uncertainty the definition of this "Business As Usual" (BAU) scenario appears to be rather tricky. We have analysed four predictions of traffic demand from (1) the official forecasts of the federal ministry for transport VP 2025 (ITP / BVU 2007), (2) the EC-funded research project iTREN-2030 (Fiorello et al., 2009), (3) the federal government's energy concept (Bundesregierung 2010) and finally (4) the forecasts of the IEKP-Makro-Project carried out by Fraunhofer-ISI on behalf of the Federal Ministry for Environment (Schade et al., 2009). Out of these only the latter two have taken full account of the crisis and its potential long term consequences. These were thus selected as baseline scenarios for the macro-economic analysis in this study (Figure).

To analyse and present the impact of more sustainable mobility patterns, a variety of indicators is used. A sample of these is listed in Table . Not all of these indicators can be transformed into monetary values and can be used for a direct benefit-cost-analysis of particular measures.



Figure 1: Selection of baseline passenger transport trends until 2030

Source: Fraunhofer-ISI with data from BMVBS (2007), Bundesregierung (2010), Fiorello et al., 2009 and Schade et al., 2009)

Table 2: Output indicators for the micr	ro and macro analysis
---	-----------------------

Indicator	Individual level	Public level
Road and rail infrastructure investment and operations		х
Public transport vehicles investment and operation		х
Private vehicles investment and operations (cars, bikes, etc.)	х	х
PT fares, car sharng / bike rental fees	х	х
Travel time costs by traffic situation	х	х
External accident costs	х	х
External cots of air pollution	х	х
Climate change costs	х	х
External costs of noise pollution	x	x
Other external costs (up & downstream)	х	x

Health effects	x	??
Comfort, perceived safety and social contacts in PT		
Employment effects		х
Gross domestic product (GDP)		х
Gross value added (GVA)		х

Source: Fraunhofer-ISI

Assessment principles

For making the consequences of individual decisions transparent to the individual, the study analyses health, time and cost impacts for travellers in detail and sets up a "personal sustainable mobility calculator". This tool, which shall be placed on the UBA web pages, will inform people on the potentially major secondary benefits of less car-centric forms of mobility. The strategic tool contains data from an average physical region or city, but also lets the user select and customize one out of several pre-defined standard regions. After entering or adapting living and work areas, distances, public transport availability and station density the user can play around with different combinations managing daily mobility.

The system then returns travel, wait and walk times, changes of health levels, investment and running costs for motor vehicles, bicycles, car- and bike-sharing systems, public transport fares, etc., and induced changes in air pollutants and CO2 emissions, noise nuisance and accidents. On the basis of current studies these effects are evaluated in physical units and are translated to monetary values to allow balancing of the various effects against each other. In the following we will briefly go over the major cost and benefit items used to express the economic impacts of private mobility decisions or transport policies.

Monetary costs of travel

The monetary costs of transport are typical private or industry-related costs as costs for one agent create income for other groups. While in the sense of a resource-consumption approach taken here, monetary travel costs are used for comparing mobility strategies only on an individual level, the macro-economic analysis with the ASTRA-D model requires this information for internal purposes.

In passenger transport the costs of travel perceived by private car users usually are restricted to fuel and maybe maintenance costs. But there are certain blocks of fixed costs to be taken into account, such as vehicle purchase costs depreciated over its life span and annual insurance costs. We take these costs, which depend on the size class of the vehicle, life span, and annual kilometres driven, from the cost database of the German Automobile Club (ADAC). Using national average parameters we arrive at costs of car use of 0.26 €/Pkm for medium sized cars.

Vehicle-	Example	Parameter		Monthly	Monthly costs				4
class		Propulsion	Motor-	Depre-	Running	Fix	Repair	per	per
			power	ciation	costs	costs	costs	month	Pkm
			Kw	€Mon.	€Mon.	€Mon.	€Mon.	€Mon.	€Pkm
Car 1)									
Micro	Smart	Petrol		142	71	60	35	308	0.16
Mini	Cuore	Petrol	51	147	118	69	35	369	0.20
Small	Polo	Diesel	66	187	78	74	35	374	0.20
Lower medium	Golf	Petrol	77	275	113	63	41	492	0.26
Medium	Astra	Diesel	74	243	109	82	47	481	0.26
Upper medium	E-Class	Diesel	125	514	101	109	82	806	0.43
Premium	S-Class	Petrol	250	1294	214	147	121	1776	0.95

Table 3: Passenger car operating costs

Source: ADAC (2011)

For cycling we did not have detailed statistics on annual kilometres at hand. Thus we estimate the depreciation costs per passenger-kilometre (pkm) with purchase costs of 750 \in , 5 years usage with 10 km per day at 150 days per year (e.g. for work trips). Insurance and repair costs are not considered. This leads to monetary travel costs of \in 0.1/pkm if the bike is only used for this specific trip purpose. But we must assume that it is used for leisure as well, and thus we cut the monetary costs by 50% leading to 0.05 \notin /pkm. For walking we do not consider any monetary costs.

In public transport we approach monetary costs across all types of tickets by dividing the annual income of public transport companies through ticket sales (€9.0 billion) by the annual passenger kilometres (98.5 billion) in 2009 (VDV 2011).

In freight transport we derive the costs of road haulage from the Cost Information System (KIS) of the Association of Logistics and Disposal (BDL, 2011) with roughly €1.50 per truck kilometre or €0.12 per ton kilometre. For rail freight transport figures of Deutsche Bahn AG (DB AG 2010) suggest a freight rate of €15/train-km or €0.03/tkm.

User time costs

User time costs constitute the largest single benefit category in German national infrastructure planning. Time costs are not like monetary resources traded between agents, but can appear on the accounts of one agent without bordering other actors. A theoretical problem in evaluating travel time savings or increases is how to deal with small travel time changes, which usually can not be used productively by the users. In this study we increase the time value from zero for marginal savings or increases up to the full value for 5 minute changes.

Mode and travel purpose	Unit	Car/HGV Rail		Bus	Air
Passenger transport					
Business	€2002 per	23.82	2	19.11	32.80
Commute (short)	hour	8.48		6.10	/
Commute (long)		10.89)	7.83	16.25
Private, short		7.11		5.11	/
Private, long		9.13		6.56	13.62
Freight transport *	€ ₂₀₀₂ /t, hour.	2.98	1.22	/	n.v.

Table 4: Values of travel time savings recommended by the IMPACT study

Source: Maibach et al. (2008) based on Bickel et al. (2006)

* Time costs in commercial transport consider forwarders' concerns for vehicle operating and rolling stock provision costs

Latest compilations of European time cost approaches have been performed by the ECfunded project HEATCO (Bickel et al. 2006), the IMPACT-study for DG MOVE (Maibach et al., 2008) and the recent update study on the external costs of transport in Europe (CE Delft et al. 2011).

More detailed evaluations concerning the impact of trip purposes in passenger transport and freight shipping characteristics can be found in Wardmann (2004) or Shires and de Jong (2009).

User health costs

When talking about different forms of mobility such as walking and cycling, the impacts of physical activity on peoples' well-being and on the public health sector becomes important issues. As the inclusion of health effects in transport benefit cost analysis is not yet a

common standard we go a bit deeper into the details. We can distinguish a number of cost items: (1) direct costs of medical treatment, (2) direct costs of post-medical treatment for support and rehabilitation, (3) indirect costs for the economy, e.g. decreased work productivity or more recreation days, and finally (4) non-monetary or intangible costs due to reduced life quality for the person in question and his relatives.

In recent times, heart disease, high blood pressure, excess weight, cholesterol, diabetes, and some types of cancer are wide-spread diseases which could, however, be prevented by a certain amount of physical activity, such as cycling or faster walking. Meanwhile, a number of studies on the topic have emerged such as the Journal of Epidemiology on "Life style risk factors" (Matin 2002) which recommends that adults should at least move 150 minutes per week with low intensity or 75 minutes with high intensity. These activity times can be distributed over the week and even in smaller units of 10 minutes over the day. Appropriate forms of physical activity include climbing stairs, quick walking or cycling, however, data availability is best for cycling as this is considered much more of a healthy activity than walking.

Cycling activates up to one third of all body muscles and is suitable for wide parts of the population as it is joint-gentle and is applicable for overweight people. Cycling can reduce the risk of heart attacks up to 50 % and increases the heart volume when it is regularly performed. In 2008, 66 % of men and 50 % of women were overweight; to lose weight cycling must be done for at least 45 minutes with mean intensity as fat is only burned within an aerobic activity range. Cycling can even reduce the risk for some kinds of cancer, such as breast cancer by up to 34 % due to a strengthened immune system. Across all positive physical effects Andersen et al. (2001) find for Denmark, regular cycling can significantly increase life expectancy. Eventually, the regular movements with cycling stimulate the production of endorphins which reduce stress and psychological diseases (ADFC 2011).

While cycling consumes about 130 calories in 20 minutes, walking burns only 80 calories in the same time. But for many activities or weather conditions walking may be the more convenient alternative. Similar to cycling, regular walking in particular under various weather conditions supports the skeleton, strengthens the immune system, produces endorphins and thus reduces stress.

The economic consequences of too little physical activity of people are enormous. About a third of annual health insurance expenditures in Germany are caused by high blood pressure, etc. Evidence from Norway suggests that a formerly inactive person who starts cycling 30 minutes per day can save annual costs of €3000 to €4000 to the health system per year (ADFC 2011). For the employer we need to consider two cost blocks in addition: absenteeism and presenteeism. Absenteeism denotes production losses when the employee stays away from work due to sickness. Related to Germany this is €1200 per year. Much higher are the costs due to presenteeism, i.e. sick employees staying at work, which amounts to €2400 per year and employee on average.

The World Health Organisation (WHO) has recognised this issue and sketched a tool for the monetary assessment of health benefits of cycling and walking within the "Transport, Health and Environment Pan-European Programme – THE-PEP (WHO-Europe 2011). The tool is intended for local planning purposes, such as bike lanes and side walks, as well as for the assessment of national initiatives. It has targeted improvements in regular cycling and walking at moderate intensity for adults ages 20 through 64. The tool starts from analyses that 3 hours cycling during 36 weeks per year reduces the risk for a pre-mature death or disease by 28 % compared to people who do not cycle. The values for walkers between 20 and 74 years are 29 minutes at seven days per week, reducing early death or diseases by 22 %. The linear extrapolation of these values was restricted to a maximum death and disease reduction rate of 50 %.

The HEAT tool uses the Value of a Statistical Life (VSL), which is commonly used in transport accident assessment. In Europe a VSL of €1.6 million per death casualty is widely accepted (compare also Maibach et al., 2008, CE Delft et al., 2011). Increasing from no physical activity to regular daily cycling and walking measured in distance reduced premature death and disease rates, as shown in Figure and Figure .



Figure 2: Financial savings for cycling reported by the HEAT tool and interpolated benefit function

Source: Fraunhofer-ISI

The values from the HEAT tool do not take into account direct or indirect medical treatment costs, nor do they account for the costs of absenteeism and presenteeism at the person's work place. In later studies it is to be discussed whether their inclusion would lead to an accounting of benefits and costs of walking and cycling. For the moment we use the values as proposed by WHO.



Figure 3: Financial savings for cycling reported by the HEAT tool and interpolated benefit function Source: Fraunhofer-ISI

Environmental and safety externalities

The classical external costs of transport as quantified by CE Delft et al. (2011) and preceding reports, Maibach et al. (2011 and 2008) include the costs of air pollution (NOX, SO2, CO, VOC and particles), climate change (CO2 and NH4), transport accidents, and noise. As much has been published in the before mentioned publications the methodology for assessing these costs will not be repeated here. But it is essential to say that all of these externalities have their very specific sensitive traffic situations. In particular, this is the case for air pollution with old diesel vehicles and within densely populated areas, and for noise during night time in residential areas.

Other elements of external costs for reduced biodiversity, habitat separation effects, urban impacts, ground sealing, etc. are not very significant in terms of magnitude and do not vary with traffic level. We also disregard congestion costs as they are closely linked to user time costs.

Impacts on the individual level

The unit costs introduced above are currently implemented in a tool similar to the HEAT tool from WHO (WHO Europe 2011) or the WOMO-Calculator for comparing different city locations provided by the city of Hamburg (HCU 2011). The user can enter vehicle classes for multi-modal trips and compose individual trip chains for different purposes for comparison. A first version of the tool is expected to be operational in mid February 2012.

To provide an idea of which direction the outputs of the tool will develop, the following tables provide first calculations of the personal and external costs of different mobility styles. We have assumed a 10 km commuting trip which is in the base case performed by a medium sized petrol powered car with a 77 kW engine and an average door-to-door travel speed of 50 kph. We compare this to a micro car (51 kW engine), public transport (1 km walk plus 6 minutes wait time and 20 kph travel speed), cycling (14 kph) and walking (4.8 kph).

We consider two cases: first, we assume that the commuter keeps its car for other than commuting purposes. In this case the fixed costs of the car for depreciation, repair, etc. remain in the calculation even for public transport, cycling and walking. The same holds for up- and downstream costs largely associated with production and disposal of the car. The results in Table 2 suggest that:

- Due to the high health benefits, the low environmental and safety impacts, and the low financial resources required, walking and cycling cause negative costs, i.e. a considerable benefit to the commuter. Here we have started from the assumption of a person not having done regular physical activity before; if we change this assumption the positive effect would be more moderate.
- Public transport, considered here as a mix out of rail and bus services, shows even higher personal costs than car travel with both car types. The main cost drivers here are time costs due to access, wait and public transport travel speeds. The health benefits of walking to the station and the lower environmental impacts can not compensate for the time losses plus the double burden of purchasing a public transport ticket and funding the still existing car.
- The downsizing of cars, i.e. changing from a mid class car to a micro car in this setting would bring about higher overall benefits than keeping the mid class car and commuting with public transport. Besides time costs of car travel, all personal and

external cost categories contribute about the same amount to the higher efficiency of the micro car.

Cost category		Car med.	Car micro	Bus/Tram	Cycling	Walking
Financial costs	Depreciation	2.00	1.25	2.00	2.00	2.00
	Operation	0.60	0.38	0.90	0.00	0.00
Time	costs	2.12	2.12	5.43	6.06	17.67
Health costs	VSL	0.00	0.00	-2.40	-16.00	-24.00
External costs	Accidents	0.40	0.40	0.06	0.00	0.00
	Noise	0.10	0.10	0.01	0.00	0.00
	Air poll.	0.02	0.01	0.04	0.00	0.00
	C. change	0.07	0.05	0.05	0.00	0.00
	Up+downst.	0.10	0.07	0.10	0.10	0.10
TOTAL		5.41	4.37	6.20	-7.84	-4.23

Table 2: Private and external cost balance for a 10 km commute trip with car kept

Source: Fraunhofer-ISI

In a second setting we have looked at the case where the commuter sells his / her car when deciding to commute by public transport, cycling or walking. The findings are presented by Table 3. The main differences in comparison to the case with keeping the car are:

- Public transport now becomes more attractive than commuting with even the micro car asthe double burden of funding the fixed car costs plus public transport fare is finally much more important than the higher time costs when using bus or tram.
- When neglecting the environmental and safety benefits, which are not directly visible to the user, the picture changes somewhat. The final costs for motorised commuting then are €4.72 (medium car), 3.75 (micro car) and 3.93 (PT). Thus, under the assumptions taken here the public transport companies need to promote its environmental and safety benefit over car travel to internalise these benefits into the decisions of the user.
- The positive valuation (negative costs) of cycling and walking now get even more expressed.

The calculation may be somewhat unfair as we have neglected the time and monetary costs of parking the car, but have taken full account of public transport access and wait time. Parking might not be an important issue for most commuters due to the provision of parking space by the employers, but it certainly will be if we turn from commuting to other trip purposes.

Cost category		Car med.	Car micro	Bus/Tram	Cycling	Walking
Financial costs	Depreciation	2.00	1.25	0.00	0.00	0.00
	Operation	0.60	0.38	0.90	0.00	0.00
Time	costs	2.12	2.12	5.43	6.06	17.67
Health costs	VSL	0.00	0.00	-2.40	-16.00	-24.00
External costs	Accidents	0.40	0.40	0.06	0.00	0.00
	Noise	0.10	0.10	0.01	0.00	0.00
	Air poll.	0.02	0.01	0.04	0.00	0.00
	C. change	0.07	0.05	0.05	0.00	0.00
	Up+downst.	0.10	0.07	0.00	0.00	0.00
TOTAL		5.41	4.37	4.10	-9.94	-6.33

Table 3: Private and external cost balance for a 10 km commute trip with car sold

Source: Fraunhofer-ISI

The results are calculated for the current (2008 – 2010) state of transport internal and external costs. As soon as we turn towards 2030 many of these parameters are about to change. In particular the impacts on air quality, climate change noise and safety are expected to decrease according to the plan of the EC 2011 transport White Paper (EC 2011). Further, travel speeds in public transport may increase due to system improvements and further infrastructure investments.

Wider economic impact assessment

From the public perspective, the study evaluates the appropriateness of certain instruments to shift mobility patterns towards more sustainability. These goals include a higher share of

walking, cycling and public transport use in cities, a reduction of trip lengths by car and the use of more environmentally efficient motor vehicles. This macroscopic assessment provides three levels of outputs: (1) direct impacts on transport sustainability indicators (focusing on environment and climate change), (2) second round impacts on the wider economy (employment rates, disposable income, GDP) and (3) the instruments needed reaching the goals. Outputs 1 and 2 are investigated in two ways: without considering the instruments required, i.e. assuming that all goals are reached by intrinsic behavioural changes of people, and with the instruments, i.e. pricing, regulation, investments, incentives, etc.

The analytical tool for analysing first and second round impacts is the System Dynamics Model ASTRA (ASsessment of TRAnsport strategies) developed since 1998 for the European Commission. A German version was recently developed in the framework of the RENEWBILITY-II project for UBA and BMU. A description of the model can be found in Hartwig et al. (2012). As ASTRA is not an optimisation model per se, the selection of instruments to achieve the sustainable mobility targets requires a pre-selection process identifying the most promising instruments and instrument combinations, and a subsequent adjustment process setting the intensity to which degree the instruments are applied.



Figure 4: Macro-economic modeling logic in ASTRA-D Source: Hartwig et al. (2012)

ASTRA-D implements the policy measures on different parts; a schematic overview is given in Figure . ASTRA-D enables a gradual scaling of policy measures over time by calculating steps each year. This makes it possible to design flexible policy instruments with regard to their intensity and to pinpoint any differences attributable to different investment paths for example.

Variable	Year	M1	M2	M3	M4	M5
GDP	2020	+0.19%	+0.24%	+0.35%	-0.02%	+0.02%
	2030	+1.11%	+1.56%	+2.23%	-0.18%	+0.02%
Employment	2020	+0.14%	+0.21%	+0.35%	-0.02%	+0.04%
	2030	+1.37%	+1.76%	+2.49%	-0.16%	-0.08%
Employment transport	2020	+3.34%	+4.10%	+3.88%	-0.34%	+0.25%
	2030	+4.14%	+5.29%	+11.74%	-0.38%	+0.60%
Investments	2020	+1.67%	+2.31%	+3.33%	-0.24%	+0.16%
	2030	+5.45%	+7.03%	+9.09%	-0.99%	-0.13%
Investments transport	2020	+3.38%	+5.17%	+16.32%	-0.13%	+0.45%
	2030	+2.65%	+5.27%	+25.09%	-0.18%	-3.96%
Investments transport	2020	+3.38%	+5.60%	+22.55%	-0.06%	+0.64%
infrastructure	2030	+3.67%	+7.48%	+37.27%	-0.19%	-9.55%

Table 4: Comparison of the macro-economic effects of all measures

Source: Doll et al. (2013)

The results of the different measures are given in Table 4. The different measures to adapt mobility have direct and indirect effects on the economy as a whole. The direct demand effects and the necessary investments in infrastructure and vehicles have a strong influence on growth and employment. The negative signs of the investment costs in some scenarios are based on declining investments in road construction and the automobile industry due to a shift of demand to other modes of transport.

Most measures have a positive effect on the national economy, with the exception of M4 (increased efficiency of car use). The shift from cars to alternative forms of mobility could have a considerable dampening effect on the automobile industry. The macro-economic magnitude of the changed value added, however, depends upon the extent to which investments to promote alternative forms of mobility are possible and necessary.

The gross domestic product develops moderately in all measures until 2020 and with the same sign as the investment impulse. The measures examined in this study mostly look at investments in the building sector due to the expansion of alternative means of transport such as cycle paths, local public transport, railways, urban redevelopment or the expansion and operation of toll systems; the latter, however, do not create any significant growth impulses for the other economic sectors. M2 is an exception with investments in the public transport vehicle industry. However, these do not generate any noteworthy impact on productivity either, as they only affect a relatively small branch of industry and are partially compensated by a reduction in the demand for passenger cars in the same sector. One stimulating macro-economic effect comes from the change in consumption structure. Transport consumption shifts from private cars, with its higher tax component due to the taxation of fuel, to transport services or even non-motorized transport. The assumption is made that, as a result, there is a shift of consumption to other sectors.

The estimates of additional investments in transport infrastructure range between one billion euros per year for cycle lanes and pedestrian zones, two billion euros for the expansion of public transport networks and 10 billion euros to create incentives for the regionalization of destinations in passenger transport. The latter measure goes far beyond the transport sector as this implies urban and regional planning redevelopments on a larger scale. The height of this investment impulse varies depending on the measure.

Employment develops positively in almost all measures. Induced by the positive investment balance of the measures examined and the growth of the GDP, employment also increases compared to the reference scenario. Spread across all sectors, this implies 1.4 % to 2.5 % more jobs for the year 2030 in M1, M2 and M3. Growth in the transport sector, which provides additionally demanded transport services, is four to five times higher.

The changes which benefit Germany in the period 2010-2030 can be determined based on the macro-economic analysis. The benefits for health, safety (reduced costs resulting from accidents) and environmental costs (particularly climate, air pollutants, noise) can be calculated. The following table shows the results of the five measures examined.

The additional benefits are the most obvious in the area of health. Interestingly enough, the biggest health benefit from physical exercise (active mobility measures) occurs for M2, not M1. Promoting local public transport generates far more non-motorized transport than concentrating exclusively on measures promoting walking and cycling. Two aspects can help to explain this: First, the selected support instruments, particularly the implementation

of city tolls (congestion charges), are identical in both measures. Second, expanding local public transport creates a real alternative to private car use, which then makes it possible to manage completely without owning a car.

As already mentioned, the traffic safety of pedestrians and cyclists is a serious problem affecting more active mobility modes in towns and cities. In spite of the enormous safety improvements assumed for cyclists up to 2030 in M1, the highest social benefit does not result from the shift to active forms of mobility, but from shortening the distances covered by car (M3). The explanation is that M3 is the only measure which reduces the absolute volume of traffic without this having an effect on other transport modes. This is also the reason why M3 has the best results for reducing the environmental effects. Reducing the distances traveled by car by 10 % means an overproportional reduction in the volume of traffic (in pkm) of 38 %. These secondary effects reduce air pollutants and CO2 emissions by 29 % to 36 %.

Table 5: Benefits of the measures?	' avoided social costs
------------------------------------	------------------------

Benefit category	M 1	M2	M3	M4	M5
Billion euro 2010	Walking and cycling	Local public transport	Shorter routes	More efficient cars	Modal split rail freight
Benefit health	11.53	18.67	12.60	17.40	0.00
Benefit safety	0.64	0.40	6.93	-0.01	0.11
Benefit environment & noise	0.76	0.51	9.10	-2.28	4.33
Total	12.92	19.57	28.63	15.11	4.44

Source: Doll et al. (2013)

These benefits are contrasted with two cost elements:

The direct public investments in transport systems and built-up areas are between 1 and 3 billion euros per year for the modal split measures (M1 and M2). These costs are significantly below the identified benefits. Only in the case of M3 (re-designing urban areas for shorter car trips) are the investment costs considerably higher than those in other measures (11 billion euros). It is assumed here that enormous planning and construction activities are required to make cities and regions sufficiently attractive to impact peoples' destination choice to a considerable degree. Virtually no investments are needed for M4. It should be noted that these investments can in turn trigger impulses for growth and employment – as shown in the analysis above.

- In the macro-economic assessment, changing the forms of mobility due to implementing the examined measures leads to time losses in many cases. These are estimated in the range of 50 to 60 billion euros for M1 to M3 and are therefore higher than the generated benefits which were monetarized. The time losses are much lower for using a more efficient car (M4) at 29 billion euros and virtually irrelevant for M5 (shifting freight transport). However, macro-economic evaluations of travel time changes over a long period of time are disputed because travelers will adapt to the changed circumstances. Furthermore, in the period up to 2030 investigated here, the aspect of transport quality, e.g. in local public transport, cannot be ignored, as this could increase the options for spending travel time in different ways (reading, working, conversing). Despite its importance for understanding the net effect of time spent under different traveling conditions, it was not possible to assess the overall time budget for all activities of transport users within the scope of this study. Thus, in order to avoid double counts, the time evaluation is not included in Table 5.
- The direct operating costs of the transport modes are taken into account, but in the macro-economic context are offset against the corresponding revenues of other market participants.
- The quality of time spent in public spaces and the design of transport areas are major arguments in favor of the redevelopment of inner cities. However, the benefits resulting from this were not assessed in this study.

When transport policies are put into practice, combinations of different measures and instruments are usually postulated. This can create additional synergies (increasing effectiveness and efficiency, heightened capacity, securing financing) and above all, increase acceptance. As non-technical environmental measures, the focus is on the following combinations of instruments:

- "Push-&-Pull" and "Modal Split": A shifting strategy focuses on two points: To improve the framework conditions for public transport or non-motorized pedestrian and bicycle transport and give incentives to make fewer car trips. This approach is suitable for both passenger and freight transport by rail and road.
- Financing and steering: Pricing instruments can set incentives for a steering effect and at the same time can finance appropriate investments. Usually this is closely related to the "push-&-pull" and/or "modal-split" strategy.

• Coordination of transport and housing developments: This tends to be a long-term strategy and combines spatial planning instruments with transport planning and infrastructure policies. The key issue here is to avoid urban sprawl and foster compact settlement structures and shorter distances between destinations.

Three main conclusions can be drawn from the practical experiences made:

- "Push-&-Pull" approaches combined with financing and steering and the redistribution of capacities between different modes of transport in the context of a "Modal-Split" strategy are the most dominant.
- Effectiveness and efficiency are mainly achieved by pricing instruments ("push"). In comparison, however, the modal split instruments (improving the capacities of local public transport and walking and cycling) enjoy a considerably higher level of acceptance and are necessary prerequisites for autonomous behavioral changes (strengthening of individuals' own incentives) and for the intended change of the modal share.

Consequently, therefore, there could be trade-offs regarding cost effectiveness, the guarantee of mobility targets and acceptance. Simply taxing motorized private car use without any visible alternative (such as the expansion of local public transport or foot paths and cycle routes) is (at least theoretically) considerably more cost effective than expanding infrastructure. However, at the same time, mobility potentials are reduced, which can result in economic losses (reduction of the value added from transport) and the loss of benefits in private households.

Discussion and Interpretation

The quick overview of the current state of play in the study "Economic Aspects of Non-Technical Measures for Emission Reduction in Transport" carried out by Fraunhofer-ISI, INFRAS and IFEU on behalf of the Federal Environment Agency (UBA) reveals that changing mobility behaviour can bring about a large personal benefit. In particular health impacts, which have not yet been recognised to sufficient detail in many studies on the social effects of transport, have the potential to compensate for increased time costs associated with public transport, cycling and walking.

Nevertheless, individual impacts strongly depend on individual circumstances. For this reason average figures can only provide a starting point for understanding the real impacts

of more sustainable forms of travel on peoples' lives. For improving the knowledge base, the study currently works at a simple software tool allowing users or policy planners to play with a large set of individual travel parameters to adapt the computations shown here to a wide range of real life situations.

In the macro-economic evaluation one can see a positive development of the gross domestic product. The GDP is slightly above that of the reference scenario in four of five measures in 2030. The additional investment impulse and the second-round effects of the measures compensate the negative effects in the automobile industry and the effects of structural changes with their impacts on sectoral demand. Funding the investments from ad-ditional revenues of the measures and the state budget is feasible. Against the backdrop of the huge uncertainty regarding macro-economic development, the consequences of more sustainable mobility for the national economy have to be termed as moderate, with changes in the GDP ranging from – 0.2 % to + 2.2 %.

References

ADAC (2011): Autokostenrechner. URI (accessed 1.10.2011): http://www1.adac.de/Auto_Motorrad/autokosten/autokosten-rechner

ADFC (2011): Radfahrer und das Gesundheitssystem. UR L (Zugriff: 19.12.20119: http://www.adfc.de/gesundheit/gesund-bleiben/studie-radfahrer-und-dasgesundheitssystem/jeder-radfahrer-erspart-dem-gesundheitssystem-1200-euro

Andersen, L. B., Schnohr, P., Schroll, M., und Hein, H. O. (2001): Bicycle Research Report N° 132.

- BDL (2011): Kosteninformationssystem Güterkraftverkehr (KIS). Bundesverband Lo-gistik und Entsorgung (BDL e.V.), Frankfurt.
- BMU, UBA (2010): Renewability-II. On-going project by Öko-Institute, DLR and Fraun-hofer-ISI. URL: http://www.renewbility.de/index.php?id=46
- CE, INFRAS, ISI (2011): External Costs of Transport in Europe. Update Study for 2008. Studie im Auftrag des Internationalen Eisenbahnverbandes (UIC), CE Delft, INFRAS AG, Zürich, Fraunhofer-ISI, Karlsruhe.
- DB AG (2010): Online-Geschäftsbericht 2010. DB Mobility Networks Logistics, Deutsche Bahn AG. URL: http://www1.deutschebahn.com/ecm2-db-de/gb
- Doll, C., Hartwig, J., Senger, F., Schade, W., Maibach, M., Sutter, D., Bertschmann, D., Lambrecht, U., Knörr, W., Dünnebeil, F. (2013): Wirtschaftliche Aspekte nichttechnischer Maßnahmen zur Emissionsminderung im Verkehr. Umweltbundesamt, Forschungsprojekt FKZ 3709 45 140. Karlsruhe, März 2013
- EC (2011): White Paper Roadmap to a Single European Transport Area Towards a competitive and resource efficient transport system. COM(2011) 144 final, Brus-sels, 28.3.2011
- Fiorello, D., C. De Stasio, J. Köhler, M. Kraft, S. Netwon, J. Purwanto, B. Schade, W. Schade, E. Szimba. (2009): The iTREN-2030 reference scenario until 2030. De-liverable D4, iTREN-2030 (Integrated Transport and Energy Baseline until 2030) funded by the EC's 6th RTD framework programme. Coordination Fraunhofer ISI, Karlsruhe, November 2009

- Hartwig, J., Schade, W., Sievers, L. (2012): Kurzübersicht des Modells ASTRA-D. Working Papers Sustainability and Innovation S 10/2012. Fraunhofer ISI, Karlsruhe
- ITP, BVU (2007): Prognose der deutschlandweiten Verflechtungen 2025, summary report to the Federal Ministry for Transport, Building and Urban Development (BMVBS). Intraplan, Munich, BVU, Freiburg, 2007
- Maar, D. C., Fricker, R., Hildebrandt, N., und Drechsler, D. M. (2011): Vorteil Vorsorge.
- Maibach, M, D. Suter und H. Lückge (2011): Mit der Umwelt Rechnen. Eine Handlung-sanleitung für den Einbezug von externen Kosten in die Entscheidungsfindung. Umweltbundesamt, Forschungsprojekt FKZ 3708 14 101. Zürich, September 2011.
- Maibach, M., C. Schreyer, D. Sutter, H.P. van Essen, B.H. Boon, R. Smokers, A. Schroten, C. Doll, B. Pawlowska, M. Bak (2008): Handbook on estimation of ex-ternal costs in the transport sector. Deliverable D1, Internalisation Measures and Policies for All external Cost of Transport (IMPACT), Study commissioned by EC, DG-TREN. INFRAS (Zurich), CE Delft, Fraunhofer ISI (Karlsruhe), University of Gdansk. Project co-ordination CE Delft, February 2008
- Matin, B. (2002): Bewegung und Gesundheit: Konsequenzen und Möglichkeiten für die hausärztliche Praxis.
- P. Bickel et al. (2006): Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO), Deliverable D5: Proposal for Har-monised Guidelines. IER, University of Stuttgart
- Schade, W., A. Lüllmann, R. Beckmann, J. Köhler (2009): Gesamtwirtschaftliche Wirkungen von Energieeffizienzmaßnahmen in den Bereichen Gebäude, Unternehmen und Verkehr (IEKP-Makro). Fraunhofer ISI im Auftrag des Umweltbundesmtes. Karlsruhe, März 2009
- Shires, J. D. und G. C. de Jong (2009): Evaluation and Program Planning. Evaluation and Program Planning 32 (2009) 315–325. Elsevier.
- VDV (2010): VDV-Statistik 2010. Verband deutscher Verkehrsbetriebe, Cologne.
- Wardman, M. (2004): Public transport values of time. Transport Policy 11 (2004) 363–377, Elsevier.
- WHO Europe (2011): Health economic assessment tool (HEAT) for cycling and walk-ing. URL accesses 20.12.2011).
- http://www.euro.who.int/en/what-we-do/health-topics/environment-and-health/Transport-and-health/activities/promotion-of-safe-walking-and-cycling-in-urban-areas/quantifying-the-positive-health-effects-of-cycling-and-walking/health-economic-assessment-tool-heat-for-cycling-and-walking
- HCU (2011): Wohn- und Mobilitätskostenrechner für die Stadt Hamburg. Hafen-City Universität Hamburg (HCU). URL: http://www.womo-rechner.de/impressum.php

CONCLUSION

TOWARDS SUSTAINABLE MOBILITY SOLUTIONS

Gebhard Wulfhorst

Chair of Urban Structure and Transport Planning, Technische Universität München

Corresponding author:

Gebhard Wulfhorst; gebhard.wulfhorst@tum.de

Background

For this last chapter, instead of a synthesis on all the insights gained from the diverse contributions to this book, the key ideas brought up in the concluding panel discussion of the mobil.TUM 2012 conference are summarized. After presentions and discussions of all papers and posters throughout the two days of the conference, selected partners have been invited for a round table linking the research findings on "Transportation Demand Management" to the crucial challenges of bringing these ideas into practice.

My special thanks go to the guests on this podium who also gave me feedback on a first draft of this text:

Huschke Diekmann, Head of Technology and Innovation, Mobility, Siemens Irene Feige, Director of ifmo Institute for Mobility Research, BMW Group Gunnar Heipp, Head of Strategic Planning at the local public transport operator MVG Magnus Lamp, National research projects agency, TÜV Rheinland Stephan Reiß-Schmidt, Department of Urban Planning, City of Munich

I would be happy to build upon this fruitful exchange of knowledge and experiences for future cooperation.

Don't fall back into the ideology of the 1980's of "fighting against the car"! However, we have to learn to understand that the crucial problem of congestion in our cities is a phenomenon for the limits to growth, the limits of the valuable resource space to increasing traffic volumes. It is therefore common sense that we cannot "combat congestion" by additional roadway extensions in urban environments. Cities fail if everybody wants to drive. Therefore, we have to be clear about our objective function that is not only about reducing private car vehicle mileage, but also about the goal of creating and maintaining livable cities and regions – for us and for the generations to come.

This challenge is much more complex than just a simple sectorial optimization problem. It is about developing a mobility system – enabling everybody to perform his/her activities – and managing daily transportation issues – specific traffic situations at a given time and place.

Before we limit car use – or perhaps better: give boundary conditions to the market mechanisms by environmental and societal constraints – we have to provide and promote "alternatives". However, we should be careful about the term "alternative". On the long-run, the first urban transport mode has been walking, and still, this mode is the basic one for urban connectivity. The massive private car use only dates back some 50 years and after decades of growth it has finally seemed to pass its peak in many cities! For the future of urban mobility, are we able, are we willing to adopt a new generation of cars and related mobility services to the city?

Today, in many fast growing megacities, some long-lasting means of transportation and mobility cultures (e.g. bicycles in Beijing) have been neglected very quickly. Others, like attractive public transport services (e.g. tram-train services in Europe) often take a lot of effort and time to be realized. The competition between urban transport modes is not only a competition in travel speed but also a competition in speed of implementation. On the one hand, urban growth and motorization sometimes develop much faster than the completion of transport infrastructure or spatial planning strategies. On the other hand, transport supply improvements always have and always will influence location choice decisions of households, private investors and public bodies and by that long-term development of spatial urban patterns.

At this point we come back to an essential question that has been raised during the discussions of this year's mobil.TUM conference:

• Who is the driver of integrated land-use and transport development?

In a more and more individualized world, each and every interest group shows its own preferences and priorities. Multiple objectives and responsibilities are assigned to diverse agencies. We have to collaborate. From the perspective of sustainable development, this is a question of societal necessity rather than a question of private actors or public authorities. We have to discuss our individual – conflicting(!) – interests. We have to look for options for fulfilling our individual (mobility) needs AND leading to common responsibility in finding paths to sustainable development. Conflicts will remain. This will keep our work interesting.

Let's provide and enjoy choice as a key element of sustainable development! Maximizing our "happiness" might be a much more reasonable motivation for investments in transportation systems than the assumption of rational choice behavior and travel time savings (cf. Zahavi, The Unified Mechanisms of Travel). But we have to go beyond the sake of our individual benefits, our self fulfillment and egoisms to address the public added value, to reach a shared return on invest, towards an altruistic logic (cf. Maslow and his latest changes to the hierarchy of needs including "transcendence" in 1970). Can we make sure as a society to give ourselves the respective framework conditions through establishing strong policies?

In trying to do so, we also need better tools for developing future scenarios and projecting ideas against clear targets from backcasting, rather than more and more detailed models of forecasting based on no longer reliable, historic trends. The more complicated, deterministic and mechanistic our models get, the less we (should) trust them. Models as tools for planning decisions need to be more transparent, more robust and clear, facilitating and supporting communication processes, based upon accessibility potential rather than on traffic volume estimations! Involving multiple stakeholders' requires for new planning instruments as a platform of discussion and as a background for envisioning the future.

Every city is unique, yet each city is the same. While every place shows its own characteristic contexts, its "genius loci", the logic of the city as a system might be generic across many different conditions of current system status. The global ideas at any time will have to be adapted to the specific local situation.

Technological developments will improve our transportation systems and will make them more efficient, but will they also be more "city-friendly" and make us "happier" in the long run? Standardization on a technical level is a crucial issue for global players, but specific local conditions and more and more diverse user needs and preferences ask for individualized services. Interestingly, there are a lot of new mobility services coming up these days. We should make the best of these opportunities and embed them into a broader understanding and assessment of sustainable urban mobility.

We should give the users information, helping them to make good decisions! And we are committed to giving the decision makers better information, sharing our knowledge and experience, giving multiple criteria to develop strategic solutions and every-day opportunities for a common goal. And then, the policy makers, public and private actors, will take decisions – every day.

This will need further research and development, also improved and continuous teaching. Fruitful cooperation on an interdisciplinary and international level will help to develop that.

And if we would go back to the question: Who is the driver of integrated land-use and transport development?

All of us – planners, researchers, policy-makers, citizens, ... the "society" – and we have to "take our responsibility and tell the truth as soon as its time has come, justified by sound reasoning and human dignity, even if there is disagreement and laughter" (cf. Romano Guardini / "Die Macht. Versuch einer Wegweisung", 1951).

Imprint

Publisher:

Univ.-Prof. Dr.-Ing. Gebhard Wulfhorst

Chair of Urban Structure and Transport Planning

Technische Universität München

Germany

Editorial:

Benjamin Büttner

Rebecca Alper

Sabine Krause

Printed by:

TypeSet GmbH, Ismaning

Place and year of publication:

München, 2013

ISBN 978-3-9814676-2-8 ISSN 2192-9459 Univ.-Prof. Dr.-Ing. Gebhard Wulfhorst Chair of Urban Structure and Transport Planning Institute of Transportation Technische Universität München Arcisstraße 21 · 80333 München

www.sv.bgu.tum.de