

Joint modeling of land-use, transport and economy

Barry Zondag

Joint modeling of land-use, transport and economy

Proefschrift

ter verkrijging van de graad van doctor

aan de Technische Universiteit Delft

op gezag van de Rector Magnificus prof.dr.ir. J.T. Fokkema

voorzitter van het College voor Promoties,

in het openbaar te verdedigen op dinsdag 24 april 2007 om 15.00 uur

door Barry ZONDAG

civiel ingenieur

geboren te Medemblik

Dit proefschrift is goedgekeurd door de promotor:

Prof. ir. F.M. Sanders

Toegevoegd promotor: Dr. R.J. Verhaeghe

Samenstelling Promotiecommissie:

Rector Magnificus,	voorzitter
Prof. ir. F.M. Sanders,	Technische Universiteit Delft, promotor
Dr. R.J. Verhaeghe,	Technische Universiteit Delft, toegevoegd promotor
Prof. dr. G.P. van Wee	Technische Universiteit Delft
Prof. dr. W.K. Korthals Altes	Technische Universiteit Delft
Prof. dr. A.I.J.M. van der Hoorn	Universiteit van Amsterdam
Prof. Dr.-ing. M. Wegener	Universität Dortmund
Prof. dr. G.C. de Jong	University of Leeds

TRAIL Thesis Series nr. T2007/4, The Netherlands TRAIL Research School

TRAIL Research School

P.O. Box 5017

2600 GA Delft

The Netherlands

Telephone : + 31 (0) 15 27 86046

Telefax : + 31 (0) 15 27 84333

E-mail : info@rsTRAIL.nl

ISBN 978-90-5584-084-7

Keywords: land-use, transport, integrated modeling

Copyright © 2007 by Barry Zondag

All rights reserved. No part of the material protected by this copyright notice may be reproduced or utilised in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage and retrieval system, without written permission of the author.

Printed in The Netherlands

Preface

Writing the preface is probably the most delicate part of writing a thesis. It is, I am sure, the part of the thesis that is most frequently read. It has some similarities with writing an award nominee speech: it is impossible to be original, and the consequences of omissions in the list of gratitude's can be far-stretching. Therefore hereby a general thanks to all the people who made at some stage a contribution, either directly to this work or to a pleasant working environment.

This thesis research forms an integral product of several activities I have been working on over the last years both in my academic– and my commercial life. The main trigger for this thesis has been the combination of academic challenges to capture the interaction between infrastructure and land-use development, and the requirements for practical application. This interest dates back to my master study, where I had the pleasure to study the issue of spatial development of the Greater Jakarta region in interaction with water resource management. This study convinced me both of the importance of integrated planning of infrastructure and spatial development, and of the many remaining challenges in this inter-disciplinary field.

A further critical step towards this thesis was the opportunity provided by Professor Frank Sanders and Dr. Robert Verhaeghe to start part-time a PhD work in this field at Delft University of Technology. They provided me with the necessary support and advice, but above all gave me the freedom to formulate my own thesis research question and approach. I would like to thank Robert for his daily support and his detailed reviewing of several draft versions of this thesis. But most of all I will remember the pleasant cooperation we had. The good atmosphere at the university was further guaranteed by a desk in a lively room with three other PhD candidates Berry, Sander and Michiel. Another important contribution to this atmosphere was made by late Ylva de Haan, her kindness and practical support was important for me and many others.

A third step, and crucial for the content of this thesis, is that my previous employer RAND Europe, got the TIGRIS XL project, comprising of the development of a land-use and transport interaction model for the Netherlands, awarded by the Dutch Transport Research Centre (AVV). At this opportunity I would like to express my gratitude to AVV for giving me the approval to use this research in my thesis. In particular I would like to thank Arnout Schoemakers and Frank Hofman, both of AVV, for their comments and support during the development of this model. I am grateful to Peter Louter and Michael Wegener for their contribution to the development of TIGRIS XL based. Their way of combining scientific knowledge and practical experiences has always been an example to me.

In general I would like to thank all people at RAND Europe who were at some stage involved in one of the TIGRIS XL projects. My special gratitude goes out to Marits Pieters and Jaap Baak for their invaluable contributions to model estimation and implementation. Although this thesis might be the closure of an exiting phase it is certainly not intended as my last word on this subject. Many research challenges are still unanswered, as can be seen in the list of recommendations at the end of this thesis. I hope to have the opportunity to answer some of them in my work for my new employer Significance.

For their confidence and support I would like to thank my family here in the Netherlands as well as my family-in-law in Indonesia. I am in particular grateful to Hanna for her daily support on this PhD work. She always kept her confidence and supported me to keep on going at the many times I got distracted. Finally I would like to mention my children Ryan and Sarah, they have contributed by keeping me happy and alert every day.

Den Haag, March 2007

Barry Zondag

Table of Contents:

PREFACE	V
NOTATION	IX
1 INTRODUCTION	1
1.1 HISTORICAL OBSERVATIONS ON LAND-USE AND TRANSPORT	1
1.2 LAND-USE AND TRANSPORT POLICY- MAKING.....	3
1.3 LAND USE- TRANSPORT - ECONOMY SYSTEM.....	6
1.4 ANALYTICAL INSTRUMENTS FOR AN INTEGRATIVE MODELING.....	8
1.5 RESEARCH OBJECTIVES AND APPROACH.....	11
1.6 OUTLINE OF THE THESIS	18
2 POLICY MAKING ENVIRONMENT FOR TRANSPORT AND LAND-USE	19
2.1 TRADITION OF LAND-USE AND TRANSPORT POLICY MAKING IN THE NETHERLANDS.....	20
2.2 POLICY MEASURES AND SPATIAL SCALE LEVEL	28
2.3 EVALUATION FRAMEWORK FOR PROJECT APPRAISAL	32
2.4 OBSERVATIONS	39
3 LAND USE – TRANSPORT - ECONOMY SYSTEM.....	41
3.1 THEORIES ON INTERACTIONS BETWEEN TRANSPORT, LAND-USE AND ECONOMY	42
3.2 A REGIONAL/URBAN SYSTEM APPROACH.....	45
3.3 TRANSPORT, LAND-USE AND ECONOMY; EMPIRICAL FINDINGS.....	51
3.4 OBSERVATIONS	59
4 LUTI MODELS AND ALTERNATIVE MODELING APPROACHES	61
4.1 REQUIREMENTS FOR MODELING	62
4.2 LUTI MODELS	64
4.3 GENERATIVE WELFARE EFFECTS	72
4.4 ALTERNATIVE APPROACHES TO MODEL SPATIAL-ECONOMIC IMPACTS	74
4.5 TOWARDS A LUTI-MODEL FOR NL	79
4.6 OBSERVATIONS FOR A NEW LUTI – MODEL	83
5 DEVELOPMENT OF THE TIGRIS XL MODEL	85
5.1 MODEL STRUCTURE OF TIGRIS XL	86
5.2 TRANSPORT MARKET.....	95
5.3 DEMOGRAPHIC MODULE	101
5.4 LAND-USE AND REAL ESTATE MARKET.....	104
5.5 HOUSING MARKET.....	108
5.6 LABOR MARKET.....	124
5.7 OBSERVATIONS	126
6 MODEL SET-UP AND TESTING	129
6.1 SCENARIO SETTINGS.....	129
6.2 REFERENCE SITUATION, REGULATED MARKET	137
6.3 SENSITIVITY OF MODELING RESULTS FOR FREE LAND MARKET REGIME	142
6.4 SENSITIVITY ANALYSIS OF STRUCTURING IMPACTS	149

6.5	OBSERVATIONS	153
7	APPLICATIONS OF THE TIGRIS XL MODEL	155
7.1	CASE STUDY: ALTERNATIVE SPATIAL DEVELOPMENT PATHS FOR THE CITY OF ALMERE.....	156
7.2	ZUIDERZEELIJN APPLICATION; AN INTER-REGIONAL TRANSPORT MEASURE	162
8	CONCLUSIONS AND RECOMMENDATIONS	169
8.1	GENERAL	169
8.2	METHODOLOGICAL LESSONS ON INTEGRATED MODELING.....	170
8.3	LAND-USE IMPACTS OF TRANSPORT- AND LAND-USE POLICIES.....	173
8.4	RECOMMENDATIONS FOR FUTURE RESEARCH	176
	REFERENCES	185
	APPENDIX A: RESIDENTIAL LOCATION CHOICE MODELING RESULTS BY HOUSEHOLD TYPE.....	199
	APPENDIX B: STRUCTURE OF LABOR MARKET	207
	APPENDIX C: DETERMINE REALISTIC CHANGES IN ACCESSIBILITY INDICATORS ...	213
	SUMMARY.....	215
	SAMENVATTING	221
	ABOUT THE AUTHOR.....	227
	TRAIL THESIS SERIES.....	229

Notation

Variables

$L_{p,c,o}(t)$	Logsum for purpose p , person type c in the origin zone o at time t
$V_{p,c,o,d}(t)$	Observed utility for tour with purpose p made by person of type c between origin zone o and destination zone d at time t
$N_{c,k}(t)$	Number of tours made by persons of type c in the origin zone k at time t
$T_{o,d,p,m}(t)$	Average travel time between origin zone o and destination zone d , for purpose p with mode m at time t
$\xi_{p,c,h,o}$	Average number of tours for purpose p , by person cohort c , as part of household type h and NMS zone z
$F_g(t)$	Freight accessibility indicator for municipality g at time t
$E_z(t)$	Total number of jobs for zone z at time t
$Tf_{o,d}(t)$	Travel time freight transport between origin zone o and destination zone d at time t
$G_{r,z}(t)$	Land in hectares for residential r use, in zone z at time t
$Pl_{r,z}(t)$	Land-use plans for residential r use, in zone z at time t
$HD_z(t)$	Housing density zone z at time t
$OD_z(t-1)$	Over demand for houses in zone z at time $t-1$
$C_z(t)$	Land use zoning, red contours, in zone z at time t
$U_{z,h}(s,t)$	Utility for choice to stay in zone z for household type h at time t
$P_{z,h}(m,t)$	Chance that a household of household type h will move in zone z at time t
$H_z(t)$	Number of houses in zone z at time t
$Vh_z(t)$	Number of vacant houses in zone z at time t
$HH_{z,h}(t)$	Number of households in zone z of household type h at time z
$HHf_z(t)$	Household/housing factor for zone z at time t
ID	Index of dissimilarity

Sets

$X_z(t)$	Set of attributes for zone z at time t
----------	--

$X_h(t)$	Set of attributes for household type h at time t
Y_n	Fraction of the total number of elements and their respective value
Z_n	Fraction of the total number of elements and their respective value
$LF_g(t)$	Set of location factors for municipality g at time t

Indices

P	travel purpose
O	origin zone
D	destination zone
H	household type
C	person type
J	combination of origin zone and mode
K	origin zone as part of j
car	car mode
M	mode of transport
G	municipality
I	combination of mode and destination zone
Z	National Model System zone
ToD	Time of day period
E	economic sector
T	year
R	residential
S	Household stays in current dwelling
mo	Household moves out of current dwelling
A	agriculture
b1	tree branch (first level) in which destination zone is located
b2	tree branch (second level) in which destination zone is located
NL	Netherlands
N	Number of elements or observations

1 Introduction

1.1 Historical observations on land-use and transport

Observations on the historical development of transport and spatial patterns in the Netherlands illustrate the strong impacts of transport on spatial development. The medieval city was compact and dense because walking was the only mode of transport available to everyone – and because of public safety (fortification). Working and living took place at the same site, quite often in the same building. Until the early 19th century the most common way of long distance public transport was horse-drawn barge transport over water or stage wagons on roads. The main cities in the west and north of the Netherlands were connected to each other by waterways; transport over water by barge was much cheaper and faster than transport by road (Filarski, 2004). Trade and urban growth was centralized in the nodal points of this water transport network.

In 1839 the first railroad connection between Amsterdam and Haarlem became operational and in the subsequent period (1839-1870), all the provinces in the Netherlands became connected to the rail network. Up to the 2nd World War spatial settlement (population, industry) adapted itself to the mobility offered by the railway network. Following the 2nd World War the private car became the dominant mode of transport, this contributed to a spatial dispersion of activities or sub-urbanization. Sub-

urbanization results in increased land needs; every ten years two percent of agricultural land in Europe is lost to urbanization (European Environment Agency, 1995).

It would however be too simplistic to explain sub-urbanization only by the introduction of massive car transport. Sub-urbanization can be further explained by changes in the socio-economic context of urban life: increase in income, smaller households, shorter work hours and a consequential change in lifestyles and housing preferences corresponding to an increasing quality of life, involving leisure and recreation. Under these conditions, first the railway and then the car and low fuel prices brought low-density suburban living within the reach of many and not only the rich; this resulted in the last thirty years in a population growth located primarily in the suburbs of cities. Another, more theoretical explanation, argues that the population is driven out of the urban core due to increasing landprices as a result of land competition by commercial actors. Nowadays there are signs that, offices, light industry, services and retail have started to decentralize as well, following either their employees or their markets or both, taking advantage of attractive suburban locations with good accessibility, ample parking and lower land prices.

An interesting constant factor found in transport behavior research, helpful to explore the potential scope of sub-urbanization, is the average time people spend per day on traveling (1-1.5 hour). According to the law of Hupkes (1977) or Zahavi (1974) the introduction of a new transport mode with a higher travel speed results in an increasing distance span for spatial interactions. As a result of widespread car use, and associated gains in travel speed, residential settlement could disperse out of the main cities into new satellite towns or suburban neighborhoods.

A more recent paper of Mokhtarian and Chen (2004) summarizes findings from the literature on travel time expenditures. Their conclusion is that travel time expenditures are not constant, except perhaps at the most aggregated level. Therefore it is not possible to apply a general rule of the thumb and the observed form of suburban spatial developments, resulting from changes in travel time, can differ widely between regions. Besides household characteristics in the region this depends on the existing spatial structure, geographical conditions and barriers, spatial planning policies and regulations, etc.

Although it differs between regions, sub-urbanization is still a dominant spatial phenomenon. There are several reverse impacts of spatial dispersion on transport, they can be listed as follows (SCATTER consortium, 2004):

- Higher costs of public services and especially transport services;
- Land use patterns which are unfavorable to the development of collective and other sustainable transport modes; hence, increase of the level of car usage;
- Increased trip lengths and fuel consumption;
- Congestion on the radial roads giving access to urban centers;
- Increase in air pollution;
- Poor access to services for those with limited mobility such as the young and elderly.

The above serves to illustrate the widely recognized relationship between transport and land-use. While on the one hand long term effects (from rather drastic technology changes) may be easily observed, it is another matter to prepare for day-to-day policy

making. This requires to project relatively small long-term incremental land-use effects resulting from particular projects (e.g. new road, railway station, etc). It becomes then a challenge to detect the interactions between transportation and land-use for relatively small differences in accessibility. Although these impacts are relatively small, compared to the impacts of particular exogenous developments, they are of relevance in the evaluation of policy packages where costs and benefits are compared for specific policy measures.

1.2 Land-use and transport policy- making

Over the last decades it has become clear that the problems of an ongoing growth of transport in urbanized regions, such as congestion and environmental externalities, cannot be solved by conventional transport measures alone. There is widespread agreement that in order to bring about sustainable transport in urban areas, integrated policy packages – comprising a cross-sector mix of regulatory-, pricing-, and technological measures among others - are needed to send the right signals to both supply and demand elements in the urban land use and transport markets (ECMT, 2002). Successful implementation of these policy packages depends, among others, on a sufficient integration of land-use- and transport planning. In the Netherlands this recognition has resulted in an ongoing integration of land-use plans, as formulated in the national physical plans, and transport plans.

Integrated-multi-sector-models have potential to support this multi-sector policy making practice. Two types of integrated models can be differentiated, namely models which predict the behavior of the urban/regional system and models which go a step further and which aim to optimize urban/regional systems using mathematical optimization techniques. Optimizing models are intended as tools which can find a ‘design’ to optimize a particular function, and are therefore quite distinct from the majority of models which respond to a ‘design’ input by the user (Simmonds, 2005). Any modeling activity aims to contribute to the optimization of a design or plan; and optimizing model offers then an attractive option to search for an optimum using a mathematical optimization technique; this however generally requires compromises to the accuracy and validity of the model. Optimizing models are therefore less qualified to tackle practical planning problems of cities and regions; the class of optimizing models has been left outside the scope of the present research.

The general use of modeling in the policy making process is sketched in Figure 1-1: policy packages to be tested are translated into specific settings of model parameters and model data. Physical effects or performance indicators, resulting from simulation of the system are valued for use in the evaluation, which produces a ranking of the proposed policy package with respect to the reference situation and alternative packages. Insights into the performance and ranking can lead to a re-design of the particular package or acceptance of the particular design of the policy package as an input to decision making. A joint modeling of land-use, transport and economy provides an analytical framework for a systematic evaluation of policies packages combining transport and land-use policies.

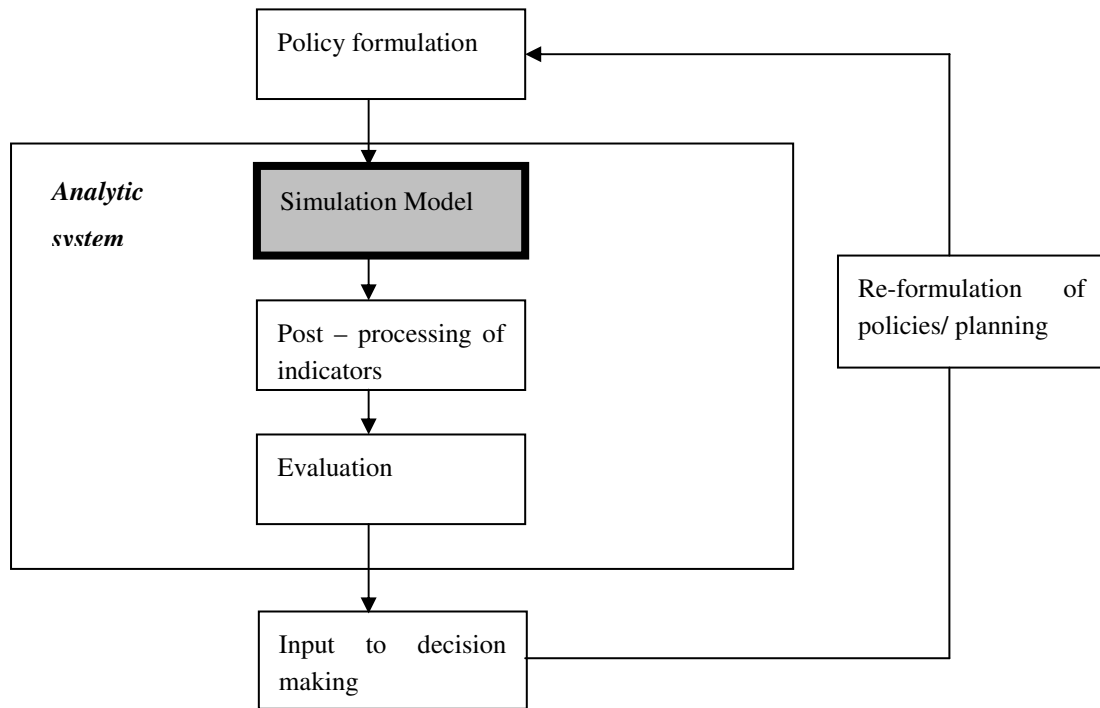


Figure 1-1: Use of modeling in the policy making process

A further detailing of the analytic system in this policy-making set-up is given in Figure 1-2. The gray box in the figure represents the core area of research in this thesis, namely integrative modeling of transport and land-use. Below, Section 1.4 will briefly highlight the analytical instruments in Figure 1-2.

Figure 1-2 presents further the evaluation framework as an essential element in the analytical system to support policy-making. This covers a description of the performance of the proposed policy set using a set of representative indicators and valuation of the contribution to welfare based on a post-processing of the indicators, followed by a ranking of the performance using an appropriate ranking method. In general this can be a combination of cost-benefit and multi-criteria analysis. An efficient linkage of the policy design, -simulation instruments and -evaluation is a precondition to take full advantage of the capabilities of the simulation instruments.

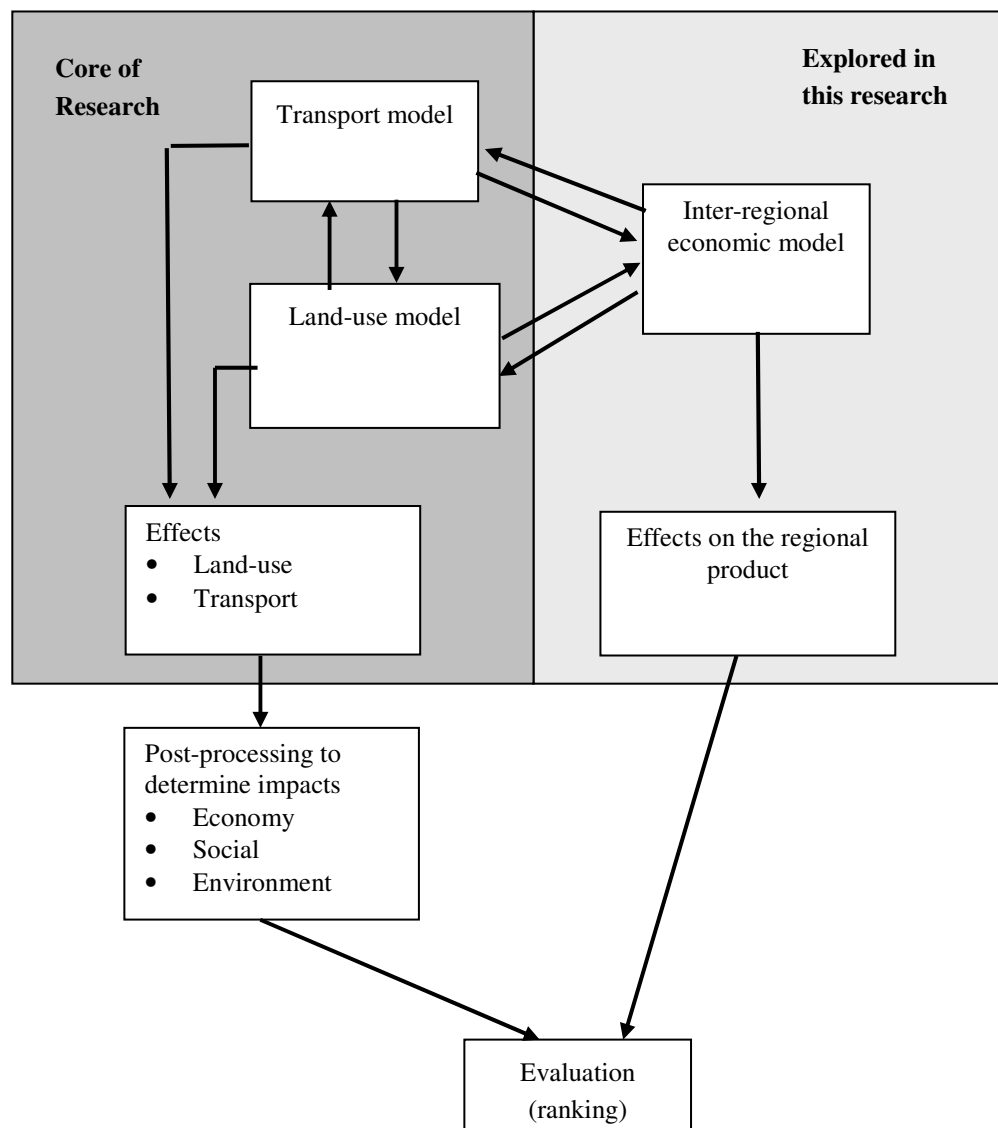


Figure 1-2: Detailing of the analytical system focusing on evaluation of impacts from a policy package

Integrative modeling of land-use with transport enriches both the scope of policy measures that can be tested, such as policy packages combining land-use and transport plans, as well as the set of evaluation indicators generated by the modeling. Generally a full set of indicators comprises all three pillars of sustainable development (European Commission, 1996; Munasinghe, 1993) pertaining to economic -, social - and environmental effects. It should be noted that for many outcome indicators a substantial post-processing is needed. The integrated model delivers intermediate input for these indicators.

Many countries have established methods and procedures for evaluation of infrastructure projects; these methods are subject to continuing debate and research. Cost-Benefit Analysis (CBA) is the primary evaluation method used of the evaluation of transport investments (Morusugi H. and Y. Hayashi, 2000; Dings et al., 2000). Traditionally a CBA for transport projects has limited the impacts to the transport sector and by considering direct user benefits and costs of the transport infrastructure measure. However, large infrastructure projects may have widespread impacts on other markets in the affected region(s), which may add considerably to the total costs and benefits.

The standardized infrastructure evaluation approach in the Netherlands, the so-called OEI-approach (CPB and NEI, 2000), follows a social Cost Benefit Analysis, addressing both the direct effects and wider or indirect effects of transport infrastructure measures. The OEI-approach uses additional or pm posts to account for non-monetary effects in addition to the effects expressed in monetary terms.

Growing energy demand and scarcity of energy resources has resulted in an increasing interest for using integrated land-use and transport models to develop strategies to reduce energy use (see for example STEPs consortium, 2006). Furthermore it is likely that the ongoing discussion about global warming will put additional demands on integrated land and transport models.

1.3 Land use- transport - economy system

Transport forms an integral part of a complex regional system and interacts with other system components such as labor market, housing market, etc. The influence of transport on these other markets depends on local conditions. In developed countries, with a high quality infrastructure, the role of transport in the regional system can be characterized as follows:

- Transport normally constitutes only a marginal part of the input of a host of production and consumption factors;
- Transport investments in a particular project will constitute only an increment on a large stock of infrastructure investment (sunk cost), which is used in this production system.

Figure 1-3 presents a schematization of the regional system, focusing on transport and its interactions with land-use and the regional economy. The regional economy comprises the consumers and producers involved in economic activities. Economic development can be represented by the developments in productivity and the labor market.

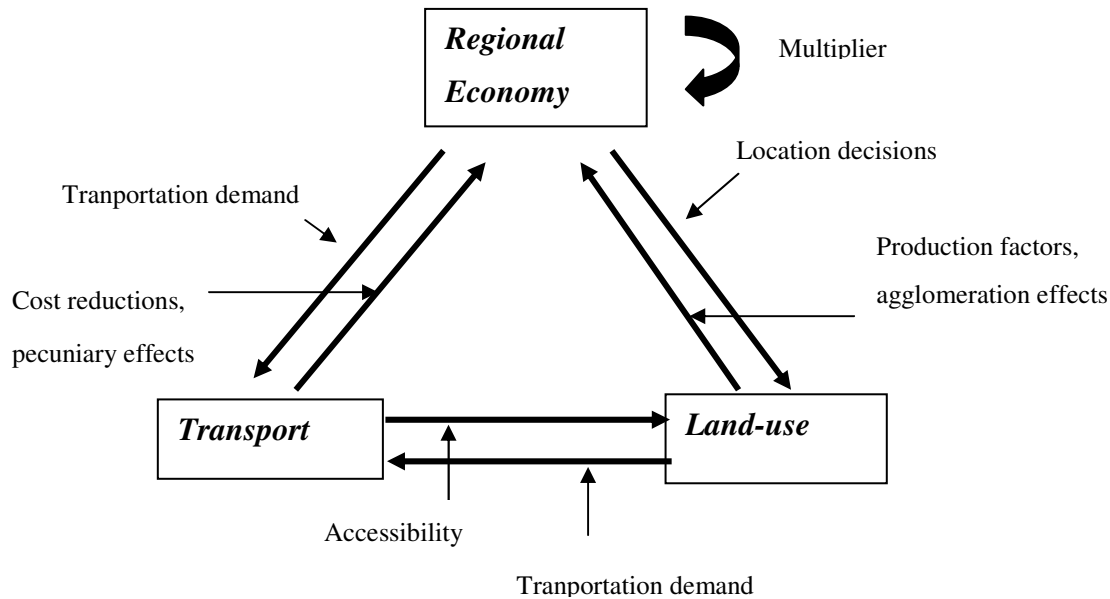


Figure 1-3: Schematization of the regional system related to transport and spatial development

Three dimensions are important to represent the regional or urban system, those are space, time and sectors/actors. Each of these dimensions has influence on the kind and size of the interactions.

Actors

Within the regional or urban system many actors (e.g. households, companies, house- or landowners, public agencies, etc.) interact with each other. To make the analysis of the complex regional system feasible, the whole system needs to be decomposed in a set of components comprising specific regional markets and processes. Such a decomposed approach enables to describe and analyze the interactions between various parts of the system. It further offers the flexibility to study and/or estimate the various components separately; taking advantage of sector specific research and databases.

Space

Different interactions and trends might occur at different spatial scale levels. For example, the trends in spatial development at the regional, national and European scale are different from those at the urban scale; within metropolitan areas the major trend is decentralization, while at the regional, national and European scale the major trend is concentration (ESDP, 1999). In this research the focus is on policy measures at the regional level and national level, in view of the small size of the Netherlands.

Another issue is that there exists a difference between the spatial scale of a specific market and spatial scale level required to analyze the spatial behavior of actors in this market. Many of the markets operate at a regional level, such as transport -, housing-, and labor market, are spatial in nature and require a high level of spatial detail in order to sufficiently capture the interactions between the sectors. A relatively detailed transport network and spatial zoning is required to meaningfully represent the functioning of these markets.

Time

A time dimension is needed to represent the evolvement of the system over time. In general the different markets (transport, labor, land, and housing) will move towards

equilibrium over fairly long periods of time. It can therefore be assumed that in reality due to frequent autonomous developments and policy changes, equilibrium will never occur. The time dimension is crucial for evaluation purposes: the essence of a Cost-Benefit Analysis is to determine the degree to which capital and operational costs of a project are recovered over its lifetime. The progression of the benefits over time is then a most important input and should cover the progression in the markets, the changes in land-use and the accumulation of effects in the regional economy.

1.4 Analytical instruments for an integrative modeling

In the above descriptions of the transport-land-use-economy system and related policy-making, the following important aspects for modeling have been highlighted:

- Time dynamics: interactions between the various system components are dynamic in nature and some of them with long time lags; timing of the impacts is of importance for policy evaluation;
- Detail in space is needed to catch the spatial nature of the regional markets and to produce a reliable modeling of the interactions in space;
- Decomposition of the system in specific components is needed to analyze the interactions and enable an empirical estimation. A modular structure should facilitate the use of a specific analytical approach for each module in line with available data sources;
- Many interactions in the system take place through markets; an explicit modeling of these markets, focusing on market behavior of main actors, is needed to simulate the key dynamics of the system.

Following the system description of Section 1.3 an integrated modeling concept can be roughly split up in three parts corresponding to traditional modeling concepts originating from different disciplines:

- Transportation modeling: simulation of the transport behavior of groups of actors for different places, different travel purposes, using different transport modes, at different times;
- Modeling of spatial development (land-use): describing the settlement pattern as associated with economic activities and in particular the behavior of the actors in the markets (housing, labor) determining this settlement pattern. The land-use model can be decomposed in several modules like land market, housing market, labor market, etc;
- Economic modeling: describing the effects of changes in the transport and spatial system on the economic performance of the different regions, affected by the changes. Two components should be differentiated in the economic impact analyzes, viz. effects associated directly with the efficiency gains from the improved transport system, and the propagation of those effects in other markets through market imperfections (for example, propagation in the regional economic production system).

Individual modeling efforts, originating from different research disciplines such as transport, geography, economy, etc., are available for those three types of modeling. It should be noted that these models are not substitutes for each other as they provide different output indicators. Furthermore the spatial scale level differs between the models, as land-use and transport models generally operate at a more detailed level than economic models. Below an overview is given of important modeling approaches for each type. It should be noted that there is further a wide variety in characteristics within each of these families of models.

Transport models

Transport models simulate transport demand and assignment on a transport network. Traditionally these models follow a four-step procedure: trip production, destination choice, mode choice and assignment (Bates, 2000). The “time-of-day choice” modeling can be seen as a “fifth stage”. Variants to this traditional procedure are available, for example, using a tour-based approach instead of trips, or a combined stage for the mode and destination choice. Other extensions, to the traditional four steps modeling, are the inclusion of car license and car ownership modeling within transport modeling packages. A typical restriction of transport models is that the socio-economic data for each zone is an exogenous scenario input. This data, typically comprising residents (by population segments) and number of jobs (by sector), is then unaffected by changes in the transport system. Transport models are widely used as transport planning instruments; nowadays almost every larger urban area has its own transport model.

LUTI-models

Land-Use and Transport Interaction (LUTI) models have been around for several decades since Lowry’s Metropolis model (Lowry, 1964). LUTI models simulate spatial markets, such as land-, housing-, labor- and transport market as one system. Such integrated modeling enables to simulate the mutual interactions between transport and land-use; the socio-economic input data for the transport model are endogenously generated within the LUTI-model. Important theoretical contributions for LUTI-modeling have been made by Alonso (1964), strengthening the urban economic foundation of the models, and McFadden (1981) allowing to model taste variation in the behavior of actors.

Although large differences exist between the various LUTI-models, several of the state of the art models follow a dynamic system approach with an emphasis on the behavior of actors, such as residents and firms, in the different markets. A restriction of LUTI-models is that these models are generally distributive models and regional/national production and economic variables are based on exogenous forecasts. LUTI-models are not as commonly used as transport models; only a few LUTI-models are available as commercial packages and have been applied to multiple policy studies.

Spatial Computable General Equilibrium models

Recently the new economic geography school (Krugman, 1991; Fujita et al., 1999) has inspired the development of a new type of economic modeling the so-called Spatial Computable General Equilibrium (SCGE) models. These models address the various regional markets and their interactions within one equilibrium framework. Generally these SCGE models focus on the production- and labor market and pay less attention to other regional market such as the housing market or land market. Transport changes are exogenous inputs to these models.

The main aim of the SCGE models is to calculate indirect generative welfare effects resulting from large-scale transport infrastructure measures. The models incorporate an explicit modeling of market imperfections to calculate indirect generative effects. The SCGE models represent a new development and only a few operational models are available worldwide.

Models and evaluation

Table 1-1 gives an overview of indicators, considered in general relevant to describe the performance of a particular transport policy package; estimation of the performance indicators can benefit from the use of integrated models compared to the use of traditional transport models. A further extension of the integrated land-use and transport model, by including a modeling of economic production processes, enables to analyze the propagation of (economic) effects in the regional economic system. Under conditions with market imperfections this can result in welfare effects additional to travel time and cost savings. The direct economic impact associated with the efficiency gains can be directly derived from the transport model results and does not need additional economic modeling.

Table 1-1: Overview of main indicators and assessment potential with combined models

Theme	Indicator	Effects contributed by integration of models		
		Transport model	Land-use and Transport model	Land-use, transport and economy
Economy	User benefits	Transport projections	Transport projections including land-use effects	Transport projections including economic growth effects
	Employment		Distribution effects (regional level generative effects)	Distribution and generative effects
	Productivity			Production effects (e.g. agglomeration)
Environment	Global air pollution	Transport projections	Improved transport projections	Improved transport projections
	Energy use	Transport projections	Improved transport projections	Improved transport projections
	Local air pollution	Transport projections	Improved transport projections and land-use changes	Improved transport projections and land-use changes
	Noise pollution	Transport projections	Improved transport projections and land-use changes	Improved transport projections and land-use changes
	Land coverage		Land-use effects	Land-use effects
	Land fragmentation		Including land-use changes	Including land-use changes
Social	Accessibility by population segment	Indicator based on Transport results	Including land-use changes	Including land-use changes
	Accessibility by region	Indicator based on Transport results	Including land-use changes	Including land-use changes
	Effects on housing market (e.g. segregation, prices)		Location effects by population segment	Location effects by population segments

1.5 Research objectives and approach

The aim of the present research has been to improve policy making in the field of transportation and associated land-use planning by facilitating the design and evaluation of diverse policy packages based on an improved estimation of the wider system effects;

those effects serve as input to the evaluation of the particular policy package. This research resulted in a modeling, complementary to classical transport modeling, making land-use projections endogenous. This integrated approach allows addressing important system and policy features, such as:

- Transport projects have effects on the composition or structure of land-use in the region; those structuring effects have in turn a long-term impact on transport indicators such as transport volumes;
- The land-use changes from land-use or transport policies, such as spatial distribution of employment and residential settlement, are important intermediate results to determine economic, social and environmental output indicators;
- Quantification of the indirect or wider economic effects of transport measures on other markets resulting from market imperfections in these markets. Examples of these effects are scale advantages in the product market or imbalances between supply and demand in the regional labor markets.

In the Netherlands the evaluation of large-scale infrastructure measures has recently been standardized by the so-called OEI-method (CPB, NEI 2000). The OEI methodology states that a broad perspective on economic welfare is needed to evaluate large infrastructure projects; such perspective includes indirect distribution- and generative effects of infrastructure measures on other, non-transport, markets. The estimation of the indirect effects of transport measures is part of an ongoing discussion in the Netherlands and abroad.

The present research aims to improve the estimation of transport and land-use effects of transport- and land use policies; this contributes to the ongoing effort in the Netherlands to improve policy making in the field of transport infrastructure by incorporating land-use and other indirect economic effects of transport measures in the evaluation of these measures. The operational target of this research is to improve the analytical tools required to perform an analysis of the impacts of integrated land-use and transport strategies on transport, land-use and the regional economy

A joint modeling of land-use¹, transport and economy should enable to address the wider system interactions. The call for an integrated modeling, as presented in section 1.4, is not new, models have been developed in the context of different disciplines, such as spatial economics, urban planning, transportation and geography, with an approach geared to the particular discipline. The use of these models in practice has been limited: many efforts have never passed the research and development phase. Developing an integrated model is a highly complex matter requiring to assess and balance theoretical soundness, data availability, integration in the policy-making process and practical issues as computation time. Many gaps and challenges still exist in this field. This thesis addresses the following gaps and challenges.

¹ In this report the term Land-use addresses much more than just what type of objects or activities occupy each parcel of land. Land-use refers to the whole range of human activity and of the built environment. A Land-use model typically covers the housing market, labor market, real estate market as well as land market.

The first gap is that most integrated model systems have an imbalance or fall short in the handling of the three dimensions of representing time, space and various actors/sectors. All three dimensions are important to calculate transport effects, and associated indirect effects, as they vary in time, -space and - by actor. An important reason for this is that a general theory, conceptualizing the development of “human society” in time and space, is absent. An impressive effort, illustrating the complexity to link different theories in time and space, to develop a general theory has been made by Isard and Smith (1969). Most other academics have refrained from developing such theory; instead their modeling efforts can be linked to specific scientific disciplines and associated theories. This research will not develop such theory either; this research follows a multi-disciplinary approach, combining existing theories and methods from different eclectic disciplines into one modular framework. In this research a specific focus will be given on the space- and time dimension.

A second gap is that many integrated model systems lack a formal statistical estimation of the influence of transportation on land-use. In many of these models informal ‘trial-and-error’ type of calibration procedures, expert judgment or/and historical validation exercises are used to derive the coefficients for the model variables (for an overview see Hunt et al., 2005), including the influence of accessibility on land-use. For example, the parameters of the former TIGRIS land-use and transport interaction model in the Netherlands have been based on expert judgment (AVV, 2001; Schoemakers and van der Hoorn, 2004). The present research aims to improve the reliability and acceptance of the modeling by a formal statistical estimation of the key relationships in the modeling, among which accessibility. A formal statistical estimation procedure ensures that the sign, size and significance of the coefficients in the modeling are based on empirically observed relationships. In this research the effect of accessibility on residential location choice or firm location choice is empirically estimated. It is important that the modeling has enough detail for its segmentation in household types and economic sectors to account for differences in behavior. The model design is oriented to empirically observable variables and based on available data sources.

A third gap is that many integrated model systems often use simplistic transport models or are poorly integrated with existing transport models. This omission has an influence on the quality of the transport responses as well as on the option to use more advanced accessibility measures. Accessibility measures in land-use and transport policy evaluations in the Netherlands often fall short in the attention paid to land-use, transport and accessibility linkages (Geurs, 2006). In this research the land-use model aims to interact with the existing national transport model “NMS”² (Hague Consulting Group, 2000), which can be considered as the standard passenger transport model for the Netherlands. Interaction with a discrete choice transport model such as NMS, gives opportunity to explore the use of advanced accessibility indicators.

A fourth gap exists between the integrated modeling instruments in the Netherlands and information required in project evaluation. The OEI methodology has standardized the process to include the different effects in an evaluation framework; it does not answer questions on the method to be used to estimate these effects, or the expected size of effects. It is clear that a method analyzing the indirect effects of transport measures should incorporate other relevant markets such as the land-, housing-, labor- or

² In Dutch “Landelijk Model Systeem (LMS)”

production market. Furthermore it should be noted that such analysis should be integrated closely with the estimation of the transport effect; ultimately all effects are the result of the change in the transport infrastructure. A report on the indirect effects of infrastructure projects (RUG/SEO, 2004) addresses the match between model output and required information for project evaluation. The report illustrates that an important omission of LUTI models is that these models do not calculate the indirect generative effects. This research explores a bottom-up approach to extend LUTI models with the modeling of the indirect generative effects of transport infrastructure on economic production.

Additional challenges in the present research on developing an integrated model, which models the interactions between land-use, transport and economy, are: the spatial policy regime and the spatial structure in the Netherlands.

- The high level of government influence on the land- and housing market in the Netherlands puts requirements on the modeling approach for the integrated model system. Moreover potential changes in this spatial policy regime requires a modeling, which is flexible to incorporate different spatial regimes;
- The spatial structure of the Netherlands, with many urban centers, separated by short distances, creates many overlapping labor- and housing markets. A solution for the Netherlands, due to its small size is to address the whole of the Netherlands as one study region. In this case the assumptions is that the labor and housing markets are restricted by the country's borders. Although ongoing European integration has diminished the impacts of national border, cross border interactions are still less frequency as might be expected from the spatial distribution of activities. The choice of the national level as study region means for the model that it has to simulate both the regional and intra-regional effects. Traditionally these two spatial scale levels are addressed in different type of models (RAND *Europe* et al., 2005).

1.5.1 Research activities

The body of the research reported on in this thesis comprises the development of the model TIGRIS XL. This model is the successor of the TIGRIS model (AVV, 2001). It should be noted that the development of the TIGRIS XL model has started from scratch; besides its name this model is independent from the previous TIGRIS model (see Chapter 5). The research activities can be divided into a positioning and design of the integrated model, -estimation and development of the model, -application in case studies, and -specification of further research directions and conclusions.

Design of integrated model system

The positioning and design of the integrated model has been based upon several elements, including:

- A review of the policy-making environment for transport and land-use (Chapter 2);
- Review of the characteristics of the land-use, transport and economy system (Chapter 3);
- Derivation of the lessons from the design and application of existing models (Chapter 4);
- A review of data availability and limitations (Chapter 5).

A review has been made for each of these elements based on existing literature. Key recognition is that the wider effects of transport measures result from a complex set of (spatially) interacting processes evolving over time. An incremental systems approach, with a modular structure linking the various components, is considered the best approach to model this system. Such approach enables to analyze and estimate specific relationships based upon available data sources for that sector. Furthermore this approach is flexible towards time dynamics and level of spatial detail. The research can be positioned in the tradition of LUTI-modeling. As stated before within this LUTI family of models a wide variety in characteristics exists.

Model estimation

The research work on model estimation is closely related to the work on model design. The key relationships to be estimated depend on the model design (Section 5.1). The literature review in Chapter 3 on empirical findings describes state-of-the-art findings for these key relationships. Key explanatory variables are identified in this literature review: the specific formulation of the variables depends on the available data. A discrete choice approach (McFadden, 1981; Ben-Akiva and Lerman, 1985) is used for a behavioral modeling of residential location preferences (Section 5.5). A nested structure is needed to handle both inter-regional and intra-regional moves within one framework. The labor market estimations are not part of this research work, but included in Appendix C to give a comprehensive picture of the TIGRIS XL model.

Linkage with transport model, accessibility indicators

Accessibility is the main ‘effect’ of a transport system influencing spatial settlement. Chapter 5 describes the use of utility-based accessibility indicators for the TIGRIS XL model. The utility-based accessibility measures for TIGRIS XL are derived from the National Model System of the Netherlands. The NMS is a discrete choice type of transport model based on micro-economic utility theory. With such a model it is possible to generate a logsum value, an aggregate value expressing the utility from multiple alternatives. The utility-based indicators in TIGRIS XL include personal characteristics and preferences, besides characteristics of the transport and land use system, to capture observed heterogeneity across individuals. Including the individual component of accessibility means that more realistic accessibility indicators, namely accessibility indicators closer representing the specific activity pattern and preferences of the households or firms, can be included as explanatory variable in residential or firm location choices

Integrated modeling and project evaluation

As stated, a key omission of LUTI-models is that these models do not calculate generative welfare effects. Section 4.3 presents an overview of the various generative welfare effects. In Section 8.4, on future research, an approach is explored for modeling of economic production effects in interaction with TIGRIS XL. The links of the transport- and land-use model with an economic productivity model are however not implemented in this research.

Sensitivity runs and case studies

The TIGRIS XL model has been applied to perform several sensitivity tests and two “real world” case studies. The reported test runs and applications in Chapter 6 and Chapter 7 have two purposes: first to test the TIGRIS XL modeling and its capability to calculate the effects of land-use – and transport policies; going further on a satisfactory

model performance, the runs are used to simulate the impact on land-use of changes in the spatial regime or transport system. In the conclusions the model tests and applications are used as input, in addition to insights from the literature review and model estimation, for a discussion on land-use impacts of land-use policies and transport policies.

1.5.2 Overview of research results

The research results of this thesis, corresponding to the aim of this research, are an improved estimation of land-use effects of land-use – and transport measures, and an improved analytical instrument for an integrated modeling of land-use, transport and economy.

In this research the impact of land-use and transport measures on land-use changes under various circumstances has been estimated. This is based on empirical evidence found in the international literature, results from the housing and labor market model estimation and sensitivity runs/applications with the integrated model. The integration of the land-use model with an advanced transport model enables the use of detailed accessibility indicators in the land-use module. Vice versa it also facilitates the analysis of the effects of land-use changes, resulting from spatial policies on the long-term transport projections.

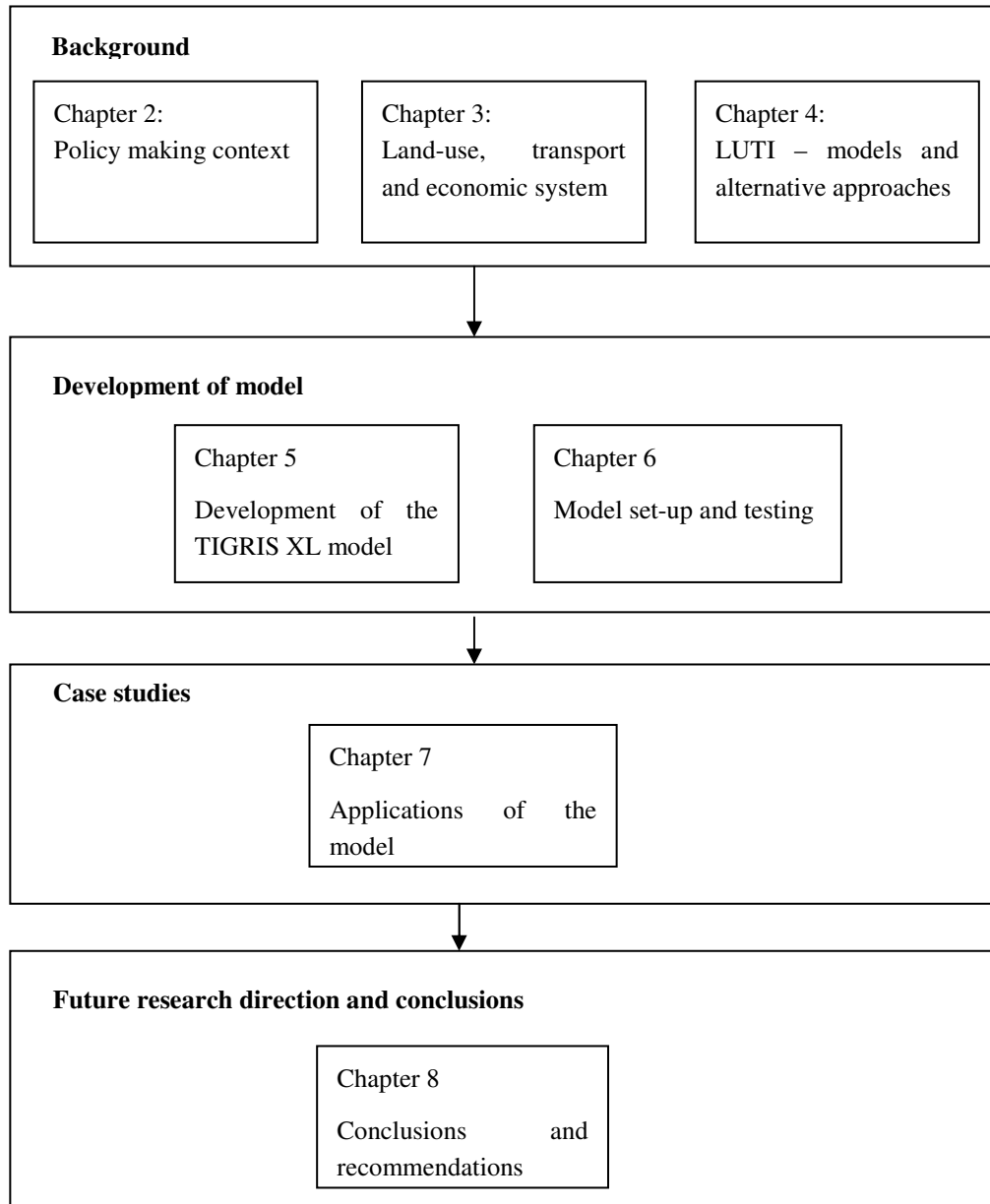
An elaborate account of the findings of this research can be found in the last chapter (Chapter 8) of this report. For a quick positioning of this research the following main contributions can be mentioned:

- Methodological lessons from the design, estimation and implementation of a land-use and transport interaction model for the Netherlands, capable of simulating national and regional transport – and land-use policies;
- Model estimation results for the influence of accessibility on residential location and firm location. The results are household type - and economic sector specific;
- The model is tailored to the regulated land market conditions in the Netherlands; it offers the flexibility to explore the effects of changes in this regulated market regime. The research illustrates the impacts of alternative spatial policies, varying from regulated market conditions to free market conditions, on land-use projections;
- Insight in the size of the structuring impacts of transportation on land-use; this includes analysis of the sensitivity of these impacts for other system settings (e.g. demographic or economic projections or spatial policies). Results for a case study illustrate the importance of these effects for policy-making.
- Positioning of integrated land-use and transport interaction models in an infrastructure evaluation framework. The thesis explores an approach to include indirect generative effects within a LUTI framework;

1.5.3 Complementary research activities

Over the last years RAND Europe in association with Bureau Louter and Spiekermann & Wegener has developed TIGRIS XL, for the Transport Research Center in the Netherlands. The author of this dissertation was the principle researcher and project leader of the TIGRIS XL projects. Bureau Louter has been responsible for the design and estimation of the labor market module and Spiekermann & Wegener had a small senior advisory involvement. This dissertation takes advantage from the results and insights developed in that project; findings on the use of the model for policy making are based on model testing and application of the model to a case study.

1.6 Outline of the thesis



2 Policy making environment for transport and land-use

The previous chapter introduces the various aspects, which define the contours of an analytical tool, which captures the structuring impacts of transport measures and improves the evaluation of combined transport and land-use policy packages. The challenges to prepare an integrated modeling instrument were indicated. In the present chapter the requirements for modeling and evaluation are further elaborated based on a review of transport and land-use policy-making practice. Such practice is strongly context specific and each country has its own tradition of government action and functioning of markets. This chapter focuses on how policies are developed and evaluated in The Netherlands.

The subsequent sections describe the character of spatial planning in combination with transport. Various levels of scale in spatial differentiation are used in the analysis. Evaluation practice has recently gone through a significant re-orientation; the implications for the evaluation framework are indicated. The chapter ends with an outline of the framework of analysis adopted in the present research, and the results to be expected from this approach.

2.1 Tradition of land-use and transport policy making in the Netherlands

In the analysis of the development of a region a differentiation can be made between autonomous and guided development, and grades in-between. “Autonomous” refers to the development of the region as result of the working of the free markets and “Guided” refers to steering of the development through governmental planning and regulations. An actual situation will be a mix of the two. The level of guidance by the government depends on the political involvement and the available regulatory apparatus to implement policy. The situation differs strongly for different regions and countries, partly reflecting the differences in pressure on land between different regions. The Netherlands has an elaborate system of spatial planning. By international standards the Dutch system is particularly comprehensive and detailed (European Commission, 1997).

Historically the key objective of the Dutch spatial development policy is to guide the urbanization process (WRR, 1998). Five basic principles form the core of the Dutch spatial policy: concentration of urbanization and preservation of the countryside, spatial coherence, spatial differentiation, hierarchical urbanization and spatial equity. These basic principles have been at the core of the National Physical Plans, see section 2.1.1, in which these principles were implemented by using concepts such as growth centers or compact city.

Institutionally, spatial planning is mainly a coordinating activity and the directive power of the Minister for Spatial Planning is limited. The main directive is that local zoning plans need to be approved by higher levels of government. In day-to-day practice the national government uses several types of financial incentives to persuade other actors, other sectors or local governments, to adopt its policies (WRR, 1998). The Ministry of Spatial Planning coordinates its policies with many other Ministries and local governments. In particular a close coordination between spatial policies and public housing policies and agricultural policies has existed to realize the target of urban concentration and preservation of the countryside. This has shifted from a coordination of national parties to coordination between the Ministry for Spatial Planning and decentralized government agencies (WRR, 2001). This integration of spatial policies with public housing policies, agricultural policies and financial incentives characterizes the spatial development in the Netherlands as strongly guided in comparison with other nations.

The understanding and interpretation of the trends in spatial development is subject of continuous study. Changing spatial policies or societal developments set new conditions for the functioning of spatial markets as the land market, housing market and labor market. These changes make their way into the functional specification of the analytical instruments addressing these markets. The role of the government in spatial developments, the type of involvement (subsidies or regulatory) and spatial scale level of involvement, are key information for a formulation of the functional specification of analytical instruments.

For practical purpose of consistency with the administrative structure, spatial planning can be divided into three scale levels: national planning, regional (provincial) planning and the urban planning. Different institutions and policy instruments are available at each of the spatial scale levels. As stated above the role of the government in spatial planning differs strongly between countries; it can range from total absence to strict

zoning regulations including regulation of the location, number and kind of houses. A less dominating role for the government results in a stronger position for private parties such as real estate developers and land owners. These private parties will optimize their benefit and be sensitive to the preferences of their customers (the land demand functions). Under these circumstances the price mechanism will function well and land-demand functions with the highest willingness to pay will settle first. In the Netherlands the land market functions in an imperfect way, due to direct government involvement; detailed zoning plans exist to allocate land functions. Land market modeling in the Netherlands is further complicated by complex market processes such as speculation on government zoning-plans by investors and land developers.

2.1.1 Brief history of national physical plans in the Netherlands

In the Netherlands there is a longstanding tradition of producing national physical plans (“nota ruimtelijke ordening”). At a local level this plans date back over a century, but the first national physical plan in the Netherlands was produced in 1960 (Ministerie van VRO, 1960). This was still in the period of rebuilding the country after World War II. In this period there was a strong, and accepted, coordinating role for the national government. In the national physical plans the Government stresses their long-term ambitions and goals for the spatial developments in the Netherlands. These documents used to have a strong directive character for regional and local government bodies.

The role of transport in these national physical plans is of specific interest for this research. In the first national physical plan there was little attention for transport; for example, the plan only states that ongoing growth in the Western part of the country might lead to higher congestion levels. In the first two physical plans the government expects a strong growth in road traffic that should be facilitated. Many new roads had to be built (Van Wee, 2002a). The second physical plan (Ministerie van VRO, 1966) only mentions for the first time the interactions between land-use and transport.

The third physical plan was written in the early seventies, in which environmental concerns play an important role (e.g. Club of Rome³, Oil crises). In the third physical plan the government proposes for the first time land-use policies to reduce the growth of car transport. The land-use policies of the third physical plan had the aim to reduce average trip length as well as to realize a modal shift from car to public transport and slow modes. The land-use policies consists of concentrating of new developments in medium sized urban regions, establishing a good connection between new residential and commercial sites and public transport services, balancing residential and commercial developments at the size of the urban region and locating employment at public station nodes (Martens, 1994).

The fourth document (Ministerie van VROM, 1988) largely continues the policies of the third plan. The fourth plan mentions quantitative targets to reduce car-based transport or more specific non-business car transport. In addition the fourth document formulated location specific restrictions on parking places for office locations; the so-called ABC-parking policy. Parking places (relative to number of working people) for office locations near public transport nodes were restricted.

³ Club of Rome is a Non Governmental Organization that studies the future of mankind. It became famous in the early seventies with a report “Limits to Growth” (Meadows, 1972) in which it related economic growth and its impact on the environment.

Experiences with the third and fourth plan indicate that it is very difficult to influence transport by land-use policies. Many of the policy intentions were not carried out due to specific lack of land-use instruments or deviations from the policies in practice (Van Wee and Maat, 2003). Another reason is that it is questionable, whether the government can effectively influence the location of firms (Martens, 1994). A shift in policy can be observed in the, never formally adopted, fifth physical plan (Ministerie van VROM, 2001), which was followed up by the “Nota Ruimte” (Ministerie van VROM, 2005). The main target is not anymore to reduce future growth of car transport but to accommodate and manage future growth. Table 2.1 presents an overview of the role of transport within the various national physical plans.

Table 2-1: Overview of the role of transport in physical plans

Physical plan	Attention for transport	Actions to influence transport
First (1960)	Little attention, recognizes that growth in Western part leads to congestion	Facilitating transport demand
Second (1966)	Increased recognition of transport and transport growth, physical planning should facilitate transport growth	Plan for dense national highway network
Third (1973 - 1976)	Recognition that unconstrained transport growth is not desirable. Plan formulates land-use policies to reduce growth in car transport.	Concentrate spatial development in medium sized urban agglomerations Balancing residential and employment growth at the level of the urban region Serve new locations by public transport Locate employment at public transport nodes
Fourth (1988-1989)	Aim of plan is to use physical planning as an instrument to reduce growth in non-business car transport.	Compact city idea, developments within city boundaries or along city boundaries. Coordination of spatial developments and public transport services ABC parking policy
Fifth (2001)/ “nota ruimte”(2005)	Recognizes that spatial planning is not a very efficient instrument to reduce transport growth. Focus on managing, not reducing, growth and mitigation of negative effects.	Urban network strategy with transport axes between core urban centers as priority corridors.

*) years of physical plans are not always exact as some physical plans consist of multiple parts produced in different years

Each of the physical plans has caused a fierce discussion, which can partly be explained by the high pressure on land in the Netherlands; scarce land resources make it impossible to fulfill land claims for all functions; typical results of the plans are restrictions for commercial and residential land developments. Furthermore unexpected changes in developments have always severely affected the implementation and usefulness of the long-term physical plans. Examples of such changes are the change from being an emigration country into immigration country and the unforeseen large drop in birth rates during the seventies. The national physical plans have also been affected by changing values in society; for example, the unconstrained and supported growth of car transport in the second national plan was superceded by the rise of environmental concerns in the seventies.

A fundamental discussion addresses the status of the national plans; the issues are two-fold. In the first place it is questioned whether the national level is the right level to

make detailed physical plans. It is argued that this responsibility, with an exception for areas of national interest, can best be delegated to regional and local authorities. Secondly, the effectiveness of the national physical plans is questioned. It is argued that changing circumstances over time, and diverging goals for different tiers of government, make it very hard to implement national physical plans.

The latest national physical plan, “Nota ruimte” (Ministerie van VROM, 2005), recognizes the above critiques and can be marked as a principal point of change in the involvement of the National government in spatial planning. The underlying principal is that the national government only takes the lead in physical planning in so-called areas of national interest. Within all other regions, regional and local authorities are the principal actors in physical planning and the national government changes its role from steering physical developments into checking and controlling if regional and local physical plans meet a set of basic criteria. In these regions the national government will no longer impose development restrictions.

2.1.2 Horizontal and vertical coordination of government

A successful implementation of government plans and policies in the field of land-use and transportation, requires a horizontal and vertical coordination of government activities. Figure 2-1 presents an overview of key institutions in the field of land-use and transport, operating at different tiers of government; only the main government players from the field of land-use and transport are indicated. In practice many other players are involved such as, for example at the national level, the Ministry of Economic affairs and Ministry of Agriculture.

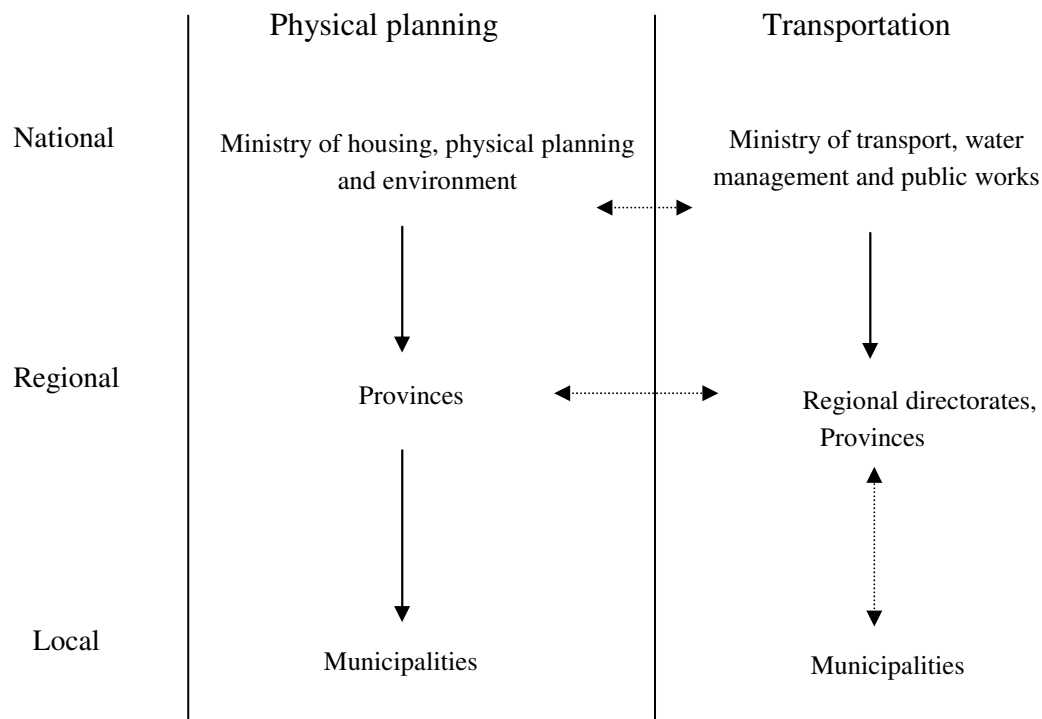


Figure 2-1 : Overview of key institutions in the field of land-use

Figure 2-1 illustrates the three tiers of government in the Netherlands for physical planning and transportation. Within the physical (or spatial) planning sector there is a hierarchical relationship from the national government via the regional level to the local level. All land-use plans are formally implemented at the local level, but the national government in coordination with the regional government can steer or disapprove these plans. Within the transport sector a hierarchical relationship between the various tiers of government does not exist. The Ministry and its associated regional directorates are responsible for the highway system, the Province is responsible for the secondary roads and municipalities are responsible for their local road network.

Horizontal and vertical coordination between government bodies is needed to realize a guided spatial development according to the national or regional targets. In a theoretical case of fully guided spatial development everything would be supply dominated: the government determines the choice set of alternative locations for individual households or firms, in the most limited form there would be only one option for each actor. In reality many actors, e.g. project developers or residents, have several options and have an important influence on spatial developments. The potential to realize the planning goals at the national level is conditioned by the following processes:

- Land demand functions: residents and/or firms, are putting pressure on the government to adjust the policies in their preferred direction. Firms or residents can reject unattractive locations and they are often capable to find alternative locations. Especially international operating firms do have a strong position; governments are often willing to comply with their wishes for competitive reasons.

- The hierarchical sequence of targets, from national targets, through regional targets to local targets is not uniform (see Figure 2-2). Governmental institutions can be in competition to meet their own targets. This competition occurs between different scale levels but it also occurs within a scale level. For example a national target for a balanced spatial distribution of social classes is in conflict with municipality targets to attract the high-income group. Another example is the competition between regions to attract the settlement of new companies.

Comparisons between the physical plans and actual spatial developments (VROM, 2001; Ransijn and Vreeker, 2001) demonstrate the above processes; for example, a part of the residential developments have taken place in so-called restricted areas. The review (VROM, 2001) illustrates that the growth of urban land use in the period 1989-1996 in the restricted areas in the countryside was similar to the growth in the whole countryside. The analysis shows that the physical plans have been rather unsuccessful to stop the development of small residential sites in rural communities, which are part of restrictive areas. The driver of this development is the preference of a majority of the households for suburban locations with single or detached houses, and the ambition of local governments to facilitate these residents.

Figure 2-2 presents the hierarchical spatial planning structure and the role/position of key actors such as project developers, land owners and residents/firms.

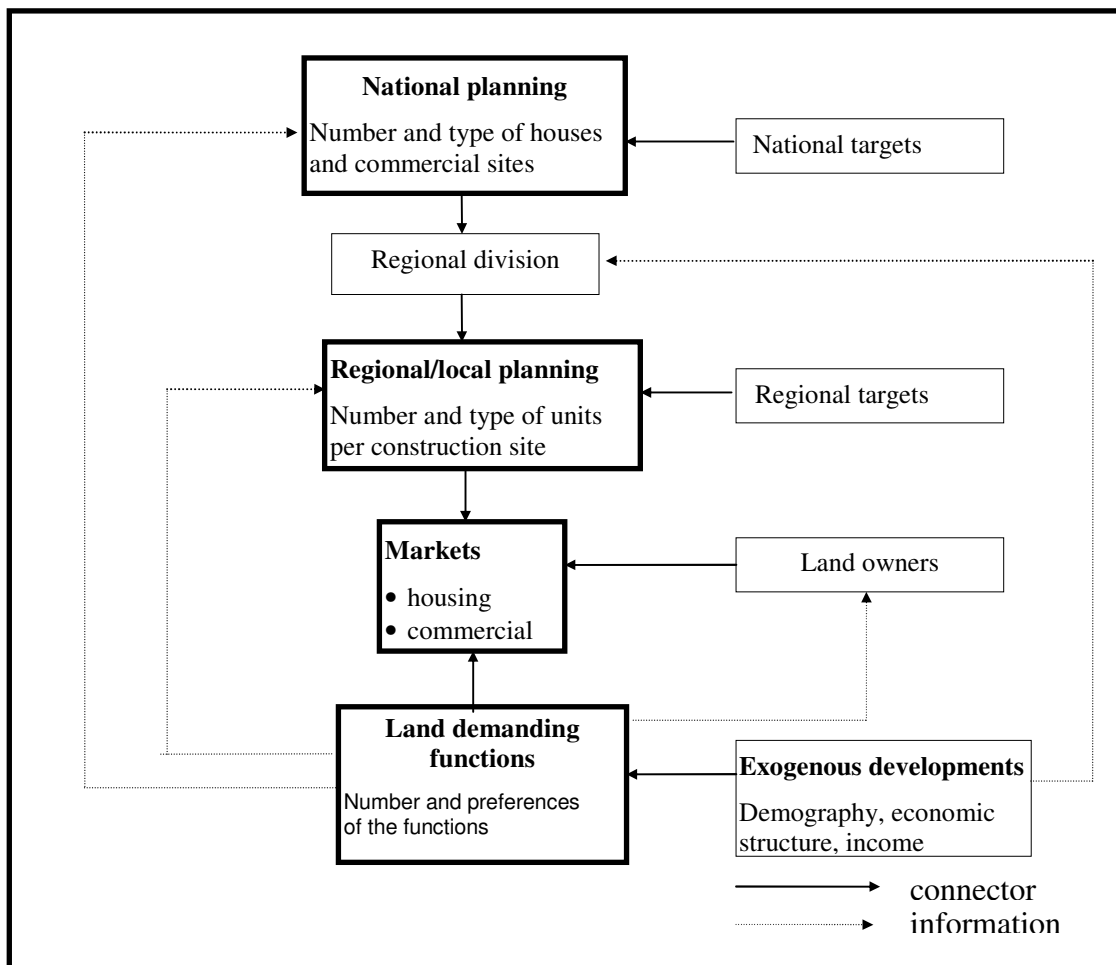


Figure 2-2: Overview of spatial planning

Figure 2-2 illustrates that the supply of available land and the land demanding functions meet each other in the land market. Actors in this land market are the government, real estate developers and residents/firms. As previously described the government and real estate developers regulate the level and type of supply. The match between supply and demand depends on the preferences for the different land demand functions. The government can steer the development directly in the desired direction by regulating the supply side or indirectly by measures influencing the preferences, for example by improving amenities in the neighborhood.

2.1.3 Implications for analytical planning instruments

Historically the use of a land-use model system in the practice of spatial policy making in the Netherlands has been limited. Sector specific models are generally used to formulate future demands by region and sector; allocation of these regional demands to land-use is coordinated in the spatial plans and implemented in local zoning policies. The spatial plans are drafted as the result of multiple rounds of interactions with the key actors.

In the last decennium this planning process has slightly changed; in several spatial policy studies land-models have been used to simulate future land-use (Groen et al., 2004). The land-use scanner model (Scholten et al., 2001; Hilferink and Rietveld, 1999) and environment explorer model (De Nijs et al., 2001) have been used to generate future maps of land-use in the Netherlands. Both of those models have benefited from the developments in Geographic Information Systems (GIS) and combine spatial modeling techniques with GIS techniques. In this research an alternative approach to land-use modeling is explored, which is more actor based and less supply driven by the land characteristics. Further this research aims to model land-use, transport and economy as one integral system. This new instrument has to operate within the context of the Dutch spatial planning practice; the demands set by the Dutch spatial planning practice on the modeling approach are discussed below.

A land-use model for the Netherlands should be capable to allocate land for specific conservation purposes, reflecting the countries strong tradition in preservation of natural and open landscapes. Future assumptions on the size and location of these preservation areas will be scenario specific; this can be implemented as a user input to the modeling. The modeling should also be capable to use local plans as input. These plans specify the future land-use and can be specific in describing the number and type of houses. In practice these local plans will only exist for the short/medium term and for long-term forecasts these concrete local plans are absent. Therefore for a realistic modeling it is required that the influence of these local zoning plans can differ over time; including a strong influence on short term developments and little influence on long-term developments. The influence of the national and local plans will also vary by spatial scale level and by sector.

Historically, all national physical plans include a stronger influence on location choices of residents than on the location choices of firms. At a national level the location of large-scale residential development sites are outlined, including a construction target. The government steering of the location of firms is delegated to the regional- and local level. For the modeling this suggests that a different approach needs to be taken for residential location choice than for firm location choice. In the modeling government policies should play a more prominent role in the residential location choice modules than in the firm location choice modules. The location choice of firms is mainly

dominated, certainly at higher spatial scale levels, by the preferences of firms. At a low spatial scale level local governments have the legal authority to draw up zoning schemes; at this level supply side restriction have an influence on the location choice of firms. However, competition between municipalities to attract jobs, spurs local governments to offer firms attractive locations corresponding with the preferences of the firms. A demand oriented firm or job location model seems to be most suitable to model firm location choices at the regional or municipality level in the Netherlands.

The development of residential locations has been strongly influenced by the National Physical Plans, examples of these guided developments are the existence of new towns such as Zoetermeer or Almere. These large-scale residential sites have been planned at the national level and formally implemented in local zoning policies. However, as illustrated in paragraph 2.1.2 illustrated, not all residential land-use developments are planned at the national level. Local governments, real estate developers and residents play an important role in the development of these unplanned residential sites.

From the above can be concluded that the development of residential locations has been based on a combination of government guidance and preferences of the residents. The modeling of the residential location choice should address the guiding role of the government as well as the location preferences of the residents. Even in a regulated framework the balance between land-use changes guided by the government and preferences of the residents might be time dependent; the government has a strong influence on short-term developments and less influence on long-term developments; preferences of the residents will affect the future government plans as well. Another argument is that the latest physical plan shows that the role of the government is likely to reduce, therefore the residential location choice model should be capable to deal with various levels of government influence.

2.2 Policy measures and spatial scale level

Over the last decades it has become clear that the problems of a continuing growth of transport in urbanized regions, such as congestion and environmental externalities, cannot be solved by conventional transport measures alone. There is widespread agreement that in order to bring about sustainable travel in urban areas, integrated policy packages – comprising a cross-sector mix of regulatory-, pricing-, and technological measures- are needed to send the right signals to both supply and demand elements in the urban land use and transport markets (ECMT, 2002). Successful implementation of these policy packages aims, among others, to integrate land use and transport planning. Identification of this policy challenge is a key step in setting model design specifications.

Each model can only address a limited set of policies and a certain geographical scale level. The whole range of policies affecting land-use and transport is potentially very large; these policies include changes in prices, regulations, infrastructure, land-use zoning, traffic management, provision of information, and subsidies. The OECD publication “Road travel demand, meeting the challenge” (OECD, 2002) presents a broad overview of successful strategies and measures, implemented in one of the OECD member states, that influence travel demand. State-of-the-art overviews of land-use and

transport policies have been prepared in the PLUME project for the European Commission; potential measures and key findings are presented by topic in synthesis reports on land use planning measures (Marshall and Lamrani, 2003), travel demand management (Lamrani, 2004) and infrastructure provision (Marshall, 2004). Another valuable source is the PROPOLIS project (PROPOLIS consortium, 2004) in which a wide set of land-use and transport policies has been tested for various urban areas.

The references show that a wide variety of policies have an affect on the land-use, transport and economic system. The number of potential policies is overwhelming and therefore the present research effort focuses on typical transport policies, such as infrastructure and pricing measures, and typical land-use policies, such as land market regime, zoning policies and specific construction plans.

Table 2-2 presents a classification of policies differentiated by the level of spatial detail, - the involved markets/processes, -potential planning instruments and -effects. The table does not aim to present a comprehensive overview, but serves in particular to illustrate the need to identify the levels of spatial scale in the analysis. Identification of the spatial detail in the analysis is important because different policies are relevant at different scale levels, different trends and developments occur at different spatial scale levels and different effects can be measured at different levels of spatial detail. The overview of involved planning instruments in Table 2-2 demonstrates that each analytical planning instrument produces only a fraction of the output needed to evaluate policies; normally a policy evaluation uses therefore information from various analytical instruments.

Table 2-2: Classification of types of policies by spatial detail in the analysis

Transport & Spatial Policies	Level of analysis	Unit of analysis	Markets/processes	Tools	Effects
High Speed train Airport	National	Regions	Regional production Labor Market Transport market	Macro economic models Regional economic models	GDP Income Employment by region Population by region
Zoning Land-use plans Housing densities Road Public transport	Regional	Zones	Housing market Real estate market Land Market Transport market	LUTI models Sector models	Vacancy/shortage housing Vacancy/shortage office space Green/brown field Employment by zone Population by zone
Noise regulations Air quality regulations	Micro level	Land parcels	Demolition/construction Change of function of land-use parcel	Micro models GIS ⁴ based models	Noise pollution Air Pollution

*) please note that this is not a complete list, but it presents an example of the relationship between policies, spatial level of analysis, tools and effects

As can be observed an analytical framework to assess all of these effects comprise different models operating at different spatial detail and addressing specific sectors. The integration of these models is normally quite poor; and communication with other instruments in the analytical framework often occurs by applying a substantial aggregation in spatial detail and socio-economic groups. An example of such simplified representation of space is the geographic zoning in the regional economic models. These models normally address land-use and transport at the aggregated level of a region and a network is often absent. It is clear that projections from these models are affected by such aggregation.

2.2.1 Scale level

For many policy measures an analysis at various scale levels is needed to assess all the relevant effects. For example, a new highway will affect the inter-regional transport flows and therefore the competition between regions. Such a highway is also often used for transport within the region and it will affect the regional market. At a further detailed level such an infrastructure measure will affect land-use activities through noise- and air pollution.

Each country has a traditional division of space into regional and local for policy evaluation studies. There is however no uniform international definition of what a region or local level should be, and very often country specific administrative boundaries are used to identify regions or local units. The definition of a region can

⁴ Geographical information system; GIS based models refers to models implemented within a GIS environment

vary from a rather small geographic area, for example one city and its surroundings, up to a combination of several provinces or states. For the Netherlands the COROP level⁵ is often considered as regional level. In Table 2.2 two geographical levels are differentiated, the first level indicates the study region as a whole, and the second level indicates the unit of analysis.

From an analytical point of view an administrative division into regions and municipalities is often sub-optimal; preferably the regional definition should be freely tailored to the size of the markets of interest. For example, to analyze the housing market a regional analysis is preferable and a finer zonal level is needed to model the spatial dimension of the housing market within the region. The adequacy of the regional level to model the housing market can be explained by looking at the supply and demand side of the market. First of all the supply side is strongly spatially defined: houses cannot be picked up and moved to another location and demolition and reconstruction of houses at another location is very expensive. These high sunk costs are a major reason for the slow and long-term changes in spatial structure. At the demand side the large majority of the households are normally connected with the region through employment, school, social network and/or information provision.

Over time the size of the housing market, and associated preferred size of the study region, is not constant. Faster, cheaper and more comfortable means of transport have resulted in larger housing markets. It is also sometimes difficult to isolate one urban/regional housing market. In the Netherlands, with its multiple urban centers at relatively short distances, a pattern of many overlapping housing markets exists and specific locations are part of several housing markets.

2.2.2 Implications for modeling

The shift in policy making from sector specific policies into multi-sector policy packages calls for the use of an integrative analytical framework; either developed based on improved integration of existing instruments or facilitated by the development of new integrative multi-sector modeling systems. It should be noted that integration in this context does not mean the construction of one instrument covering an in depth modeling of all markets and effects. Aiming for such modeling will result in an oversized instruments and is a well-known recipe for “disastrous” model development. Instead integration in this context refers to development of more strategic integrative model covering wider parts of the system at less depth. These models focus on the interactions between the system components rather than on detail within each component.

A decision on linking existing modules or developing new integrative instruments requires a clear understanding of the relationships and interactions between the various parts of the system, including spatial scale level of interaction and time dynamics. Highly integrated parts of the system, including dynamic interactions, are complex to simulate by integrating different parts of the system via linking individual instruments. One integrative instrument is preferred for these parts of the system; this further facilitates the testing of policy packages on the contribution of combining certain policies. Linkage of existing modules is a preferred approach in the case of interactions in mainly one-direction.

⁵ COROP zones are statistical zones within the Netherlands; in total there are 40 zones; they are conform to the European NUTS 3 classification

It is important by setting up the modeling to identify the required spatial scale level for application of the modeling. The present research focuses on an improved estimation of land-use -, transport - and economic effects of national and regional transport policies in the Netherlands. A modeling of the regional housing and labor market is needed to explain the influence of transport changes on residential and firm location. The spatially overlapping labor and housing markets in the Netherlands make it difficult to identify a stand-alone study region; a modeling of the whole, relatively small, country seems more straightforward.

As stated, the system will be developed to support policy making at the levels of national and regional government. As a result local transport policies or local environmental effects will not be simulated. The link with more detailed environmental models is outside the scope of the present research. However, linking land-use and transport interaction models and environmental impact models is certainly an interesting future research direction. For significant work in the field of linking land-use and transport interaction models and the assessment of local environmental effects, reference can be made to the PROPOLIS project (PROPOLIS final report 2004).

2.3 Evaluation framework for project appraisal

The tradition in project appraisal in a country, and the existence of a standardized evaluation framework, is of importance for the design of the analytical instruments. The output of the analytical instruments, either directly or following a post –processing step, forms input to the project evaluation phase. Model development should therefore be tailored to the needs in the project appraisal phase. The paragraphs below present a brief introduction to project appraisal, including a brief overview of international practices and specific attention to the standardized appraisal method in the Netherlands.

2.3.1 Introduction

In most countries, infrastructure development puts a heavy strain on public finances. This emphasizes the need for a proper evaluation of all estimated costs and benefits to society and a ranking of infrastructure projects. Various methods exist to evaluate transport infrastructure measures; two well-known approaches to evaluation are Multi-Criteria-Analysis (MCA) and by Cost-Benefit-Analysis (CBA).

The term Multi-Criteria-Analysis (Voogd, 1983; De Brucker et al., 1998) represents a wide variety of methods; they can be classified into overview table methods and ranking methods. A main characteristic of the MCA is that it does not use one overall objective, but many sub-objectives can be handled addressing the interests of various stakeholders. The MCA ranking methods use relative weights on the different criteria to produce an overall score for each of the alternatives.

Cost-Benefit Analysis (Anderson et al., 1979; Dasgupta 1972; Brent 2006) is the most common approach used by decision makers in the evaluation of transport investment. Investments in public infrastructure need to be based on a societal CBA, in which the assessment of all costs and benefits are based on the concept of welfare economics. The welfare change for the society, resulting from the investment, depends on the change in utility for all members of the society between the situation with and without the investment. The CBA produces an evaluation in terms of an overall net contribution to

welfare, which takes into account the interests of all sectors affected by the infrastructure project. The CBA uses a prescriptive approach; the preferences to which decision makers should compare alternatives are constructed by the researcher: for example, determining the value of time of transport time savings. A sensitivity analysis can be performed to test the influence on the benefits of changes in factors like the value-of-time.

An important category of impacts are the indirect effects. Large infrastructure projects may have widespread impacts on other markets (e.g. labor-, production or housing market) in the affected region(s), which may add considerably to the direct user benefits. Evaluation of large-scale infrastructure projects should therefore include the likely regional impacts arising from the investment (OECD 2002). These so-called wider or indirect impacts are usually heavily debated in the public discussion on the infrastructure project.

It follows then that many governments, in the search for improved appraisal methods have defined direct user benefits and costs as well as the indirect impacts. The inclusion of these indirect impacts depends on the possibility to sufficiently estimate (quantify) those impacts, which has proven to be difficult. Estimation of these indirect impacts, through an integrated modeling effort, as stated in Section 1.5, is a main objective of the present research. Below an overview is given of some practices in transport project evaluation in an international context.

2.3.2 Brief overview of international practices in transport project evaluation

Many countries have established methods and procedures for evaluation of infrastructure projects; these methods are subject of continuing debate and research. In most countries CBA is the primary evaluation method and, for example, in Germany and the UK, regulations exist about how a CBA should be applied to infrastructure projects. These focus especially on road infrastructure projects (Rothengatter, 2000; Vickerman, 2000). In the USA there is no standardized practice but CBA is the primary evaluation method at the federal level (Lee, 2000). In France there is a shift in method from MCA towards CBA (Quinet, 2000).

Although there seems to be a general preference for the CBA-method as evaluation method among the EU-countries, large differences exist in the complexity and scope of its application in evaluation. Overall there is a high level of consensus as to the direct impacts, namely impacts on transport users and operators that should be included in a CBA. However, when dealing with impacts for which there are no markets, the so-called external effects, such as the value of time or accident costs, impact estimation diverges. With regard to environmental impacts there is a degree of consensus on which impacts should be included, but less agreement on the appropriateness of using monetary values for the impacts. The situation is even more diverse for inclusion of indirect economic effects, such as indirect generative or distribution effects on other markets than the transport market. It is a widely held view that the indirect socio-economic impacts are of relevance for decision-making; however there is little agreement on how such impacts should be included in the appraisal. Views vary under what circumstances and to what extent they are perceived as indirect impacts, additional to the direct impacts (Bristow 2000).

In practice the wider- or indirect effects of transport measures on the region are often not included in the CBA. An important reason is that it is difficult to disentangle direct and indirect effects and that one should be careful to avoid double counting of benefits.

Because of the complexity, well-established and accepted methods and instruments, to address these indirect impacts are missing. Equity effects, or indirect distribution effects, are sometimes considered as a separate analysis additional to a cost-benefit analysis.

In several countries specific appraisal methods and procedures exist for investments in transit projects (Van der Loop and de Jong, 1998). For example, Sweden follows a cost-benefit approach in which effects are expressed in monetary terms as far as possible. Effects, which cannot be transformed in monetary values, are left out in the evaluation. Germany follows a very detailed and strictly standardized method for public transport project appraisal, the so-called “Standardisierte Bewertung”. Projects can only classify for government support, around 60 percent of the total investment costs, if the standard appraisal method has been followed. The method has four stages addressing a cost-benefit analysis for the transport sector, a societal cost-benefit analysis, quantitative non-monetary indicators and qualitative indicators. The societal cost-benefit analysis includes, stage one and two, namely direct effects and external environmental effects. Stages 3 and 4 of the method address distribution effects and other effects. The method can be considered as data intensive. In Japan an analytic hierarchical process of evaluation is followed with a tree structure for main indicators and sub indicators. This method has a lot in common with multi criteria analysis.

In most countries land-use plays a minor role in the evaluation procedures in spite of the widely recognized interactions between land-use and transport. Land-use impacts play a role in the evaluation of urban transport projects in France and form one of the criteria in the evaluation in Germany. In the USA land use effect plays a role in the evaluation only in the case that land use impacts affect travel demand (Hayashi 2000). An explanation for this generally limited explicit attention for land-use effects in the evaluation is that land use impacts are hard to estimate and classifying the economic impacts of these land-use changes, redistribution or generation of activities, is even more complex.

The above review illustrates that the wider impacts of transport policies are most often not taken into account in a traditional CBA. Two alternative approaches to include those impacts are, are the following:

- Extending the scope of traditional CBA by incorporating indirect effects expressed in monetary terms, including multiplier effects and market imperfections. Social and regional equity effects, which are difficult to transfer into monetary terms, can be included as PM items within a social CBA;
- A wider appraisal framework in which direct user benefits and wider impacts are presented as complementary analysis (e.g. PROPOLIS project 4th RDF EC). Such an approach combines principles from CBA and MCA. The PROPOLIS study uses metropolitan land-use models and does not calculate generative effects as it uses regional control totals as input.

The text hereunder will discuss the social Cost-Benefit-Analysis method in the Netherlands. It should be noted that this represents a wide scope, compared with international practice.

2.3.3 Project evaluation method in the Netherlands

Many Dutch research institutions have participated in the research program on the economic effects of infrastructure (OEEI). This has resulted in ten topical reports and a guideline for cost-benefit analysis. The full OEEI approach targets for the evaluation of large infrastructure projects, for smaller projects a less comprehensive method can be used. The OEEI methodology states that a broad perspective on welfare economic is needed to evaluate large infrastructure projects. A theoretical discussion on the welfare aspects of infrastructure projects is presented in Rouwendal and Rietveld (2000).

A review of international practice made in within the OEEI research program (Dings et al., 2000) states that cost-benefit analysis is the most adequate method for evaluating investment in infrastructure in the Netherlands. A cost-benefit analysis can be included in several stages of the policy making process, early in the process a rough cost-benefit analysis can be used to select promising alternatives, and a thorough cost-benefit analysis can be carried out to support the final decision.

The OEEI guideline (CPB, NEI 2000) describes the main elements of the cost-benefit analysis and presents an outline of the way such analysis needs to be made. Some main elements are pointed out below, for a more in depth description reference is made to the guideline. Main requirements are:

- Clear description of alternatives and careful formulation of the without project alternative;
- Use of scenarios to represent uncertain external factors;
- Full accounting of project costs, including planning costs, construction costs, operating expenses during the life time of the project and the costs of dismantling the infrastructure at the end;
- The evaluation should commence with a careful market and competition analysis, this phase should identify the effects for operators and users and the effects on other means of transport (including network effects). The product of this step in the evaluation is a partial cost-benefit analysis addressing external effects and probable distribution effects;
- Estimate the indirect effects on other sectors of the economy. This analysis results in a general cost-benefit analysis at the national level;
- Specific attention needs to be paid to the risks and flexibility of the project, including an analysis of phasing and delay in the project.

The OEEI method, recently re-phrased into OEI, has now been in use for several years, comments on the approach and the application in practice have been noted. In general it can be observed that OEEI has contributed to a more transparent and systematic discussion on the evaluation of large infrastructure projects. Some general comments on the OEI method are:

- A cost-benefit analysis can lead to an unbalanced focus on the monetary effects. Although the OEEI guideline emphasizes the importance of a PM item for distribution effects, in practice a cost-benefit approach seems to lead to less attention to these types of effects. This is in conflict with the needs for policy making;

- In practice a large share of all policies and projects focus on distribution effects, as transport measures result in winners and losers. A general cost-benefit analysis based on the overall societal costs and benefits is therefore not sufficient to characterize the impacts from a particular policy. Policy makers need to know whom the winners and losers are, these effects need to be consistent with policies in other fields to ensure policy coherence;
- Experts involved in OEEI reviews have estimated indirect generative effects as significantly smaller than the direct effects. Some suggest that the indirect effects are in a range of 10-30%. (Workshop Rotterdam, 2002). A report of SACTRA in the UK based upon theoretical exercises suggests that the indirect effects are maximally 60% of the direct effects (SACTRA, 1999). All recognize the large uncertainties and indicate that indirect effects strongly differ between projects. Dominant in the discussion of the indirect welfare effects is the uncertainty in estimating them. Depending on the scale level of analysis, for example the difference between a regional and national level of analysis, many of the indirect generative effects become distributive of vice versa;
- The difference between direct- and indirect effects is sometimes rather vague in the guideline and the definitions are difficult to apply in practice; especially network effects that are defined as indirect effects are often considered as direct effects in practice. The distinction between direct and indirect effects becomes even more superfluous if the dynamics of the system are included. An example of such a long-term system effect is a change in transport demand resulting from residential and firm movements. An elaborate discussion on indirect effects in OEEI can be found in Tavasszy, 2002. Tavasszy addresses the following effects as indirect:
 - Scale advantages and disadvantages;
 - Effects of other markets on the transport market, e.g. long term effect of household movements;
 - Additional gains or losses resulting from imperfect market conditions.

Tavasszy further emphasizes that indirect effects can be both positive and negative. The complexity of assessing indirect effects and unique characteristics of each project makes it impossible to use a fixed percentage of direct effects as indirect effects. Therefore new/improved methods are needed to assess these indirect effects;

- The potential of existing instruments to estimate indirect effects has hardly been addressed in the OEEI-guideline; in an additional publication existing instruments are only compared from the perspective of economic theory (RUG/SEO, 2004). The usefulness of the models in policy-making practice, answering questions on what type of projects, spatial scale level and empirical foundation of the results, has been ignored up-to-now. Clear guidance and recommendations on how different types of instruments can be used for project evaluation purposes are needed.

2.3.4 Evaluation method and integrated modeling

The above observations indicate a need for further specification and detailing of the OEI method. The present research focuses on the derivation and application of an analytical instrument to improve the estimation of direct and indirect effects through a sufficient integration of transport-, spatial-, and economic processes. The OEI issues highlighted below are of particular interest in situating the research challenges associated with the systems approach in the present research.

Integrated land-use and transport models have the potential to improve the estimation of several effects of policy packages as follows:

- a) Improved set-up of socio-economic input data for transport models; a land-use model can improve the consistency and transparency of the forecasts of socio-economic data by transport zone, this is in practice often a rather arbitrary process;
- b) Estimation of the long term transport effects can be improved by incorporating long-term secondary system effects on transport demand;
- c) The social and regional distribution effects of transport measures are estimated;
- d) Changes in land-use and transport form an improved input for calculating indirect generative economic effects;
- e) Integrated models can deliver improved input for estimating environmental effects.

Those improvements are elaborated below:

a) Uncertainty in direct effects: quality of land-use data

The spatial dispersion of residents and firms (and their socio-economic characteristics like income) forms a main component in travel forecasting; residents and firms play a role in explaining both the origin and attraction of trips. Uncertainties in the future spatial distribution of residents and firms results in uncertainties in the travel forecast. As stated earlier the current practice of setting up the socio-economic input data for a forecast year, typically 20 or 30 years into the future, is a process with rather limited projection power. A project specific approach is normally taken, based on isolated components such as short-term changes in socio-economic data and existing land-use plans; for long term changes a rule of the thumb is commonly used, such as a proportional allocation of the growth.

A land-use model in combination with socio-economic data can improve current practice by standardizing the process. Such modeling can give a conceptual basis for modeling the long-term changes in land-use and associated socio-economic input data. The changes in socio-economic data by zone can, for example, depend on the location preferences of households and firms.

b) Long term transport demand effects

In current practice the travel time and cost savings, resulting from a transport project, are calculated at one point in time. These savings are calculated for the affected, existing, volume of traffic and an assumption (linear demand curve) is made for new travelers. The so-called rule of a half is applied to calculate the direct effects. Land-use is considered as an exogenous input and therefore assumed to be unaffected by the transport measure.

In the long term the two-way links between land-use and transport result in a different spatial pattern and therefore different transport costs and time savings. A well-known phenomenon is that if travel becomes faster and less expensive people choose to make more and especially longer trips, partly initiated by a more dispersed spatial allocation pattern. The land-use module in LUTI-models improves, through interactions between land-use and transport, the long-term transport projections and therefore the prediction of the transport effects. Firms and residents can resettle to take advantage of new infrastructure and this resettlement influences travel times and costs; in current practice of large project evaluations this long-term effect is not incorporated; the existing transport models use exogenously fixed land-use scenarios. By using an integrated model the long-term transport effects can be estimated more accurately by including second and third order system effects.

c) Indirect social and regional distribution effects

In a national cost-benefit context a project is considered beneficial if the benefits to the winners are larger than the costs to the losers. A general problem of an aggregated (national) cost-benefit analysis is that such analysis does not identify winners and losers of transport measures. Typically for transport infrastructure there are many winners and losers. The distribution of costs and benefits can be a mayor aspect of policy-making and the public debate. Elaboration of the distribution of effects is particularly important because in practice there are no well-developed compensation mechanisms, and insight in these distribution effects may support additional developments in this field. Considering the complexity of assessing infrastructure effects it is unlikely that “perfect” compensation mechanisms will be developed in the near future. Conversely it can be argued that the current practice of largely ignoring distribution effects is not sustainable either; it easily results in public resistance from groups negatively affected by the measure.

Current evaluation practice can be significantly improved by a better identification of winners and losers and a quantification of the impacts accruing to them. This includes a better identification of effects for different cities or regions as well as for socio-economic population groups. Many national policies focus on target groups (elderly, low-income, households without car access, etc) or target regions (regional equity strategies). Policy makers need adequate, preferably quantitative, information to weight distribution effects as part of an overall evaluation. An adequate estimation of distribution effects provides highly needed information to establish policy coherence of the proposed measure with other national policies. Spatial detail and detail in socio-economic classification of integrated models make them suitable to calculate distribution effects. Integrated models can address regional distribution effects, e.g. in number of jobs, as well as transport- and housing market effects differentiated by socio-economic group

d) Indirect generative economic effects

The estimation of the indirect generative effects, following the OEI – definition, depends on market structure: indirect generative effects on other markets occur only if market imperfections exist. Possible reasons for generative effects are existence of scale advantages, imperfect labor market matches or imperfect competition. In a densely populated country as the Netherlands with a high standard of infrastructure provision the contribution of additional infrastructure on improving the competitiveness in the market might be ignored.

For the inclusion of scale advantages a reliable/accepted estimation of the economic impacts from agglomeration and efficiency effects is needed. In most existing integrated models the producer location decisions are not modeled using a distinctive profit maximizing behavior. Therefore those integrated models cannot directly generate additional producer benefits, as is needed for the indirect effects in a CBA. The development of post-processing modules or inclusion of productivity effects within the integrated land-use and transport models is a key research challenge and will be explored in Chapter 8.

e) Improved input for estimating environmental effects

Environmental effects are generally derived by a post-processing on the results of an integrated model; transport volumes form a key input. The environmental effects can be subdivided in global and local effects. Integrated models have some additional value for the global effects, because of the inclusion of second and third order system effects in the predicted transport volumes.

Local environmental conditions are affected by changes in transport as well as land-use, both produced by an integrated model. Often the spatial detail in integrated models is not high enough to enable calculation of the local environmental effects. An integration of integrated models and detailed GIS-based databases, is therefore a significant area of research and development (e.g. PROPOLIS project, SACRAMENTO model). The present research limits its scope to improving the production of the transport and land-use changes at the level of transport zones. These results can be used as intermediate input for a more detailed analysis of local environmental effects in GIS.

2.4 Observations

This Chapter has reviewed the policy making environment for transport and land-use. Issues reviewed in this chapter are the tradition of land-use and transport policy making in the Netherlands, the relationships between policies, spatial scale level and impacts, and the evaluation framework for project appraisal in the Netherlands. This review sets out the context in which an integrated model needs to function.

The review of the National Physical plans illustrates that there is a longstanding tradition of government involvement in spatial planning in the Netherlands; the spatial planning regime in the Netherlands can be marked as relatively regulated. However, the latest physical plan can be earmarked as a principal point of change in the involvement of the National government in spatial planning. The review of the planning tradition in the Netherlands leads towards several important observations for the design of an integrated model, such as:

- A land-use model for the Netherlands should be capable to allocate land for specific conservation purposes, reflecting the countries strong tradition in preservation of natural and open landscapes;
- Historically, all national physical plans had a stronger influence on location choices of residents, through supply of houses, than on the location choice of firms. This suggests that in the modeling a different approach needs to be taken for residential location choices than for firm location choices;
- The spatial planning regime in the future is uncertain, which makes it important for the modeling to be flexible towards different spatial planning regimes.

The review of land-use and transport policies also resulted in several observations for modeling. The observed shift in policy making from sector specific policies into multi-sector policy packages calls for the use of an integrative analytical framework; such instrument should focus in particular on the interactions between the system components.

The overview of scale level specific policies, instruments and effects illustrates that it is important to identify the required spatial scale level for application of the modeling. The present research focuses on an improved estimation of land-use -, transport - and economic effects of national and regional transport policies in the Netherlands. A modeling of the regional housing and labor market is needed to explain the influence of transport changes on residential and firm location. The spatially overlapping labor and housing markets in the Netherlands make it difficult to identify a stand-alone study region; a modeling of the whole, relatively small, country is therefore indicated.

The review of project appraisal methods indicated that in many countries Cost-Benefit-Analysis has been adopted as the appropriate evaluation method. In the Netherlands a standardized method has recently been developed and adopted for the appraisal of infrastructure projects; the so-called OEI (formerly OEEI) method takes a broad perspective on welfare economics and it uses Cost-Benefit-Analysis as evaluation method. There is still a gap between the information needed for this appraisal method and the output of standard instruments.

This chapter pointed out the potential that integrated land-use, transport and economy models have to improve the estimation of the various effects of policy packages. Those can be summarized as follows:

- Improved set-up of socio-economic input data for transport models; a land-use model can improve the consistency and transparency of the forecasts of socio-economic data by transport zone, this is in practice often a rather arbitrary process;
- Estimation of the long term transport effects can be improved by incorporating long-term secondary system effects on transport demand;
- The social and regional distribution effects of transport measures are estimated;
- Changes in land-use and transport form an improved input for calculating indirect generative economic effects;
- Integrated models can deliver improved input for estimating environmental effects.

The observations for integrated modeling as identified in this chapter are input for Chapter 4, which sets out the model requirements and reviewed several modeling approaches. The lessons from the review in this chapter are used to design the model in Chapter 5. The test runs in Chapter 6 and applications in Chapter 7 contribute to the discussion on the impacts of changes in the spatial regime.

3 Land use – Transport - Economy system

The issues in policy-making and the policy making process as described in the previous chapters, indicate the challenges in- and the expected benefits from simulating transport, land-use and economy as an integrated system. Such an integrated model aims to quantify the impacts of integrated land-use and transport strategies on the whole system; this is based on a representation of the interactions between transport, land-use and economy over time.

The present chapter describes the integrated land use-transport-economy system by outlining the interactions between the system components and the boundaries. As background an overview of existing theories on transport, land-use and economy is presented in Section 3.1. Section 3.2 gives a description of the interactions between transportation and the region or urban area following a systems approach. This section also describes approaches to the representation of the time dynamics of the land-use, transport and economic system. In Section 3.3 the key inter-relationships between land-use, transport and economy are discussed based on a review of the literature; as far as possible empirical evidence on the different relationships is presented.

3.1 Theories on interactions between transport, land-use and economy

In general it should be noted that available theories addressing the inter-related transport-land use and economy system are highly diverse and fragmented, reflecting the variety in academic disciplines active in this field; each of the theories represents at best part of the phenomenon of human settlement, mobility and economic performance constituting major aspects of human society. A general theory conceptualizing the development of “human society” in the long run is absent, and most academics have refrained from even attempting to develop such a theory. One of the most comprehensive efforts in this field was made by Walter Isard dating back to the sixties (Isard 1969). In this work he highlighted imbalances in the contributions from different fields of research, in which economic research had been the major contributor, and emphasizes that the fields of sociology, geography, political science, anthropology, planning and decision making are equally important for the understanding of urban, regional and spatial problems.

A generally agreed aspect of theory for urban/regional developments is that it should contain a temporal and spatial dimension to explain the changes in time and space. Many theories, strong in explaining certain phenomena, are not performing well on both dimensions. For example Forrester’s (1973) work on his first dynamic urban model addresses time dynamics but has a very limited spatial dimension. Another well-known example is the development of theories within the general economic equilibrium framework. Historically this framework has suffered from limitations on the spatial dimension, one zone, and temporal dimension, modeling of a static equilibrium. Recent developments, following the so-called New Economic Geography school, have mitigated the spatial limitation to some extent.

Below the interactions between transport, land-use and economy are reviewed based on existing literature on urban and regional development theories. The review can be structured by type of theoretical approach; Wegener and Fürst (1999) grouped major theoretical approaches differentiating by technical-, economic- and social theories. Another way to group theories is by scale level of analysis; different processes and theories are applicable at the international, interregional and urban level (Zondag, Wegener and Louter, 2005). Below the theories are grouped by economic and other theories, reflecting the dominance of economic contributions in this field.

3.1.1 Economic theory

The most important feature of economic theory, differentiating it from other theories, is the use of markets to explain urban/regional development. Underlying driver is specialization of labor, which leads to trading and establishes the market place. From this angle the process of urbanization is to a large extent the reflection of changes in economic structure.

Various economic theories exist which, besides some common features, differ in particular in the explanation of phenomena at different scale levels. At the inter-regional level economic theories focus on the issue of agglomeration or dispersion. An early attempt to address agglomeration forces was made by Myrdal (1957) with his cumulative causation techniques. In contrast with traditional theories which assume an uniform production in space, based on perfect competition and perfect mobility of production factors, the theory of Myrdal incorporates the principle of economies of

scale. However it lacks transport costs to establish a trade-off between economies of scale advantages and transport costs.

The concept of a trade-off between transport costs and economies of scale is at the heart of the New Economic Geography (NEG), with Krugman (1991) and Fujita as leading researchers. In this theory firms receive both internal economies of scale advantages, related to size of production, and external economies of scale through increasing product differentiation, better labor market matches and knowledge spill-overs in agglomerations. Fujita (1999) illustrates that the NEG theory adopts a lot of issues already raised by Isard in his book on location and space-economies, explaining core – periphery processes and non-linear developments in space. A key element is the use of Chamberlin's concept of monopolistic competition, which enables the development of a spatial dimension within the general equilibrium framework. The monopolistic competition concept of Chamberlin has been put in a mathematical formulation by the so-called Dixit-Stiglitz formula, which facilitates the use of this concept within models.

This formula allows for substitution between input factors, which is a significant step forward compared to the traditional Leontieff input-output method for analyzing “spatial” interactions between economic sectors. One of the weak points of the NEG theory was that transport was unrealistically incorporated by a so-called Iceberg function, this function models transport cost by diminishing the freight load. Extension of the theory has overcome this omission: transport is included as a sector in the modeling and substitution with other sectors can take place.

3.1.2 Other theories: behavioral- and system theories

Other, non-economic theories, are often based upon observed human/societal behavior. These theories can be based upon observed regularities, such as observations on regularities in the travel behavior, or settlement behavior of individuals, or regularities in the behavior of the system as a whole.

A well-known theory based upon observed system regularity is the gravity model. This model, originating from natural sciences, explains the spatial interaction between two locations by assuming that it is proportional to the size of the activity at the locations, e.g. number of people or jobs, and inversely proportional to the distance between the two locations. Although the gravity model has proven its value in practice, a main criticism on the gravity model is that it lacks a conceptual explanation for the spatial behavior of the actors in the model.

Another example of a spatial interaction model, based upon system observations and combining gravity theory and economic base theory, is Lowry's (1963) Model of Metropolis, which he constructed for the city of Pittsburgh (USA). Lowry's model follows a stepwise procedure: in the first step employment in the basic, exporting, industry is projected exogenously for a region. In a second step a region will attract workers (and their households) to fill in these jobs. These residents will attract in a third step services and retail employment; employment in the service sector will attract additional residents as well and step two and three will continue an iterative interaction until the additional number of jobs and residents reach an equilibrium. The principle structure of the Lowry model has been followed in many model systems (e.g. MEPLAN, TRANUS) afterwards.

An example of a socio-geographic theory is the theory on action space; in this theory the action space of individuals depends on personal characteristics, age, gender, time - and financial budget constraints, the spatial distribution of activities, and performance

of the transport system. Hägerstrand has been a leading researcher on action-space theory; in his theory a person has a fixed time budget, e.g. 24 hours a day, and a fixed money budget to perform his activities. Hägerstrand has been inspiring a large group of researchers following his ideas on time-geography (Miller, 1991; Kwan, 1998). This approach has often been used to illustrate the social exclusion of certain socio-economic groups. For example, an enormous difference can exist in action-space between car owners and non-car owners or between poor and rich, gender, ethnicity, age, etc.

Another concept related to the work of Hägerstrand is the rule of Zahavi (Zahavi, 1974) concerning constant travel times and -money budget. Zahavi assumes that a person maximizes his activities/opportunities within a fixed time and money budget for travel. The policy implication of this rule is that improved travel speeds will result in longer distance trips and the total time budget spent on transport remains constant. The concepts of Hägerstrand and Zahavi do not only explain transport behavior phenomenon but are also powerful concepts to explain land-use trends like sub-urbanization and de-urbanization. Increased travel times and lower transport costs result in people choosing to locate in suburban or rural locations without increasing their time or money budgets.

The housing market is a critical component of urban and regional developments and its modeling concepts often focus very strongly on demography. The spatial distribution of households is largely explained by demographic developments and processes like household formation, household size, age of household members and household dissolution, are explicitly modeled. These demographic developments take place at a spatially disaggregated level. In combination with the spatial restrictions of the housing market, a large majority of households move over a short distance, such an approach gives reliable forecasts. However, other variables influencing the location choice, such as income, accessibility, housing prices are often ignored in these approaches. A second omission is that taste variation between households is often not included in the modeling. In general a demographic approach towards housing market modeling, is more appropriate for generating forecasts and is less useful for the analysis of policy measures; this is caused by the minimal amount of behavioral information.

A subject receiving increasing attention is heterogeneity in behavior between different types of households and firms. Since the 1970's random utility theory has become very popular to explain human decision behavior, and discrete choice modeling is part of many state-of-the-art transport models (Mc Fadden, 1981; Ben-Akiva and Lerman, 1985). The theory is founded in micro- economics and assumes that all humans or firms behave as utility maximizing actors. An error component in the utility function, representing missing information, allows for heterogeneity in behavior. This heterogeneity is used to explain, for example, why not everybody with the same age, income and workplace uses the same mode of transport. An extension on this method is made by a so-called mixed logit approach with random coefficients for taste variation (Train, 2003).

Recently, agent based micro modeling has generated high interest within the research community as it further expands the possibilities to model behavior; an important stimulator for this trend has been the ongoing growth of computational resources. The method treats every person, household or firm as an unique agent and both data storage and modeling takes place at the level of individual agents. The method enables to use agent specific data features and decision-making processes, including the use of historical data for each agent. In most circumstances, agent base data does either not

exist or cannot be used because of privacy protection regulations. In these cases it is necessary to create synthetic databases at the agent level.

Random utility theory assumes that the behavior of the actors is to maximize their utility. Recently the idea of humans or firms as “satisfiers” has become more popular and, for example, Elgar and Miller (2005) present a theoretical framework for firm behavior based on a satisfying behavior instead of a maximizing behavior. A weakness in the satisfying approach is the lack of a theoretical underpinning; response functions of the actors are often rather arbitrarily chosen. On the contrary, utility maximizing functions are rooted in micro-economic theory and model behavior is consistent with economic theory. An additional advantage is the good theoretical integration of models, based on random utility theory, and economic evaluation methods such as CBA. Utility based models can be used to calculate for a consumer the change in utility (or consumer surplus) resulting from a specific investment. This information can be used to calculate the consumer benefits (for the whole society) needed as input for a CBA.

3.2 A regional/urban system approach

The overall objective of the transport system is to contribute optimally to social welfare. The impacts should be correctly estimated in order to differentiate the contributions of different policy packages affecting the transport system. As stated before these impacts are much wider than the transport sector itself and a system approach, including other sectors, is needed to estimate these wider impacts. This section describes transport as part of the regional system providing a background to the development of analytical instruments. The time dynamics of the system and the implications for the modeling approach are highlighted.

3.2.1 Description of the system

Figure 3-1 presents a schematization of the regional system focusing on transportation and its interactions with land-use and the regional economy. The regional economy comprises consumers and producers involved in economic activities; economic development can be represented by developments in productivity and the labor market.

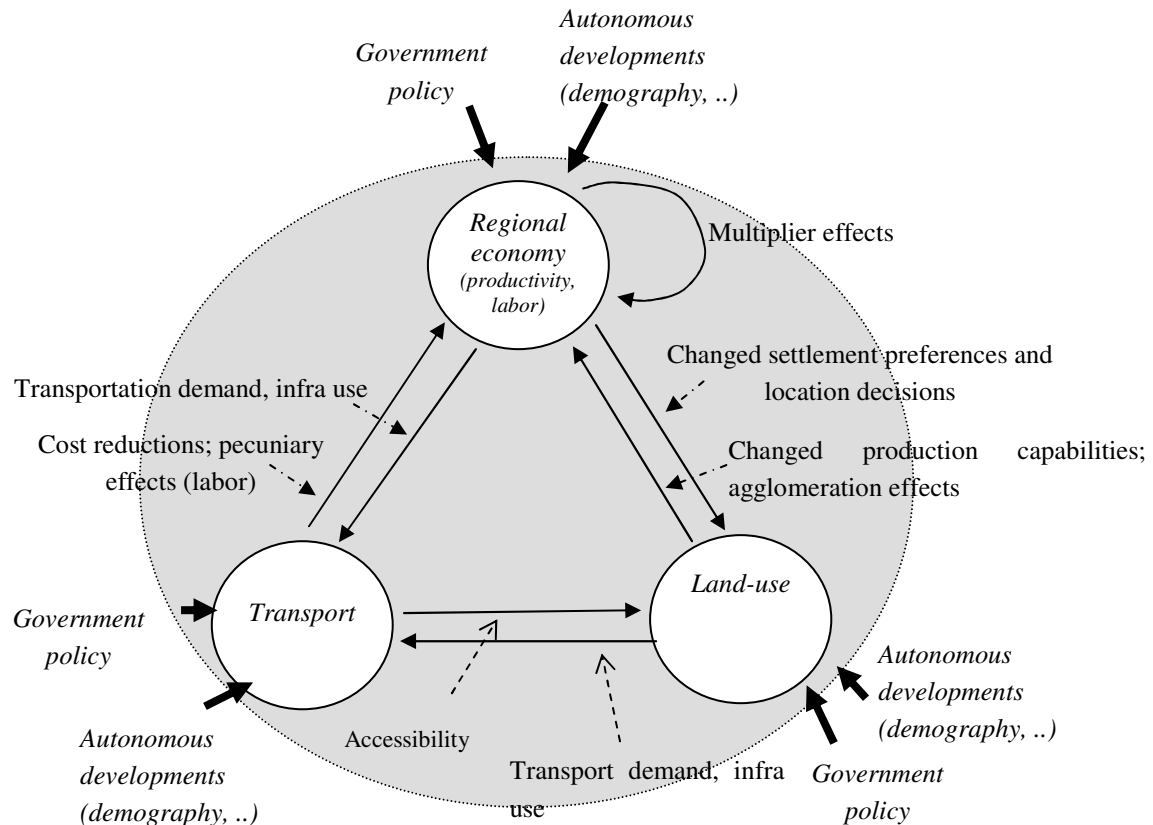


Figure 3-1: Schematization of the welfare production system (contribution from transportation)

The total contribution of policies on social welfare is represented by the total net value/utility associated with all the activities in the system. In view of the inter-linkages through different markets (passing-on of effects) special care should be taken to avoid double counting. This schematization is used to situate the different relationships and impacts (below) and to position ongoing modeling efforts and further challenges (see later sections).

Using Banister & Berechman (2000) as main source on the effects of transportation infrastructure, the following main relationships can be differentiated:

- Cost reductions (consumer and producer surplus) and production and transaction cost savings affect the regional economy;
- The demand for transport and thus infra-use are determined by the regional economy (consumers and producers with their activities) and influenced by land use; those interactions with the supply of transportation infrastructure constitute the transportation market;
- Transportation affects other markets (pecuniary effects) through accessibility/attractiveness changes, in particular the labor and land market are involved;
- Changing accessibility affects location decisions which in turn cause changing production capabilities and potential welfare gains to consumers and producers;
- Transportation investment results in changes in external effects (e.g. congestion);

- Multiplier effects on the direct effects, in the form of second and further rounds of creation of additional income, consumption and employment.

An analysis of contributions to welfare from transportation will need to consider scenario's outside transportation such as e.g. policy measures specifically influencing land use and autonomous developments such as demography.

Economic distribution and generative effects resulting from a transportation investment originate from the primary effects of cost savings and changing accessibility, and can be traced through the relationships of Figure 3-1; the following main mechanisms can be differentiated:

- Primary- and multiplier effects of cost savings affect income, consumption and employment in the region; formulated at a macro-scale they influence capital accumulation in the region and the labor market, the main determinants of the regional product;
- Improved accessibility affects the spatial patterns of households and businesses; this spatial change can increase spatial efficiency and spur economic growth via agglomeration economics.

Important features, influencing the estimation of economic - and land-use effects of transport measures, are the following:

- In general transportation constitutes only a marginal part of the production costs for companies next to a host of other production factors;
- A specific investment in a particular project will constitute only an increment on a large stock of infrastructure investment (sunk cost), which is used in this production system;
- The complexity and marginality leads to difficulties for empirically establishing relationships and impacts for the whole system. A disentangling of the system in sub-systems is indicated to enable an empirical estimation of the relationships in sub-components;
- In the representation of the effects a time dimension needs to be considered to analyze the evolvement of the different interactions over time and to represent growth (Vooren van de, 1999). Representation of a time pattern of the impacts of an investment is essential for a CBA analysis to represent adequately the degree to which capital and operational costs of a project are recovered over its lifetime; the progression of the benefits over time is then a most important input and should cover the progression in the markets, the changes in land-use and the accumulation of effects on the regional economy;
- The land-use and economic effects of transport measures occur in a spatial pattern; analyzing the transport, land use and economic system requires a relatively detailed transport network and spatial zoning. Different aspects may be represented meaningfully at different degrees of spatial detail; to represent the economic production system some degree of spatial averaging is necessary.

3.2.2 System dynamics

Wegener (2004) decomposes the regional/urban system and identifies nine inter-related key elements. A change in one element will affect other elements within the system. The dynamics of these responses differ strongly due to sunk costs, transaction costs, construction times and administrative regulations. The key elements of the urban/regional system are classified by their dynamics in Table 3-1. The time span differs from more immediate daily travel choices to very long-term changes, e.g. centuries associated with land-use. For example, many Roman cities are still important cities today and their center is located at the same location.

Table 3-1: Nine elements of the urban/regional system and the time span of changes

Dynamics	Subject
Immediate	Travel Goods transport
Fast	Population Employment
Slow	Work places Housing
Very slow	Networks Land-use

Table 3-1 indicates that changes in transport infrastructure networks occur at a very low speed. This is in line with the long time period between initial plans for new transport infrastructure and final project realization.

3.2.3 Equilibrium versus incremental approach

Quantification through modeling is the only way to trace system evolution as described above. It requires keeping track of different sectors of activities, spatial locations and times. Two main modeling approaches, equilibrium versus incremental, can be differentiated, those are elaborated below.

presents the key difference between the two approaches. The incremental approach focuses on the changes in time (e.g. the moves of households or firms during a particular time interval). The equilibrium approach addresses the full range of the system variables but does this for only one moment in time (e.g. location of all households or firms). In practice incremental models usually have shorter time steps than equilibrium models; related to generally shorter calculation times for incremental models.

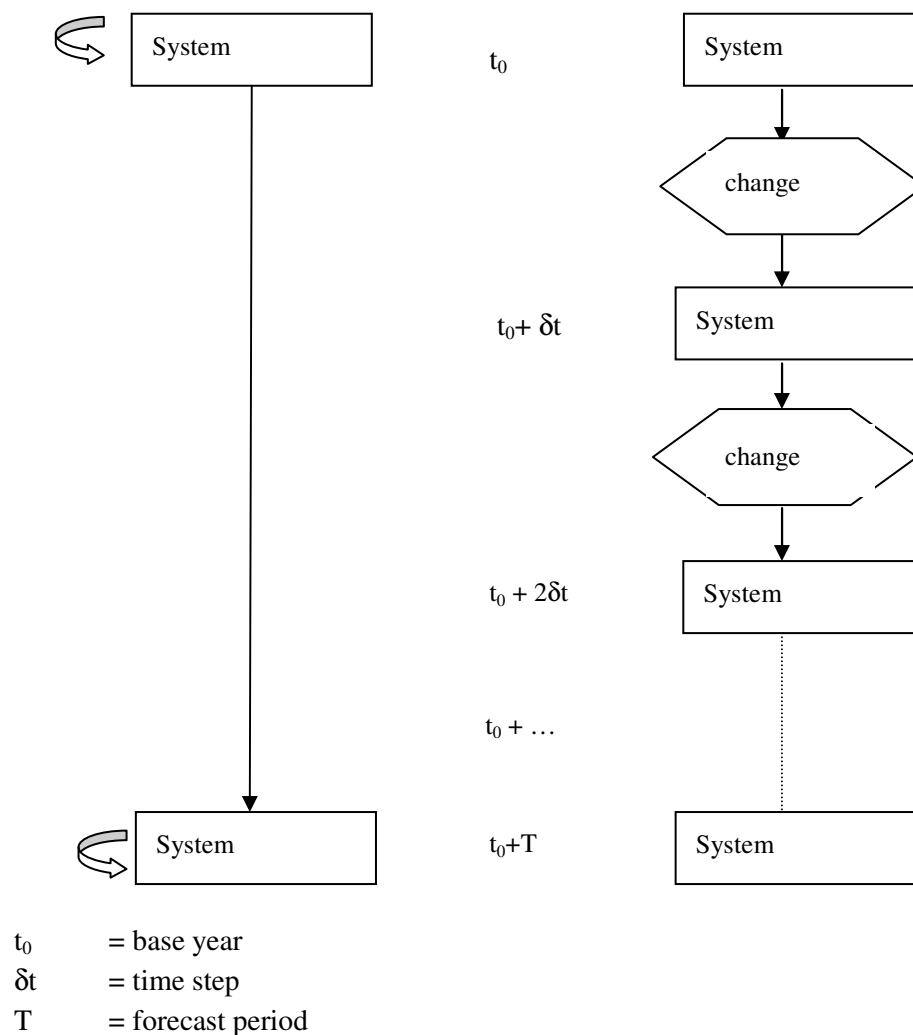


Figure 3-2: equilibrium - versus incremental approach

The two approaches to address the land-use and transport system can be discussed from an urban system point of view or an economic theory point of view. A review of the urban system and its dynamics indicates that the urban system will move towards equilibrium, but such equilibrium will not be reached within a more or less standard forecasting period of 20 or 25 years. This means that in practice if the forecast period is split-up and modeled in time steps to capture the changes over time, equilibrium conditions will certainly not be met within these shorter time steps. This indicates a conceptual difficulty of the equilibrium approach to represent the urban/regional system. Important observations clarifying this issue are (RAND, 2003):

- Supply side changes are very slow due to high sunk costs of infrastructure and building stock, and complex, time consuming, decision making processes;
- High transaction costs are associated with some of the changes, such as for example moving location for residents or firms;
- Demand conditions are continuously changing due to external developments such as demographic or social-economic changes.

The above observations argue for an incremental approach, focusing on the magnitude and dynamics of the changes within the system. Such an approach is in line with the strong path dependency of the system and rather low speed of changes. For example, the housing market responds very slowly to changes in demand preferences both for type of house or location. In areas with an over-supply of houses these houses are not demolished immediately and in areas with over-demand new houses are not realized immediately. The yearly changes in the housing stock are very low; not more than 1 or 2 percent in most areas.

The moving behavior of households is also rather limited; around 9%, based on WBO 2002 statistics, of the households in the Netherlands moves within a year. High transaction costs, including high taxes for purchasing a house, and supply shortages keep this number so low. Even if these obstacles are removed and the percentage will rise, for example to American levels of 20% a year, the majority of the households will not react immediately on these changed conditions. As Weisbrod (1978) stated “in reality only recent movers may be in some form of equilibrium with respect to their tradeoffs of dwelling attributes, neighborhood attributes and accessibility”.

The location of houses and households at a previous point in time, for example previous year, is a very valuable source of information to determine a new spatial distribution of houses and households. An important difference between an incremental approach and equilibrium approach is that an incremental approach will only adjust the data of households that change location; an equilibrium approach will recalculate the equilibrium of all households and resettle them all.

The nature of the urban system, as described above, seems to argue for an incremental approach. With the exception that short term equilibrium conditions might apply to parts of the markets within the system; in the private housing market, house owners willing to sell and house seeking households negotiate a market price.

Nevertheless the equilibrium approach is quite commonly used in integrated models; besides arguments against there are several arguments in favor of this approach. The equilibrium approach can be subdivided in partial equilibrium and general equilibrium. A partial equilibrium calculates the changes in the market itself, for example the effects of a new railroad link on the transport market, but it ignores that this may induce further changes in the economy, for example on the housing or labor market.

Economic theories rely largely on the equilibrium approach in order to produce a mathematical formulation of the theory. A key advantage of following an equilibrium approach in the modeling is then the possibility to root it in economic theory and in addition the link with economic evaluation methods. Changes in one of the markets, for example due to a transport measure, result in a new equilibrium. For policy analysis the consumer surplus in this new equilibrium will be compared with a reference situation; using a welfare approach this forms the input to a CBA. Modeling a general equilibrium is relatively straightforward under assumption of perfect market conditions (perfect information, direct responses, equilibrium prices etc). The complexity increases however rapidly if processes like response times, economies of scale, transaction costs and spatial detail need to be incorporated within the framework.

In the present research an incremental approach will be followed as the overall approach. It should be noted, for some elements of the system a short term equilibrium is considered to be reached within a time step (and applied in the modeling), e.g. traffic assignment on the road network.

3.3 Transport, land-use and economy; empirical findings

The transport-, housing-, and labor market and other economic components influence each other directly or indirectly. Figure 3-1 indicates six key relationships categorized by two-way interactions between land-use, transport and economy. The system approach chosen in this research includes representation of all of these key causal relationships. In this section the key relationships within the transport, land-use and economic system are elaborated individually. International literature presenting empirical results is used to compose an assessment on the nature of these relationships and their role in the total system. A focus on empirical results is chosen.

3.3.1 Transport – Land-use

Accessibility of a location, determined jointly by the transport system and land-use pattern, is in general an important determinant of the development potential of a location. Most actors, such as households, shops, industrial firms, value accessibility in their location choice. Especially the location of offices and shops seems to be sensitive for accessibility. It should be noted that accessibility is a general term and every firm or household has its own perception of accessibility. For example, a household with two workers, two children and two cars will value the accessibility of location x very differently from a household with two retired persons without car. These two households have, in the first place, a very different activity pattern. For example, the household with two children will look at the accessibility of schools. Car ownership is also an important characteristic and households without a car are likely to base their accessibility measures largely on the performance of the public transportation system. Following from the above observations it can be expected that changes in the transport system will have a very different impact on the residential location choice of different type of households.

A similar observation as for households can be made for the location choices of firms. In general accessibility of a location is an important explanatory variable in the location choices of firms, but large differences exist between different types of firms. In most studies a classification of firms (often represented by a number of jobs) by economic sectors is used to study the impact of accessibility on location choice. A categorization into minimally three categories is usually made: agriculture, industry and services. However, more detailed classifications (for example TIGRIS XL uses seven economic sectors) illustrate that at a more detailed level still a significant difference exists between economic sectors in parameters for accessibility (see Chapter 5).

Above the relationship between transport and location preferences of households and firms is addressed. The relationship of transport with land-use is more complex and includes the behavior of landowners, project developers and government. These actors can disturb the observations of the changes in land-use, driven by preferences of the land demand functions, as a result of changes in the transport system (accessibility). These disturbances can lead to an overestimation of the accessibility parameter as well as to an underestimation of the accessibility parameter. For example, an underestimation can easily result from strict government policies restricting residential development at good accessible locations. It is often difficult to isolate these influences in an empirical analysis and add government policies to historical data series. An overestimation can, for example, occur if accessibility is more important in the perception of project developers or governments than in the perception of the actors. In this case accessibility and supply variables are easily mixed in the analysis.

Empirical results on transport and residential location choices

The number of empirical studies on the impact of transport on land-use is quite marginal compared with the empirical studies on the impact of land-use on transport. However many authors recognize the strong impact transport has had on land-use changes in the past two centuries (van Thünen, 1826; Hyot 1939, etc). The causal relationship between the large scale introduction of the private car and dispersed spatial patterns with multiple centers is, even in the absence of much empirical work, accepted by most researchers. Some reasons for this minimal attention from empirical researchers in developed countries may be:

- In developed nations current transport policies do not result in dramatic changes in accessibility and therefore in large changes in land-use. The relative difference in accessibility within a country or study region has an important effect on the significance and size of accessibility parameters. For example, the structuring land-use effects of a new road are likely to be larger in an area with a sparse road network than in an area with a dense road network. An example of this phenomenon is the strong influence of highways in the greater Jakarta region on land-use developments (see Sanders et al., 1997). One would expect a strong interest in this issue in developing countries, however these in the literature potentially large system effects in developing countries have been largely ignored.
- The time lag between a transport measure and land-use change is rather long. Land-use changes occur much more slowly than, for example, changes in transport behavior. This time lag puts high demands on an empirical analysis to collect data for a sufficiently long time period (e.g. 10 to 20 years) and to control for all other relevant developments, which might influence land-use changes, in this period. According to Miller et al. (1998) none of the empirical studies has succeeded in meeting these problems so far. Their report noted that in virtually no case the study design provided an adequately controlled 'experiment' to properly isolate the impacts of transport investments from other evolutionary factors at work in the urban region.

Although the difficulties are clear and methodological questions remain, a number of studies are certainly worthwhile to be mentioned. One of the first persons illustrating the relationship between land-use and transport was Hansen (1956). He analyzed the Washington DC area and found that locations with a good accessibility had a higher chance of being developed, and at a higher density, than remote locations. A study of Giuliano (1993) for the San Francisco area resulted in the conclusion that the impact on land-use of transit developments after 5 years of operation was insignificant.

Most of the empirical studies have limited their scope to transit developments; this is counter-intuitive to the expectation that larger land-use impact will result from road transport measures (as road transport is in most areas the dominant mode). Miller et al (1998) made an extensive review of studies of the impacts of transit projects in the US and Canada. The key observation is that land-use impacts from transit developments, if observed at all, tend to be small and concentrate around the stations. This finding is likely to be affected by the small share of public transport in North America. In regions with a higher share of public transport and/or higher energy prices the land-effects might be more substantial.

Several research projects have focused on the relationship between transport and urban form, and more specifically on the trade-off between housing type (residential densities) and accessibility. Hunt (2001) concludes, based on Stated Preference research in Edmonton, that very dramatic improvement in travel times to work would be required to compensate the typical household for a move into higher density dwelling forms. A Stated Preference study for six cases in Belgium and the Netherlands of Molin and Timmermans (2003) confirms these findings. They concluded that regardless of the study area and the model specification, accessibility considerations are significantly less important than housing attributes, and attributes related to the neighborhood.

A study of Weisbrod et al. (1980), based on revealed preference data, emphasizes that available transport policies only have marginal influence on residential preferences. Factors beyond the scope of public policy, such as the desire for single-family, detached homes among families with children, and reduced moving rates for older persons and families with several children, all affect mobility and location patterns more than other factors related to public expenditures. A similar model as Weisbrod his model has been estimated for the Netherlands as well, namely the residential location choice model (Jong et al., 1991)

The study of Weisbrod also highlights the importance of housing costs in residential location decision. It is often suggested that transport policies have a strong impact on house prices. A study of Pagliara and Preston (2003) however suggests that transport changes appear to have relatively modest impacts on house prices.

In general it can be stated that accessibility seems to have a modest influence on residential location choice. This makes accessibility an explanatory variable for residential location choice. However demographic developments, neighborhood amenities and especially housing attributes seem to be more dominant explanatory variables. This increases the problem of empirically identifying the relatively smaller influence of accessibility.

It should be noted that these findings vary for different study areas or research methodologies. In the studies reported in the literature Stated Preference as well as Revealed Preference research methods have been used. Another distinction can be made between cross-section and dynamic analysis. The literature is unfortunately not rich enough to analyze the impacts of different research methods, for example Stated Preference versus Revealed Preference, or to draw conclusion about the extend finding are transferable between different regions.

Empirical results on transport and firm location choices

Because of the large differences between economic sectors and the many factors influencing location of businesses, it is hard to make a general description of the importance of accessibility in location choices of firms. It can be stated that accessibility has a measurable influence on the location choices of firms. Empirical research shows that businesses are, controlling for other factors, especially sensitive to accessibility to freeways. Kawamura (2001) and Bok (2005) show empirical evidence that over time businesses have moved closer to the freeway ramps. A stated preference study by Leitham (1999) concludes that the importance of road links to location choice varied considerably between groups of firms. For national and local relocations access to road links is in most cases important and for foreign inward investors it is unimportant. A firm survey in the Netherlands indicates that access to a highway is considered to an important location factor, although land prices, available subsidizes by the government

and space at the location are considered to be more important location factors (Bruinsma, 1995). The same survey indicates that access to public transport, e.g. train stations or bus stops, is valued much lower than access to highway infrastructure.

Kawamura (2001) and Shukla (1991) observed a sub-urbanization pattern of businesses along the freeways. A MEPLAN application to the Sacramento region in the US shows that the movements of industry are substantial, and are much larger than the movements of households (Abraham and Hunt, 1999). Transport costs and times play a crucial role in these movements; spatial economic input-output modeling uses generalized cost variables to address the spatial relationships.

The predominant findings of significant effects for freeway access in the location choice of firms cannot be confirmed for transit infrastructure. Transit seems to have at most a marginal impact on the location choices of firms, if all firms are included. However for specific sectors such as public services transit accessibility can be an important variable. Another exception can be made for locations with a very high market share for public transport, like in the central areas of a large metropolis.

3.3.2 Land-use – Transport

The spatial distribution of land-use, including residential and commercial, determines the spatial distribution of human activities such as working, living, recreation, etc. This distribution of activities co-determines transport volumes and performance. The location of residence has a dominant impact on almost all personal transport trips, an exception are business trips. The location and design of the residential areas has a theoretical impact on trip length and mode choice. High-density residential areas are a prerequisite for efficient public transport, this relationship is widely confirmed in empirical studies, for a review of empirical studies reference is made to Wegener and Fürst (1999). Probably the most frequently quoted study in this field is by Newman and Kenworthy (1989). They analyzed 32 cities in four continents and found a significant negative statistical correlation between residential density and transport-related energy consumption per capita. This study has been criticized frequently as it does not correct for differences in income and fuel prices or transport costs (Van Wee, 2002b). The authors updated the study, correcting for important intervening factors, which resulted in a remaining strong relationship between densities and energy use for transport.

An important determinant for trip length is the distance between the location of residence and main employment centers. In a review paper Stead (2001) presents multiple empirical sources confirming the relationship that increasing distance from home to the urban center is associated with increasing travel distance, an increasing proportion of car journeys and increasing transport energy consumption. However, it is recognized that urban areas are normally not mono-centric and the distance between home and urban center may only be a rough indicator.

Naess (2003) reviewed several empirical studies in Norway and Denmark and comes to similar conclusions as above. He concludes that the location of the residence relative to the city centre exerts the strongest influence on traveling distance, modal split and energy use. Furthermore population densities at a local scale as well as for the city as a whole are also important to the amount of travel and car usage. Van Wee and Van der Hoorn (1996) reviewed several Dutch studies on the impact of firm locations on travel behavior. They concluded that car use of people working at firms located near railway stations to be much lower than for people working at other locations.

Other theoretical relationships are that a higher residential density combined with mixed land-use will lead to shorter trips or that an attractive neighborhood design can attract more local, shorter, trips. Empirical analysis in this field is complicated because of the strong effect of socio-economic characteristics of the population on transport behavior. Many so-called land-use effects occur if a study does not account for these socio-economic characteristics. Another difficulty is that transport performance often depends on a combination of land-use and transport characteristics; transport services require a certain land-use pattern to operate efficiently. Disentangling the system to measure the impact of one element is often complicated.

The spatial distribution of firms also co-determines the volume and performance of personal transport, especially business and commuting trips, and freight transport. A theoretically expected impact is that a high concentration of firms (extreme case: all jobs located in the Central Business district) increases average trip length. A countering effect is that it is more efficient to serve a few concentrated employment locations by public transport than a dispersed pattern of firms. Empirically it was only possible to clearly prove the relationship between concentration of jobs and trips length in more extreme cases such as for mono-centered areas or for dormitory suburbs (Wegener and Fürst, 1999).

3.3.3 Transport – Economy

A typical economic production sector adds value to a product by changing its physical characteristics. The link of such sector with the economy is rather direct. The transport sector is not a typical economic production sector in this sense. Transport adds value to a product by changing its geographical location; changes in transport costs and times do not only affect the transport sector itself, through its specific characteristics many different sectors in the economy are affected. This section briefly describes economic effects in the transport sector itself as well as effects on other economic sectors such as productivity gains and market integration.

Transport sector

The turn-over in the transport and logistic sector is around 5 % of gross national product in the Netherlands. The sector creates about 7 percent of total employment in the Netherlands. The sector can be subdivided into sub-sectors such as sea, air, inland waterways, road, rail and urban public transport. Wit de and van Gent (1996) concluded that, based on several macro-economic indicators, road freight transport and air transport are the most important subsystems for the economy.

Productivity effects

The literature on the relationship between transport measures and economic development has mainly focused on changes in accessibility through transport investments as driving force for economic growth. These studies have limited themselves by disregarding other key effects from transport measures such relocation of firms and -households and environmental effects. By not including these effects the studies only address a part of the overall economic effect, namely the changes in employment and productivity of firms resulting from transportation policies. At the micro level there is still no satisfactory method to measure the relocation and environmental effects; the relationship between transportation measures and economic growth has mainly been studied at a regional level or even national level.

The debate about “is public expenditure on transport infrastructure productive” has been pushed in the early 90’s as a reaction to a classical paper by Aschauer (1989). Aschauer concluded in this paper that investments in core infrastructure, such as road or transit, have a high explanatory power for productivity. Aschauer demonstrated econometrically, using a Cobb-Douglas production function with infrastructure as an additional input next to labor and private capital, that the output elasticity of infrastructure has values between 0.4 and 0.5. This means that the social rate of return would be in excess of 100% on such investment. The work of Aschauer resulted in a lot of follow-up research; his very positive findings on the economic effects of infrastructure were reduced in most studies. For example, Munnell (1990), Holtz-Eakin and Swartz (1995) found a more modest positive contribution to the economy. The work of Lau and Sin indicates output elasticity in the order of 0.1. The findings so far have been very different and it is not possible to draw a general conclusion on the relationship between public expenditure on infrastructure and economic productivity.

Vickerman (2000) concluded that the best that can be said with any confidence is that infrastructure investment will have a modest positive contribution on economic growth, but that the more accurately the opportunity costs are measured, the less attractive return infrastructure investment offers. The main disadvantage of the aggregate production function method is that this method typically operates at a country or state level. It is questionable how applicable relationships found at the macro level are to specific projects that are located in a specific area. Furthermore the findings with these aggregated production functions have also been questioned on theoretical and empirical grounds (e.g. Berechman (1994), Vickerman (2000)). Especially the mutual interdependencies of transport investments and economic growth are overlooked.

Market integration and economies- and diseconomies of scale

Transport measures, resulting in a reduction of transport costs and -times facilitate the development of larger and more integrated markets. This phenomenon has been mainly studied at the aggregated inter-regional level. The regional economic impacts of an improved transport connection between region x and y can be positive as well as negative for region x. For region x the exported as well as the imported products become cheaper. Cheaper export products from x to y result in an expansion of total production, economies of scale advantages and positive impact on the regional economic product of region x. Cheaper import products from y to x result in a substitution of production in x by region y and a negative impact on regional economic product of region x. The net economic effects for region x are difficult to predict, additional compensating forces may further complicate this. For example, price of the products in regions hurt by increased competition will decrease, so that consumers can spend more on other products, part of which will be produced in the region itself (Rietveld 1989).

These wider markets (e.g. labor) can lead to a concentration of activities, so-called agglomeration economies. Agglomeration economies arise from the geographical association of a large number of economic activities (Armstrong 1985), examples of agglomeration effects are concentration of firms or increasing labor markets. Agglomeration effects can have a large impact on productivity. Empirical results from Ciccone (1999) for five European countries suggest that the estimated elasticity of average labor productivity with respect to employment density is 0.045. Agglomeration effects can also have negative impacts on productivity, examples of negative effects are higher land prices or higher congestion costs.

Imperfect markets

A critical assumption in evaluating transport improvements is the condition of perfect versus imperfect market situation for the sectors using transport. Under perfect market conditions all the effects, in these transport related markets, are fully transferred into the direct transport effects. However in reality many market sectors can be considered to be in a state of monopolistic competition or even a monopoly (e.g. network services). Under these situations the market transactions do not fully measure the marginal costs and benefits to the transacting agents. The presence of imperfect competition means that firms set prices above their marginal production costs, and this creates, besides the direct transport effects, an additional source of potential welfare gain from transport measures.

3.3.4 Economy – Transport

The relationship between economic growth (GDP development) and transport production has been observed to be strong in many cases. Conceptually this relationship is not as obvious as it may seem at first glance, or as Vickerman (2000) puts it: ‘empirically we can observe a remarkable constancy in the relationship between transport growth (both passenger and freight kilometers) and economic growth over the long period in many countries. This is particularly remarkable given the technical changes that have occurred in transport by all modes over the years. It might be expected that if transport is only a means to an end, if it can be economized then we should expect to see a reduction in the amount of transport necessary to achieve a given level of welfare.’

The relationship between economy and passenger- as well as freight transport comprises many linkages, such as through household disposable income, labor participation, structure of the economy, trade patterns and time routines. A study of RAND Europe (2003a) concludes that household disposable income is the most important driver of demand for personal travel, but there is considerable variation in transport demand volumes between countries and regions with similar incomes. An important intermediate step to understand this relationship is that disposable household income is by far the most explanatory variable of household car ownership (National Academy of Engineering 2003). Private vehicle ownership enables people to undertake faster and therefore longer trips within the same time budgets. These rather constant time and cost budgets (Zahavi, 1974) are crucial to understand Vickerman's point. Higher incomes and access to faster modes are not used to perform the same activities (level of welfare) but are used to take advantage of a larger geographical supply of activities. The use of fast modes is also stimulated by the high value-of-time of the growing high income groups.

The relationship between economic growth and freight transport depends on the economic structure. Because of changes in the economic structure in developed countries, from agriculture and industry towards services, future increases in economic activity will likely result in smaller increases in freight transport (RAND Europe, 2003a). Other drivers such as changes in logistics and spatial organization of manufactures are important drivers of freight growth as well.

3.3.5 Land-use – Economy

An essential economic feature of land is that it is scarce and subject to competing potential uses. This is reflected by the existence of positive prices for land, if scarcity of land increases then land prices go up. The von Thunen model suggests that price gradients affect location choices in such a way that zones result with dominance of

certain types of land use, for instance, housing, offices, industry, forestry, grazing or crop growing (Hubacek 2002). In general it can be stated that the role of land as production factor has diminished over time and land has lost its central position in classic economics as principal source of wealth. Currently the contribution of land receives very little attention or as Hubacek and Vazques (2002) states “Despite its obvious importance land has almost disappeared from economic analysis”. In the available literature the contribution of land-use to economic growth is included in a direct or more indirect way.

A direct link between land-use and transport exists if land-use is considered as a production factor. This is a commonly used approach by classical economists in agricultural analyses. The concept of land as production factor has been used by Louw (2004) for industrial land; this research focuses on the productivity of industrial land (added value per hectare of industrial land). This study illustrates the significant differences in productivity of industrial land between different regions. In urbanized regions the productivity of industrial land is higher than in less urbanized regions. Another finding is that there seems to be a relationship between land productivity and land supply. This means that a restricted land policy can be an important driver of land efficiency.

The production factor approach is more complicated for less land extensive economic sectors and economic sectors operating in buildings. The other sectors are affected by high land prices, as a result of scarce resources, through high prices for floor space and therefore higher production costs. Although there is little empirical evidence, limited land resources and high prices are generally considered to be an important negative agglomeration effect in metropolitan areas.

In the “indirect” relationship between land-use and economy the idea is that land provides the field for spatial interactions. The affects of land-use changes on the economy can be addressed through the housing market and labor market. The housing market structures the spatial distribution of the population and therefore the labor supply. A combination of the housing market and transport system sets the spatial constraints for the labor market; almost all the commuting trips are made within a time limit of one hour. The match or mismatch in the regional labor market results in e.g. unemployment, vacancy rates and wage corrections. These factors co-determine the economic performance of a region and the competition between the regions. The migration and settlement of new firms and/or residents depends, among other regional and social factors, on the regional labor market conditions and the regional housing market conditions.

The ‘Nota Ruimte’, which is the most recent national physical plan of the Netherlands, recognizes this relationship between land-use and economy. Its core message is that land-use plans and developments should support economic growth and the way to achieve this goal is to give more opportunities and fewer restrictions to firms and residents. The national plan, however, misses a conceptual framework addressing this relationship and therefore also an operational analytical framework to quantify this relationship. Evaluating different physical plans, including economic effects, is therefore a non-standardized expert based task. This is certainly an area that needs future research work on a conceptual and operational level.

3.3.6 Economy – Land-use

The relationship between the economy and land-use is both direct as well as indirect. The direct link is that all kind of economic activities need land to perform their activities. However, the average land-use by employee or unit of GDP production differs widely between economic sectors (White, 1999). The structure of the economy in a region has therefore an important influence on the land-use pattern in a region.

In the housing market, a similar effect can be observed, and land-use for residential buildings increases with the income level of a household. Overall increasing welfare leads towards a higher demand for floor-space. The growth of the typical American Metropolis has been influenced strongly by the growth in income and the improvement of travel times (Anas, 1978).

An indirect link exists between economy and land-use via the transport system. Economic growth (and associated higher incomes) leads to higher car ownership rates and travel budgets. The effect on land-use is that it spurs sub-urbanization and even de-urbanization. The demand for larger floor-spaces and gardens can be realized by the access to car transport and higher travel budgets. In this way transport facilitates the households to choose their preferred residential location.

Determination of the direct and indirect relationships between economy and land-use require a joint framework to analyze economy, land-use and transport. Such an integrative framework should include the most important direct and indirect links. In the next chapter analytical instruments covering important parts of the framework are discussed. The features of different approaches, operational in practice, will be briefly highlighted and a method will be selected for further research.

3.4 Observations

This chapter reviewed theories on interactions between transport, land-use and economy, key characteristics of the regional/urban system, and in particular empirical findings on the relationships between transport, land-use and economy. The review of theories resulted in the conclusion that many valuable theories exist which cover parts of the system. A general theory, conceptualizing the development of “human society” in time and space, is absent. In general, economic theories are powerful in explaining the interactions between urban actors; but they suffer from a lack of spatial and temporal detail to explain the changes in time and space. Other behavioral and system theories are often more flexible to address space and time, however these theories often lack a good explanation for the interactions between actors. In the absence of a general theory the next best approach to an integrated assessment of inter-related space-transport-economy effects is to combine elements of several theories and methods.

The description of the urban/regional system illustrates that (in developed countries) an infrastructure investment will constitute only an increment on a large stock of prior infrastructure investment (sunk cost). The total stock forms input to the system, besides a host of other factors. A relatively detailed transport network and spatial zoning is needed to analyze the indirect effects of an infrastructure measure. Disentangling of the urban system in nine elements illustrates that the time span of changes is very different for these elements. This is one of the main arguments supporting the conclusion that an urban system is expected to move towards equilibrium, but that such equilibrium will

not be reached within a more or less standard forecasting period of 20 or 25 years. This observation calls for a dynamic incremental approach, which is justified by the strong path dependency of the system and rather slow speed of changes.

The empirical findings for each key relationship have been elaborated in the respective section. As this thesis aims to improve the estimation of land-use effects of land-use and transport policies, the empirical findings for the relationship between transport and land-use are most important. Some key observations for this relationship are:

- Historically there is a clear recognition of the influence of transport on land-use. However it should be noted that this influence is context specific, the land-use effects of massive motorization after the 2nd World War is not an appropriate indicator for the land-use effects of a specific transport infrastructure project. Recent empirical findings show that in developed countries the structuring impacts of changes in transport are modest, but large impacts can still be observed in developing countries;
- The time lag between a transport measure and land-use changes is substantial (e.g. 10 to 20 years before the full impacts are visible);
- The land-use impacts of transit developments tend to be small and concentrated around the stations. Accessibility to road infrastructure is more important, especially for firms;

In an empirical estimation of the influence of transport on the location choices of residents or location choices of firms, it is important that other relevant explanatory variables are included as well. The literature included characteristics of the household, housing attributes and/or neighborhood amenities. It is further emphasized that the findings might differ strongly between economic sectors or household types.

The observations in this chapter, especially on time dynamics of the system and existence of equilibrium conditions, are input for Chapter 4, which sets out the model requirements and reviews several modeling approaches.

Chapter 5, on the development of the TIGRIS XL model, uses insights from this chapter for the overall system design as well as specification of individual relationships.

4 LUTI models and alternative modeling approaches

In Chapter 3, the theoretical and empirical issues regarding the land use - transport-economy system have been discussed. In this section the analytical instruments modeling the land use – transport –economy system will be reviewed. The review will focus on models suitable to perform policy analysis studies on land-use and transport. The family of LUTI models, with its specific features and differences, forms the core of this review. In addition alternative modeling approaches are reviewed to complement the review. These findings are used to get an insight on the specific strength and weaknesses of the LUTI approach in comparison with other modeling approaches.

This chapter starts with identifying the requirements for modeling in section 4.1, following the policy-making environment as specified in Chapter 2 and system characteristics as specified in Chapter 3. A review of LUTI models is presented in Section 4.2. This is followed in Section 4.3 by a discussion on the modeling of generative effects, a specific challenge in modeling. Section 4.4 compares three main approaches to the integrated modeling of transport, land-use and economy. Building on the earlier Sections, Section 4.5 explores the development of a new LUTI model for the Netherlands.

4.1 Requirements for modeling

A variety of requirements can be put on the modeling depending on the subject of study, demands on the theoretical foundation of the model and the use of the modeling in evaluation of planning- and policy measures. Different type of transport policy measures or methods of evaluation set different demands towards the modeling. In principle such a specific set of requirements could be determined for each study, however in practice because of high investment costs to develop analytical tools and the wish of comparable results among studies, the use of standard analytical tools is necessary. It is further important to note that such a list of requirements is disputed; researchers from different disciplines are likely to set different requirements. The list of requirements in this section is therefore undoubtedly influenced by the author's research discipline and positioning.

Important considerations, from a policy-making perspective, for such a standard transport-land-use-economy modeling tool are the following:

- The present research aims to contribute to the evaluation of the impacts of integrated land-use and transport strategies, consisting of a wide set of policy measures including infrastructure measures. The focus is on infrastructure measures at a regional and national level, such as a new road connection between two cities within a region or an inter-regional rail line connecting several regions. The requirements put on the modeling will then be different (outside the scope of this research) for international and urban transport measures. It is assumed that the regional and national transport measures do not have any international effects on the location choice of residents and firms;
- The modeling should provide for the existing evaluation methods in the Netherlands. The formal project appraisal method is a societal (or wide) Cost-Benefit Analysis, addressing welfare effects at a national level. This appraisal method requires assessment of direct, indirect as well as external effects;
- The project appraisal method in the Netherlands includes distribution effects as a PM post. These distribution effects deserve increasing attention from the perspective of equity and consistency in policy-making; many policies in different domains of the government focus on equity. Transport measures always benefit a segment of the population and are normally paid for by public means. Regional equity strategies are often an important focus of government policy; a particular example, are the structural funds of the European Commission. In spite of the current focus of Dutch government on optimizing national welfare, regional distribution and equity will remain a topic of public concern. Transport policies play traditionally a prominent role in equity strategies.
- The model needs to be capable of analyzing the impacts of a wide set of types of land-use- and transport policies. A joint modeling of land-use, transport and economy should be able to support policy evaluation challenges such as:
 - Development of integrated regional plans, including land-use and transport strategies;
 - Forecasting the impacts of long-term socio-economic scenarios on transport and land-use;

- Analyzing the land-use and spatial-economic effects of transport measures.

The above points do set the general context for the modeling. The literature review in Chapter 2 and 3 highlighted the context of modeling in the Netherlands and specific characteristics of the land-use, transport and economy system in general. More specific requirements are the following:

- Sufficient spatial detail to enable the appraisal of specific regional or national infrastructure projects. A detailed zoning is needed for a reliable modeling of the land-use effects of these types of transport projects. A modeling at a regional or national level is not suitable to address the effects of specific projects; the outcomes of such macro models become easily indifferent for project characteristics; for example, the impact of a new rail line will be different for two cities, A and B, both located in region x, if city A has a station and city B does not have a station. Local detail is needed to account for the spatial dimension of transport projects; it is also necessary for a sufficient impact estimation;
- Sufficient detail in socio-economic segments and economic sectors. This is necessary to account for differences in the availability of choice alternatives and in choice behavior, and to provide impacts by socio-economic group;
- The government largely regulates the land market in the Netherlands, especially the location of large-scale residential housing sites. This might shift in the future as the spatial policy of the Dutch Government is changing towards a less regulated regime. Furthermore the forecast period of the modeling, e.g. 30 years, is often much longer than the period for which zoning plans exist. To simulate long term developments the user either has to develop land-use plans or assume less regulated conditions following the demand preferences. The model should be capable to simulate residential location choices under different levels of government influence on the land market;
- Improved simulation of direct transport effects. The direct transport effects of transport measures are, normally, by far the largest effects of transport measures and an accurate estimation of these effects is essential (see Chapter 2). The transport effects can have a significant variation over time in particular when long-term land-use effects are considered. The simulation of direct effects can be improved, in comparison with traditional transport models, by including long-term demand effects and the generation of time path results. A dynamic systems approach, including land-use changes caused by changes in transport, produce time paths of long-term transport demand effects;
- Indirect or wider economic effects, occurring in other markets than the transport market, can only be estimated accurately if a detailed link exists in the modeling between transport effects and indirect effects. An aggregated treatment of transport effects makes the estimation of indirect effects unreliable or less meaningful. A modeling instrument is required which provides a sufficiently detailed and reliable projection of the transport results as well as a sufficient representation of the associated indirect effects. These joint requirements have consequences for the practical set-up of the modeling instrument;

- As stated in Chapter 3 there is no general equilibrium in the urban or regional system and different kinds of processes operate on different time scales. A dynamic approach towards the modeling, with sufficiently small time steps, should enable a realistic representation of the changes over time. For example, the land-use effects of a new infrastructure project will be realized gradually over a longer time period. A dynamic modeling should enable to analyze how the system evolves over time; the delayed land-use responses to transport measures should be included. A time pattern of impacts is further required as input to a cost-benefit analysis over the life cycle of the project;
- An empirical foundation of the modeling is of critical importance. As described in Chapter 3 a general theory, describing the development of human settlement, is not available. Therefore a theoretical model without an empirical basis will generate dispute. Empirical verifications should allow to appropriately balancing the various effects, without such empirical foundation effects can be easily over- or underestimated. Empirical estimation has however its limits which are in particular determined by the available data. Therefore not all relationships of a joint land-use, transport and economic model system can rest on an empirical foundation. A priority should be given to an empirical foundation for the key variables linking the components in the modeling, covering especially the link between transport and land-use. A critical requirement to the modeling is then that the effect of accessibility on residential location choice or firm location choice needs to be empirically estimated to get an adequate estimation of the influence of accessibility on residential of firm location choices.

4.2 LUTI models

The present research on a joint modeling of land-use, transport and economy can be positioned in the research tradition of Land-Use and Transport Interaction (LUTI) modeling. This section briefly introduces LUTI models.

4.2.1 Introduction to LUTI-models

A common feature of LUTI-models is the recognition that trip- and location decision co-determine each other. An often used diagram to illustrate the interaction between land-use and transport is the ‘land-use and transport feedback cycle’ by Wegener and Fürst (1999).

The set of relationships in this diagram can be summarized as follows:

- The distribution of *land uses*, such as residential, industrial or commercial, over the urban area, determines the location of human activities such as living, working, shopping, education or leisure.
- The distribution of human *activities* in space requires spatial interactions or trips in the *transport system* to overcome the distance between the locations of activities.
- The distribution of infrastructure in the transport system creates opportunities for spatial interactions and can be measured as *accessibility*.

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

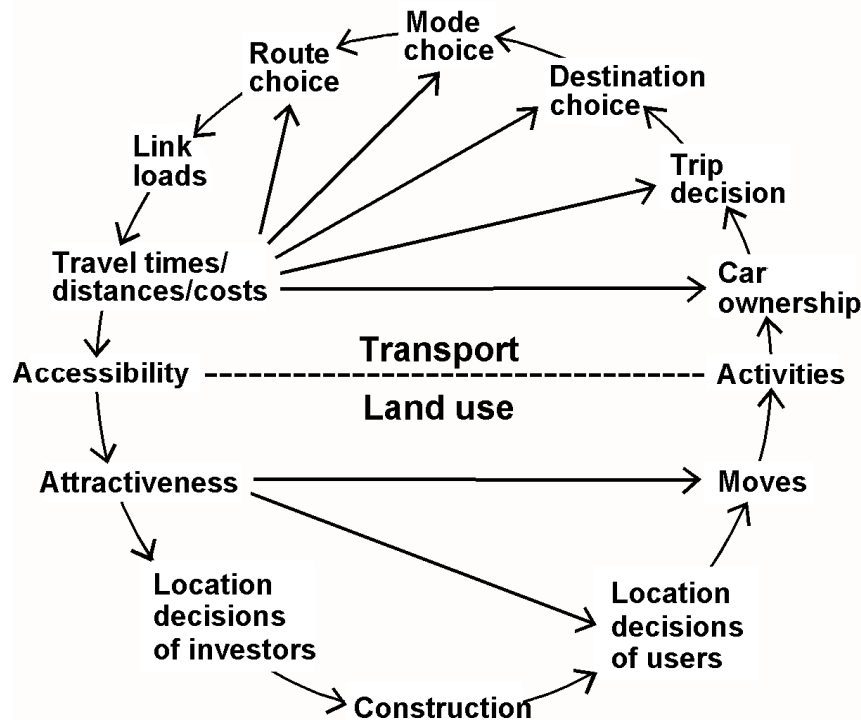


Figure 4-1: The land-use transport feedback cycle (source Wegener and Fürst, 1999, 6)⁶

The history of computational LUTI-models start in the 60's with the rise of computer power. The work of Lowry (RAND, 1963) is probably the most famous of that period. Another famous example of that period is Wilson's entropy model (Wilson, 1970). Most models at that time follow a "technical" approach to explain urban development and apply analogies with other processes like gravity or entropy.

In the 1980's a new generation of models has been developed with a focus on economic and human behavior to explain urban developments. The so-called Martin center models (Simmonds, 1994), developed at University of Cambridge, are the most well-known and applied models of this generation; they are characterized by a spatial input-output framework which covers the interactions between places and hence the demand for transport. Other model developers have built on the urban economics work of Alonso (1964) and develop LUTI-models characterized by a foundation in urban economic theory using a bid-rent framework (Martinez 1996, Miyamoto 1993). A third group of researchers, inspired by the IRPUD model of Wegener (1998), has followed a dynamic system approach with explicit attention for the time dimension of interactions and developments. The DELTA model of David Simmonds (Simmonds 1999) and the Urbansim model of Paul Waddell (Waddell 2001) both developed in the 1990's, and continuously updated, are important examples of this type of dynamic modular models. For all types of modeling a move towards more spatial and socio-economic detail can be observed as computer power increases.

⁶ Permission was granted by the authors to reproduce figure 4-1.

The paragraphs below present general features of- and differences between state-of-the-art LUTI-models. The review will only focus on relatively new LUTI-models developed from the 1980's and still operational; LUTI-models currently under development, but not yet operational, are not included. The review of the LUTI-models will be brief; for an in depth review of existing LUTI-models and their characteristics, reference is made to Miller et al., 1998, EPA 2000 (all land-use models), Simmonds et al., 1999, Wegener and Fürst, 1999, Zondag, 2001, and Wegener 2004.

Table 4-1 presents an overview of the LUTI-models, which are reviewed below and which literature sources have been used. All of the reviewed LUTI-models have been applied in practice in at least one urban area. Several of the models, like MEPLAN, TRANUS and URBANSIM, have been applied in a (large) number of cities. It should be mentioned that several of these modeling packages are frequently updated and new features or characteristics are added.

Table 4-1: Land-use models included in the literature review

LUTI-model	Sources
MEPLAN	Pagliara (2001), Simmonds (1994), Williams (1994), Webster(1988), Abraham (1998)
TRANUS	De la Barra (1995), De la Barra (1997), Wegener (1999)
URBANSIM	Waddell (1998, 2000, 2001), University of Washington (1998, 2000)
IRPUD	Wegener (1998a-g), Webster (1988)
DELTA	Simmonds (1999), Still and Simmonds (1997), Simmonds and Feldman 2005

In paragraph 4.2.2 and 4.2.3 the general characteristics and key differences of the models are addressed.

4.2.2 General characteristics of LUTI models

Besides considerable differences between the LUTI models, e.g. in model structure, dynamics, scale level, interaction with transport model and way of validation and calibration, there are common elements in the state-of-the-art LUTI models, the following can be mentioned:

- LUTI models address several markets influencing the land-use and transport system. The following markets are regularly addressed within LUTI-models:
 - Land market
 - Real estate market
 - Housing market
 - Labor market
 - Transport Market

A typical characteristic of the system approach within LUTI models is that these markets influence each other.

- The markets mentioned above operate on different components of the system. The three components, or layers, of the land-use⁷ system are:
 - Land
 - Objects
 - Activities

Each component of the system has its own time dynamics. This split in three components or layers is implemented in most LUTI models. The main focus of LUTI models is on the activities: in particular where people live and work. LUTI models are generally less concerned with the physical use of land itself: in general the models do not simulate land-use changes in great detail.

- LUTI models calculate the distributive impact of infrastructure measures and do not calculate the generative impacts at the level of the whole study region, they focus on the changes in distribution of employment instead of on the changes in total employment or GRP for the study region. In general LUTI models use exogenous projections for total employment and population, at the level of the study region. The models lack a modeling of production decisions by firms as cost and/or production functions are not included in the models.
- The variety in basic theories for explaining demand behavior of residents in integrated land-use & transport modeling has diminished throughout the years and nowadays almost all 'state of the art' models rely on discrete choice theory to explain and forecast residential settlement behavior. All state-of-the-art models incorporate also some level of segmentation of the population to account for differences in choice behavior between the different household types.
- The modeling of firm behavior within LUTI models is still in an early stage of development; in practice changes are modeled at the level of jobs as a proxy for firm behavior. Furthermore in most models only the location choices of part of the firms are included endogenously. The location choices of large industrial plants or other exporting firms following the basic economic theory, are often taken as exogenous. In these cases the model only predicts changes for a part of the economy, namely the service sector or population following economic activities.
- LUTI models are predictive models and not optimizing models. The output of a LUTI-model will not be a prescriptive solution to a problem, but LUTI-models can be used to evaluate and compare several solutions to a problem.
- LUTI-models are more suited to estimate the impacts on intra-regional location decisions than to estimate inter-regional location effects of transport measures. In practice LUTI-model applications focus on one specific urban area and interactions with other urban areas or the rest of the country are treated exogenously. In most LUTI-models the economic modeling is not sophisticated enough to explain inter-

⁷ It should be noted that in land-use and transport interaction models the term land-use refers also to interactions between activities.

regional moves resulting from regional economic features as wages or job vacancies. The importance of this omission depends on the size of the differences between the regions. It should be noted that the size of large urban areas is a relative term varying from strict municipality boundaries to areas as large as South - East England. The boundaries of the study region depend on the spatial configuration and if it is possible to define relatively stand-alone labor and housing markets.

4.2.3 Key differences between LUTI models

In the discussion of the modeling methods that can be used to assess the impacts of transport change on regional and local economies, LUTI models are often referred to as if such models, past and present, were a single homogenous commodity. This impression should be corrected as there is considerable difference among LUTI-models. Below some key features of the main models or modeling packages in the LUTI tradition are compared and contrasted, particularly those which are generally recognized as constituting the current “state-of-the-art”, or at least the “state of practice” (Simmonds 2005).

Wegener, 1994, demonstrated for the MEPLAN and IRPUD model that the political and intellectual contexts in which LUTI models are developed, have a significant influence on the selection of processes to be modeled, the theories that are applied, the definition of sub-models, the solution algorithms, and kind of results the models were designed to produce. Of particular importance is the different use, which is made (or not made) of spatial input-output models in the different approaches (Simmonds 2005).

At an abstract level there are two basic methods for linking the land use and transport components in a combined model, those are:

- “connected”: the spatial distributions of population and employment determined in the land use component are fed as activity totals into the trip generation step of the transport component; the transport component performs the classical four steps, including trip distribution in particular; and
- “integrated”: the spatial distribution of flows of economic interactions between activities determined in the land use component are fed as origin and destination movements into the transport component and the transport module performs the remaining steps.

Of the listed models in Table 4-1 the TRANUS and MEPLAN model can be referred to as “integrated” models, these models generate the spatial flows within their input-output framework, and the URBANSIM and DELTA models as “connected” models. The IRPUD model is also an “integrated” model, although it does not use a spatial input-output framework to calculate the spatial flows. It uses a micro simulation approach, which integrates the residential location choice and work location choice.

The second or “integrated” option would seem to be the most elegant option and assures the best integration of the two components. This option avoids inconsistency caused by the double use of the spatial interaction (origin-destination) matrix. In the “connected” option this matrix is used to derive accessibility indicators used as explanatory variables in the land-use modules, and as OD-matrix in the transport model. In the OD matrix in the transport model each individual has a unique working location and in the accessibility indicators a potential is used regardless the unique working location as assumed in the OD-matrix.

In practice however, the “integrated” option results in severe restrictions towards the calibration of the model. A feature of the “connected” model is that the calibration is undertaken for each sub model individually. This gives the opportunity to calibrate the transport behavior as trip generation or travel distance on transport statistics, and to calibrate housing market behavior or firm location behavior on respectively housing market or labor market specific statistics. An integrated structure, due to its intertwined and simultaneous choice for spatial interactions or locations, results in a stepwise trial-and-error calibration process based on travel behavior statistics and population or job totals in the zones.

As indicated above model calibration or estimation procedures differ widely between LUTI models and specific applications. A further major distinction can be made between the equilibrium type of models, normally calibrated on the base year, and incremental models calibrated on the changes over time. Another differentiation can be made between a formal statistical and informal calibration procedure. The coefficients in most LUTI models (DELTA, TRANUS, MEPLAN, and IRPUD) are calibrated informally by matching model results with observed data sets or by using expert judgment values for the coefficients. These procedures do not indicate, such as in formal statistical estimation methods, whether coefficients are significant or not, and whether model A is better than model B. Only few examples are available of LUTI models with coefficients estimated following a statistical procedure, for example, a least squares or maximum likelihood estimation. A statistical estimation of the model coefficients is especially important for a realistic representation of the influence of transport on land-use. As illustrated in the empirical literature review, in Chapter 3, transport is not the most dominant factor in explaining the distribution of residents or firms; an informal procedure leaves then too much space for interpretation of the parameter value by the model designer. Therefore a more objective, empirically founded, method is required to ensure a realistic representation of the influence of transport on the spatial distribution of residents and firms

All of the LUTI-models assume a short-term equilibrium in the transport module for the assignment on the network. Substantial differences exist between models with respect to their dynamic behavior in the land-use modules. With respect to the land-use modules the LUTI models can be differentiated into equilibrium and incremental models. In the equilibrium model, market prices are used to calculate the equilibrium for one point in time and all households or firms are assumed to be in equilibrium. In an application the model calculates a new equilibrium for all households and firms for a future point in time. The incremental models focus on the dynamics and speed of change, and typically follow a two-step procedure, addressing the move/stay choice first and conditional location choice next. Each choice is based on a set of explanatory variables and time lags can be included in the responses on changes. Incremental models can have some equilibrating mechanism as well and for example prices can respond, with some time lag, to market conditions.

In many LUTI-models a representation of freight transport is absent or included in a very simplistic way. A reason for this is that so-called “connected” LUTI-models are often linked with existing passenger transport models. Certainly at the urban level the existence of freight transport models is limited. The “integrated” LUTI - models using a multi-regional input-output framework for their origin-destination matrix, treat freight transport at least as extensively as passenger transport. Within such input-output framework the inter-industry linkages, including flows of goods, are modeled.

4.2.4 General review of LUTI-models

Since their introduction, as computational instrument, in the early sixties the popularity and rise of LUTI-models has not been a steady way forward. In the early 1970's Lee's article (1973), 'Requiem for large scale urban models', expressed the feeling of that period that these large-scale models are inaccurate, data hungry and non-transparent. Some of Lee's concerns have been overcome in the LUTI-models developed in the 1980' and 1990's. However, many theoretical and practical challenges still remain for the next generation of models; recently Timmermans (2003) wrote a conference paper with a rather similar title as Lee: "The Saga of Integrated land use – Transport Modeling: How many more dreams before we wake up?".

Timmermans (2003) comments mainly concern the lack of theoretical progress and he questions the validity of existing LUTI-models. His criticism focuses on the behavioral modeling within the LUTI-models, which lacks the necessary detail, complexity (for example multi-actor decision making) and uses inappropriate modeling techniques. Other elements of his critique refer to the often used calibration methods based on distance decay functions, the lack of integration of models and spatial planning practice, and the imbalanced representation of accessibility in the modeling of location choices. In a sense, some of his critique refers to the lack of a general theory towards the development of human society as expressed in Section 3.2. Many methods applied within LUTI-models are pragmatic in nature and are often borrowed from other disciplines without a critical reflection of their appropriateness to explain causalities within the land-use and transport system.

Oosterhaven and Knaap (2002) have expressed their critique on LUTI-models from another perspective and, unlike Timmermans, their critique is not oriented at more detail in space and socio-economic units or a better representation of complex decision-making structures. Their fundamental critique is the lack of integration of LUTI-models with economic theory. They especially criticize the modeling of the labor market and lack of modeling of producer surplus using production functions.

As stated before LUTI-models aim to model a very complex system, studied in many different disciplines and conceptualized in various theories; as a consequence each LUTI-model will be a compromise on available data sources, -policy demands, -available and applicable techniques, and -the perception of the modelers. Critique on LUTI-models, and the many options to improve these models, a logically associated with the modeling of a system as complex as the urban system (which comprises a complex human organization). The stepwise improvements of the LUTI-models over the years, e.g. incorporation of behavioral choice modeling for residential location choices or improved interaction with GIS and spatial detail, should not be underestimated. Nevertheless these improvements might seem to be minor steps in the light of a probably never-ending search for a general theory.

4.2.5 Development of LUTI models and application in practice

It is questionable whether theoretical concerns, as expressed by members of the academic community, are the main obstacle towards a large-scale implementation and societal contribution of LUTI-models. Ambitious theoretical developments will most likely result in even more complex models, LUTI-models are already often referred to as black boxes, with a growing gap with available data sources. Especially this last point is part of a complicated trade-off. As the interactions between transport and land-use are complex they are extremely difficult to identify or judge as an expert and an

empirical foundation for the relationships is called for. However, such an empirical foundation of the relationships can only be estimated if the complex interactions are simplified.

Large-scale implementation of LUTI-models is needed to develop our insight about the performance of these models in practice. The good news is that the number of applications of LUTI-models, although still marginal compared to the application of standard transport models, has been growing significantly over the last years. Lessons from these applications in combination with theoretical progress can steer the development of a new generation of these models. The LUTI-research community according to a discussion at the annual TRB meeting 2005, sees practical application of the LUTI-models, as a higher priority than theoretical progress. These applications are needed to learn about the strengths and weaknesses of the different modeling approaches, including the transferability of results between regions.

This short-term ambition does not preclude that in the long run theoretical progress from the perspective of economic theory and behavioral modeling will be a necessity. Current research progress in the field of LUTI-models focuses on the development of micro-simulation models. Examples are the ILUTE –modeling project (Salvini and Miller 2003) in Canada, ILUMASS – modeling project in Germany (Moekel et al. 2003) or Spatial Firm demographic Micro simulation model at Delft University in the Netherlands (de Bok and Sanders, 2005). These developments can result in another stepwise improvement of LUTI-models. It is anticipated that the progress of LUTI-models will consist of mixed phases of application and development. The applications are important not only from a commercial point of view, to keep interest of society alive, but also from a scientific point of view to test and verify theories and methods.

Another aspect of the development of LUTI-models is the recognition that the explanation of land-use and transport interactions relies on many different disciplines such as economic theories (utility theory, markets, and macro economy), demography and social sciences, urban design and transport planning. The many public agencies and stakeholders in the organizational framework that are involved in the field of land-use and transport planning reflect this. The many stakeholders and academic disciplines complicate the development of a LUTI-instrument.

4.2.6 Requirements for modeling and LUTI models

Comparing the characteristics of the LUTI models and the requirements formulated in the first section of this Chapter. The following conclusions can be drawn from the characteristics of LUTI models and requirements for modeling:

- Strong link between direct and indirect effects, the transport effects are well integrated in the decision processes in the land-, housing- and labor market;
- High level of spatial detail in both the transport model as well as the land-use model. This level of detail should enable an adequate estimation of the effects: the effects of infrastructure projects occur at a spatially detailed level;
- LUTI –models are generally strong in modeling location choices in the regional housing and labor market. The LUTI models generally do not model economic performance indicators such as wages or job vacancies, and therefore are less suitable tools to explain inter-regional migration flows;

- The interactions between land-use and transport within LUTI –models enable to analyze the long-term effects of transport measures on transport demand. A transport change results in a change in land-use and this results in additional transport demand;
- Some of the LUTI models offer a flexible framework to tailor model specification and data availability. The lack of a formal statistical estimation of the key relationships within most of the existing LUTI-models affects the credibility of the models negatively;
- The dynamic structure of most of the LUTI-models facilitates an analysis of how the system evolves over time. This is important to capture the full time dependent impact of a measure and provides the input to a suitable evaluation method such as Cost-Benefit-Analysis;
- In general LUTI-models do not address generative effects of transport measures; these models therefore cannot predict the indirect generative effects of transport measures as required for a societal Cost-Benefit Analysis.

As stated before a large variety exists in LUTI models and comparing the features of the LUTI-models and model requirements is not always straightforward. The above comparison presented a mixed score for the LUTI-models; especially on the specified economic requirements (see Section 4.1) the LUTI-models do not perform adequately. Below in Section 4.3 the generative welfare effects are discussed in more detail and in Section 4.4 alternative modeling approaches will be discussed with a specific focus on the modeling of economic impacts.

4.3 Generative welfare effects

As identified earlier generative welfare effects usually play an important role in the policy discussion on large-scale infrastructure projects; such discussion will benefit from a “reliable” quantitative input. Most LUTI models do not address the generative welfare effects and predict only the distribution effects. In this section the generative welfare effects are briefly introduced. The generative effects can be diverse in nature; the most important generative effects of transport measures at a national level, from a conceptual perspective, are the following, categorized by market (RUG/SEO 2004):

- product market: generative effects can result from imperfect competition, scale advantages and product differentiation;
- labor market: scale of the labor market, and imperfect match between demand and supply at a regional level;
- knowledge spill-over effects;
- international effects: mainly consisting of relocation effects;
- housing and land market restrictions and regional imbalances.

Through an adjustment of the product market several generative welfare effects can occur resulting from imperfect competition, scale advantages and product differentiation. The effect of transport measures on changing the competitive situation in an economic sector in the Netherlands can be considered as absent or minimal; the current level of accessibility throughout the whole country can be considered as good

and none of the regions are isolated. In such a situation it is unlikely that a transport measure can change the level of competition. The other effects, scale advantages and product differentiation, result from an increase in market size; lower transport costs and times result in a geographical increase of market size.

The indirect generative welfare effects in the labor market are also related to the size of the markets. The change of a successful match between supply and demand is higher if the size of the labor market increases. Such a match can result in more high productivity jobs, less vacancies and unemployment. The additional benefits to society consist of additional tax income and less unemployment benefit costs. Another additional welfare effect might occur if two regions get a better connection and commuting between the two regions becomes feasible. This effect depends strongly on the labor market conditions in the two regions and is potentially highest when a region with ample vacancies is connected with a region with a high unemployment rate.

Knowledge spill-over effects are also related to scale advantages, either benefiting from a clustering of sectors from the same sector or from interactions between firms from different sectors. Additional welfare effects occur only for knowledge exchanges without a market price. To include knowledge spill-over effects in the project appraisal it is necessary to estimate the effect on the non-monetary knowledge exchanges of a specific transport project.

The international effects relate the settlement climate of a specific country and consist mainly of relocation of international firms. The argument is that a transport measure improves the accessibility of a certain country and therefore its competitive position. An international model, including at least competing neighboring countries, is needed to simulate such effect. The SASI model (Wegener and Bokemann, 1998) and GC Europe model (Bröcker et al., 2002) are examples of such models; the SASI model models the international effects as redistribution effects. The modeling of international relocation effects falls outside the scope of this research.

The interest in this research is in extending LUTI-models to model indirect generative welfare effects as described above. A basic requirement is that the extensions stay as close as possible to the basic design principles as listed in Section 4.1. These design principles include:

- an emphasis on detail, both spatial as well as in socio-economic segments, to account for differences in the availability of choice alternatives and in choice behavior, and to provide impacts by region and socio-economic group;
- for an infrastructure project the effects on transport services are modeled at a detailed level;
- the requirement that the included relationships have an empirical basis.

Preparation of an operational model instrument to compute generative welfare effects and application are outside the scope of this thesis. An approach, which follows the above requirements, is explored in Chapter 8 on future research recommendations. The approach to incorporate the indirect generative economic effects is essentially based on a bottom-up approach by using the detailed spatial representation of the LUTI-models to define agglomeration effects and effects associated with the housing and land market. The next paragraph presents alternative modeling approaches and discusses their way of calculating the generative welfare effects.

4.4 Alternative approaches to model spatial-economic impacts

The literature about the regional economic impacts of infrastructure measures is extensive and a large variety of research methods exist (see Rietveld and Nijkamp 1992, Rietveld en Bruinsma 1998, van de Vooren 2001, Oosterhaven 2001, for overviews). A variety of methods are used for estimation of the spatial-economic impacts of transport changes. Frequently used methods are:

- Micro entrepreneurial surveys
- Ex-post analysis
- Macro economic models
- Input-output method
- Quasi production function approach
- Land-use and transport interaction models
- Spatial computable general equilibrium models

As stated before this research focuses on modeling tools to calculate the land-use and economic effects, in time and space, of land-use and transport policies. The focus is further on modeling tools, which have functionality to be used in the design and analysis of land-use and transport policies. A review of selected existing research methods is made below and summarized in Table 4-2. First the methods outside the scope of the present research are mentioned:

- Non-modeling methods, like surveys or ex-post analysis of similar cases. These methods are useful to verify or complement modeling results; they are more limited as a generic planning tool. For example, an expert judgment or survey method cannot be used to test the impacts of strategies other than those considered in the questionnaire. Another limitation of these studies is that they often suffer of a lack of spatial detail and/or the scope of the impact assessment;
- Methods without a spatial dimension, in which the impacts of specific infrastructure projects are calculated for the whole country. This is typically a characteristic of many macro economic models, such as the Athena model in the Netherlands (Broer 1998, CPB 1990); their representation of the wider economy is often non-spatial. For project appraisal purposes these models do not have the necessary spatial detail to analyze the spatial-economic impacts of specific transport measures. These models analyze the effects of an investment in infrastructure on the wider economy, but they lack detail to differentiate between projects.

The present research focuses on models with a spatial dimension, a modeling of multiple regions and zones, and capable of quantifying land-use and economic effects. The discussion includes regional economic models, spatial computable general equilibrium models and land-use and transport interactions models.

The discussion of regional economic models does not aim to be comprehensive and is limited to the frequently applied quasi production function approach, an overview of the production function approach in infrastructure models can be found in Bruinsma, 1992. In the production function models, infrastructure is a production factor additional to traditional factors such as labor and capital. Recent applications of this method, with a

regional dimension, are the MOBILEC model in the Netherlands and the European SASI model (Wegener and Bokeman 1998, Marcial Enchinique & Partners Ltd et al. 2001). Another type of regional economic models, the input-output method, is operational at a regional level in the Netherlands. This method will not be discussed separately, because it forms an important component of several Land-Use and Transport interaction models and spatial computable general equilibrium models. A more detailed description of the MOBILEC model is presented in Section 4.4.2 and serves as a state-of-the-art example of a regional economic model based on the production function approach.

Another type of economic model discussed in this section is the so-called Spatial Computable General Equilibrium model. The “new economic geography” school has inspired the development of these models: for theoretical background on this development see Chapter 3. Researchers following the new economic geography school, represented by leading researchers such as Krugman and Fujita (Krugman 1991; Fujita et al., 1999), are using a theoretical economic equilibrium framework to address regional developments. The RAEM model (Oosterhaven et al., 2001; Thissen et al., 2006) is included in Table 4-2 as a state-of-the-art example of the application of this Spatially Computable General Equilibrium modeling in the Netherlands. A consortium of TNO-INRO, University of Groningen and Free University of Amsterdam has developed the RAEM model (the abbreviation of “Spatial General Equilibrium Model” in Dutch).

4.4.1 Spatial computable general equilibrium model (SCGE)

The SCGE-models are the first group of models that are strongly founded in mainstream economic theory. These static equilibrium models of inter-regional trade and location are, based on micro-economics, using utility and production functions with substitution between inputs (Oosterhaven 2000). These models are theoretically strong by explicitly including producer production- and price decisions, and scale advantages. The model suffers from practical problems as computation time and problematic estimation of parameters. The struggle to fit the theoretical economic framework to an urban/regional area with its many dimensions and processes of change has been identified by Krugman and Fujita in an interview (Florax 2004).

Besides the RAEM model in the Netherlands, the number of applications of the SCGE method is growing rapidly and includes examples such as the CG-Europe model of Bröcker (Bröcker 2002) and the theoretical model of Venables & Gasoierk in the UK (Venables and Gaisorek 1999). First experiences with SCGE models illustrate that still several conceptual barriers need to be passed (Tavassy et al., 2002). Furthermore data limitations are a severe barrier to properly estimate these models and many parameters need to be based on expert judgment. The complex non-linear behavioral equations, needed to incorporate imperfect market features such as scale advantages, are hard to estimate at a regional level due to a lack of adequate data. Bröcker (2004) states that research on parameter estimation within a general equilibrium framework is still in its infancy. In his view this is related to the lack of data as well as to a lack of knowledge.

Especially critical, for an instrument estimating the wider impacts of transport measures is the question if the influence of transport cost on final production is incorporated adequately. This means that appropriate assumptions are needed about transport costs, for freight and business, by sector and for the substitution factors between transport input and other inputs if the transport cost change. In practice for the base year the

modeled input and output flows are calibrated on constructed bi-regional input and output tables for the base year. Such calibration procedure by changing model coefficient values to reproduce a constructed base year input-output matrix does not guarantee statistically verifiable, correct coefficients. As indicated in the literature review of Chapter 3, in most developed countries accessibility plays only a modest role in explaining land-use and economic changes. It is hard to determine the size and significance of the coefficients of such a non-dominant variable in an informal calibration procedure such as described.

An interesting comment on SCGE models has been made by Vickerman (2000): SCGE modeling offers an approach which can deal with these factors (imperfect competition, role of labor markets) more effectively, although typically at some greater distance from real data. As a result of the high data demands, this type of approach may be employable only at the fairly aggregate macro-level to explore the wider effects of broad policy measures, and not at the local level to examine the impacts of individual investments or implementation of local policy. Gunn (2004) also emphasizes the potential contribution of SCGE in evaluating transport investments; however their field of application is restricted to large scale (inter-regional) transport investments only.

Different comments were made by Anas (2001). He underlines that SCGE models have a strong foundation in economic theory and should be considered as an important development. However several assumptions are debatable in his view, examples of debatable assumptions are:

- Infinite desire for taste variation of the consumer; are people in reality behaving in this way or are they more showing a satisfying behavior?
- The production of unique goods at only one location, can Coca-Cola or another firm not produce the same product in two locations?
- Are scale advantages the single driver of agglomeration? It may seem that life-style issues or desire to use the same product, e.g. beer, at different locations play an important role as well. This argument of Anas can be illustrated by for example analyzing the revitalization of urban areas in Western countries. This phenomenon is closely linked with the demographic trend of more single and two person households;

Comparing the characteristics of the current SCGE models and the requirements formulated in the first section of this Chapter, the following conclusions can be drawn:

- SCGE models have a good link with the economic indicators needed in a CBA (RUG/SEO 2004): the representation of market imperfections in the production market enables the calculation of indirect generative effects of transport changes;
- A disadvantage of SCGE models is that they are static models. They provide no insight in how the system evolves; the lack of a time pattern is also a disadvantage for the use of this model within a CBA framework. Theoretically a dynamic SCGE model might be possible, but considering the huge problems of implementing a static model, this may be considered as a very long-term research challenge. An argument for a dynamic modeling is that the annual changes in land-use are relatively small and next years land-use pattern is quite well predicted by this year's land-use pattern. A practical disadvantage of an equilibrium approach is that it forecasts all land-use and not only the changes in

land-use; potentially resulting in instable forecasts and unrealistic dynamics for land-use changes;

- The link between direct transport effects and wider economic effects is theoretically strong. However in practice the quality of this link is rather questionable because of the high spatial aggregation level and absence of statistically estimated parameters for the influence of transport;
- SCGE models are theoretically sound to answer core–periphery questions; however they lack an explanation for intra-regional processes like sub-urbanization. This makes the models qualified for the analysis of large-scale inter-regional infrastructure projects and less qualified for regional projects;
- The SCGE models focus strongly on economic processes such as producer decision; other important spatial processes, like for example residential location choices, and dynamics of the regional/urban system are not included or only marginally. Examples of components of the urban/regional system, not adequately addressed in SCGE models, are spatial policies, land market, real estate market, housing market and demography. Or as Fujita (1999) states “for the development of human society in the long-run, economic aspects represent merely a part of the phenomenon, perhaps not even the most important ones”.

In general it would seem that the wish to operate within a theoretical sound general equilibrium framework comes at a high price. It makes the modeling less flexible, much more complicated to estimate and not responsive to dynamic developments. Furthermore it is difficult to benefit from research findings in other relevant fields which help explain urban and regional development. Important question is then: is the general equilibrium framework and consistency with economic theory so important that it is worth to ignore other above mentioned aspects?

Some explorative research work of Rouwendal, 2003, shows that little difference can be observed between the outcomes of general and partial equilibrium models. In such case the flexibility and simplicity of partial equilibrium models is preferable above general equilibrium models. However, much more research is needed to make a better trade-off possible between the complexity of general equilibrium models and the deviation from the more flexible and less complicated partial equilibrium models.

4.4.2 Production function approach

The MOBILEC model can be described as a modified neo-classical growth model. The description is based on articles of the developer F. van de Vooren (1998, 1999). The MOBILEC model describes the relationship between the economy, mobility, infrastructure, and other regional features in an inter-regional dynamic way. The main characteristic of the model is the representation of the two-way interaction between economy and mobility. In the traditional transport models, transport is estimated as a derived demand from the economic development scenarios. The MOBILEC model also determines the contribution of infrastructure to economic development.

In MOBILEC a modified Cobb-Douglas production function describes, at a regional level, the relation between the input of production factors and the output of commodities. The transport infrastructure is added in the production function as an additional production factor besides the usual factors such as state of technology, labor and capital. It should be noted that it is not the capacity of the infrastructure that is included as production factor, but the part of it that is utilized for the production.

Elasticities, adopted from the literature, are used to link changes in the infrastructure, affecting travel times and costs, and changes in travel volumes.

The so-called productive mobility (goods and business transport) is expressed in terms of passengers and the number of tons of goods. The causality of the consumptive mobility is the other way around. The consumptive mobility depends on the income and is the result of the economic development of a region. The MOBILEC model has been used to make multi-regional long-term projections (2030). The model is dynamic and it uses time steps of three years. The present spatial scale level is at the COROP-region level. The Netherlands is subdivided in 40 COROP-regions (European NUTS 3 zones). Besides the model for the Netherlands, the MOBILEC model has also been applied in Belgium. The University of Antwerp has developed the model for Belgium and an extension to include Luxembourg is on the way. The fact that the model is operational in two countries and has been applied to several case studies in the Netherlands illustrates its flexibility.

Comparing the characteristics of the MOBILEC model and the requirements formulated in the first paragraph of this section the following conclusions can be drawn:

- The dynamic structure of the model enables the user to analyze how the system evolves over time and matches well with a time dependent evaluation method such as a Cost-Benefit Analysis;
- The inclusion of the mutual influences of the economy and mobility over time in the modeling is a strong point, although the discussion on the status of commuting travel, to be classified as productive or consumptive transport, is still unsettled;
- A limitation is that the model only includes one sector of economic activity. The model is not capable to represent the very different impacts of transport changes for the different sectors in the economy;
- The model fails to recognize, due to the production function approach, the importance of demand factors on regional growth. All changes in the region are explained by changes in the production factors. The model does not simulate the housing market and changes in the population are exogenous;
- The MOBILEC model does not differentiate between direct and indirect effects, as required in the standard project appraisal method in the Netherlands (CPB/NEI 2000), and all effects are estimated simultaneously. In principle the indirect welfare effects in MOBILEC should be largely absent due to the omission of market imperfections such as scale advantages;
- The transport modeling approach is simplified and aggregated (no network, COROP as zone level): the transport results are not very reliable;
- The MOBILEC model does not model land-use changes. For the modeling of land-use changes the model misses spatial detail and the modeling of the housing- and labor market.

4.5 Towards a LUTI-model for NL

The modeling approaches discussed in Section 4.2 and 4.4 will be compared in sub-section 4.5.1. The arguments for using a LUTI approach are presented. Section 4.5.2 discusses the expected contribution of LUTI models to policy making in general.

4.5.1 Brief comparison of modeling approaches - selection of LUTI-approach

In this sub-section some key features of three modeling approaches, namely SCGE, LUTI and production function approach, are compared. The modeling approaches are compared by using the operational models in the Netherlands representing each of the approaches. Those are RAEM model (see sub-section 4.4.1), - MOBILEC model (see sub-section 4.4.2), and - the TIGRIS XL model (see Section 4.2 and Chapter 5, presenting the structure and features of the TIGRIS XL model).

Table 4-2 below summarizes some key characteristics of those three operational models in the Netherlands. It should be noted that those models are continuously under development and characteristics may change.

Table 4-2: overview of land-use and economic evaluation models in the Netherlands⁸

	LUTI TIGRIS XL	SCGE RAEM	REM MOBILEC
General model characteristics			
Type of model	Land-use and transport interaction model	Spatial computable general equilibrium model	Modified neo classical growth model
Dynamic status	Dynamic	Equilibrium model	Dynamic
Spatial scale level	Local zones (1308)	COROP	COROP (NUTS3)
Labor market			
Labor market	Detailed demand and supply modeling	Detailed demand, supply simplistic	Simplistic
Economic sectors	Sector disaggregation	Sector disaggregation	One aggregated sector
Empirical foundation	Yes, formal statistical estimation of relationships	No formal statistical estimation of relationships	None
Demography and housing market			
Housing market	Detailed demand and supply modeling	Demand response, only for employed people	None
Demography	Endogenous within national totals	Exogenous	Exogenous
Empirical foundation	Yes, formal statistical estimation of relationships	No formal statistical estimation of relationships	None
Transport			
Transport	Endogenous integration with advanced transport model (disaggregate choice model)	Exogenous, link at aggregated level	Endogenous, basic model (no network)
Interaction transport – economy	One way	One way	Two way interaction
Interaction transport – land-use	Two way interaction, level of 1308 zones	One way	No explicit modeling of land-use

⁸ It should be noted that these models are under continuous development and some of the information in this table might not apply to more recent versions.

	LUTI TIGRIS XL	SCGE RAEM	REM MOBILEC
Policy analyses			
Interregional projects	Yes	Yes	Yes
Regional projects	Yes	Less qualified	Less qualified
Passenger transport	Yes	Yes	Yes
Freight transport	Less qualified	Yes	Yes
Economic effects	Distribution of jobs by region and zone per sector, time path	National and regional economic distribution and generative effects per sector, projection year	National and Regional economic impacts, time path
Complexity of equations	Moderate	High	Moderate
Understandable	Reasonable	Complex	Reasonable

It follows from the above comparison of different modeling types that the selection of a most adequate modeling approach is not straightforward. A profile of the preferred approach will depend on the specific characteristics of the application and in particular the required spatial detail, desirable indicators (generative and/or distributive effects, transport effects, spatial effects, etc), the need to represent time dependent changes, etc.

In practice the selection of a particular approach appears to be strongly related to schools of thought; economists are likely to select the SCGE approach because of its strong foundations in economic theory. An urban/regional or transport planner is less likely to select such a model because of its lack of spatial detail, poor integration with existing transport models and lack of attention to many drivers (e.g. demography, residential amenities) of urban/regional change. The scope of the total planning problem is very large and inevitably a selection of a particular approach will reflect the research focus and will involve assumptions.

The present research proposes a dynamic system approach towards the integration of land-use, transport and economy and can be located closer to the tradition of planners/engineers than economists. The modeling approach in this research has its strength in the interaction between the different system components rather than in the most advanced modeling of one of the components. Such a model, integrating many components, needs to be flexible to benefit from theories and knowledge from very different scientific fields like geography, housing, economy, transport, demography and urban and regional planning. This makes a modular set-up preferable and the use of a more inflexible framework, like SCGE models, less useful. Other key points are, as stated in Section 4.1, modeling of time dynamics and spatial detail. Another important selection factor is the wish to base the essential relationships in the modeling on an empirical foundation. Inevitably this calls for a modeling concept that is tailored to available databases. Considering the above factors the LUTI-model approach appears to be the most promising approach for the present research. The LUTI-models offer an analytical framework, comprising several modules addressing the various markets or

system components, capable of simulating how development of the transport infrastructure can affect land-use in time and space.

4.5.2 Expected contribution of LUTI-approach

This paragraph highlights some main contribution of the LUTI-approach for transport policy making. Important characteristics of the LUTI models with specific value for the evaluation of transport projects are:

- *Explicit and detailed link between direct and indirect effects*
Indirect effects of transport measures are always causally related to the direct effects. Land-use effects, within the current definition, form part of the indirect effects: the changes in land-use result from a change in transport costs and/or times; accessibility is used as an intermediary variable to link transport and land-use. Without a rather precise estimation of the direct effects of transport measures the estimation of the indirect effects becomes a hazardous task. A precise estimation of the direct effects includes sufficient spatial detail as well as detail in type of economic activity or personal behavior. In current practice LUTI – models seem to offer the best link with the transport system based on the detailed modeling of space and socio-economic groups. Other analytical instruments addressing the indirect effects are often not at all, or poorly, linked with the instruments for calculating the direct impacts (sometimes only at a very aggregated level).
- *Dynamic impacts*
A cost-benefit analysis requires a projection of the cost and benefit pattern over the lifetime of the project. To make such projection preferably a dynamic model should be used addressing the build-up of effects. An equilibrium type model is less suited to project such pattern; usually with such model only a final year is computed and interpolation is used to determine the intermediate years. Many of the economic models follow a comparative-static equilibrium approach and are applied for only one or a few future point(s) in time. The family of the LUTI-models includes both static and dynamic models (see sub-section 4.2.3) and the dynamic feature is of specific interest for this research.
- *Spatial detail*
A reliable and precise assessment of the direct- as well as the indirect effects requires a detailed spatial analysis because transport measures have their main impact at the local level. An example may illustrate the importance of sufficient spatial detail: consider for example that a particular analysis aims to address the impacts of a transportation measure in region X, and in this region there are 4 medium sized cities A, B, C and D. A new station and rail connection is projected between city A and other regions. The most likely effects are that city A is getting more attractive and cities B, C and D are becoming relatively less attractive. Regional averaging for all cities, as practiced in regional models, will lead to a serious miscalculation of the effects for the individual cities. In an analysis at the regional level the impacts will be positive for all cities. A major strength of the LUTI models is that they operate with a detailed zoning and can calculate the intra-regional or intra-urban differences in land-use and economic effects of a transport measure.
- *Detail in the representation of different sectors and in the household/person segmentation.*

A strong point of the LUTI-models is that they can operate with a range of economic sectors, addressing the different types of economic activities, and detailed person/household type segmentation. Such detail is necessary to adequately present the location preferences of different type of actors, including accessibility as a location factor. Accessibility is relative in space as well as for each actor. Different firms, for example an administrative consultant or an industrial complex, do have a completely different perception of accessibility. The same holds for households or persons, a household with two elderly persons has a completely different perception of accessibility than a household with two workers and children. For example, the spatial-economic effects of a new train connection, as presented under the previous bullet-point, depend strongly on the type of households and economic structure in the four cities.

The key contribution of the LUTI-models to policy making is that these models can calculate the long-term effects of transport policies on land-use changes. LUTI-models can enrich the project appraisal of a transport policy measure with quantitative information on the land-use changes resulting from this measure. Another important contribution to policy making is that LUTI-models can improve the estimation of long-term transport effects as well; in current practice benefits from transportation projects are predominantly represented by the direct effects based on changes in transport decisions and under the assumption of a fixed spatial distribution. In contrast with traditional transport models the LUTI-models can also model the long-term effects of transport policies, due to changes in land-use resulting from those transport measures, which are jointly influencing.

4.6 Observations for a new LUTI – model

This chapter has listed the requirements for modeling (with input from Chapter 2 and 3), presented a general review of LUTI-models and some LUTI-models in specific, described generative welfare effects, discussed alternative modeling approaches, and argued to develop a new LUTI-model. A LUTI-model is preferable as it can incorporate of a dynamic system approach with a high level of spatial detail; in addition LUTI models can have a modular structure addressing components (or markets) of the system. Such modular structure can easily incorporate theories and knowledge from different scientific disciplines; furthermore such system is flexible to tailor the modules in the model to existing databases to allow a statistical estimation of the key relationships.

The requirements for modeling as described in this chapter indicate that developing a new LUTI-model for the Netherlands brings several challenges and opportunities. The challenges and opportunities are context specific and depend on spatial policy regime, spatial structure and data availability. However, many of these issues can be transferred to regions or countries with similar characteristics or data sources.

Main challenges for developing a LUTI model in the Netherlands are:

- *Statistical estimation of the key relationships between land-use and transport*
Components of LUTI-models, following a modular set-up, can be associated in a rather flexible way to available data sets. The spatial data situation is rather prosperous in the Netherlands; a main challenge is to use this situation to

estimate the key relationships between land-use and transport following a formal statistical procedure (see sub-sections 4.2.3, 5.1.1, 5.5.1)

- *Develop a model, which is flexible to incorporate different spatial regimes.*

A land-use model for the Netherlands should be capable to simulate various land-use regimes, varying from a regulated regime to a free market regime. This feature is needed to represent the current regime, cope with future changes in this regime and explore long-term potential developments (see sub-section 2.1.3, 5.1.4).

- *Develop a model for the whole of the Netherlands*

The spatial structure of the Netherlands, with many urban centers, separated by short distances, creates many overlapping labor- and housing markets. Therefore the model needs to address the whole of the Netherlands as study region; the model needs to simulate both the effects of inter-regional as well as large-scale regional transport infrastructure measures (see Section 2.2, 5.1.5).

- *Interaction of Land-use model with state-of-the-art disaggregated transport model*

The land-use model aims to interact with the existing national transport model (NMS), which can be considered as the standard passenger transport model for the Netherlands. Interaction with a discrete choice transport models such as NMS, gives opportunity to explore the use of advanced accessibility indicators (see Section 5.2)

- *Address indirect generative effects of transport changes.*

A key omission of LUTI-models, and a limitation for their use in policy-making, is that these models do not calculate indirect generative effects (see sub-section 2.3.3). The challenge is to include this economic modeling within the LUTI-framework without reducing the above indicated strengths of the LUTI-models. Key elements which should be preserved are spatial detail, socio-economic detail and an empirical foundation of the relationships. Alternative approaches can be considered to enlarge the LUTI-models with an economic component. Chapter 8 explores the modeling of generative effects within LUTI-models using a bottom-up approach.

The main challenges highlighted in this paragraph will be addressed in Chapter 5, which describes the development of the TIGRIS XL model. In Chapter 6 the model is tested for its response to different spatial planning regimes; also the sensitivity of the model output, spatial distribution of residents and jobs, is tested for changes in the accessibility indicators. The indirect generative effects of transport changes are addressed in Section 8.4, on future research: an approach is explored for modeling of economic production effects in interaction with TIGRIS XL.

5 Development of the TIGRIS XL model

This chapter focuses on the design and estimation of a new LUTI-model for the Netherlands: the so-called TIGRIS XL model. The model has been developed in sequential steps for the Transport Research Center; this chapter describes the features of the TIGRIS XL model. The TIGRIS XL model is the successor of the TIGRIS model (AVV, 2001). It should be noted that the development of the TIGRIS XL model has started from scratch; in comparison with the TIGRIS model, the new TIGRIS XL model uses a different methodology for the housing and labor market, other databases, a different approach to model calibration/estimation and it is implemented in different software.

The aim of the TIGRIS XL model is forecasting the spatial impacts of integrated land use and transport strategies in the Netherlands in a consistent way. The model also aims to represent the long-term effects on transport performance, including changes in land-use, caused by changes in the transport system, and having in turn an effect on transport demand. From these objectives the following requirements can be derived:

- The model must adequately respond to changes in transport policy and the model should calculate valid (proper causality and size) effects of transport changes on residential and commercial land-use;

- The model should be capable of addressing these effects under different social – economic scenarios and spatial policies. The model structure needs to be flexible towards more or less government influence on the housing market;
- Changes in land-use should affect transport forecasts in a dynamic process. A long-term analysis of a transport policy measure needs to include additional effects through changes in land-use.

The model is described by component in Sections 5.1 to 5.6. Section 5.1 presents the overall model structure and sections 5.2, 5.3, 5.4, 5.5 and 5.6 present respectively the transport market, demographic module, land market, housing market and labor market.

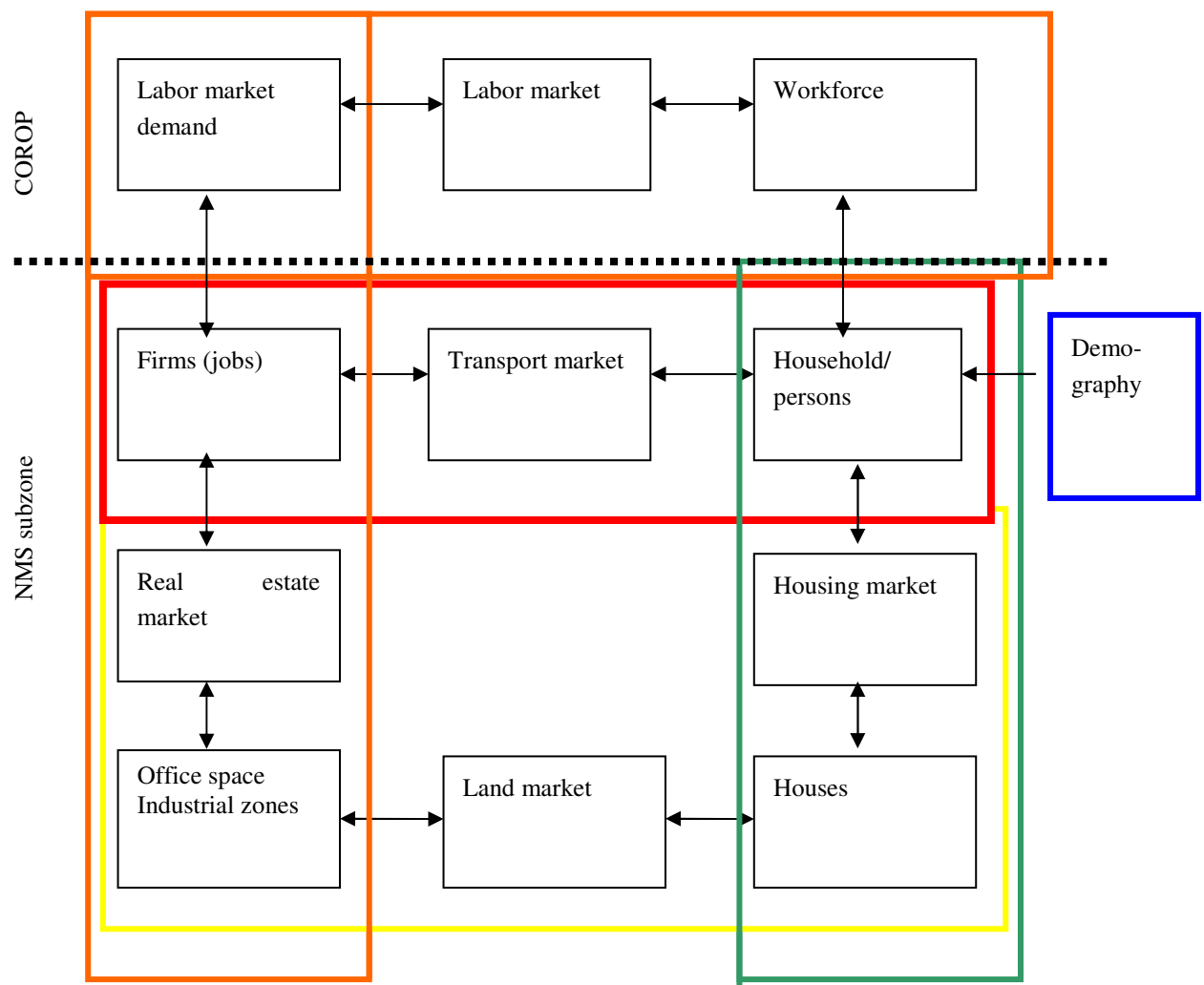
5.1 Model structure of TIGRIS XL

As discussed in Section 4.2, a wide variety of models exists within the family of LUTI models. A key distinction has been made between LUTI models classified as “connected” or “integrated” models; models are classified regarding to their structure and interaction between modules. The “connected” models have a composite structure and are built up by interactions between the sub-models. An advantage of a composite structure is that the sub-models can be estimated or calibrated independently. Another advantage is that the system is flexible to change one specific module to include new developments in a specific market.

For TIGRIS XL a composite structure has been chosen for reasons of transparency, flexibility, time dynamics and especially model estimation. A composite structure allows the flexibility to estimate modules, like the housing- or labor market, individually and the module specific parameter estimation can be tailored to available databases. A trade-off is that the integration of the system components is less optimal and a crucial feature of a composite model is the handling of the interactions between the various sub-models.

As stated, a composite model as TIGRIS XL comprises of several modules linked with each other within one modeling system. A housing market and labor market module, including the effect of transport changes on residential or firm settlement behavior, is necessary to link changes in the transport system with changes in land-use. A land and real estate module is needed to simulate supply constraints and define different levels of government influence on this supply. Feedback loops from the housing market, showing the match between supply and demand, are needed to simulate the influence of demand on supply. Demographic information is needed in the housing- and labor market module at a local/zonal level. This implies that a demographic module is needed to simulate demographic changes at this level. At the regional or national level the model output needs to be consistent with existing social-economic forecasts.

Figure 5-1 presents the main relationships between the modules; two spatial scale levels are differentiated, namely the regional level (COROP, 40 representative regions in the Netherlands) and local transport zones of the National Model System (NMS sub-zones, 1308 sub-zones covering the Netherlands).



*) The TIGRIS XL model consists of a labor market module, demography module, land market and real estate market module, housing market, and it interacts with the transport market

Figure 5-1: design of the prototype TIGRIS XL model

Each of the modules in TIGRIS XL represents specific markets or processes. In the paragraphs below some main design decisions are discussed in more detail. Section 5.2 discusses in detail the integration of the transport market within the framework. In Section 5.3 and 5.4 the scope and key features of the demographic module and land market module are discussed. Section 5.5 presents the design and model estimation of the housing market in TIGRIS XL. The structure and estimation results for the labor market are discussed in section 5.6.

The incremental structure of the model implies that within each time step the different modules are executed subsequently where the input for a module is provided by output in the previous time step or by output from the other modules in the same time step. Figure 5-2 gives an overview of the interdependencies between the modules across the different time steps. The Demographic- and Land use and real estate modules are executed first. These modules use exogenous scenario data (birth and death ratios and spatial planning policies) and output from other modules in the previous time step. The Demographic module uses the spatial distribution of persons and labor participation

from respectively the Housing market- and Labor market modules. On a 'free' land market setting, the Land use and real estate module allocates new dwellings proportional to a local surplus in dwelling demand, computed in the housing market module in the previous time step.

The Housing- and Labor market modules use the output from the Demographic- and Land use and real estate modules in the same time step. The Land use and real estate module specifies the dwelling supply for the housing market and the supply of firm locations for the Labor market module. The Demographic module provides the population- and household composition in the housing market and the potential labor population for the Labor market module. Next to that, the choice models in the Housing- and Labor market modules use accessibility indicators from the transport model as input.

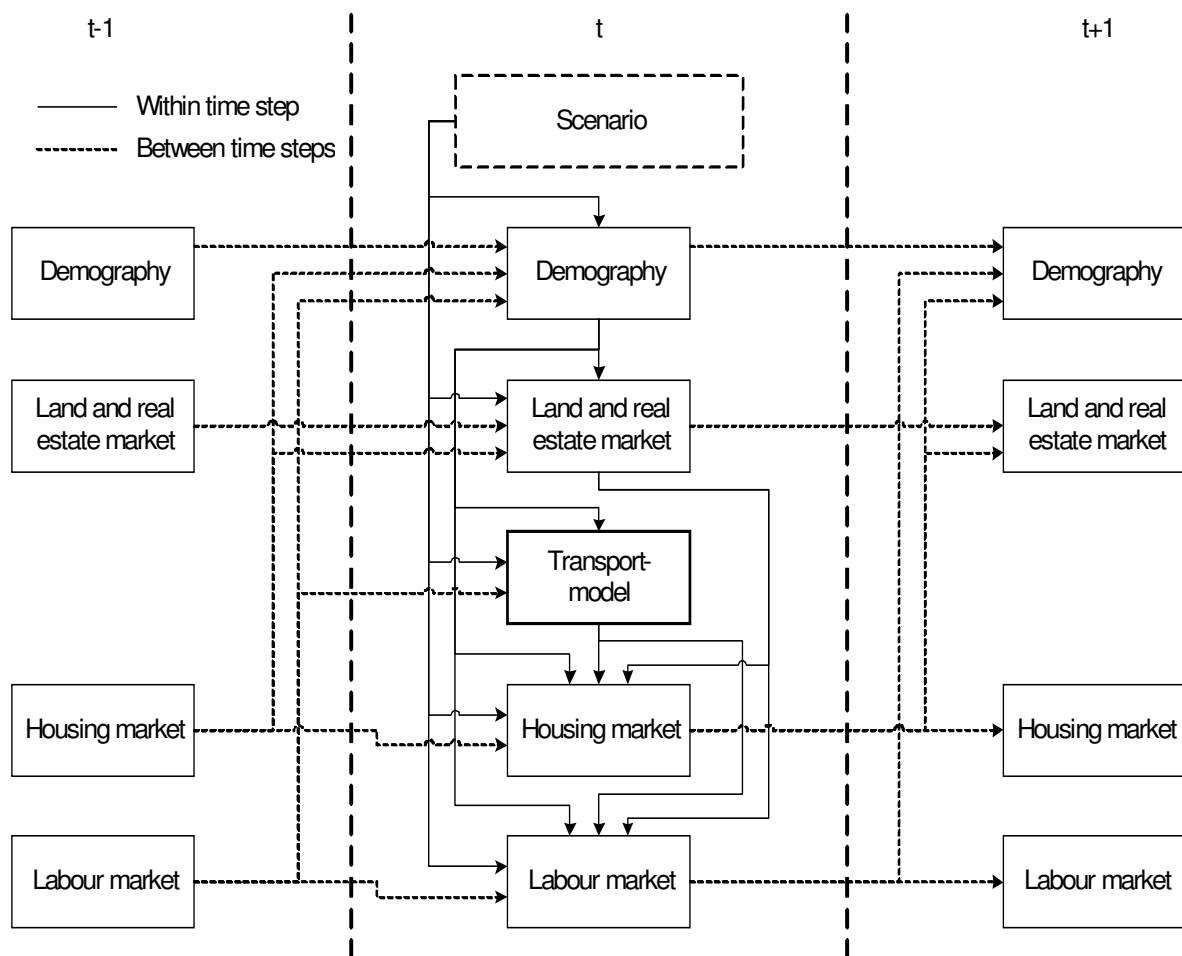


Figure 5-2: flowchart of the TIGRIS XL model

5.1.1 Model estimation/calibration

A requirement for the design of TIGRIS XL is that the relationships modeled have an empirical basis. This should be at least the case for the key interactions between transport and residential location choices and transport and firm location choices. A statistical analysis is required to estimate the parameters for the accessibility variables

linking transport and location choices. This requirement puts challenges on the design of the TIGRIS XL model as the availability of data sources co-defines the design of the model. It is also an important distinctive factor between TIGRIS XL and many other LUTI models for which parameter values generally are determined on the basis of expert judgment or informal calibration procedures matching historical developments or land-use patterns at a specific point in time.

For example, in the MEPLAN (Williams, 1994; Simmonds, 1994) and TRANUS (De la Barra, 1995), models classified as integrated model, the spatial choices on the labor market, housing market and origin-destination choices of the transport model are inter-related and solved simultaneously. The many inter-twined processes in these models make it complex to estimate and calibrate the model; and model specific procedures have been developed to calibrate the model in an iterative process both on transport statistics, as average trip length, and the spatial distribution of residents (see LASER enhancement report, ME&P 2002). The model parameters are not statistically estimated and statistical indicators for the model fit, such as R-square or log likelihood value, and significance of the parameter estimates are missing.

URBANSIM (University of Washington, 2000), DELTA (Simmonds, 2005) and IRPUD (Wegener, 1998 a-g) are three incremental models and therefore their calibration procedure is very different. The models are calibrated or estimated on the changes in time rather than on totals at one point in time. For example, the labor market module of the URBANSIM model in the Eugene-Springfield application (Waddell 1998) is statistically estimated on longitudinal data. The composite structure of this model enables an individual calibration of the sub-models. And therefore the calibration of the model can be tailored to local data conditions. The parameters of the IRPUD and DELTA models are more informally calibrated on their ability to reproduce historical developments, preferable for time periods in line with the forecast period. Statistical indicators for model fit and significance of the variables are not available for the IRPUD and DELTA model.

As stated for the TIGRIS XL model it is a design requirement that the key relationships, linking the transport and land-use system, are based on a formal statistical estimation. The relatively good spatial data conditions in the Netherlands make such a requirement realistic. The composite structure of the model enables that for each module a suitable database can be used for the estimation of the model parameters. In section 5.5 and 5.6, addressing the housing- and labor market, the model estimation process for the respective modules is described.

5.1.2 Incremental versus equilibrium

Another important structural decision, which needs to be made, is between a dynamic model, focusing on the changes, and an equilibrium model explaining the location of all households or jobs in one time-step. The option of a dynamic model calculating a general equilibrium for each time step is still for a longer time to come outside computational reach. And even if this option becomes available, the equilibrium assumptions are still not valid and a path-dependent and incremental approach is preferable. For the TIGRIS XL model a dynamic approach, focusing on the incremental changes, has been taken. Reasons for a dynamic incremental model are the need to explain time dependency of the changes. A dynamic model allows for the inclusion of time lags in the responses. This feature is important for the modeling of land-use

changes resulting from transport measures; the literature review in Chapter 3 illustrates the importance of time lags in observing land-use effects of transport measures.

Another reason for dynamic and incremental modeling is the small size of the annual changes in land-use; a large part of the land-use will be unchanged in a future period of for example 20 or 30 years. The small size of changes in land-use makes the spatial distribution at time t a good starting point to explain the land-use pattern at time $t + 1$ year. An equilibrium model does not use the previous patterns as input and allocates all land-uses at a future point in time following market equilibrium conditions. Therefore an equilibrium model might easily overestimate these land-use dynamics: this often results in the use of high location specific impedances needed to represent the current pattern and correct the spatial dynamics. Location specific impedances represent the not explained part of the spatial distribution by the specification of the modeling. These impedances are usually derived in the base year to represent an observed distribution. A disadvantage of high location specific impedances is that these values are fixed (often to keep existing build up areas at their location) and do not respond to changes in the scenario settings or policies.

The decision between an equilibrium and incremental model does not have to be absolute for all components of the modeling. It is possible to calculate a short-term equilibrium only for parts of the modeling. For example, in most LUTI-models a short-term equilibrium is used to match demand for transport and capacity in the network assignment module. Another example is the use of prices to calculate equilibrium in the housing market. In an incremental set-up this market equilibrium will only address a part of the housing market: covering the households willing to move and number of vacant houses in a certain year. In TIGRIS XL an iterative procedure is incorporated to match supply and demand in the housing market within a time period.

5.1.3 Link between housing market and labor market

An ongoing debate in spatial sciences centers on the question: are jobs following people or are people following jobs? A frequently used way to link residents and labor in LUTI-models based on the economic base theory, and applied in the Metropolis model of Ian Lowry (1964), assumes a hierarchical relationship between location of employment and residents. Step one in the modeling is the settlement of basic or exporting employment, which is an exogenous input to the modeling; step two is the settlement of residents attracted by the jobs. In step three the population growth will attract services and these services will bring additional employment; this additional employment attracts residents and so on. The iteration stops when the additional effects become marginal. This hierarchical, step-wise, approach of Lowry has been followed by many researchers in the field of land-use and transport modeling, for example, the frequently applied MEPLAN and TRANUS model follow this principle.

This hierarchical link between employment and population, as described above, has however lost much of its appeal over the years. There is empirical evidence that firms in the Netherlands are more responsive to location of employees than that the population is to location of firms (Sorber 2001; Vermeulen and van Ommeren, 2004). This evidence is sensitive to economic cycles and regional differences, urban or rural areas. However, a conclusion that employment growth is a main driver of population growth has not been found for any of these circumstances.

In general it can be observed that using a pre-imposed relationship between jobs and people is not adequate for land-use modeling in the Netherlands. Important arguments supporting this observation are:

- A more dominant position of the service sector and a less dominant position of the industry. The service sector is less bound to location as the industrial sector, which depends more on the location of natural resources or transport nodes;
- A significant and growing part of the population is inactive and does not take employment opportunities into their residential location decisions;
- Employees, and especially higher educated persons, have a strong market position and they are often not willing to move for a specific job. This flexibility to move is further constrained by the increasing share of two-earner households. Firms, also exporting firms, take these considerations into account and the location of potential employees is an explanatory variable in their location choice;
- Social welfare conditions in the Netherlands reduce the willingness to move for job opportunities. The high costs of moving are often not recovered by small increases in income, for example between a low-income job and unemployment benefit. Changes in regional employment in the Netherlands mainly interact with regional labor participation ratios (Broersma and van Dijk 2001).

TIGRIS XL does not use a pre-imposed link between jobs and people and calculates both the influence of population on firm location and the influence of jobs on location of households. The estimation of the parameter values for the labor market and housing market module will define how important the mutual influences are. Empirical results will define the relationship between jobs and people in TIGRIS XL instead of theoretical assumptions.

Interactions of land-use and transport with the economy

The TIGRIS XL model addresses only a fraction of the full interactions of land-use and transport with the economy. First of all the TIGRIS XL model is, in line with other LUTI models, a distributive model; generative economic effects are not calculated. Secondly, exogenous scenario inputs are used at the national level to forecast growth in income and these scenario figures are used as input for the land-use and transport modules.

There are various options to strengthen the economic component of the TIGRIS XL model. An option is to extend (or link) the model with an inter-regional economic module, which enables an endogenous modeling of the Gross Regional Product, employment and income. A way forward for such component, linking the TIGRIS XL model in the Netherlands with the MOBILEC model (see 4.4.2), has been explored in Zondag (2002). An alternative option is to develop a post-processing module calculating the indirect generative economic effects following a “bottom-up” approach. This approach is worked out in Section 8.4.

5.1.4 Spatial market and market regulation

A rather unique feature of the Netherlands is the strong regulatory framework governing spatial planning. This framework, presented in Chapter 2, includes three tiers of government, national, regional and local, and several agencies at each level. The level of market regulation by the government is substantial and needs to be incorporated in

the modeling. In the Netherlands the main regulation is on the land market, where the government uses its planning authority to allocate building permits. These permits include regulations defining the exact location of residential development but also incorporate regulations regarding housing densities and number of houses in different price segments.

In the modeling it is therefore important that the location and number of houses can be specified exogenously. Some further elaboration on this option is desired based on the following arguments:

- There is debate in the Netherlands about the consistency between the development of construction sites and the original physical plan. Chapter 2 discusses several influences: inconsistencies in policies between tiers of government or agencies and the influence of market preferences, explaining the observed deviations in actual development and original plans;
- Land-use forecasts used in strategic transport studies cover time spans of 25 to 30 years. In general, municipalities have concrete land-use plans for the coming 10 or 15 years at maximum. For example, in the new map of the Netherlands (NIROV/Ministerie van VROM, 2006), a database collecting bottom-up land-use plans from all municipalities, the number of land-use plans after 2015 is small. Generally land-use models are used for long-term forecasting, e.g. 30-years period. This means that the model users will have to design input for a significant period of time, if alternative endogenous supply mechanisms are not included in the modeling;
- The traditional steering role of the Dutch government is likely to change in the future; in the last national physical plan (Ministerie van VROM, 2005) market forces play a much more dominant role and traditional government regulation of the land-market will only apply to specific regions. In other regions a much more free market oriented spatial development is foreseen, at least from the national perspective.

5.1.5 Spatial scale level and unit of analysis

Most LUTI-models are developed for urban areas, although some frameworks like TRANUS or MEPLAN are capable to operate at an inter-regional level. The URBANSIM, IRPUD and DELTA model are developed to operate at an intra-regional level. In these models the distributive impacts of land-use and transport policies are modeled at a metropolitan scale level and the modeling incorporates the urban area and its suburbs. The DELTA package has been extended with a regional model, comprising an economic- and migration model, to model changes at the regional level (Simmonds and Feldman, 2005).

The TIGRIS XL model is rather unique in its ambition to calculate the structuring impacts of inter-regional as well as intra-regional transport measures. This ambition is supported by a layered spatial structure, with a modeling of the changes at regional and local level. The model is developed for the whole of the Netherlands with the intention to make it applicable for policy questions throughout the country. The small size and homogenous spatial structure of the Netherlands facilitate the modeling of the entire country. In larger and spatially more diversified countries the absence within TIGRIS XL of a regional economic module, simulating spatial differences in income and unemployment, would be more problematic. Modeling the entire country has as

important advantage that the boundaries are rather clear. The border of a country is still serving as an important boundary, regardless of European integration efforts. Identifying a rather stand-alone study region in the Netherlands with its multiple centers and overlapping labor- and housing market would be difficult.

The relatively homogenous spatial structure and level of accessibility throughout the country makes it more acceptable to use the same parameters for the entire country, contrary to countries with large differences in spatial structure. For example, the EU sponsored SCENES project (SCENES consortium, 2000) classified all NUTS 2 zones in Europe; all provinces in the Netherlands were classified as category 3 or 4, out of seven categories.

A clear trend can be observed in all the spatial models towards more spatial detail. Increasing computing power and the availability of detailed spatial databases are the driving forces for this trend. The URBANSIM model is an example of a land-use model operating at a very detailed spatial scale level of GIS grid cells for the supply side. The demand side of the URBANSIM model uses the transport zones as spatial unit.

In the case of TIGRIS XL the spatial level depends on the nation wide set up of the model and computation time restrictions. The TIGRIS XL model runs at two spatial levels, a regional level, and a detailed zoning at the level of the NMS sub-zones. In this way the land-use model and transport model operate at a consistent level of spatial detail. For the supply side a more detailed spatial level can be used as input, in as far as the data is available.

The coverage of the Netherlands with COROP regions (40) and sub-zones (1308) is presented below in Figure 5-3 and Figure 5-4.



1 Oost-Groningen	11 Zuidwest-Overijssel	21 Aggl. Haarlem	31 Zeeuwsch Vlaanderen
2 Delftzijl eo	12 Twente	22 Zaanstreek	32 Overig Zeeland
3 Overig Groningen	13 Veluwe	23 Groot-Amsterdam	33 West-N-Brabant
4 Noord-Friesland	14 Achterhoek	24 Het Gooi en Vechtstreek	34 Midden-N-Brabant
5 Zuidwest-Friesland	15 Arnhem/Nijmegen	25 Aggl. Leiden Bollenstreek	35 Noordoost-N-Brabant
6 Zuidoost-Friesland	16 Zuidwest-Gelderland	26 Aggl. s-Gravenhage	36 Zuidoost-N-Brabant
7 Noord-Drenthe	17 Utrecht	27 Delft en Westland	37 Noord-Limburg
8 Zuidoost-Drenthe	18 Kop v. Noord-Holland	28 Oost-Zuid-Holland	38 Midden-Limburg
9 Zuidwest-Drenthe	19 Alkmaar eo	29 Groot Rijnmond	39 Zuid-Limburg
10 Noord-Overijssel	20 IJmond	30 Zuidoost-Zuid-Holland	40 Flevoland

Figure 5-3: map presenting the regional COROP level



Figure 5-4: map presenting all 1308 transport zones

5.2 Transport market

In TIGRIS XL the National Model System (NMS) of the Netherlands is used as transport model. This model is rooted in discrete choice theory and a first version of the model has been operational in the Netherlands since the mid 1980's. The current version v7 of the NMS transport model (Hague Consulting Group, 2000) differentiates 335 person types, 8 purposes, 5 modes and 1308 zones. Important issues for the integration of the NMS model within the TIGRIS XL framework are the following:

- Timing of interactions between land-use and transport model;

- Socio-economic output from the LUTI-model needed as input for the transport model;
- Accessibility indicators needed as input for the land-use model (5.2.1)

A basic requirement for joining models is consistency between the land-use and transport model. The interaction should be such that significant changes are timely transferred to the other model. A practical problem may arise with the run time of the models. In most cases, when using transport models with a considerable run time, a trade off between the overall run time of the LUTI-model and the frequency of interaction between the land-use and transport model need to be made. An alternative option is the use of a less detailed transport model. For example, the IRPUD model makes every time step (it uses time steps of one year) a transport model calculation at the beginning of the time step and at the end of the time step. The IRPUD transport model is rather aggregated and does not have a long running time like most transport models; such frequent interaction poses therefore no practical problems with computation.

The current run time of the NMS is an obstacle to develop a frequent dynamic interaction (for example yearly) between the transport model and land-use model. In an expert workshop on LUTI-models there was consensus among the experts that the transport model needs to run at least once every five years (RAND, 2003a). This is considered sufficient to capture changes in transport performance. An interaction between the land-use model and the transport model once every five years reduces the problem of calculation time considerably. In addition a fast version of the NMS has been developed to operate within the TIGRIS XL model. In this version the spatial detail of the transport model has been aggregated from 1308 zones into 348 zones. The TIGRIS XL model can run both the fast and full version of the NMS.

The socio-economic segmentation in the demographic module of the TIGRIS XL model is consistent with the segmentation in the NMS. For other modules in the TIGRIS XL model more aggregated social-economic segmentation might be used in combination with conversion tables.

5.2.1 Accessibility indicators

Accessibility is the main 'effect' of a transport system influencing spatial settlement; it further facilitates economic and social activities and supports welfare. In addition accessibility is a spatial phenomenon and it serves as a location factor influencing the advantage of a region relative to all other regions. Indicators of accessibility measure the benefits households and firms in a region enjoy from the existence and use of transport infrastructure relevant for their region, (SASI final report 2001). A key task of a LUTI-model is then to address the effects of changes in the transport system on land-use. Selection of appropriate accessibility indicators for households and firms is therefore an important step.

A detailed overview of accessibility indicators can be found in Hilbers and Verroen, (1993), or in Geurs and Ritsema van Eck, (2001). Geurs and Ritsema van Eck categorizes accessibility measures into three groups following different perspectives, those are:

1. Infrastructure-based accessibility measures: those are used to analyze the (observed or simulated) performance of transport infrastructure;

2. Activity-based accessibility measures: those are used to analyze the range of available opportunities with respect to their distribution in space and the travel impedance between origins and destinations. Activity based measures can be further subdivided into geographical (or potential) and time-space measures;
3. Utility based accessibility measures: those measures are used to analyze the benefits individuals derive from the land-use transport system.

In this research the utility-based accessibility measures have been selected as the preferred accessibility measure. Reasons for this choice are:

- Utility-based accessibility indicators are rooted in economic theory and follow the principle of utility maximization. Therefore the behavior of these accessibility measures is consistent with rational economic behavior;
- The utility-based accessibility measures fit nicely into an economic evaluation framework such as a cost – benefit analysis. The changes in utility between policy run A and a reference run can be calculated. Such change in consumer surplus can be transformed, e.g. by a cost coefficient into benefits in monetary terms;
- The utility-based accessibility measures can also cover a nested structure as shown by Zachary's theorem (Daly and Zachary (1976)). In such a nested logit the integral of the probability function is the logsum and this can represent for example the utility of combined mode- and destination choices. This option facilitates the integration of multiple choices in one value, hereby reflecting the relative importance of each option.

Combinations of activity-based and utility based accessibility indicators exist as well. Daily activity patterns have been included in the utility measures in the work of Bowman and Ben-Akiva (1998) or Dong et al. (2005). The approach includes activity-based travel choices throughout a whole day activity schedule, and thereby covers multiple choices for multiple trips conducted in different time periods of a day. The foundation in micro-economic theory, via calculation of utility measures, differentiates this work substantially from other work on activity based accessibility measures, e.g. Kwan (1998) or Miller (1991), originating from Hagerstrand's theory on time-geography.

5.2.2 Accessibility in TIGRIS XL

The utility-based accessibility measures for TIGRIS XL are derived from the National Modeling System of the Netherlands. The NMS is a discrete choice type of transport model based on micro-economic utility theory. With such a model it is possible to generate a logsum value, an aggregate value expressing the utility from multiple alternatives. Well-known references for such type of models and the logsum variable are McFadden (1981), Ben-Akiva and Lerman (1985), and Daly and Zachary (1976).

The utility-based indicators in TIGRIS XL include personal characteristics and preferences, besides characteristics of the transport and land use system, to capture observed heterogeneity across individuals. Including the individual component of accessibility means that more realistic accessibility indicators, namely accessibility indicators closer representing the specific activity pattern and preferences of the households or firms, can be included as explanatory variable in residential or firm location choices. A limitation of the accessibility indicators in TIGRIS XL is that there

is no interaction with the daily activity schedule of households. The number of activities per person per day is unaffected by changes in the transport system.

The NMS produces person type, and purpose specific, logsums. These logsums express the utility of different modes and destinations. The logsums are calculated in the combined mode – destination zone choice module of the NMS. In formula:

$$L_{pco} = \ln \sum_i \exp[V_{pcoi}] \quad \text{Equation 5-1}$$

Where $L_{p,c,z}$ is the logsum of purpose p , person cohort c in NMS origin zone o , V is the systematic part of the utility by purpose p , person cohort c , origin zone o and combination of mode and destination zone i .

Logsums by household types in residential location choice module

Residential location choice decisions are made at a household level and therefore depend on the composition, number and type of persons, of a household. In a first step the tour-based logsum values are transformed into person type specific logsum values depending on the tour generation characteristics of the person types. Secondly the person type specific logsum indicator, need to be transformed into household type specific logsum indicators. The following formula has been applied to calculate utility accessibility indicators by household type, purpose and origin zone:

$$L_{hpo} = \sum_c \xi_{pcho} * L_{pco} \quad \text{Equation 5-2}$$

where L_{hpo} is the logsum for household type h , purpose p in NMS origin zone o . The household type specific logsum depends on the household members. In Equation 5-1 person type specific logsum values are calculated, where L_{pco} is the logsum of purpose p , person cohort c in origin zone o . L_{pco} needs to be summed for the numbers of tours and the match between person types and household types. The so-called person to household type fractions are used to derive values for ξ_{pcho} , where ξ_{pcho} is average number of tours for purpose p , by person cohort c , as part of household type h , and origin zone o . All logsum values are for an average working day. The fractions of person types by household type are available in the National Model System; they have been derived from the national travel survey.

“Reflected” logsums to measure accessibility of business locations

In TIGRIS XL the labor market uses also utility accessibility indicators to represent the accessibility of a location for business trips or commuting. These accessibility measures are not related to the activity pattern of companies, due to a lack of information on this and the enormous diversity in travel behavior between firms. The accessibility indicators can be considered as purpose (business or commuting) specific, and reflect the accessibility to other businesses or employees for firms in specific zone. The accessibility indicator for the travel purpose business is origin based and calculated in a similar way as in Equation 5-1.

The accessibility measure for travel purpose commuting is more complicated than the other measures. The challenge is here to estimate destination accessibility given measures of origin accessibility. A location choice criterion for firms is the

accessibility of employees and in particular employees with the right skills and wage demands. It is however unrealistic to demand such level of detail from existing transport models; the labor force will not be differentiated by skills of employees. Second point is that the transport model such as the NMS, depict commuting as a tour originating at the residential location of the employee. The transport choices are thus modeled from the perspective of the employee.

For the accessibility measure “commuting” for firms it is necessary to use a destination-based model instead of an origin based model, as used for the previous accessibility measures. The destination-based choice model should be operational as utility maximization model as well to ensure that the accessibility measures will behave themselves consistent with economic intuition. In this set-up it is assumed that the accessibility of employees for an employer depends on the number of employees and takes into account travel utilities involved between the residential and work location. Locations with ample supply of employees in the surroundings are therefore more attractive than locations without such supply of employees in the near surroundings. Under this assumption the model can be specified.

Equation 5-3

$$L_{pd} = \ln \left[\sum_c \sum_o N_{ocp} \exp[V_{pcdo}] \right]$$

where L_{pcd} is the logsum accessibility indicator for destination zone d and purpose p (commuting in this case). The value of the logsum indicator depends on N_{kpc} the number of tours produced in origin zone o by person cohort c and purpose p and the logsum value of these tours. The logsum value of these tours depends on the travel utility between the origin and destination zone; the travel utility consist of a logsum over travel modes. Travel utility V_{pcdj} , where o is the origin zone, p purpose and c cohort. This destination logsum is called the “reflected logsum”. As can be observed, the specification for the reflected logsum has a similar form as the origin based model.

The “reflected logsum” specification in Equation 5-3 includes an additional assumption: competition between firms for employees is ignored and a firm searching for employees is not affected by the existence or absence of firms in other destination zones. The utility of a tour originating in origin zone o is unaffected by the other opportunities from zone o . This model will ignore that a zone that has many opportunities will contribute less to accessibility of destination zone d than a zone with the same travel utility and number of generated tours but with fewer opportunities.

It is questionable whether such interactions, as competition between actors in the labor market, should be included in the accessibility measure. In principle, accessibility of a location should be treated as only one of the explanatory variables in the location choice function of firms and additional variables are needed to represent the whole attractiveness of a location. These other explanatory variables can include issues like level of competition, for example, by using a variable expressing the presence of other economic activities in the region.

Travel time indicators

The housing market is a geographical market and the number of interactions decreases with distance (or increased resistance). Transport plays a role in defining the size of the housing market, as it influences the resistance between two locations. In TIGRIS XL a travel time indicator is used to express the resistance for a residential move between old and new location. The travel time indicator differs by household type and a distinction is made between employed and unemployed household. For employed household travel times for the purpose commuting are representative and for unemployed households travel times for the purpose “other” are representative.

Two steps are needed to calculate the average travel time by purpose. In the first step an aggregation, over time of day periods in the NMS, is needed to calculate the average travel time by car.

Equation 5-4

$$T_{odp,car} = \frac{\sum_{ToD} (N_{odp,car,ToD} * T_{odp,car,ToD})}{N_{odp,car}}$$

where $T_{odp,car}$ is the average travel time by car for a working day; a weighted summation has been applied to incorporate time of day differences in travel time by car. The NMS distinguishes three time periods (ToD), morning peak, evening peak and rest of day, and the travel times by time period are weighted with $N_{odp,car,ToD}$ the number of tours by car for that time period per origin and destination relation od relation and purpose p .

In a second step the travel time is calculated as an average over the various modes of transport.

Equation 5-5

$$T_{odp} = \frac{\sum_m N_{mp} * T_{odpm}}{\sum_m N_{mp}}$$

where T_{odp} is the average travel time between origin zone o and destination zone d , with mode m for purpose p . The average daily travel time T_{odpm} for the car mode is obtained from Equation 5-4, for the other modes this is not needed as they do not vary by time-of-day. The purpose “dimension” is not aggregated because the dominant purpose and associated travel times differs for different household types. For example, the purpose “commuting” will be important for employed households. Not because of the wish to travel between the old and new house, but because of the likelihood that these households are employed nearby the former location. Travel times for the purpose “commuting” are generally larger due to a high number of movements in the congested morning and evening peak periods.

Accessibility freight transport

For several economic sectors accessibility for freight transport might play a role in their location choice and an accessibility variable for freight transport is needed. The NMS is primarily a passenger transport model and only freight movements by truck are included in the assignment phase to calculate congestion on the road network. The freight accessibility indicator for TIGRIS XL will therefore be only addressing road freight transport. The freight accessibility indicator $F_g(t)$ expresses how centrally municipality

g is located within the Netherlands for road freight transport (a municipality usually contains several zones), as follows:

Equation 5-6

$$F_g(t) = \left(\sum_d \sum_{o \in g} \frac{E_o(t)}{E_g(t)} * E_d(t) * Tf_{od}(t) \right)^{-1}$$

Where $Tf_{od}(t)$ is the travel time for road freight transport at non-peak hours between origin zone o and destination zone d . The travel time values are based on the NMS. A weighted summation is used to transfer the zonal travel times into municipality values; the travel times are weighted with $E_d(t)$, number of jobs in destination zone d , and the share of employment in the origin zone $E_o(t)$ in the total employment of a municipality $E_g(t)$.

The formulation, as presented in Equation 5-6, of the freight accessibility variable is simplistic in nature; it follows a gravity type of formulation and addresses only road freight transport. This makes the current version of the TIGRIS XL model not qualified to analyze the land-use effects of transport changes in rail freight or inland waterway transport.

5.3 Demographic module

Several national scenarios are available (e.g. CBS/CPB, 1997) for demography in the Netherlands. For the TIGRIS XL model these existing national projections of the demographic changes are used as input, however this is not sufficient due to the spatial nature of its markets. Demographic developments at a local level are likely to differ substantially from national changes. For example, a zone with a relatively old population will have a higher mortality and lower birth rate than the national average. Demographic projections are not affected by demographic features such as age structure alone, other features, be they cultural or economic, have a significant effect as well. For example, ethnicity and religion are important characteristics influencing the birth rates per woman (Duin van et al., 2006).

A demographic module projecting the demographic changes at a detailed zonal level is therefore needed to generate demographic projections with sufficient spatial detail for the markets in TIGRIS XL. Integration of the market modules of TIGRIS XL with existing spatial demographic models for the Netherlands, such as PRIMOS (Heida and Gordijn, 1985; Heida, 2003) or PEARL (Jong et al., 2005), is not an option due to the endogenous modeling of household moves within TIGRIS XL. An endogenous modeling of household moves is needed to model the interaction between the housing market and transport. And as such an exogenous projection of demographic developments is not an option for LUTI-models.

Therefore the demographic module has a central position within the TIGRIS XL model. Demographic changes in the composition and size of the population are an important driver of change in other markets within the TIGRIS XL model. This comprises:

- Demographic characteristics like number of people, age, household composition which are important variables to estimate the number of tours and their purpose;

- Demographic forecasts and housing market demand forecasts are strongly related issues, both from a quantitative (number of houses) and a qualitative perspective (type of houses);
- For the labor market, demographic projections and supply side forecast for the workforce are closely related. The labor participation ratio of a person cohort co-depends on demographic features such as age, gender and household composition.

Figure 5-5 presents an overview of the input and output flows of the demographic module. In this figure the abbreviations are as follows; t is time, nl is Netherlands, C is COROP region, and z is zone.

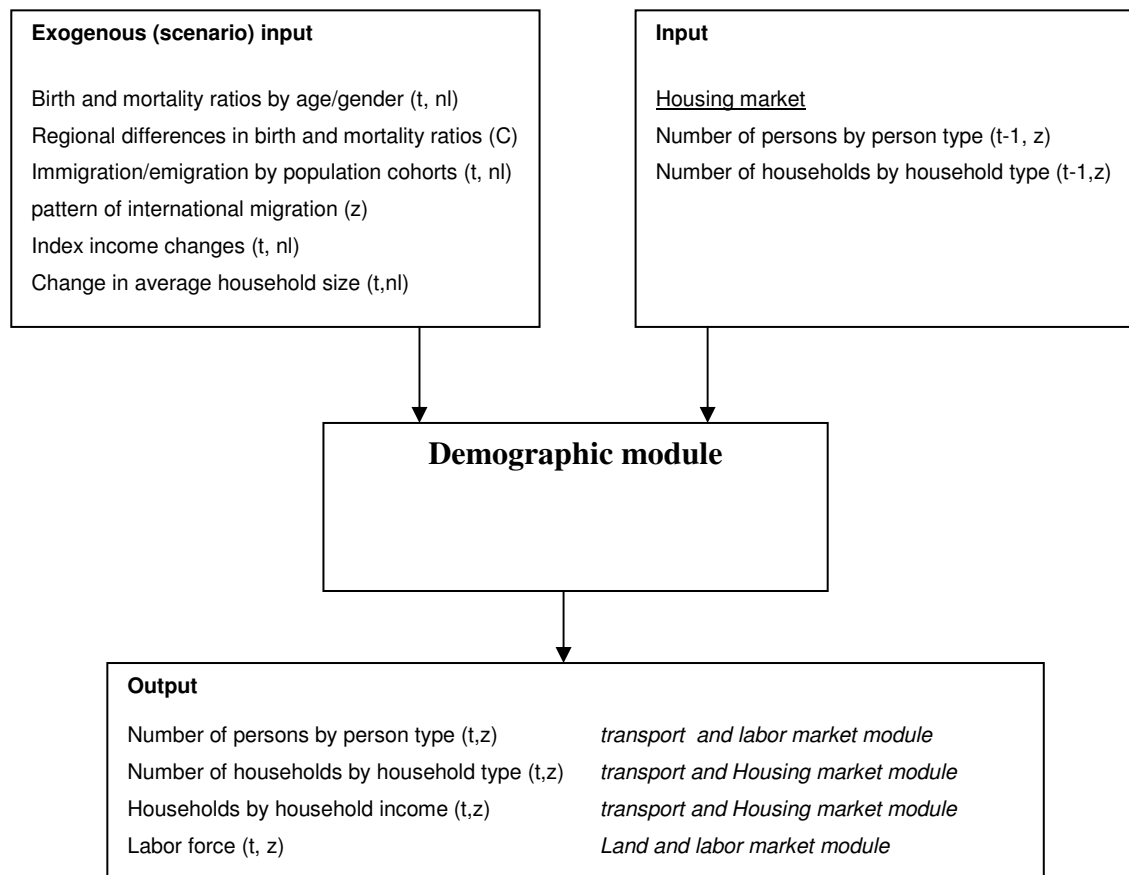


Figure 5-5: interactions of the demographic module

5.3.1 Method

The demographic module in TIGRIS XL calculates changes in the number of persons and households by segment resulting from international migration and demographic processes. Changes in number of persons and households by segment resulting from domestic moves are calculated in the housing market module. At the end of housing market module the number of persons and households by segment are updated by zone. The calculation steps or sub-modules within the demographic module are presented in Figure 5-6.

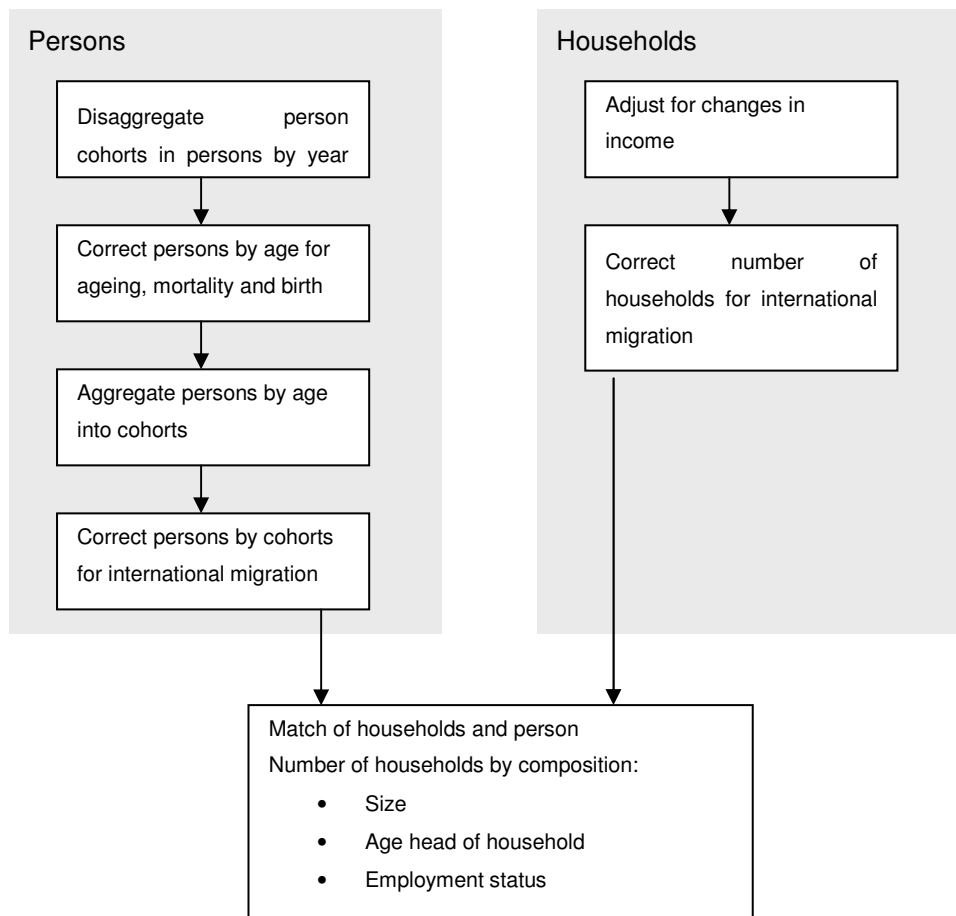


Figure 5-6: flow diagram of the demographic module

International migration

International immigration and emigration are forecasted and distributed exogenously over the zones. Existing scenarios for international migration at the national level can be implemented. For the distribution of immigration and emigration flows over the zones the user can input a pattern. An option, implemented in the prototype version of TIGRIS XL, is to generate such a pattern from historical data on the location choice of immigrants.

Person types

In the NMS model population cohorts are used to segment the population by age group (0-14, 15-34, 35-65, 65+) and gender. Within the demographic module of TIGRIS XL detail is used in the population segments, comprising number of persons by gender and year of age. In this way TIGRIS XL takes advantage of available data from Statistics Netherlands (CBS) on age (by year) and gender specific birth and mortality rates for the year 2000. Additional CBS sources are used to include a temporal and spatial component in these demographic figures. In TIGRIS XL, changes in the number of persons by person type are calculated each year by zone.

Data of the CBS on future trends in birth and mortality rates are used to adjust base year birth and mortality rates by age and gender. For example, a man of 70 years has a different mortality ratio in 2000 than in 2020. In this way the model can handle issues such as the land-use and transport effects of increased life expectancy. CBS data on

COROP specific birth and mortality rates, by five-year population cohorts, is used to differentiate by region. Regional differences in demographic features, resulting from various reasons such as the social and cultural environment, can be substantial and for an adequate calculation it is necessary to include region specific features.

Household types

The household type segmentation of TIGRIS XL targets to include key household characteristics of importance to explain differences in behavior at the housing market. A study of Clark et al. (1990) uses the household characteristics, income, age of householder, marital status householder, size of household, own children under 18 and race of householder as predictors of housing choice. The URBANSIM model uses income, age of head, persons, workers and children as household characteristics in its Eugene-Springfield application (Waddell, 2002). A paper of Cheshire and Sheppard (1998) highlights the importance of household income to explain housing demand characteristics. Of course other, less measurable, household characteristics such as life styles (Pinkster and van Kempen, 2002) are important to explain residential preferences as well. However it is not possible to apply such feature for the whole population as relevant data is missing. Based on available data, integration with the NMS and the literature above the segmentation of household types in TIGRIS XL classifies households by number of workers, size of the household, age of the head of the household and household income.

Household formation, dissolution and transformation are not endogenously modeled. The complexity of underlying processes like marriage, living-together, divorce or separation, or death of a single household member and data restrictions on these processes prevent such an approach. Household transformations are included at an aggregated level and the total number of households per zone is affected by the ongoing trend of a reduction of the average household size.

Matching persons and households

In the demographic module a quadratic minimization procedure is used to match person and households. As input aggregated zonal targets, like the total number of households or male residents between 0 and 15, are used. These targets are matched with a prototypical sample for observed fractions of persons by household types. The fractions of persons by household type have been derived from the National Travel Survey as part of the NMS development. In TIGRIS XL the procedure and data of the NMS have been adopted. A difference is that within TIGRIS XL the zonal targets are yearly updated based upon the calculations in the demographic-, housing market and labor market module. The quadratic minimization program in TIGRIS XL also runs yearly to match the updated zonal targets and the pattern of fractions as close as possible (see RAND Europe, 2004).

5.4 Land-use and real estate market

The land-use and real-estate market module in TIGRIS XL calculates the changes in land-use by type, office space and housing stock. The land-use sub-module produces the changes in land-use by type. Depending on the land market regime assumption, this calculation varies from (exogenous) scenario input, to endogenous based on the market

situation as calculated in the housing market module. In the real-estate sub-module the land-use changes, from agricultural into residential, are transformed in numbers of new houses.

Figure 5-7 presents an overview of the input and output flows of the land-use module. In this figure the abbreviations are as follows; t is time and z is zone.

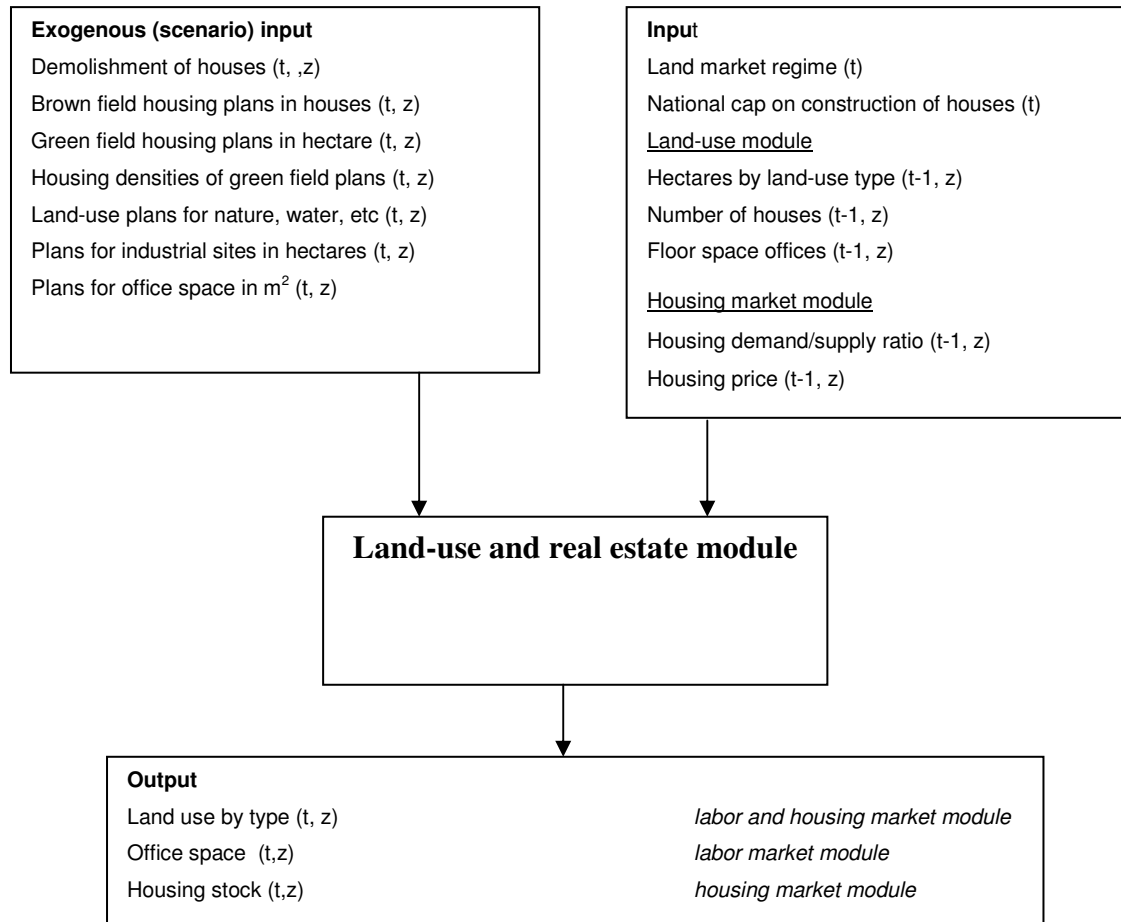


Figure 5-7: interactions of the land-use module

5.4.1 Land market regime

The discussion in sub-section 5.1.4, on land market regulation, calls for the design of a land market module capable of handling different levels of market regulation by the government. In TIGRIS XL the land market module has been set up in such a way that the model can calculate the spatial impacts of different land market regimes. The user has several modeling options for the level of government influence on spatial development. The land market regime is specified by year and alternative land market regimes can be chosen for the short and long term. The land market regime options in TIGRIS XL are, as follows:

Regulated land market regime

Under this regime spatial developments can only take place on planned locations. Changes in land-use and housing density are specified exogenously.

Flexible plans (semi-regulated land market regime)

Under this regime, land-use plans are specified exogenously, similar to the regulated land market regime. However, the size of development plans depends on demand factors. This option might refer to actual developments where highly attractive regions tend to develop faster than permitted and plans are not always realized in their full scope on less attractive locations. In the modeling a constrained is used to limit the flexibility of the plans; and plans in highly attractive areas can grow maximally by a factor of 1.5 (this for VA/BF values of above 1.5), and plans in unattractive areas are realized minimally by a factor 0.5 (this for VA/BF values of under 0.5).

Equation 5-7

$$\Delta G_{r,z}(t) = \frac{VA_{z,t-1}}{BF_{z,t-1}} * Pl_{r,z}(t)$$

Where $\Delta G_{r,z}(t)$ is the change in land (hectares) for residential use r , in zone z at time period t . $Pl_{r,z}(t)$ are the land-use plans of the government for residential use r , in zone z at time period t . The factors BF and VA are both indicators for the housing demand/housing supply ration in zone z at a previous time period ($t-1$, time periods are one year). The reason to use both factors is technical in nature; it enables that both factors can be taken after the final iteration in the housing market module, to match housing demand and supply, and there is no need to store intermediate results.

BF is the balance factor actor from the housing market module, which is 1 in the first iteration for all zones at the housing market. If housing demand exceeds housing supply in the first iteration for zone z than in the second iteration the BF value for zone z will be lower than 1 to reduce the attractiveness of this zone. VA is the housing demand/housing supply ratio for zone z at time $t-1$. This factor is affected by the BF factor; for zones with a high VA ratio in the first iteration, the BF factor will decline in the second iteration and subsequently the VA factor will also be lower in the next iteration. The factors used in Equation 5-7 are the final values after the last iteration at time $t-1$.

Zoning policy

The government gives, under this regime, a particular status to zones, e.g. residential construction permitted or not, but the actual realization depends on the market. The zoning policy can be used to allocate large areas as potential location for new developments and market forces determine the size and exact location of such development. This setting can also be used to apply different planning regimes for different areas within the country. For example, in the high density Western part of the Netherlands, a strict zoning policy can be followed in line with the regulated development, and in the more Northern part of the Netherlands the zones can be as large as all agricultural land.

In the modeling zoning or contour policies are specified by zone as $C_z(t)$, the maximum amount of available developable land at time t in NMS zone z . Under this market setting the change in land-use, from agricultural into residential, is calculated as follows.

Equation 5-8

$$\Delta G_{r,z}(t) = \min\{OD_z(t-1)/HD_z(t), C_z(t)\}$$

Where $\Delta G_{r,z}(t)$ is the change in hectares of agriculture land-use into residential land-use r in NMS zone z at time period t . The changes depend on the demand surplus in the housing market $OD_z(t-1)$ for NMS zone z at time $t-1$ as calculated in the first iteration of

the housing market (following an iterative procedure the allocation module will improve the match between supply and demand at the housing market, see sub-section 5.5.5). Further the change in hectares of land in a zone depends on the housing density $HD_z(t)$ for new residential sites in zone z at time t . The change in hectares of land into residential land is restricted by the maximum amount of available developable land in zone z at time t , $C_z(t)$.

Free land market regime

Under this regime spatial developments and changes in housing supply follow the preferences of households. The construction of new houses is only restricted by availability of land (agricultural land). The formulation for the free market is similar to Equation 5-8; only the maximum available developable land at time t in NMS zone z does not depend on the contour policy $C_{c,z}(t)$, but on agricultural land in the zone $G_{a,z}(t)$.

Discussion of land market modeling

The land market- and real-estate market mechanisms as discussed above simplify these complex markets into a simple market with two actors, a government or housing supplier and households seeking a house. In reality the interactions at the supply side of the housing market are complex and include various government agencies (with sometimes conflicting agendas), developers, financial institutions and landowners. An in-depth modeling of the supply would require the modeling of processes like land speculation and negotiation. This issue falls well outside the boundaries of this research.

5.4.2 Housing stock

Changes in the housing supply depend predominantly on the functioning of the land market. In a regulated land market planners have an important impact on the supply of houses through the control of the supply of land available for new housing construction. Planning constraints restrict the functioning of the land market and high housing demand does not automatically lead towards the construction of additional houses. Conversely in a free market, the supply of houses will respond, via a time lag, to changes in housing demand and the construction rate will depend on the housing prices in the market and the land and construction costs.

In reality completely regulated and completely free land markets do not exist and some kind of mixture exists. It should be noted that it is very difficult to model the supply side of the housing market in the Netherlands in its full complexity; due to strategic/speculative behavior of landowners and project developers and complex negotiations between municipalities and these project developers or landowners. Within TIGRIS XL a simplified approach has been adopted to address demand and supply interactions (see sub-section 5.4.1). Such an approach is needed because in reality transport policies also have an impact on the location of construction of new houses. This influence of transport policies on the location of new houses needs to be included in the modeling to capture the full effects of transport on housing location. Sub-section 2.1.2 illustrated that even in tightly regulated housing markets the location of construction of new houses is affected by demand preferences of the households.

The above discussion has focused on so-called green field developments, but a large number of the developments take also place at so-called brown field locations; specified as locations within the existing urban areas. Densification- and urban renewal projects are important housing market policies of the Dutch government. In the modeling there

is no endogenous modeling of brown field developments but a number of houses on brown field locations can be specified as part of the housing policy.

Overall the housing stock for a zone within the TIGRIS XL model changes by green field housing construction, brown field housing construction and demolishing of houses.

5.4.3 Supply of industrial sites and office space

In the TIGRIS XL model the supply of the labor market, office space and industrial zones, is assumed to follow demand. If demand exists for a certain location, calculated by firm location preferences, it is assumed that supply of space will be created. This assumption is supported by the following observations:

- Location refers here to rather large areas or regions. In such a large area there is always space available to create supply of industrial land or offices. This might not be the case for zones at a lower level of spatial detail;
- The current practice that virtually all municipalities compete with each other to attract employment is unchanged;
- The high vacancy rates in office space, and ambitious plans of most municipalities for more office space, as presented in the new map of the Netherlands (NIROV/Ministerie van VROM, 2006), illustrate that supply shortages for the service sector are rather unrealistic;
- The assumption is however rather questionable for specific types of industries with a high negative impact on their surrounding. Environmental regulations and resistance by the population makes the assumption for these sectors unlikely. The size of these economic sectors is rather small;
- Another pragmatic argument is that good data on office supply is missing in the Netherlands, especially the registration of office space on informal, non-industrial or commercial locations is missing at a national level.

5.5 Housing market

One of the spatial markets with a strong influence on land-use changes is the housing market. The housing market can be disentangled as follows:

- a demand side: households searching for a place to reside;
- a supply side: number of residential units or more precise the number of vacant residential units;
- a market clearance mechanism.

For example, in a free market a price adjustment mechanism is used to match supply and demand and reach equilibrium within one time step. In this section each of the components of the housing market, and the key features are discussed, focusing on how these components are made operational in the TIGRIS XL model.

The aim of the housing market sub-model is to model the moves of the households and to simulate the impacts of transport measures on these moves. The housing market model aims to make two important contributions to the field of transport policy

analysis. The first contribution is that the model simulates the moving behavior of households such that alternative quantitative spatial projections can be generated as input for transport analysis. The model operates at a similar spatial level as the NMS (see sub-section 5.1.5) and there is consistency in base year data and segmentations between the two model components. The second contribution is that the impact of transport on household moves is explicitly estimated. The housing market sub model can be used to model the structuring impacts of transport measures on the spatial distribution of the population.

An essential feature of TIGRIS XL is that the housing market module operates within a larger framework for land-use and transport studies. The design of the sub-model takes into account the interactions with other modules like land-market, demography, labor market and transport market (see Figure 5-8). The housing market sub model has not been designed to evaluate specific housing market policies, such as urban renewal projects or taxation and subsidy policies. It primarily models those elements of the housing market, which influence the spatial distribution of residents; it ignores, for example, income effects of different housing market policies.

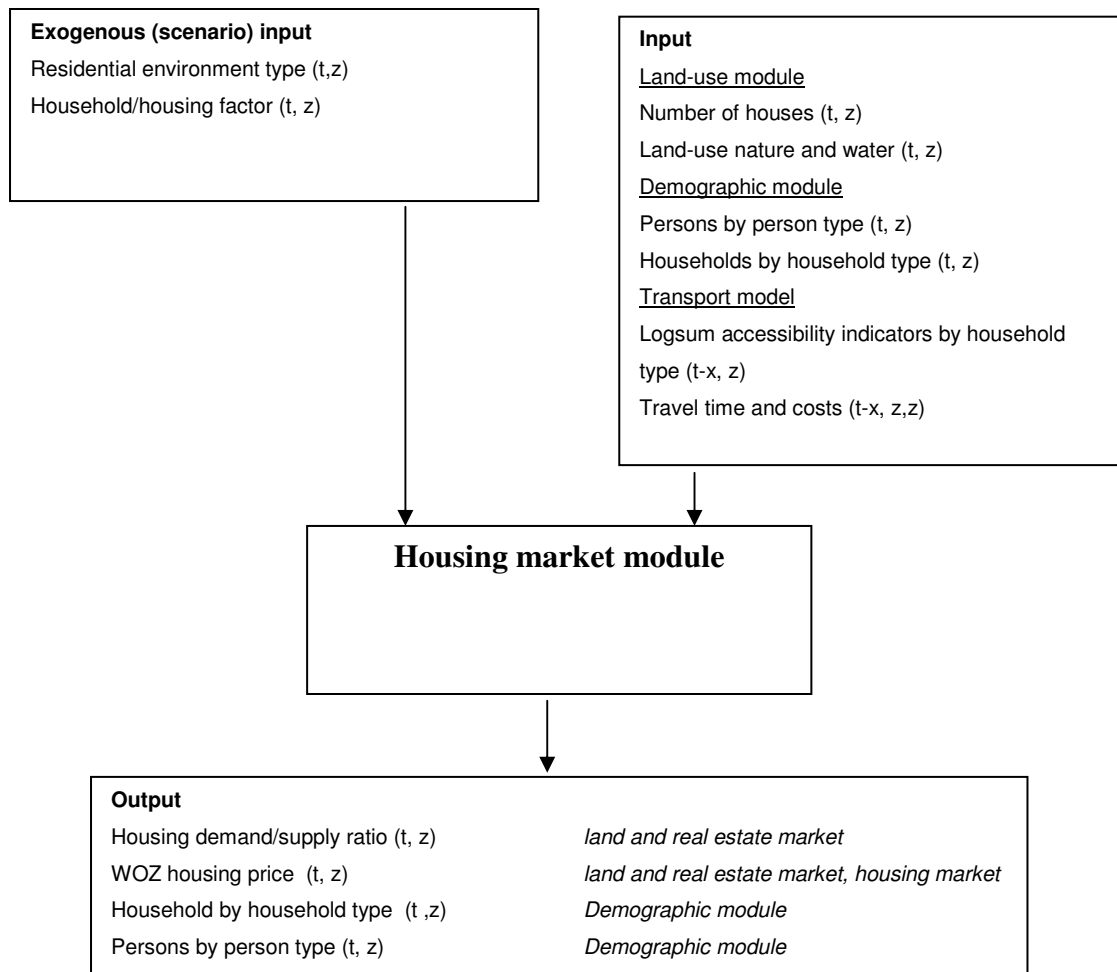


Figure 5-8: Interactions of the housing market module

5.5.1 Housing market demand

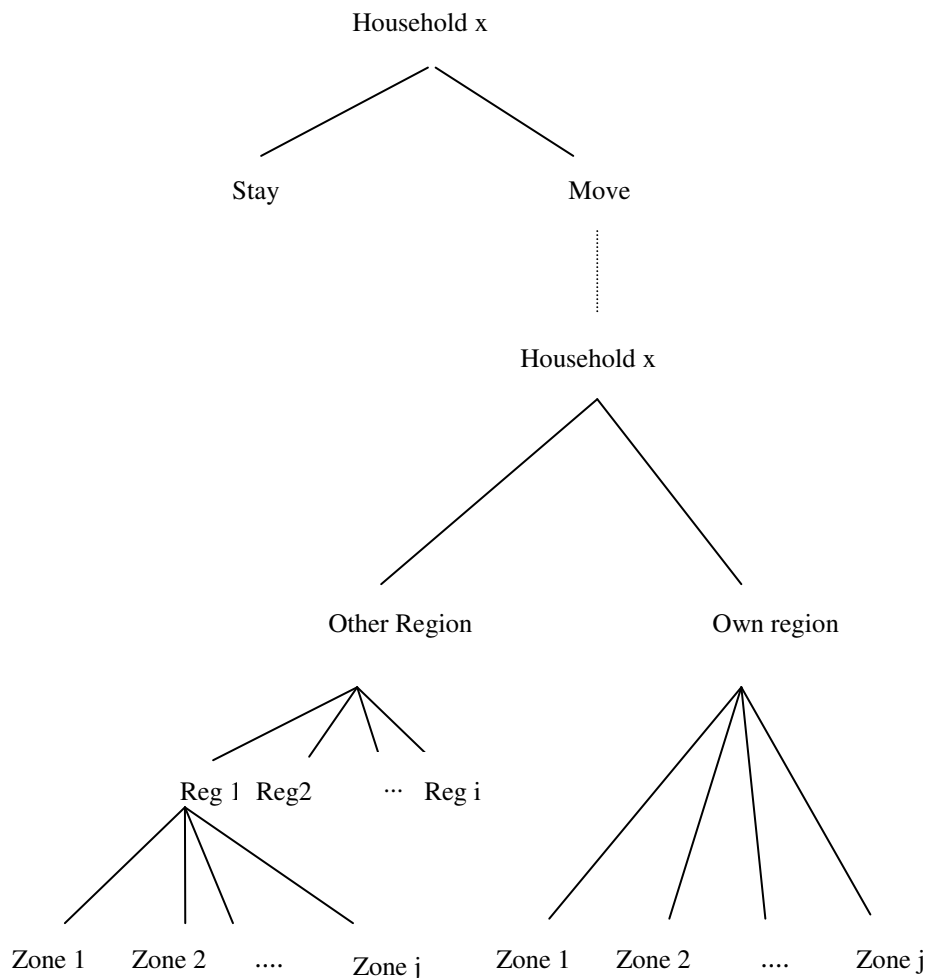
A review of the theory (see sub-section 3.2.3) and existing LUTI-models (see sub-section 4.2.3) shows that incremental models in comparison with equilibrium models appear to have more strength in explaining how the urban system progresses over time and what the main drivers are. As mentioned before an important trade-off in considering these incremental models is that these models are normally less well-rooted in economic theory. TIGRIS XL is an incremental model and as such the housing market modeling will focus on the changes rather than on explaining the current situation.

Important features for the housing market modeling in TIGRIS XL, resulting from its integration within a wider model, are:

- As mentioned before, the modeling of the housing market will be at the level of NMS zones to be consistent with the transport modeling;
- The modeling of individual houses as objects or houses by type classification is outside the scope of this research;
- A two-layered spatial approach, including a regional and transport zone level, is used to test different explanatory variables affecting long distance, inter-regional

moves, and short distance intra-regional moves. Such division results from the requirement to operate TIGRIS XL both for national and regional studies.

The modeling of the demand side of the housing market considers the household level as decision-making unit; housing mobility and location decisions are household decisions (Wegener, 1983). Figure 5-9 presents the various steps at the demand side of the housing market. First a household makes a decision to move or stay. Once a household decides to move, this household enters the residential location choice module. The residential location choice module has a nested structure: a household chooses first a region and subsequently a specific zone within a region.



i = number of regions (40)

j = number of zones in a region, total number of zones in NL is 1308 zones

Figure 5-9: Structure of the housing market module

The national housing market survey, the so-called WBO-2002 survey (website VROM 2003), in the Netherlands was used as primary data source to estimate both the move/stay module and the residential location choice module. The national housing market survey is a four-annual survey comprising over 100 thousand records. The survey contains Revealed Preference as well as Stated Preference information on the move/stay decision. The households were asked whether they have made a move in the

last two years, and if so, from which location to which location, and the households were further asked if they were planning to make a move in the next two years. The residential location choice is only addressed in the Revealed Preference part of the survey. Further it should also be noted, because of constraints and lack of opportunities on the housing market, a large discrepancy exists between stated preferences and actual behavior (Oskamp, 1997). In this research only the Revealed Preference information from the WBO-survey was used.

The key advantage of the WBO-2002 survey, in comparison with previous surveys, was that the records were coded at a very detailed spatial level, namely the four digit postal zones, which is even finer than the transport zone level. For the TIGRIS XL model this means that it was possible to estimate the housing market module at the level of transport zones. In this way the geographical dimension of the land-use model coincides with the transport model and the impact of accessibility at the zonal level on the move/stay decision and location choice could be tested.

In the housing market module the logsum has been used as accessibility indicator (see sub-section 5.2.1 for description of logsum). The transport model also contains substantial detail in its social-economic segmentation and therefore household type specific logsums, consistent with the activity pattern of the household members, were generated for six household types in the residential location choice module. A wide set of other explanatory variables were included in the move/stay and residential location choice model estimation to determine the relative importance of accessibility versus other variables.

5.5.2 Move/stay choice model

A household making a decision to move or to stay in the current residential unit makes a discrete choice. The micro-economic utility theory assumes that such a household will make a rational decision and chose the option with the highest utility. However, because consumers (i.e. households in this context) are diverse, i.e. have different preferences, the alternative that gives maximum utility may be different for different consumers. Furthermore it is not possible to measure the utilities perfectly; any predictions of choice can therefore be made only in the form of probabilities.

The above observations form the basis of the Random Utility Model framework, in which consumers are represented as utility maximizers, but that this utility is considered random, to reflect that the analyst cannot measure the utilities perfectly or that the consumer does not act consistently. McFadden's 1981 publication presented the mathematical formulation for the link between the random utility model, choice models and welfare functions.

The move/stay choice model in TIGRIS XL is a random utility model. Equation 5-9 is an equation for the utility of staying.

Equation 5-9

$$\begin{aligned} U_{zh}(s, t) &= V_{zh}(s, t) + \varepsilon \\ &= \alpha \cdot \mathbf{X}_z(t) + \beta \cdot \mathbf{X}_h(t) + \varepsilon \end{aligned}$$

where $U_{zh}(s, t)$ is the utility that a household to stay in zone z at time t . The utility depends on an observed part $V_{zh}(s, t)$ and a non-observed part ε . The observed part consists of both attributes for the zone $\mathbf{X}_z(t)$ and attributes for the household $\mathbf{X}_h(t)$.

The utility function, as specified in Equation 5-9, allows estimating the chance that a household will move. A binomial logit model is used to estimate this chance:

Equation 5-10

$$P_z(mo, t) = \frac{1}{1 + \exp[V_z(s, t)]}$$

where $P_z(mo, t)$ is the chance that a household living in zone z will make a move at time t .

The move/stay decision of households is mainly influenced by dynamic changes such as change of job/study or changes in the household composition (e.g. marriage, birth of child). Rossi (1955) showed a distinct correlation between mobility and the family life cycle, each stage leading to different housing demands, and therefore triggering moves. Based on the WBO data set it is not possible to estimate the move/stay decision on this type of dynamic changes between stages of the life cycle; such information is not available for the households deciding to stay. Therefore in the model estimation static variables, such as age or household size, were used to represent the household's characteristics.

The explanatory variables in the move/stay model are household characteristics, neighborhood characteristics, vacant houses in the region and accessibility. Table 5-1 summarizes the explanatory variables and includes a brief description. Column three and four of Table 5-1 present the estimation results consisting of the value of the coefficient and significance of variable (t-value); the table only includes significant variables. It can be concluded that all variables have, at a certain confidence level, a significant influence on the move/stay decision.

Table 5-1: estimation results explanatory variables move – stay choice model (coefficients refer to stay alternative)

Variable	Description	Coefficient	t-value
Cstay	Constant stay coefficient	0.473	4.7
HS2	2 – person households	0.212	7.1
HS3	3 – person households	0.759	21.7
HS4	4 – person households*	1.07	29.1
HS5	5 > person households*	1.08	23.6
Empl1	One person employed	0.0824	2.4
Empl2	Two persons employed	-0.509	-12.1
Inc2	Household income between €12639 and €20220	-0.101	-3.2
Inc3	Household income between €20221 and €30330	-0.177	-5.1
Inc4	Household income between €30331 en €42969**	-0.230	-5.6
Inc5	Household income €42970 > **	-0.244	-5.2
Age2	Age of head of household between 35 and 65 years	1.27	56.0
Age3	Head of household older than 65 years	1.93	42.2
NT_1	Neighborhood type 1	-0.0036	-5.8
NT_2	Neighborhood type 2	-0.0029	-5.8
NT_3	Neighborhood type 3	-0.0026	-4.3
NT_4	Neighborhood type 4	-0.0019	-3.2
PVH_C	Percentage vacant houses at regional level	-0.829	-2.0
Lszone	Logsum, accessibility current house	0.0172	5.7

*) Number of observations is 74191, Final log (L) is -31379, D.O.F. is 19 and Rho² is 0.390

**) Estimation results for 4-person households and 5+ person households are so similar that these groups can be merged.

***) Similar reasoning applies as under *) for Income category 4 and 5

Below some further explanation is given on the variables and their estimation results:

- *C-stay* is the constant coefficient for the utility to stay, although not explicitly modeled this refers to both social as well as financial transaction cost for moving;
- *Household size*, this attribute gives the influence of household size on the utility to stay. In the estimation procedure the influence of the household size categories: 2 person, 3 person, 4 person and 5+ persons, have been estimated in comparison with one-person households. The estimation results show that household mobility decreases with household size, especially up to 4 persons;
- *Employment situation of the household*, the households are classified in three categories regarding their employment status, namely, unemployed, one-person employed or two or more persons employed. The influence of the employment status (category two and three) of a household on the stay utility has been estimated in comparison with unemployed households. The results are mixed and show that households with one employed person are less likely to move than unemployed households and households with two or more employees are more likely to move than unemployed households;

- *Income*, the households are classified by income group depending on their household income. The influence on the utility to stay for the various household income categories has been estimated in comparison to the low-income category one. The results show that likelihood of household moving increases with the household income. Higher income households are more mobile and this is in line with their greater opportunities in the market;
- *Age head of household*, the age of the oldest household member, reflecting its position in the life cycle, is an important variable in explaining the chance of a household move (Oskamp, 1997). Important motives for a household move are study, employment (or change of job) and change in household composition (e.g. marriage, birth of children, death). Most of these changes occur more frequently for households at a younger age. In the estimation procedure the influence of the age variable (35-65, 65+) has been estimated in comparison with young households (age<35). The results show that the utility (or likelihood) of staying increases with age as expected;
- *Neighborhood types*, five different types of neighborhoods are identified and each zone in the model has been coded according this definition. The neighborhood classification consists of the following five classes: 1 urban center, 2 urban, 3 local village center, 4 local village green neighborhoods and, 5 country side. Each neighborhood class has its own characteristics for residential density, services, etc. The 4-digit postcode zones in the Netherlands have been classified based on this neighborhood type definition (www.ABFresearch.nl). The influence of the neighborhood type on the utility to stay has been estimated in comparison with neighborhood type 5 (rural area). General conclusion is that urban households are more mobile than rural households;
- *Vacant houses*, this variable addresses the opportunities in the surroundings of the current location of a household. The variable expresses the percentage of vacant houses in the region (COROP region) where the household resides. The negative coefficient for the stay utility shows that the likelihood of a move increases if the percentage of vacant houses in a region increases (e.g. via construction of residential units);
- *Accessibility*, a logsum variable is used to express the accessibility level of the current location of a household. The logsum variable is an aggregated variable summarizing the accessibility for all purposes and all households at that location (see 5.2.2). The coefficient of the logsum variable is positive, which shows that households are less likely to move from more accessible locations.

Overall the annual percentage of households moving to another house is around 9 percent in the Netherlands. Significant differences in the percentage of households moving exist between regions in the Netherlands, mainly because of differences in population segmentation and types of residential locations. Interesting outcomes of specific interest for policy makers are the estimation results for the variables vacant houses in the region and accessibility. It can be concluded that the percentage of vacant houses in a region has a significant impact on the dynamics of the housing market. This finding confirms an ongoing discussion in the Netherlands that supply side restrictions in the housing market seriously affect the dynamics of housing and labor market. Accessibility has a significant impact on the willingness of people to move from a location: less people are willing to move away from easily accessible locations than

from less accessible locations. This finding confirms the hypothesis that people are moving away from less accessible locations in the periphery of the country (ESPON, 2006).

5.5.3 Vacant houses

In the reviewed LUTI-models (see section 4.2) different approaches are followed in the construction of the choice sets, namely the number of available houses at time t . The equilibrium models consider all houses as an option, regardless of the existing occupancy rate, and other models consider only vacant houses as an option. In an equilibrium model all households find their equilibrium location within each time step. In these models household moves are not explicitly simulated.

In TIGRIS XL vacant dwellings are used instead of total number of houses or floor space to represent the opportunities for the house-seeking households. In a certain time period, for example a year, most of the dwellings are occupied (with household not considering a move) and cannot be considered as alternative options. Housing market models using total number of houses, for example the LASER 3.0 model in the Thames Gateway study (Department for Transport, 2003), are often less responsive to new residential locations than housing market models using vacant houses as size variable. A size variable is used to ensure that utility, and chance that a household will prefer a certain location, is proportional to the number of vacant houses. The reason for this is that housing market models using vacant houses are more closely representing the actual housing market supply conditions in a certain year, than models considering all houses as an option.

In TIGRIS XL the number of vacant houses in a zone depends on housing supply calculated in the land-use and real estate module by the number of houses, adjusted for changes in year t by demolition and construction of houses. Changes in housing occupation are calculated below. The changes in the number of households by type in a zone are calculated in the demographic module. Equation 5-11 uses both the information on the number of houses H from the land-use module and the number of households HH by type from the demographic module. The formula adds the chance that a household makes a move, and leaves a vacant house. Sub-section 5.5.2 presents the factors influencing the probability that a household will move or stay in a certain year at a specific zone. The household / housing factor HHf corrects for differences between the number of households and houses, for example in areas with many students. Overall the number of vacant houses VH in a zone depends on the changes in the housing stock and factors influencing their occupation such as demographic changes in the number of household and migration of households.

Equation 5-11

$$VH_z(t) = H_z(t) - \frac{\sum_h ((1 - P_{zh}(mo, t)) * HH_{zh}(t))}{HHf_z(t)}$$

where $VH_z(t)$ the number of vacant houses in zone z at time t is calculated as the number of houses $H_z(t)$ minus the number of occupied houses. The number of occupied houses depends on the number of households staying, calculated as chance that a household will stay multiplied by $HH_{zh}(t)$ the number of households in zone z by type h at time t . The probability that a household will stay is calculated as one minus $P_{zh}(mo, t)$ the chance that a household of type h , in zone z at time t will move. The number of

households staying in the zone is transferred into the number of occupied houses by $HHf_z(t)$ the household to houses factor for zone z at time t .

5.5.4 Residential location choice model

The residential location choice model in TIGRIS XL depends on the input, the number of household willing to move and the number of vacant houses, elaborated in sub-section 5.5.2. The residential location choice model can be described by some key features, which will be described in the text below. Important features of the residential location choice model in TIGRIS XL are:

- Random utility theory is used to model the location preferences of the households. This theory accounts for the probabilistic nature of residential moves;
- Households are segmented into social-economic groups to account for heterogeneity in residential location choice behavior;
- A large set of explanatory variables is tested in the model estimation phase to ensure an appropriate representation of the influence of transport on residential location choice. Important features are:
 - The location choice of a household is co-determined by its old residence zone. In this way, the spatial dimension of the housing market is explicitly included in the modeling;
 - The number of vacant houses (see housing supply) in a zone is included as a size variable. Each vacant house is assumed to be an option.

Nested logit model

Similar to the move/stay model, a discrete choice model has been used to estimate the residential location choice. The location choice preferences of the household have been estimated using a nested or tree logit structure (see Figure 5-9) and the model includes regional as well as zonal variables. The nest consists of three layers: at the highest level a choice is made between a move within the own region or outside the region; for the interregional move the utility depends on the utility of all other regions; the choice between the regions depends on the utility of the zones within the regions.

The work of McFadden (1978) shows that nested logit can be used as a special form of the GEV theorem. The nested logit model satisfies the conditions as stated in the GEV theorem. McFadden also derived the restriction on the nesting coefficients as < 1 for global consistency with Random Utility Maximization (if nesting coefficient is 1 than a Nested Logit model is similar to a Mutli-Nominal Logit model). In a nested logit model the inclusive value or logsum represent the utility of all alternatives within a tree branch and influences the choice probabilities at a higher level in the tree.

A nested logit model can be decomposed into a series of logit models; for the residential location choice model it can be decomposed in three logit models as it consists of three layers. Each layer of nesting in a nested logit introduces parameters (or nesting coefficients) that represent the degree of correlation among alternatives within nests. With the decomposition of utility, the nested logit probability can be written as the product of standard logit probabilities (Train 2003).

The residential location choice model calculates the probability that a household of household type h and moving out of origin zone o will choose destination zone d as alternative at time t . The probability of choosing zone d as part of subnest b_2 and nest b_1 can be expressed as the product of three probabilities (see Equation 5-12). The indice b_2 refers to one of the 40 COROP regions in the Netherlands, and b_1 refers to an intra-regional or interregional moves. $P_{oh}(b_1, b_2, d)$ is the joint probability that b_1 , b_2 and d are chosen.

Equation 5-12

$$P_{oh}(b_1, b_2, d) = P_{oh}(d \in b_2, b_1) P_{oh}(b_2 \in b_1) P_{oh}(b_1)$$

Equation 5-12 is the product of the probabilities, namely in reverse order: the probability that an alternative within nest b_1 is chosen, the probability that an alternative within subnest b_2 is chosen given that alternative b_1 is chosen, and the probability that alternative d is chosen given that an alternative in nest b_1 and subnest b_2 is chosen. $P_{oh}(d \in b_2, b_1)$ is the conditional probability of chosen alternative d given that an alternative in subnest b_2 and nest b_1 is chosen can be expressed as follows:

Equation 5-13

$$P_{oh}(d \in b_2, b_1) = \frac{VH_{dt} * \exp(\alpha_h X_{odt} + \beta_h X_{dt})}{\sum_{i \in b_2, b_1} VH_{it} * \exp(\alpha_h X_{oti} + \beta_h X_{ti})}$$

In Equation 5-13 the vacant houses VH_{dt} in destination zone d are included as a size variable. This means that the chance in the choice of a destination zone d doubles as the number of vacant houses doubles in destination zone d . The set of coefficients α and β are estimated for X_{odt} , attributes for the deterrence function between origin zone o and destination zone d , and X_{dt} attributes of the destination zone d at time t .

The probability of choosing the subnest b_2 and nest b_1 is affected by the parameters σ and τ , which are the inclusive value coefficient or so-called nest coefficients for the subnest and nest. The nest model structure is valid, globally consistent with random utility maximization, if the nest coefficient is between 0 and 1. τ is the nest coefficient for the higher level branch (see Figure 5-9), of which the inclusive value is $IV1$. σ is the nest coefficient for the lower level tree branch consisting of zones within a region, of which the inclusive value is $IV2$ (see Equation 5-14).

Equation 5-14

$$IV2_{ohb_2} = \ln \left[\sum_{i \in b_2} VH_{it} * \exp(\alpha_h X_{oti} + \beta_h X_{ti}) \right]$$

$P_{oh}(b_2 \in b_1)$ is the probability that subnest b_2 is chosen by household type h moving out of zone o at time t , given that nest b_1 is chosen, and can be expressed as follows:

Equation 5-15

$$P_{oh}(b_2 \in b_1) = \frac{\exp(\chi_h W_{b_2t} + \sigma_h IV2_{ohb_2t})}{\sum_{j \in b_1} \exp(\chi_h W_{tj} + \sigma_h IV2_{ohb_2t})}$$

Where χ is the set of coefficients estimated for $W_{b_2}(t)$ attributes of region b_2 at time t .

The alternatives at the higher branch are inter-regional and intra-regional moves, both are part of b_o . The inclusive value depends here on the utilities of the underlying

available regions (for the intra-regional alternative this is of course only one region). The inclusive value is calculated as follows:

Equation 5-16

$$IV1_{ohb_1} = \ln \left[\sum_{j \in b_1} \exp(\chi_h W_{tj} + \sigma_h IV2_{oh tj}) \right]$$

$P_{oh t}(b_1)$ is the probability that an alternative in nest b_1 is chosen, which can be expressed as follows:

Equation 5-17

$$P_{oh t}(b_1) = \frac{\exp(\tau_h IV1_{ohb_1})}{\sum_{k \in b_0} \exp(\tau_h IV1_{oh tk})}$$

Explanatory variables

The explanatory variables in the residential location choice model of TIGRIS XL are summarized in Table 5-2 and include type of neighborhood, local amenities, social-economic indicators, average price of houses in a zone, vacant houses, accessibility and travel time between current location and new location. A “_C” behind the variable means that this is a regional variable (COROP regions in Netherlands or NUTS 3 level according to European classification); all other variables in the table are zonal. The location choice of a household depends also on the characteristics of the household itself. The differences in location choice behavior between household types are addressed by estimating household type specific models. Therefore different household types have different estimation results (coefficients, t-values) for the explanatory variables (see Appendix A for estimation results per household type).

Table 5-2: Explanatory variables residential location choice model

Variable	Description
Price_WOZ	Average price of houses in a zone
VacHo	Number of vacant houses in a zone
NT_1	Neighborhood type 1 – Central urban areas
NT_2	Neighborhood type 2 - Urban areas
NT_3	Neighborhood type 3 – Sub-urban areas
NT_4	Neighborhood type 4 - Villages
l_time	Travel time measure between current and new residential location
Log_time	Natural logarithm of travel time measure between current and new residential location
l_cost	Travel time measure between current and new residential location
Log_cost	Natural logarithm of travel cost measure between current and new residential location
Pricem2	Indicator for housing price, (average housing price*number of houses)/ land housing
Water	water per zone (hectares)
Green	Public open space per zone (hectares)
Services	Services in a zone
Density	Residential density in a zone
Inc_med	Percentage households with middle incomes
Inc_high	Percentage households with high incomes
Acc_tot	Logsum for all travel purposes, accessibility indicator
Acc_wrk	Logsum for commuting, accessibility indicator
Acc_oth	Logsum for purpose other, accessibility indicator
Acc_ced	Logsum for purpose education, accessibility indicator
Pricem2_C	Indicator for housing price, regional variable
l_time_C	Travel time measure between current and new residential location, regional variable
Logtime_C	Natural logarithm of travel time measure between current and new residential location, regional variable
l_cost_C	Travel cost measure between current and new residential location, regional variable
Logcost_C	Natural logarithm of travel cost measure between current and new residential location, regional variable

According to Kendig (1984) the most important determinant of housing choice is the ratio of price and income. In the Netherlands this is less important as prices do not play a strong role in the constrained public housing market where 95% of all rental dwellings are subject to rent control (Oskamp, 1997). The residential location choice modeling in TIGRIS XL addresses the whole housing market including the public rent market.

Neighborhood characteristics are an important dimension in housing search (Clark and Onaka, 1983). In existing LUTI – models these variables are incorporated in various ways; the MEPLAN model uses one constant zonal attractor representing all neighborhood characteristics (Mott MacDonald, 2004; Department for Transport, 2003). In the DELTA model an area quality indicator is used resulting from rising average income and decreasing vacancy rates in a zone (Simmonds, 2005). The URBANSIM model uses neighborhood land-use mix, density and employment as explanatory variables in the household location choice module (University of Washington, 2000). As stated before, the philosophy is to use a wide set of explanatory variables in the TIGRIS XL residential location choice module to test the influence of transport relative to other explanatory variables.

As described in Table 5-2 several transport related variables were included in the model estimations, which form a combination of the distance deterrence function and accessibility indicators for the zones. The transport related variables in TIGRIS XL are explained below in more detail.

- *Travel time variables* (1_time, logtime, 1_time_C, logtime), the travel time variables express the travel time between location of origin and new location (see 5.2.2 for more detail) A combined function of logtime and 1/time has found to address the spatial behavior of household moves in the best way. The coefficients of the travel time variables are different for intra-regional moves and inter-regional moves.
- *Accessibility variables*, household type specific logsum variables (see 5.2.2 for more detail) have been tested for all six household types. For each household type, purpose specific logsums, such as work, education, other and all purposes, have been tested to select the variable with best fit.

As stated a difference with the move/stay estimation, besides the use of a nested logit instead of a binominal logit model, is that individual models are estimated for the various household types instead of incorporating household characteristics as explanatory variables. In this structure it is possible to estimate the parameters of household type specific logsum accessibility indicators.

Household types

The move/stay model was estimated on 74 thousand respondents from the housing market survey. The residential location choice model was estimated on a small sub set of households making a move, within the two year survey period, of almost 12 thousand respondents. The number of household types in the modeling is based on differences in behavior between household types and available number of observations by household type. Earlier estimation results were based on 13 household types, but several household types were aggregated because of similarity of the parameters or lack of observations (see Appendix A).

The residential location choice modeling in TIGRIS XL consist of six sub-models simulating the location choice of six different household types, the six types are:

- A Non-employed households under 65⁹
- B Employed, one-person household under 65

⁹ Age refer to head of household

- C Employed, 2/3+ persons household under 65 with a low income
- D Employed, 2/3+ persons household under 65 with a medium/high income
- E One person household above 65 (non-nested structure)¹⁰
- F 2/3+ persons household above 65 (non-nested structure)

Estimation results

The residential location choice models have been estimated for each household type with the ALOGIT software (www.hpgholding.nl). The estimation results for the individual household types are discussed in Appendix A.

For most household types the parameter for the nesting coefficient is between 0 and 1 and this confirms that the nested structure for household types A, B, C and D is globally consistent with random utility maximization. For all household types dominant variables in the model estimations were the number of vacant houses in a zone, incorporated as a size variable in the modeling, and travel time between current location and new location. Even within a region itself, household moves are mainly a quite local process and the majority of households settle down in the same municipality; the intrazonal dummy reflecting moves within the current zone is positive and significant for all household types. The travel time and cost variables capture various factors such as imperfect information about alternatives, social-networks at the old location and location of employment.

5.5.5 Market clearance mechanism

Supply and demand conditions in the housing market have various effects both short term as well as long term. In the short-term and under free market conditions the demand/supply ratio has an influence on the housing prices. Under regulated market conditions, for example used in the allocation of social housing in the Netherlands, the demand/supply ratio has an impact on average waiting time for people seeking a new dwelling. The demand/supply ratio can also have an effect on the occupation ratio as a correlation is expected between housing price and the average number of households per housing unit. High market prices might prevent young, one or two person households, to acquire a residential unit of their own. Changes in the housing market prices can also have many long run influences. The housing price affects the housing density, floor space as well as the size of gardens, social segmentation of a neighborhood and housing demolition and construction. In the modeling the different responses need to be addressed individually on their own merits.

For the short-term effects it is important to recognize that the housing market is dynamic in nature and at a certain point in time only a fraction of the households is actively involved in searching for a house or selling a house. Under free market conditions housing prices can be used to simulate a short-term equilibrium for the active players in the market and the pricing mechanism can be used to clear the market among these players. However, in areas with a partly regulated market, like in the Netherlands

¹⁰ Household type E and F do not have a nested structure, because the estimations results for their nest coefficient rejected such a structure

for social housing, a way has to be found to allocate house-seeking households to vacant houses. Such a mechanism is worked out in Figure 5-10.

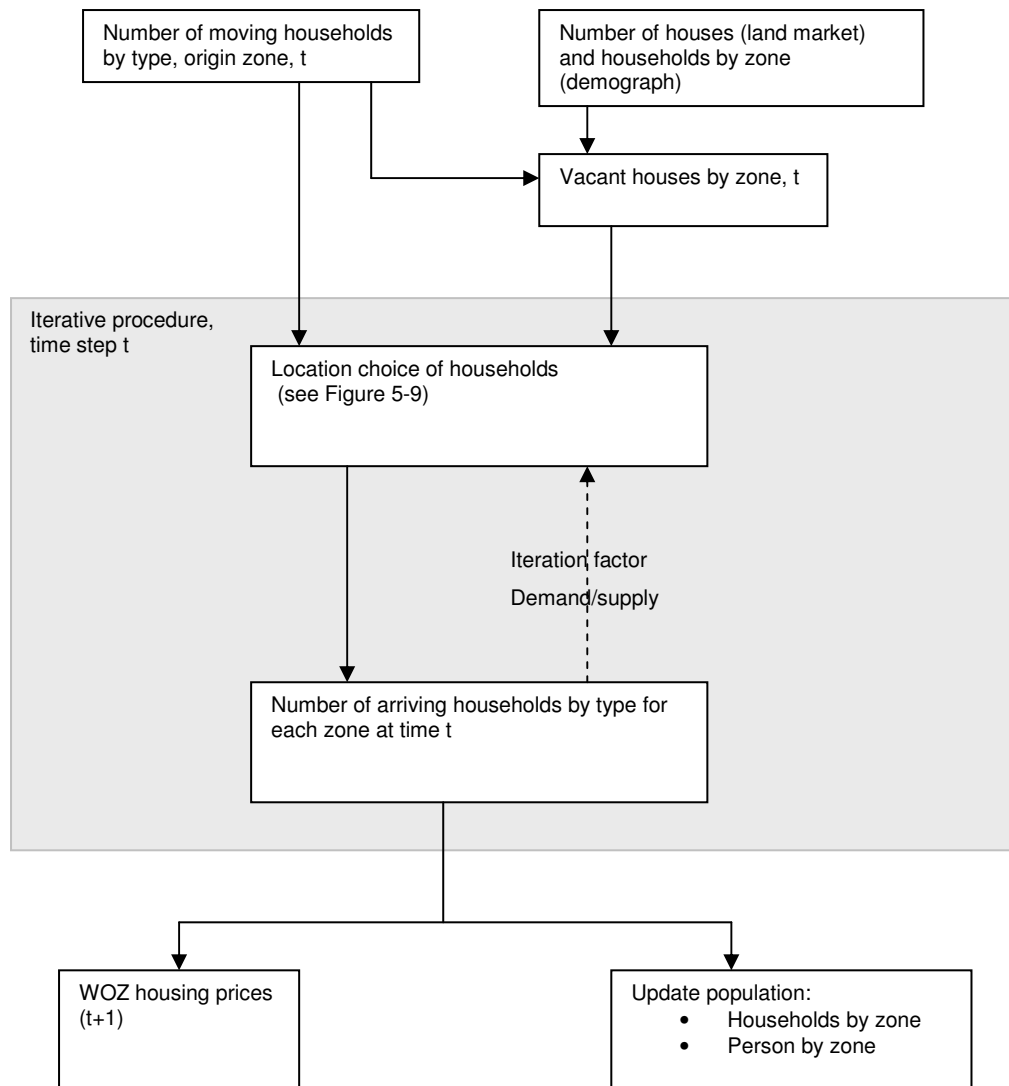


Figure 5-10: allocation mechanism within housing market module

Within TIGRIS XL the whole housing market is cleared within a time step by adjusting for each of the six household types the utility of locations with excess demand in an iterative procedure. The utility function in TIGRIS XL includes a price variable, but an explicit adjustment of only this variable would lead towards a mismatch in areas with a lot of public housing like for example in the large cities.

The long-term adjustments in TIGRIS XL are incorporated via the housing price variables. The housing price variable at time $t+1$ is adjusted based on the market condition, housing demand/supply ratio, at time t . The housing price affects the residential density of new construction sites and, depending on the assumption for the land market regulation, the number of houses to be constructed at a specific location.

As mentioned a limitation of the TIGRIS XL housing market module is that it lacks detail in housing supply to differentiate between public rent, private rent and ownership. An explicit modeling of these markets is therefore infeasible with the present version; it is certainly suggested to include this in a future version. Such an extension would also affect the preferred allocation mechanism in the modeling. A disadvantage is that such

an additional dimension results in substantial data requirements, often beyond the specification of future spatial plans.

5.6 Labor Market

The various existing LUTI-models follow different approaches towards the modeling of the labor market. The labor market in LUTI-models is generally simplified as the modeling of the spatial distribution of jobs and the interaction with the labor force. The MEPLAN model (Williams, 1994) distinguishes basic (exporting, not producing for the region) and non-basic employment according to the economic base theory. The hierarchical structure in MEPLAN is similar to Lowry's Metropolis model; basic employment attracts the population and the population attracts the local (non-basic) employment. Within the MEPLAN model basic employment is an exogenous user input and only non-basic employment is endogenously determined. The distribution of the non-basic employment follows the distribution of the population within MEPLAN.

The URBANSIM (University of Washington, 2000) and IRPUD (Wegener, 1998d) models follow a different approach; in these models all employment is exogenously forecasted at the level of the study region. However, within the study region the employment totals by sector are endogenously distributed over the modeling zones. The hierarchy of the relationship between people and jobs differs between the IRPUD and URBANSIM model. In the IRPUD model, the labor demand side, location of jobs, is dominant at the labor market and the population will follow changes in employment. The URBANSIM model has a less hierarchical structure and the accessibility of the population is a variable in the location choice of the jobs. Vice versa, the accessibility of jobs is an explanatory variable in the location choice of residents.

It should be noted that in reality firms are making the location decisions and not individual jobs. However, due to data restriction and lack of a clear definition of what a firm is, it is complicated to use firms as the unit of analysis in the modeling and all three land-use models use jobs as unit of analysis. At the supply side in land- and real estate market model, the supply of available workspace is often expressed as floor space and for the industrial or agricultural jobs available land is used.

The aim of the labor market module in TIGRIS XL is to simulate the regional distribution of employment for different sectors. At the national level total employment by sector will be consistent with existing macro-economic scenarios for the Netherlands. Therefore at the national level the model can only calculate distributive effects of transport measures on employment and not generative effects. At a regional level TIGRIS XL can generate distributive effects as well as generative effects resulting from shifts between regions.

Based on the above discussion and modeling requirements as presented in section 4, key features for a labor market module for the TIGRIS model are:

- A division of the jobs into economic sectors, minimally involving agriculture, industrial and service jobs, is needed to address key differences in location decision. In the labor market module of TIGRIS XL specific models are estimated for seven economic sectors;

- The modeling of firms was infeasible for the TIGRIS XL model, due to data restrictions and conceptual challenges, and as practical solution jobs are used as the unit of analysis;
- As stated a point of discussion is the relation between the number of jobs and population; are jobs following the people or are people following jobs? Both causal relations seem to be partially true and a non-hierarchical structure is used in TIGRIS XL. For all economic sectors (exclusive agriculture) the influence of people (or more specific labor force) as location factor has been included;
- An important factor in the labor market of the Netherlands is the labor participation ratio. Changes in employment do not only influence unemployment, migration and commuting but also the participation rates. Therefore labor participation is calculated endogenously in the modeling.

BureauLouter¹¹ has developed the labor market module in the TIGRIS XL model. For a comprehensive description of this module reference is made to the report on the functional design of TIGRIS XL and the report on model estimation (RAND et al 2003c, 2004). In Appendix B a description on the structure of the labor market module and estimation results is included; this is included to complete a comprehensive picture of the TIGRIS XL model for the reader.

The labor market module is affected by changes in other modules within the TIGRIS XL model, such as demography, land and real estate market, housing market and transport market. Therefore, similar to the housing market, its design has been tailored to operate within such an integrated framework. The labor market is linked with the demographic and housing market module via the changes in population and more specifically changes in the potential labor force. As described in appendix B the labor market module is a demand model at a higher spatial level of municipalities. However at a lower spatial level, of NMS zones, it assumes, depending on the economic sector, that supply of floor space, industrial sites or size of the population is determining the distribution of jobs over the zones within a municipality.

¹¹ The labor market module in TIGRSI XL has been developed by Bureau Louter. A description is included in this thesis as an essential component to explain the overall framework and functioning of other components. Bureau Louter is an expert consultant in the field of spatial economy

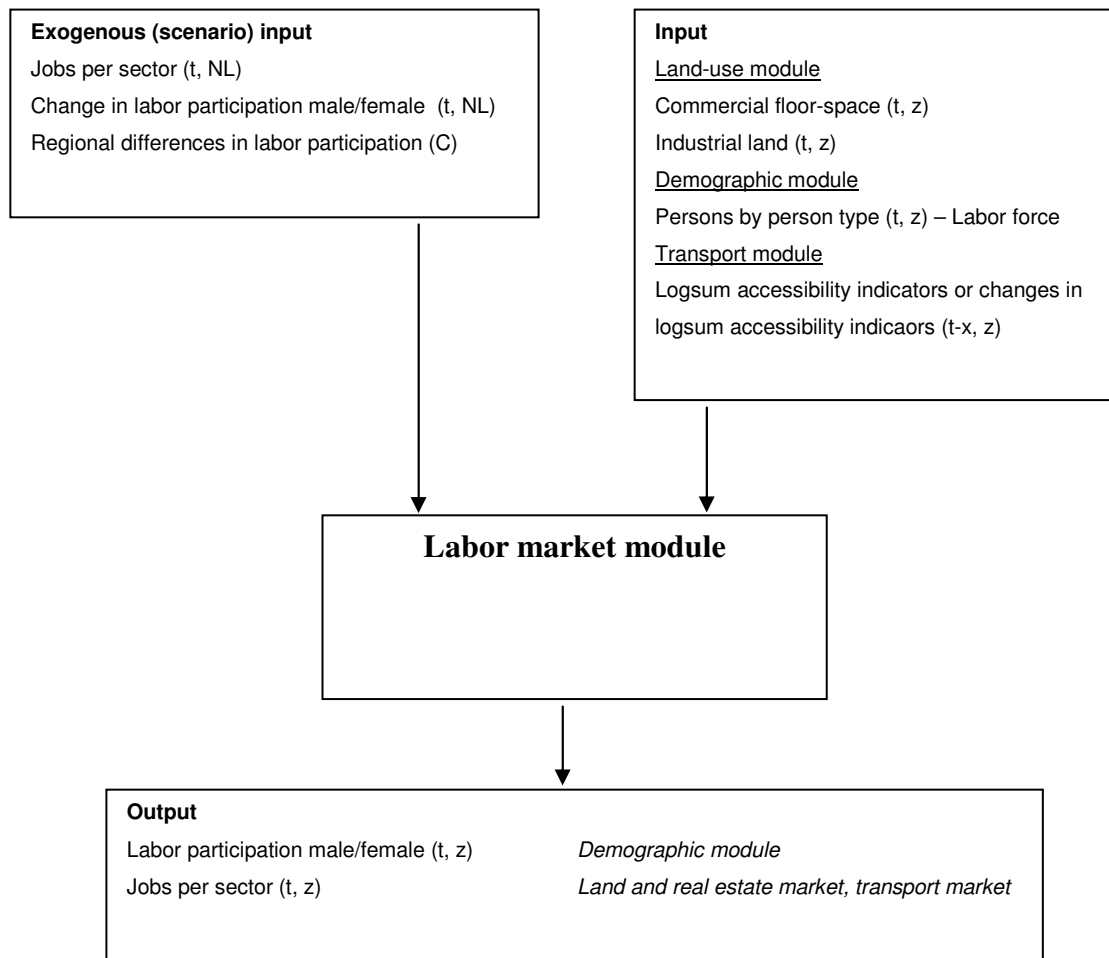


Figure 5-11: Interactions of the labor market module

The mutual interactions between the labor market module and the transport model consist of using accessibility indicators from the transport model as explanatory variables in the location choices and using the spatial distribution of jobs as input for the transport model. As stated the influence of accessibility on the spatial distribution of employment is of key interest for this research and the labor market sub module can be used to model the structuring effects of transport measures on the spatial distribution of employment.

5.7 Observations

This chapter presents the structure of the TIGRIS XL model including - the linkage with the NMS transport model, - the design of specific modules, and model estimation results for the housing market module. The TIGRIS XL model has a modular structure for reasons of transparency, flexibility, time dynamics and especially model estimation (each sub-model can be estimated or calibrated separately). Other key characteristics of the model are:

- The model comprises a demography -, land market and real estate -, housing market -, labor market -, and transport module;

- TIGRIS XL is an incremental model with time steps of one year (only the link with the transport model is once in the five years);
- The model operates at two spatial levels : 40 COROP regions and 1308 transport zones;
- The TIGRIS XL model does not adopt a hierarchical link between employment and population. It calculates both the influence of population on the location of jobs and the influence of jobs on the location of households;

The land market module in TIGRIS XL is a stock keeping model for different functions of land and uses many exogenous scenario inputs. Key feature is that the module is flexible towards different spatial market regimes, varying between a regulated regime and a free market regime. Under a free land market regime, spatial developments and changes in housing supply follow the preferences of households as calculated in the housing market module.

The link with the National Model System (NMS), a discrete choice type of transport model based on micro-economic utility theory, makes it possible to generate so-called logsum accessibility indicators. The logsum is an aggregate value expressing the total utility in the system for a particular alternative. Section 5.2 describes the use of utility-based accessibility indicators for the TIGRIS XL model. The utility-based indicators in TIGRIS XL include personal characteristics and preferences, besides characteristics of the transport and land use system, to capture observed heterogeneity across individuals. Including the individual component of accessibility means that more realistic accessibility indicators, namely accessibility indicators closer representing the specific activity pattern and preferences of the households, can be included as explanatory variable in the estimation process of residential location choices.

The housing market module consists of a housing supply -, housing demand -, and allocation component. The demand side of the housing market has been modeled as a discrete choice model; the model structure identifies various steps in the choices that are made in the demand side of the housing market. First a household makes a decision to move or to stay. Once a household decides to move this household enters the residential location choice module. The residential location choice module comprises a nested structure, first a household chooses a region and second a specific zone within a region. Final allocation follows from an iterative procedure matching housing supply and demand.

An important difference between the TIGRIS XL model and many other LUTI-model is that the relationship between transport and residential location choice and job location choice, has been formally estimated using respectively a log likelihood en least square estimation procedure. Advantage compared to informal calibration procedures is that the significance and size of the coefficients for the explanatory variables is statistically determined. Furthermore, it is possible to compare the overall fit of alternative model specifications. Separate models have been estimated for different household types (or economic sectors); in each model the influence of accessibility has been estimated among many other explanatory variables.

Detailed conclusions of the present study on the role of accessibility in residential location choice are:

- The model estimation results suggest that accessibility is a significant variable in the Move/Stay choice. It is less likely that households are going to move away from

a more accessible location than from a less accessible location. This finding confirms that households are more likely to move away from remote areas than from central areas;

- The model estimation results suggest that accessibility of a specific location is for many household types not a significant variable in their location choice. The findings confirm that demographic factors, neighborhood amenities and dwelling attributes are more important variables to explain residential location choices. The context of the Netherlands, as described, is an important factor which helps to explain the findings;
- The model estimation results for the travel time variables illustrate the important role of the transport system in defining the sizes of the housing market. Travel time variables are significant for all household types and therefore changes in the transport system will affect the size of the housing market and location preferences of the households.

In the next chapter the model set-up is described and several model tests are reported to analyze the performance of the modeling. In chapter 7 the model has been applied to two “real world” applications. An approach for an extension of the modeling with indirect generative effects is proposed in Section 8.4.

6 Model set-up and testing

This chapter discusses the set-up of the modeling and the sensitivity of the modeling results for some main policy levers in the modeling. To perform the test runs a socio-economic reference scenario is needed to set-up the modeling environment. Such scenario comprises of key factors affecting the future spatial development and land-use changes in the Netherlands. The scenario settings include demographic developments, economic developments and non-disputed land-use and transport policies.

The settings for these components are presented in Section 6.1 on scenario settings. Section 6.2 discusses the simulation for the reference situation. Key policy levers are reserved in the modeling to accommodate land-use and transport policies. In Section 6.3 the impact of a free land market regime on the spatial distribution of residents and jobs is tested. Section 6.4 presents a set of sensitivity runs to test the impact of changes in transport on the spatial distribution of residents and firms.

6.1 Scenario settings

The TIGRIS XL model uses exogenous data for the national forecasts, which needs to be collected and implemented as part of a consistent scenario. Existing scenario forecasts of the National Bureau of Economic Analysis or Statistics Netherlands are

used as input. It should be noted that the user can change these scenario settings to implement a specific scenario or test the sensitivity of the model output for different scenario settings. In principle the scenario settings cover all future aspects, which are either outside the policy scope of the modeling instrument or which are not considered to vary among alternatives. It should be noted that the scenario settings, as described below, are specifically set-up to facilitate the test applications. For other planning studies more refined scenario settings may be needed.

In the test applications the land-use effects of various settings such as spatial plans, level of market regulation and the impact of specific transport measures (see Chapter 7) will be tested. To execute the test applications the model will require the following scenario input for the period 2000 – 2030:

- Demographic data;
- Economic data;
- Transport data;
- Land-use data, reference case.

6.1.1 Demographic data

The demographic module within TIGRIS XL uses exogenous data for the birth and mortality rates by gender and age, and changes in the average household size for each forecast year. In the modeling these variables are endogenously differentiated by region based on collected base year differences in these rates. The model also needs predictions for international migration flows for each forecast year by gender and age category.

All demographic scenario variables are based upon 2004 predictions of the National Statistical Office, including birth and mortality rates and international migration in the period up to 2020. In the period 2020-2030 it is assumed that the birth and mortality rates for the year 2020 are unchanged. In addition it has been assumed that the yearly international migration flows in the period 2021-2030 are similar to the migration flows in 2020. The distribution of international migration over the Netherlands follows the base year distribution in this scenario. The average household size is predicted to change from 2.31 in 2000 towards 2.09 in 2030, as the trend over the last decades of smaller households is foreseen to continue. Figure 6-1 illustrates the trend of a diminishing average household size and the number of households is growing much stronger than the population. Changes in the average household size do have an impact on transport, but especially the housing market is affected by changes in the number of households.

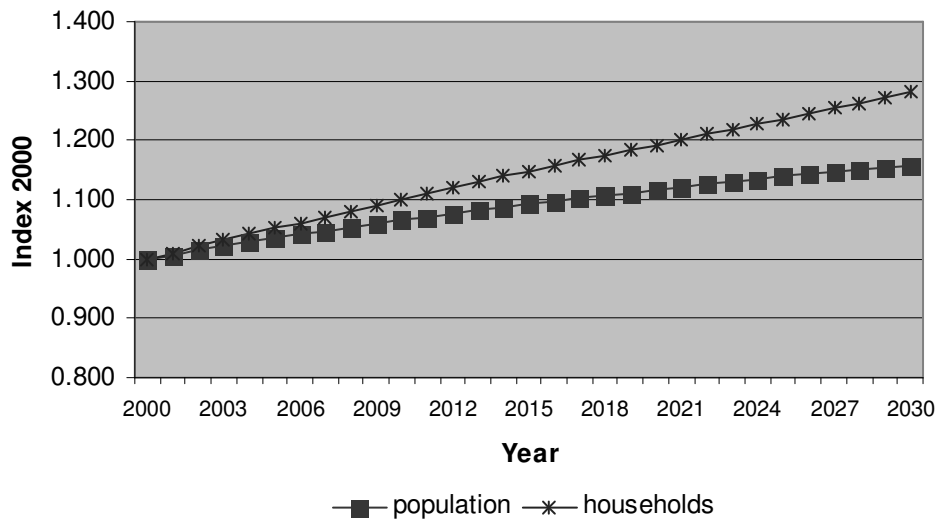


Figure 6-1: Index of growth in population and households (NL) in the period 2000 – 2030

The demographic composition of the population is also changing in the future. Figure 6-2 and Figure 6-3 illustrate the high growth rates for the population segment above 65. The size of this population segment almost doubles in the period between 2000 and 2030. The population segment 35-64 years presents a modest growth, which especially takes place in the first ten years; the younger population segments can be regarded as stable in the period 2000 – 2030.

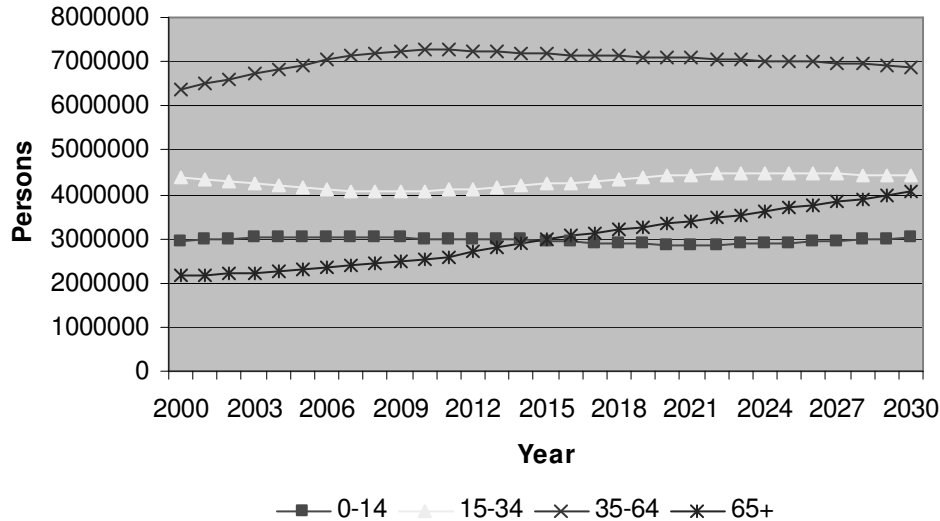


Figure 6-2: Changes in population by age category in the period 2000-2030

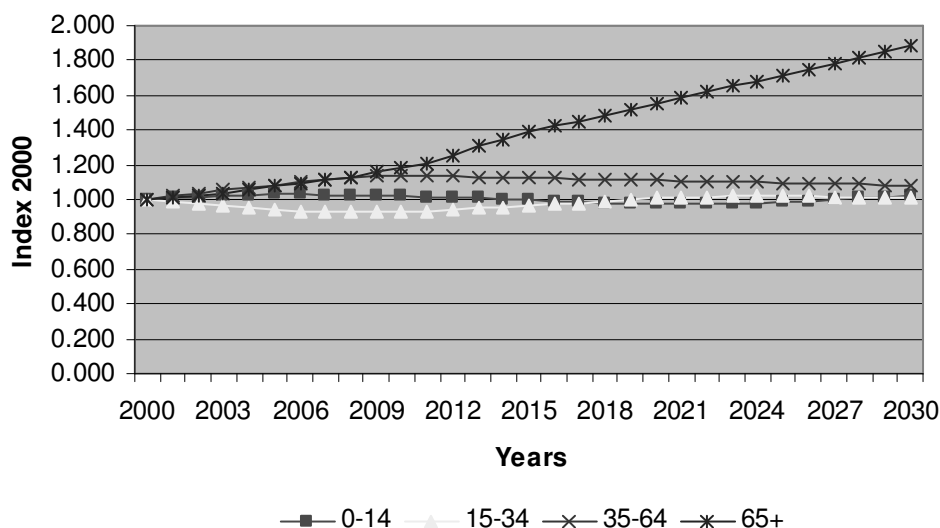


Figure 6-3: Index developments in population by age category in the period 2000 -2030

6.1.2 Economic data

A variety of economic input data is required for the period 2000-2030, including developments in household income, labor participation by gender, and number of jobs by economic sector. The European Coordination scenario forecast of the National Bureau of Economic Analysis (CPB, 1996) has been used as data source and this data has been processed into the data format for the TIGRIS XL model (Figure 6-4). This scenario covers the time period 2000 – 2020; additional assumptions have been made for the period up to 2030. An informal forecasting study of CPB for the period 2020-2030 has been used for this.

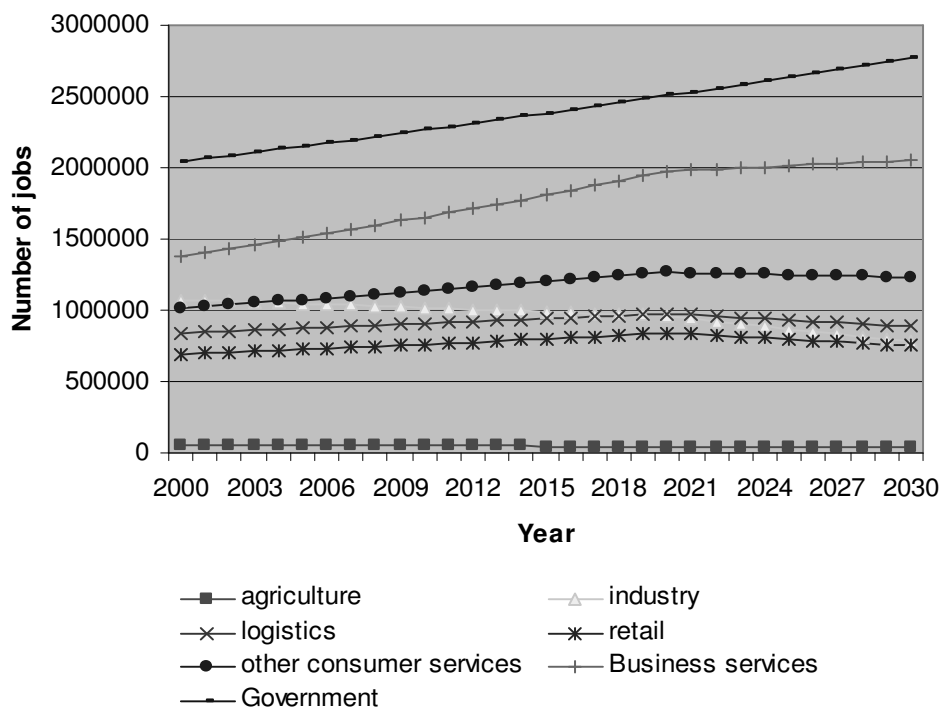


Figure 6-4: Developments in jobs by sector European Coordination scenario 2000-2030

In the period up to 2020 an overall growth in the number of jobs of around 1 percent per year is forecasted. After 2020 a trend break is foreseen for most economic sectors, excluding the non-profit sector, and overall the number of jobs is decreasing by around 0.1 percent a year on average. This trend break has been adopted and incorporated in the scenario for the TIGRIS XL test applications. In this way the model will calculate the effects both for a period of economic growth and -decline.

Table 6-1 presents in table form an overview of the structural changes in the economy at a national level. It should be noted that these changes in economic structure can have a very different impact on each of the regions depending on the economic structure of a region.

Table 6-1: Structural changes in the economy (national level in jobs)

Sector	2000	2030	Index 2030_2000
Agriculture	52,852	39,741	0.75
Industry	1,073,628	783,546	0.73
Logistics	842,602	889,425	1.06
Retail	689,335	755,023	1.10
Other consumer services	1,015,180	1,230,991	1.21
Business	1,384,949	2,050,920	1.48
Government	2,044,293	2,776,691	1.36
Total employment	7,102,839	8,526,337	1.20

The changes in labor participation are also generated based upon total labor force data according to the European Coordination scenario. The total labor force has been derived based on predicted unemployment data, number of jobs and population between 15 and 65 years. Males and females have very different labor participation rates and also their predicted development differs strongly. Both issues are presented in Figure 6-5. The labor participation rate of females is predicted to increase significantly, contrary to the labor participation rate of males, which is predicted to fall slightly.

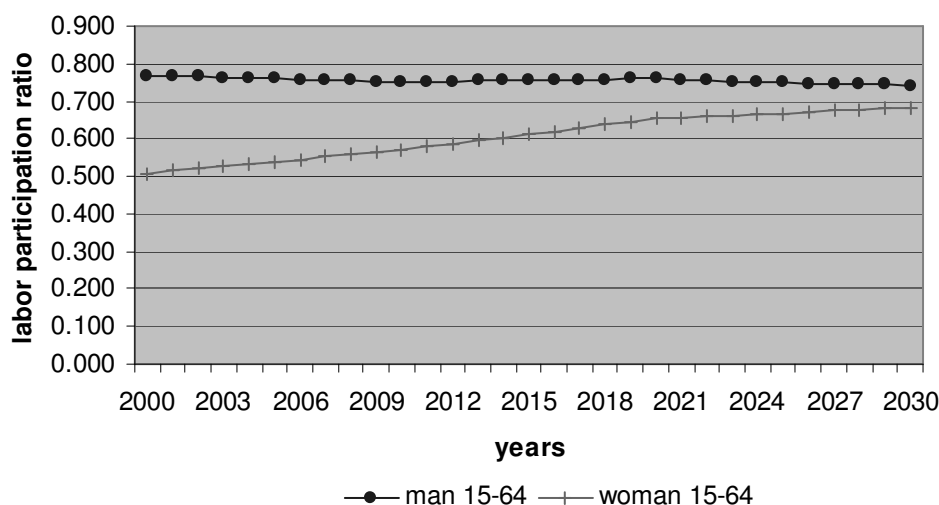


Figure 6-5: Developments in labor participation for man and females (European coordination 2000-2030)

6.1.3 Transport settings

The transport model “NMS” (Hague Consulting Group, 2000) as part of the TIGRIS XL model system needs to receive input on a reference road network and level-of-service matrix for rail transport. This is needed for the years 2005, 2010, 2015, 2020, 2025 and 2030. The data used for the TIGRIS XL test application is in line with data generally used for reference runs with the NMS for 2020 and occasionally 2010. The road network in these reference runs are derived from the MIT 2004 (medium term investment program in transport infrastructure), which includes the projects likely to be funded in the short and medium term (Ministerie van Verkeer en Waterstaat, 2004). For the period after 2020 detailed plans are absent, and the 2020 road network has been assumed for 2025 and 2030.

The level-of-service matrices for rail are derived from the rail network for 2010 as used in the NMS application “Mobiliteitsanalyses Deltametropool” (RAND Europe, 2004b). For 2005 a rail network has been assumed based on an interpolation of the 2000 and 2010 level-of-service matrices. For the years after 2010 an unchanged level-of-service matrix has been assumed reflecting the fact that the 2010 rail network level-of-service can be considered as highly ambitious.

The fuel price and car ownership assumptions for the period up to 2030 have been derived from the NMS application “Mobiliteitsanalyses Deltametropool” (RAND Europe, 2004b). This study had a similar time horizon, 2030, as the present test applications with TIGRIS XL.

6.1.4 Land-use plans

The most relevant land-use plans for TIGRIS XL are plans for new residential locations, office space, and industrial sites. Existing plans of municipalities, collected in the New Map of the Netherlands (NIROV/Ministerie van VROM, 2006), have been used as source of information to create this reference scenario. The time horizon of the new map is limited and the number of land-use plans after 2015 is limited. Therefore an alternative way is needed to generate land-use plans for the period after 2015 in addition to the plans in the New Map.

By setting-up the input for the housing construction plans at new locations for the TIGRIS XL model three time periods, and associated data preparation methods, have been identified, as follows:

- Period 2000 – 2005: for this period data from the National Statistical office website (www.cbs.nl) is available for the actual realized number of new houses at a zonal level for each of the years in this period;
- Period 2006 – 2015: for this period the land-use plans of the New Map of the Netherlands have been used as input. A GIS overlay procedure has been used to allocate the plans to the zones. The plans have been allocated to the zones proportional to their size;
- Period 2016 – 2030: for this period an alternative solution has been chosen, due to a lack of existing land-use plan. For each year in this period a fixed total number of new houses for the Netherlands has been proportionally distributed among the zones with vacant land, weighted with their current population and a historical factor. The total number of new houses for the Netherlands is based upon a national, scenario specific, construction target and serves as an upper-limit for construction plans. The construction limit under this scenario is 76

thousand new houses a year, consisting of new houses at both “green field” and “brown field” locations.

Figure 6-6 presents the combined result, number of newly constructed houses in the period 2000-2030 at new residential locations, for the three time periods as described above. The map shows a dispersed pattern for the residential development sites, which could be expected from the regional nature of the housing markets. It also illustrates that the Province of Flevoland remains an important location for the development of new residential sites. An important share of the growth in houses for the North-wing of the Randstad is planned in Flevoland. In the Southern part of the Randstad the development sites are less concentrated.

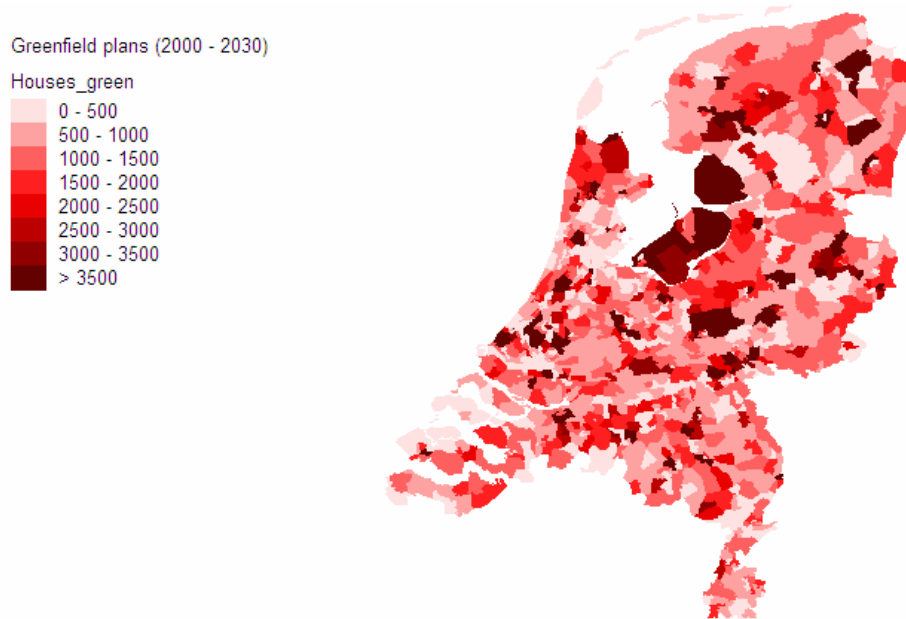


Figure 6-6: Greenfield housing construction plans for the period 2000-2030

In addition to information on new residential development sites information is needed on housing construction plans within build-up area, to fill-up open spaces or as part of densification strategies, and house demolition. In the reference case for the test applications, the housing construction data on brown field locations are balanced with the demolition rates. In the reference case, the active densification policies are limited to zones with existing brown field plans in the New Map of the Netherlands. For all other zones, and the period after 2015, it has been assumed that houses are constructed on brown field locations as replacements for housing demolition. Figure 6-7 presents housing construction at brown field locations in the period 2000 – 2030. As expected most of the brown field housing development takes place in the larger urban areas. In these areas land resources are scarce and infill locations might be economical feasible.

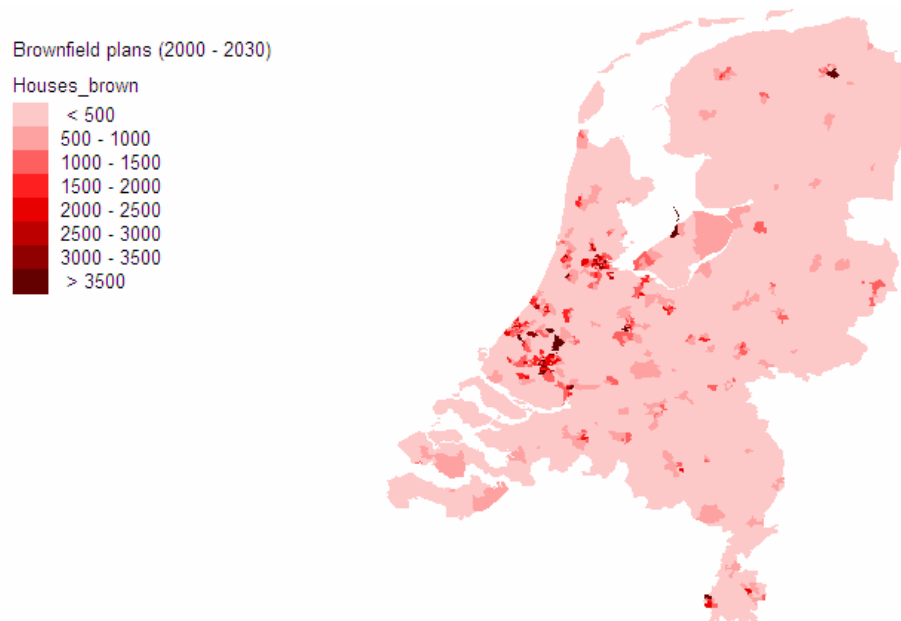


Figure 6-7: Brownfield housing construction plans for the period 2000 - 2030

Housing demolition figures are derived for the base year by neighborhood type and for each zone; depending on its neighborhood type, a demolition percentage has been included varying between 0.08 and 0.51 percent of the housing stock. The base year data are also used for the forecast years in the reference scenario, however the model user can specify an alternative demolition percentage for each zone and for each forecast year to account for specific policies.

6.1.5 Overview scenario settings

As specified in sub-section 5.4.1 the land-use plans only play a role in the spatial development under a regulated or semi-regulated market. The regulated market regime has been chosen for the reference scenario. It should be noted that the reference scenario should not be considered as a most “likely”, but as a consistent do-nothing base case, which can serve as a reference to evaluate alternative policies. In a sophisticated application the robustness of results can be tested under various scenarios.

Table 6-2 presents an overview of the various scenario settings for the reference case of the test applications.

Table 6-2: Overview of key scenario settings for the TIGRIS XL model

	2005	2010	2015	2020	2025	2030
Demography						
Population (*million)	16.4	16.9	17.3	17.7	18.1	18.4
Households (*million)	7.2	7.5	7.9	8.2	8.5	8.8
Immigrants (year, *1000)	104	120	125	130	130	130
Emigrants (year, *1000)	86	87	90	94	94	94
Economy						
Households income index relative to 2000	117	137	153	170	190	212
Index Labor participation ratio female	106.0	112.4	120.4	128.9	131.8	135.0
Index Labor participation ratio male	98.7	97.6	98.1	98.7	97.5	96.5
Number of jobs (*million)	7.43	7.79	8.17	8.57	8.54	8.52
Land-use plan¹² + construction						
NL housing projection (year)	76000	76000	76000	76000	76000	76000
Land-use plans	New Map of NL	New Map of NL	New Map of NL	Proportional*	proportional	proportional
Transport reference						
Car network	MIT 2004	MIT 2004	MIT 2004	MIT 2004	unchanged	unchanged
Train network	interpolation	2010 NMS	2010 NMS	2010 NMS	2010 NMS	2010 NMS
Fuel price index 2000**	111	113	109	105	105	105
Car ownership (*million)	7.0	7.65	8.22	8.78	9.43	10.1

*) Number of new houses is proportional to share in national population of a zone controlled for land-availability in the zones

**) In more recent long-term economic scenario's higher fuel prices are foreseen than in this European Coordination scenario

6.2 Reference situation, regulated market

The regulated market situation is selected as the reference situation. In a regulated market the government controls the location and number of new houses. Within these supply limits, households are free to make their choice for a house. A regulated land

¹² The land-use plans are only used under regulated or semi-regulated market land market conditions.

market policy therefore only constrains the number of options and does not influence the choice among these options. Under these circumstances the steering effect of new construction sites on the spatial distribution of residents is likely to be large, although location preferences and supply/demand conditions in the market still play an important role. In a market situation with supply shortages, like in the Netherlands, the preferences of the households play a less dominant role reflecting the lack of opportunities in the housing market.

Figure 6-8 and Figure 6-9 present for the regulated, reference, the population developments by COROP region for the period 2000-2030 in the format of index value (2030/2000) and absolute number. The presented figures are output of the TIGRIS XL model depending on scenario input for e.g. demography and housing construction plans.

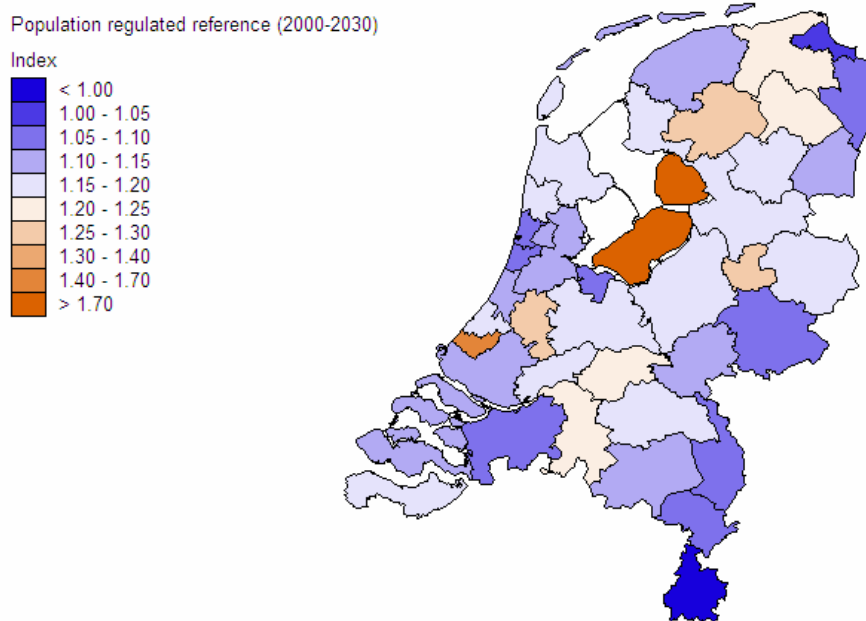


Figure 6-8: Index population development in the period 2000 - 2030 by COROP (regulated market)

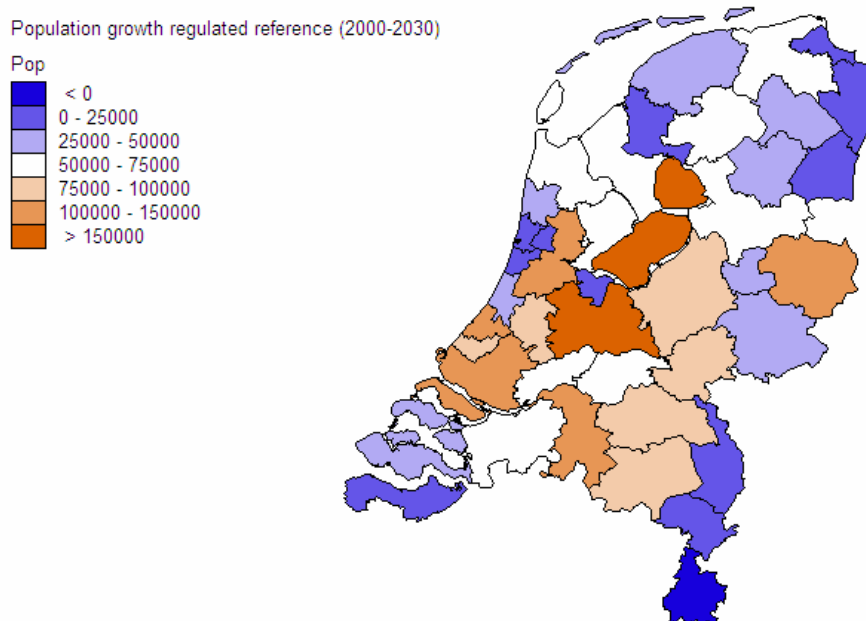


Figure 6-9: Population growth in the period 2000 and 2030 by COROP (regulated market)

The large differences in size between COROP-regions, varying between just over 50 thousand and a million residents, is the cause that a map presenting absolute figures will show the highest absolute growth for the largest COROP regions like Amsterdam and surroundings, Utrecht and Rotterdam and surroundings. A remarkable growth is forecasted for the Flevoland COROP reflecting the ambitious plans for residential development sites in this area, especially within the city of Almere.

Figure 6-8 presents relative growth figures; a mixed growth pattern exists of COROP areas over the country. The fastest growing province is as expected Flevoland, which comprises one COROP. Many other Provinces present a more mixed pattern among their COROP regions with faster and slower growing regions. This reflects the spatial dimension of the housing market and a growth in a certain region most likely occurs at the expense of another region in the neighborhood. Zuid-limburg is the only COROP region facing a decline in population in 2030; this is mainly the result of demographic dynamics in this part of the country with a relatively aged population.

The growth of Flevoland can be explained by the substantial residential construction plans for this part of the Netherlands. In this part of the country densities are lower, and lower pressure on land seems to result in less restriction on housing construction plans. The future map of the Netherlands, with residential construction plans, might be negatively biased towards areas with a high land-pressure and controversial development plans.

Spatial distribution of jobs

The labor market module in TIGRIS XL has been estimated at the regional level and this level is the most appropriate level for analysis of the results. The number of jobs in a region is affected by structural changes in the economy and changes in features (e.g. accessibility or level of urbanization) of the location. The labor market is indirectly affected by land market regulations via changes in regional features as the number of residents, work force and accessibility.

The structural changes in the economy are a scenario input at the national level, as presented in Table 6-1. It is clear that these changes in economic structure can have a very different impact on each of the regions depending on the economic structure of a region. Disentangling the effect on the regional economy of changes in economic structure and location factors is the key to estimate the influence of location factors like level-of-service of the transportation system.

Figure 6-10 presents, for the regulated variant, the development in total number of jobs at a regional level. The presented changes are the result of combined structural changes and changes in regional features. The pattern shows similarities with the spatial distribution of residents, and this illustrates the influence of population changes on the location choice of firms for several major economic sectors. Areas with relatively large residential construction sites, compared to the population size, such as Flevoland and Southern Friesland, and the non-urban centrally located COROP regions, also face a relatively large increase in the number of jobs.

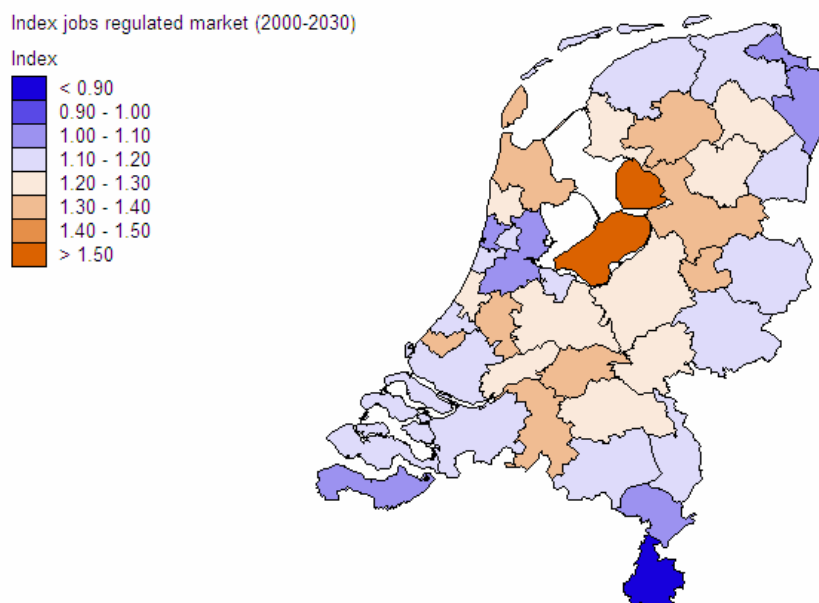


Figure 6-10: Index total jobs 2030 versus 2000 by region (regulated variant)

Figure 6-10 illustrates that regional development differs significantly from the national changes in overall employment. Differences in regional economic structure and regional location factors are the explanatory variables for this variation (see Section 5.6 for the explanatory variables by sector). The standard deviation from the national growth index, of 1.20 (see Table 6-1), of the job development indexes at a COROP level is 0.23.

Figure 6-11 presents differences in number of jobs at a COROP level for the regulated market variant between 2000 and 2030. It should be noted again that the highest growth indices can be found in regions surrounding the urban core of the Netherlands, however in absolute numbers the highest growth will take place in the large COROP regions of the Netherlands.

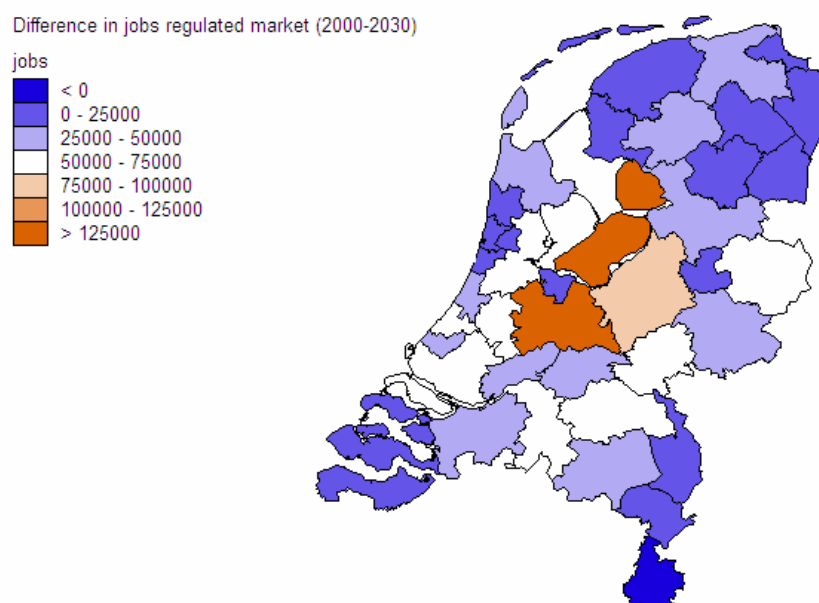


Figure 6-11: Difference in number of jobs - regulated market, 2000-2030

Figure 6-10 and Figure 6-11 present the combined results for all economic sectors; however these results vary strongly by economic sector depending on the estimation results of the specific sector and national changes in economic structure. Table 6-3 presents the variation at a regional, COROP, level for six economic sectors in the TIGRIS XL model. The variation is expressed by sector as the standard deviation in the regional development from the national trend. The agricultural sector is not explicitly modeled in TIGRIS XL and all regional changes are following the national change in economic structure. The table shows that considerable variation exists between the regions in development of number of jobs by sector.

Table 6-3: Standard deviation in development in jobs by sector at a COROP level

Sector	National level Index jobs 2000 – 2030	Standard deviation at COROP level
Agriculture	0.75	0
Industry	0.73	0.15
Logistics	1.06	0.22
Retail	1.10	0.20
Other consumer services	1.21	0.20
Business	1.48	0.44
Government	1.36	0.28
Total employment	1.20	0.23

6.2.1 Dynamics of the model

The performance of the LUTI-model is tested on its spatial dynamics. Wrong specifications in the modeling might easily result in unrealistic spatial dynamics and patterns. For example, a problem with gravity type of land-use models is often that these models tend to over-estimate the process of centralization. In this paragraph the dynamics of the TIGRIS XL model, for the reference situation, are compared with historical observations on dynamics of changes in land-use patterns.

Table 6-4 presents the share of national population by province, both for the historical period of 1970 –2000 as well as for the forecasting period of 2000 – 2030. The table shows a remarkable stable pattern for the whole period; this illustrates that long distance moves are a rarity and most of the spatial dynamics is regional. The changes in the forecasting period are in line with the historical changes; most provinces show, similar to the historical period, only a marginal change in the period 2000 –2030. Most important changes in population share in the period 2000-2030 is the ongoing growth of Flevoland and decline of Limburg; the first is inspired by large housing construction plans and the second by demographic conditions.

Table 6-4: Share of national population by province (between 1970 and 2030)

Province	1970	1980	1990	2000	2010	2020	2030
Groningen	3.99	3.93	3.72	3.55	3.46	3.49	3.51
Friesland	4.03	4.14	4.02	3.94	3.89	3.91	3.98
Drenthe	2.83	2.97	2.96	2.97	2.93	2.99	3.02
Overijssel	6.81	6.9	6.86	6.79	6.81	6.93	6.97
Flevoland	0.42	0.8	1.42	2.00	2.37	3.06	3.49
Gelderland	11.66	12.07	12.13	12.11	11.91	11.78	11.90
Utrecht	6.39	6.6	6.89	6.99	7.15	7.13	7.04
Noord-Holland	17.38	16.42	16	15.87	15.86	15.52	15.32
Zuid-Holland	22.61	21.54	21.48	21.45	21.85	21.68	21.54
Zeeland	2.36	2.47	2.39	2.34	2.35	2.30	2.28
Noord-Brabant	13.82	14.58	14.72	14.80	14.61	14.68	14.65
Limburg	7.7	7.58	7.41	7.21	6.80	6.53	6.30

*) source for the 1970-2000 period data is the website of the national statistical office (www.cbs.nl) and for the forecast period 2000-2030 TIGRIS XL output has been used

The standard deviation, in population or job growth, from the national development can be used as an indicator for the spatial dynamics at a COROP – level. For the period 1970 – 2000 the variation in population development at the COROP-level was considerable and the standard deviation was 25%. The population growth for the whole of the Netherlands was a factor 1.22 for that period. In the forecasting period, 2000 – 2030, a national population growth of 1.16 is foreseen. The standard deviation in population growth over the COROP regions is 16%. The dynamics in spatial distribution of residents are forecasted to be lower than the historical differences in growth dynamics between COROP-regions. This is line with the lower level of population growth for the whole country.

6.3 Sensitivity of modeling results for free land market regime

In TIGRIS XL several land market options can be set varying from a regulated market up to a free market (see sub-section 5.4.1). Below, the free market land market regime, as specified in 5.4.1, is tested for its impacts on the spatial distribution of residents and jobs. The scenario settings from Section 6.1 are used and the time horizon of the forecast is 2000-2030. The assessment of the impacts will be focused on changes in the spatial distribution of the residents affected by regulations on the supply side of the housing market. The spatial distribution of jobs at a regional level is indirectly affected by different kinds of market regulations through changes in the spatial distribution of residents and performance of the transport system. Only at the local level of NMS zones the spatial distribution of jobs is affected by the location of office space or industrial sites. This results from the model assumption about the dominant market position of firms at a higher geographical level; it is assumed that if demand for office space exists

at a regional or municipality level than local governments will facilitate supply to attract firms.

6.3.1 Free market

In a free land market, all agricultural land can potentially be used as a residential construction site; this results in an alternative spatial development pattern as presented in Figure 6-12.

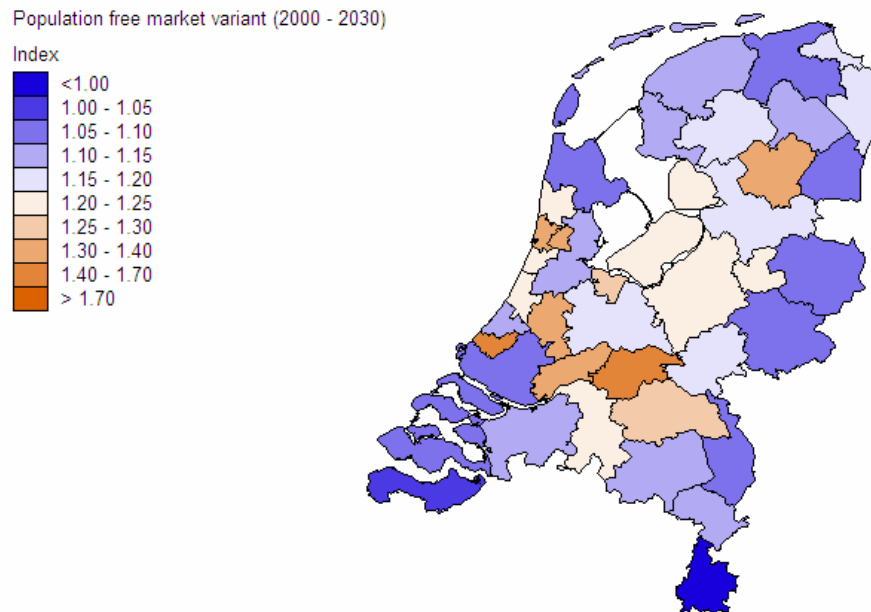


Figure 6-12: Index population between 2000 – 2030 for free market development

The spatial pattern of change in Figure 6-12 above illustrates that significant differences exist between a free market and regular development as presented in Figure 6-8. Below, in Figure 6-13 and Figure 6-14, these differences are presented in more detail.

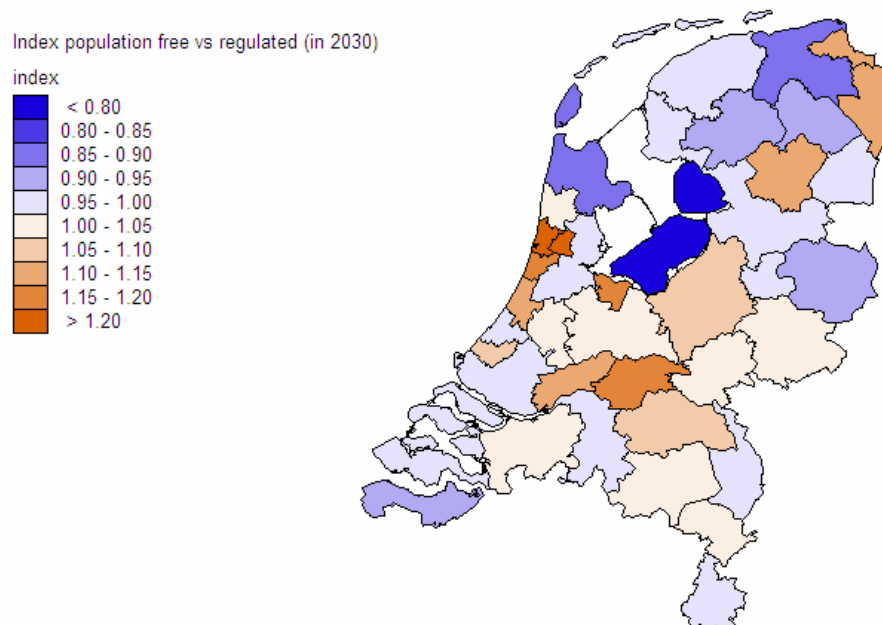


Figure 6-13: Index difference in population in 2030 between free market- and regulated scenario

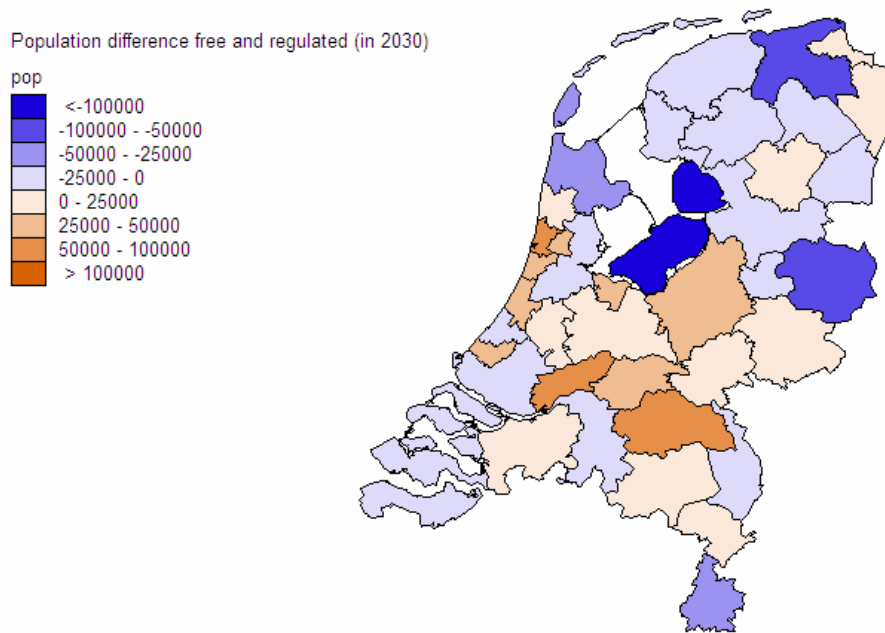


Figure 6-14: Difference in population in 2030 between free market and regulated development

Figure 6-13 compares the free market and regulated development through an index score by region, which is calculated by dividing the 2030 free market population by the 2030 regulated population in a region. At a national level a mixed pattern of index scores above and under 1 can be observed, although under a free market regime the COROP regions in the center of the country seem to grow faster. Again this reflects the spatial dimension of the housing market and a growth in a certain region most likely occurs at the expense of another region in the neighborhood.

Some of the differences, already observed in the semi-regulated market variant, are more profound in the free market variant; such as the high growth rates for the non-urban regions in- and around the Randstad, at the expense of the urban COROP regions and less centrally located COROP regions such as located in the Province of Overijssel or Province of Friesland. In the free market variant the restrictions on building in popular COROP regions like Veluwe or Gooi en Vechtstreek are largely removed; natural land remains restricted under all circumstances. Consequence is that households moving out of the urban areas in the Randstad, which are settling down in Overijssel or Friesland under a regulated market, have in the free market the opportunity to settle down in a similar non-urban residential environment at a shorter distance from the urban centers in the Randstad. A similar reasoning explains the lower growth under a free market in the Province of Zeeland and COROP Kop van Noord-Holland.

Counter-intuitive results are found for the two small COROP regions in Eastern Groningen, in these two regions the free market variant predicts a higher growth than the regulated growth, which seems inconsistent with existing high vacancy rates in these regions. A potential explanation is the unique status of the city of Groningen, which has a very high share of students among its population. These students are often temporary visitors from other parts of the country, and frequently return to more centrally located regions after finishing their study. The TIGRIS XL model does not distinguish this specific group of households and their behavior has been estimated among a larger group of households and for the whole of the Netherlands.

Effects of market regulation on distribution of jobs

As discussed before, the type of market regulation has an indirect impact on the spatial distribution of jobs via changes in the spatial distribution of residents. A direct relationship via the supply side of the labor market, e.g. office space or industrial land, exists only at a detailed spatial level for the distribution of changes in number of jobs within a municipality. Supply of office space or land does not have an impact on the spatial distribution of jobs at a municipality or regional level.

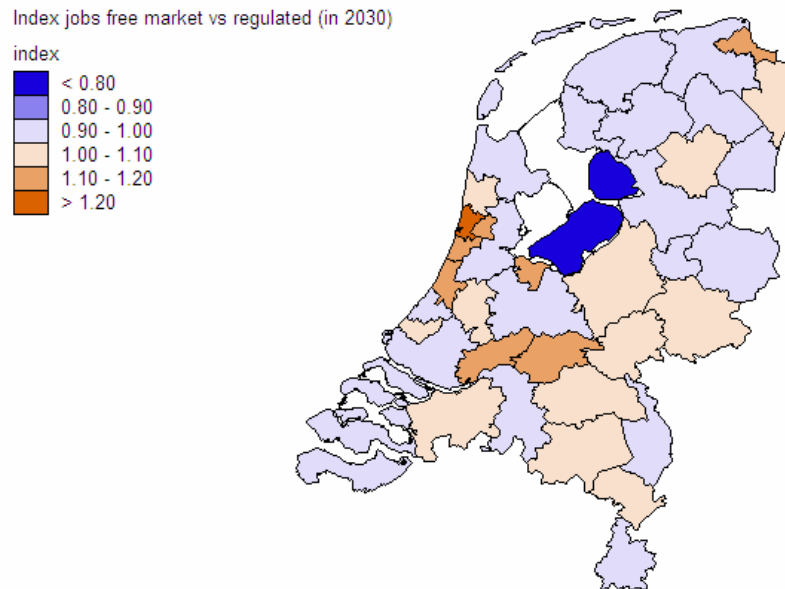


Figure 6-15: Index jobs in 2030 for free market versus regulated market

Figure 6-15 presents differences in employment in 2030 between the free market and regulated variant by economic sector. As expected the difference in employment development between the free and regulated market shows a clear similarity to Figure 6-13 presenting the difference in population development. Small differences between the two patterns reflect issues like impact of population changes on congestion or differences in the demographic composition.

The difference in jobs development by region, between a free market and regulated market development, varies by economic sector (see Table 6-5) depending on the sensitivity of the economic sector for changes in the population and associated indicators such as accessibility for the labor force. For total employment, the standard deviation for the difference in employment development of 0.10 (index national is 1), between free market and regulated, at a regional level, is rather similar to the standard deviation for the population of 0.11.

Table 6-5: Standard deviation in employment in 2030 at a COROP level between free market and regulated market

Sector	Standard deviation at COROP level
Agriculture	0
Industry	0.07
Logistics	0.08
Retail	0.11
Other consumer services	0.08
Business	0.12
Government	0.11
Total employment	0.10

6.3.2 Sensitivity of model results for level of market regulation

Table 6-6 presents differences in population development by province between different kinds of market regulation for the period 2000 – 2030 by Province. The table presents the total population by Province in 2030 for the regulated market and free market development.

Table 6-6: Population differences by Province

Province	Population 2000	Population regulated in 2030	Population free market in 2030	Index free vs regulated in 2030	Dif. population free vs regulated (in 2030)
Groningen	563,254	645,869	619,609	0.96	-26,260
Friesland	624,495	733,432	705,187	0.96	-28,245
Drenthe	470,760	555,796	551,162	0.99	-4,634
Overijssel	1,076,974	1,282,456	1,217,974	0.95	-64,482
Flevoland	317,201	642,772	394,297	0.61	-248,475
Gelderland	1,920,380	2,189,895	2,298,456	1.05	108,561
Utrecht	1,108,376	1,295,232	1,304,488	1.01	9,256
Noord-Holland	2,517,975	2,820,941	2,936,369	1.04	115,428
Zuid-Holland	3,402,917	3,964,649	4,060,534	1.02	95,885
Zeeland	371,440	420,570	395,873	0.94	-24,697
Noord-Brabant	2,347,138	2,697,717	2,785,460	1.03	87,743
Limburg	1,143,142	1,160,639	1,136,502	0.98	-24,137

The figures illustrate that significant differences exist between the regulated- and free market variant, especially if these differences are compared with the overall population growth of 16% (2000 – 2030) for the Netherlands. In general the differences at a province level are expected to be modest; this reflects the small number of large distance movements. Most striking is the difference for the Province Flevoland. Under a free market scenario the fast population growth of this Province diminishes and is replaced by higher growth figures for neighboring Provinces such as North-Holland and Gelderland. A general impression is that more central and populated Provinces show a higher growth under a free market regime than under a regulated regime. This confirms the influence of land-use restrictions in the Randstad on the development of this area.

National centralization or decentralization

A measure to calculate spatial concentration or de-concentration is the so-called Gini coefficient (Mills and Zanvakili, 1997). More general the Gini coefficient was developed to measure the degree of concentration (inequality) in a distribution. The Gini is the area between the uniform distribution (or line of perfect equality) and the observed Lorenz curve of a ranked empirical distribution, as a percentage of the area between the line of perfect equality and the line of perfect inequality. The Gini coefficient is a number between 0 and 1, where 0 corresponds to perfect equality and 1 corresponds to perfect inequality. The Lorenz curve is a graphical representation of the cumulative distribution function of probability distribution, which always starts at (0,0) and ends at (1,1).

Several other measures of inequality are closely linked tot the Gini Coefficient. The Index of Dissimilarity *ID* (Equation 6-1) is related to the Gini coefficient as it compares the evenness of two distributions across the elements (for example geographical regions); the index varies between 0 and 1, where 0 corresponds with perfect evenness and 1 corresponds to completely uneven distributed.

Equation 6-1

$$ID = 0.5 \sum_{n=1}^N |Z_n - Y_n|$$

Where *Z* and *Y* are percentages (or fractions) of the total number of elements and their respective values. *N* is the number of observation. If this coefficient is applied to the spatial distribution of residents (or jobs) over the provinces than 0 would indicate a perfect decentralization of residents over the provinces, in line with area size of the provinces, and 1 would represent that all residents live on the same location.

The centralization or decentralization of residents (or jobs) at a national level can be calculated by the index of similarity for the spatial distribution of residents. The Provinces were used as elements and *Z* represents area size and *Y* population or jobs. Table 6-7 presents the results for the regulated market and free market in 2030.

Table 6-7: Index of dissimilarity for population and job distribution over the provinces (2030)

	Index of dissimilarity		
	Regulated market	Free market	Difference free – regulated
Population distribution over provinces	0.232	0.249	0.017
job distribution over provinces	0.262	0.276	0.014

The ID results show that for both variants the distribution of jobs is more unequal, and centralized, than the distribution of residents. This is reflected by the function of urban areas as employment centers. A free market development results in a less equal, more centralized, distribution of both residents and jobs over the provinces. This centralization of activity will result in increasing regional disparities in pressure on land resources.

The above results may depend on the spatial scale level of the elements. Table 6-8 presents the results of the same analysis for the COROP level. The results at a COROP level show a similar difference between the market variants and the distribution of residents and jobs. Overall the inequality is larger as would be expected from a more refined level of spatial analysis.

Table 6-8: Index of dissimilarity for population- and job distribution over the COROP regions

	Index of dissimilarity		
	Regulated market	Free market	Difference free – regulated
Population distribution over COROP regions	0.272	0.289	0.017
job distribution over COROP regions	0.301	0.315	0.014

Regional centralization or decentralization (or sub-urbanization)

The regulated market and free market variant can also result, besides the differences at a national level, in different spatial development pattern at a regional level. Table 6-9 presents the *ID* for the distribution of residents and jobs over the zones within the Randstad region (defined as province of North-Holland, Zuid-Holland and Utrecht). It should be noted that overall the inequality is larger as would be expected from a more refined level of spatial analysis. The table shows a similar difference between the spatial distribution of residents and distribution of jobs; the inequalities in the distribution are higher for jobs than for residents. However, the table presents an opposite result for the difference between the regulated market and free market development. At a regional level a free market regime results in a less centralized or more suburban development.

Table 6-9: Index of dissimilarity for population and job distribution over the zones within the Randstad region

	Index of dissimilarity		
	Regulated market	Free market	Difference free – regulated
Population distribution over Randstad zones	0.504	0.496	-0.008
job distribution over Randstad zones	0.541	0.536	-0.005

Overall conclusion is that the model setting for differences in market regime has an impact on the spatial distribution of residents and jobs. A free market setting results (in comparison with a regulated market based on existing plans and patterns) in a more centralized development at a national level; more densely populated areas are growing faster and regional disparities are increasing. At a regional level a free market development results in the opposite trend of a less centralized and intensified sub-urban development. These findings are consistent with the findings in the literature; which indicates that at the interregional level centralization forces are dominant market forces and at a regional level sub-urbanization forces are dominant (RAND *Europe*, 2005).

6.4 Sensitivity analysis of structuring impacts

The “structuring impacts” of transport are defined here as the impacts of transport measures on the spatial distribution of residents and jobs. Not only changes in accessibility, but many other conditions are influencing the spatial distribution of residents and firms, and pre-condition the effects of accessibility. Influencing conditions are, for example, the existing level of accessibility and differences within the study region, social-economic dynamics resulting from demographic or economic developments, or spatial regulation policies.

The many influencing conditions and a long time gap between changes in the transport system and resulting land-use effects make it a complex task to use empirical techniques to estimate land-use effects of transport measures. A controlled environment, such as offered by a dynamic model of the system, is needed to analyze the effects under different settings. Logically the findings of such analyses do not have the same status as ex-post empirical findings and it should be noted that the validity of these findings depends on the adequacy of the model structure in combination with estimated model coefficients for model components.

In the sensitivity analysis a former, so-called prototype, version of the TIGRIS XL model is used, in this version the land-use and transport component are not yet fully integrated. Exogenous files with alternative accessibility indicators are used as input for the land-use module of TIGRIS XL. A reason for this simple set-up was that excluding the transport model results in a spectacular drop in calculation time of around 80%. However this time gain comes at a price and a limitation is that socio-economic input data of the transport model is not updated by changes in the land-use modules. This means that the sensitivity analysis addresses only part of the system interactions and long-term feedback effects from land-use on transport are ignored.

The sensitivity analysis comprises then two steps to assure a realistic exercise, these are the following:

- Identification of realistic changes in accessibility indicators used as explanatory variables within the housing and labor market of TIGRIS XL. The magnitude of the changes to be used in step 2 is based on analyzes of existing NMS-runs;
- Analysis of the impact of changes in accessibility on the spatial distribution of residents and firms. The changes in accessibility, determined in step one, are exogenous input for the land-use model in TIGRIS XL.

The test to determine realistic changes in accessibility indicators, specified as step 1, are described in Appendix C. Below the results will be presented for step 2.

Step 2: sensitivity simulations

In this step sensitivity simulations are performed to test the effects of changes in accessibility, as determined in step 1, on the spatial distribution of residents and jobs. It should be noted that these structuring effects of transport measures are affected by the context of the analysis. To reflect this context in the TIGRIS XL modeling, various settings can be changed to test the influence of changes in these conditions on the structuring impact of transport policies. In these sensitivity runs the settings have been changed for the future spatial policy of the government, the point in time of change in accessibility, and size and sign (positive or negative), of a change in accessibility. For each run the settings have been changed to observe the impact of transport on the spatial distribution of residents and jobs. A change in the level of land market regulation results in an alternative spatial pattern as presented in Section 6.3. Multiple reference cases are therefore needed to analyze the impacts of accessibility on land-use for different levels of market involvement. Table 6-10 presents the reference cases and variants that have been tested; the magnitude of the changes is presented.

Table 6-10: Overview of the key settings for the sensitivity runs

Variant	Change in travel time (%)	Change in logsum (%)	Scenario setting	Point in time
Reference free market	-	-	Free market	-
Free v1	-10%	+2.5%	Free market	2011
Free v2	-10%	+2.5%	Free market	2001
Free v3	+10%	-2.5%	Free market	2011
Free v4	+10%	-2.5%	Free market	2001
Reference regulated market	-	-	Regulated market	-
Regulated v1	-10%	+2.5%	Regulated market	2011
Regulated v2	-10%	+2.5%	Regulated market	2001
Regulated v3	+10%	-2.5%	Regulated market	2011
Regulated v4	+10%	-2.5%	Regulated market	2001

It should be noted that accessibility is a spatial phenomenon and these changes need to be interpreted in this context; accessibility is a relative term and the accessibility of a

zone depends on a comparison with the accessibility of other zones from the perspective of residents and firms. Therefore the changes in accessibility have been applied to a specific zone or region for each variant.

Applying changes to only one zone or region would fail to observe the potential differences resulting from the local context, e.g. a rural or urban environment. To get a feeling for the influence of such specific local conditions on the structuring impacts the following variations have been tested: for each variant the accessibility of two specific zones and two regions has been changed. To avoid that the results for the different zone and regions will affect each other, the zone and regions are selected in different parts of the Netherlands. At such a distance these areas are likely to have little effect on each other, since the areas are operating in different regional housing- and labor markets. A change in accessibility in one of these regions will have a neglectable impact on location choices for the other selected locations.

In each variant the accessibility of the same zones and regions has been changed, namely:

- The accessibility changes for employment have been applied at a regional level to the COROP regions of “Agglomeratie Leiden Bollenstreek” and “Zuidoost-Friesland”. One region, Leiden, located in the urban center of the Netherlands and one region, ZO Friesland, located in the Northern periphery;
- The accessibility changes for the housing market have been applied to all zones within these two regions and to two individual zones, one in the central Province of Utrecht and one zone in the peripheral Province of Limburg in the South of the Netherlands. The zones are located in the municipalities of Houten and Meerssen.

The structuring impacts for each variant and the selected zones and regions were computed with TIGRIS XL. Table 6-11 presents the impacts of changes in accessibility on the spatial distribution of residents.

Table 6-11: Index of changes in population resulting from changes in accessibility (pop variant/ pop reference)

Variant	Leiden	ZO Friesland	Houten	Meerssen
Population free market reference	406,775	227,048	2,646	14,984
Free v1	1.03	1.03	1.02	1.02
Free v2	1.06	1.05	1.04	1.02
Free v3	0.98	0.98	0.99	0.99
Free v4	0.96	0.97	0.99	0.99
Population reference regulated	396739	215814	2547	17746
Regulated v1	1.00	1.00	1.00	1.00
Regulated v2	1.00	1.00	1.00	1.00
Regulated v3	1.00	1.00	1.00	0.98
Regulated v4	1.00	1.00	1.00	0.98

Table 6-11 shows a clear difference in response between a free market and a regulated situation. The responses under strictly regulated circumstances are negligible: land regulations forbid developers to take advantage of better accessible locations. It should be noted that even in a completely supply regulated market, household responses may become significant in a case of over-supply in the market. In that situation households have the opportunity to move to better accessible locations. In all sensitivity simulations shortages exist in the housing market, in line with current market conditions; consequently the number of alternatives is limited for households to respond to changes in accessibility.

Under a free market regime these restrictions do not apply and the simulated changes in the distribution of residents can be indicated as modestly significant. These changes confirm theoretical expectations that the population will grow if a location gets better accessible and the population will decline if a location becomes less accessible. The results illustrate that the impact of time on the effect is significant: a twice as long response time (20 years instead of 10) doubles the effect on the population growth in Leiden and Houten. In COROP region ZO Friesland the same effect can be observed but less dominant and in Meerssen the full response has been achieved after ten years. This might be related to the overall future decline in population in the area surrounding Meerssen, which will affect the local housing market conditions concerning supply shortages.

A decline in accessibility as simulated in variant v3 and v4 results in a decline in population as well. However the effect is weaker than the effect of improved accessibility on population growth. An explanation is that a household leaving a zone leaves a vacant house behind, which is an alternative option for house seeking households to move in. The high sunk costs of houses prevent large-scale demolition and reconstruction of houses at more accessible locations.

The same sensitivity analysis as for the distribution of residents has been executed for the distribution of jobs. The results are presented in Table 6-12 for each variant and for the COROP regions “Leiden” and “ZO Friesland”.

Table 6-12: Effects on number of jobs by region, total number of jobs

Variant	Leiden	ZO Friesland
Jobs reference free market	221217	95798
Free v1	1.06	1.05
Free v2	1.09	1.07
Free v3	0.95	0.96
Free v4	0.93	0.95
Jobs reference regulated market	203,934	98,407
Regulated v1	1.04	1.03
Regulated v2	1.04	1.03
Regulated v3	0.97	0.98
Regulated v4	0.96	0.97

The land market assumption concerning a regulated or free market is of less relevance for the structuring effects on the number of jobs. This is a result of the dominant position of demand in the labor market; see also discussion of the results in Section 6.3. The responses for the regulated variant are slightly lower because of the additional influence of the population growth in the free market variants.

The direction of the responses of number of jobs to changes in accessibility is confirming the theoretical expectations. A positive effect on the number of jobs occurs if accessibility improves and a negative effect occurs if a region becomes less accessible. It can be concluded that the influence of accessibility on the change in jobs is somewhat higher than on the change in residents.

Differences in structuring impacts can also be observed between regions, the region “Leiden” is more sensitive to changes in accessibility than the region “ZO Friesland”. This is related to differences in the structure of the economy. The COROP region “Leiden”, for example, has a high share of business services and this sector is more sensitive to changes in accessibility than other sectors. The model estimation results indicate that the structuring effects on employment differ widely by economic sector. In Table 6-13 the structuring impacts on the distribution of jobs are presented for six economic sectors for the free market variant v1. It is assumed that changes in accessibility will not affect the agricultural sector.

Table 6-13: Effects for the free market variant v1 by economic sector.

Economic sector	Variant	Leiden Number of jobs	ZO Friesland number of jobs
Industry	Free market reference	16,092	13,239
Logistics	Free market reference	20,212	8,483
Retail	Free market reference	24,692	11,449
Other consumer	Free market reference	27,544	15,453
Business services	Free market reference	50,374	17,168
Government	Free market reference	78,249	25,447
		Index (v1/reference)	Index (v1/reference)
Industry	Free v1	1.06	1.05
Logistics	Free v1	1.04	1.04
Retail	Free v1	1.04	1.04
Other consumer	Free v1	1.04	1.04
Business services	Free v1	1.10	1.08
Government	Free v1	1.06	1.06

6.5 Observations

In Chapter 5 the structure of the TIGRIS XL model was presented including the model estimation results for key components of the modeling. The performance of the model as a whole has been tested in the present chapter. Sub-section 6.2.1 illustrates that the

dynamics of the model projections are in line with observed historical changes in the spatial distribution of residents and jobs. The variation in population development at the level of COROP-regions for the forecast period, 2000 – 2030, is in line with the variation for the period 1970-2000.

The model tests in Section 6.3 indicate a plausible sensitivity of the model results for changes in the spatial regime. Overall conclusion is that the model setting for differences in market regime has an important impact on the spatial distribution of residents and jobs. A free market setting results (in comparison with a regulated market based on existing plans and patterns) in a more centralized development at a national level; more densely populated areas are growing faster and regional disparities are increasing. At a regional level, a free market development results in the opposite trend of a less centralized and intensified sub-urban development. These findings are consistent with the findings in the literature; which indicates that at the interregional level centralization forces are dominant and at a regional level sub-urbanization forces are dominant.

In Section 6.4 the sensitivity of the distribution of residents and jobs for changes in accessibility has been tested. Overall the effects, of changes in accessibility, on the spatial distribution of residents and jobs have the expected direction and are within the margins of findings in the literature (see Section 3.3). Some specific results are:

- The impact of changes in accessibility on the spatial distribution of residents depends on the market regime. Under free market conditions the impacts are modest; the effects consist of a few percent of total population. The responses under strictly regulated circumstances are negligible: land regulations forbid developers to take advantage of better accessible locations. Under regulated market conditions the effects might become significant in a case of over-supply in the market;
- The analysis illustrates the importance of the time dimensions as effects increase steadily over time;
- A decline in accessibility results as expected in a decline in population. However the effect is less strong than the effect of improved accessibility on population growth. The high sunk cost of housing prevent large-scale demolition at less accessible locations;
- The influence of accessibility on the changes in jobs is somewhat higher than on changes in residents. Further it should be noted that these effects differ by economic sector; the highest effects can be observed for business services.

General conclusion is that the results for the various model tests, as described above, have been satisfactory. The model can subsequently be applied to case studies; Chapter 7 will report on model performance and results for two applications.

7 Applications of the TIGRIS XL model

Changes in land-use and transport affect many other sectors and therefore these changes are highly debated within society. In many countries, including the Netherlands, the government is a key player, formulating policies or policy bundles, to influence these transport and land-use changes. Analytical instruments, such as the TIGRIS XL model, contribute to this policy making by quantifying the effects of the policy measures. The main promise of the TIGRIS XL model to policy making is by answering the following questions:

- How do different land-use policy options affect land-use changes and associated forecasts for the spatial distribution of residents and jobs?
- What are the structuring (on the spatial distribution of residents and jobs) effects of transport measures?

The first question is important because the spatial distribution of residents and jobs forms the main input for deriving transport demand. A UK expert workshop on the modeling of household and employment location (WSP, 2003) also emphasizes that the influence of the planning system on housing and employment location concerns an important issue in land-use and transport interaction modeling. In Section 6.3 of the previous chapter the impacts of alternative governmental land market regulation schemes on land-use changes have been analyzed. In this chapter, city/region specific

alternative land-use plans are tested in a set of regional test applications for the city of Almere. Section 7.1 presents the results of these Almere test applications.

A land-use and transport interaction model is needed to answer the question about the structuring effects of transport measures. In Chapter 3 an overview has been presented of findings in the literature on the relationship between transport and land-use. It was stated that a fully empirical analysis is not feasible because of the large time lags in land-use response and the many factors which are likely to disturb this response: a pure long-term effect from a certain measure cannot be empirically observed. A controlled environment is needed to analyze the impacts of transport on land-use; a model like TIGRIS XL has sufficient functionality including sufficient empirical rooting, to offer such an environment. Sections 7.2 reports on the set-up and results of a test case exploring the impacts of a transport measure on the spatial distribution of residents and jobs within the Netherlands; the impacts of an inter-regional high-speed train are analyzed.

7.1 Case study: Alternative spatial development paths for the city of Almere

The Almere case has been set up to analyze how the effects of alternative spatial policies work out at a regional level. In this Section the focus will be on intra-regional effects, specifically the effects for the municipality of Almere, rather than on effects for a whole region. The city of Almere has been chosen as case study because of the large residential development plans of the government in this area. In this test application government policies are varied regarding to the size of the construction plans for Almere, national construction restrictions, and market regulation. The test can serve as an illustration of the variation in future development options for Almere. The test will also indicate under which conditions it is possible to realize the ambitions of the government for the city of Almere. In the test applications alternative combinations of policies, consisting of market regulation, specific land-use plans and national construction restrictions, have been defined and analyzed for their impact on population and employment developments in Almere. Housing construction rates and/or housing vacancies rates are the key factor for explaining the differences in population and employment.

The size of the housing construction, in a semi-regulated market, varies as a result of market preferences of the residents. Residential construction in a free market, within the limitation of land availability and restricted areas, is fully based on the market preferences. For all market settings, the national construction limits set an upper limit for the total number of houses constructed within one time period in the Netherlands. This setting reflects issues like capacity limitations of the construction industry, and administrative limitations of public administration agencies. In the case of a year with a tendency to exceed the national construction limit, all plans will be reduced proportionally. The spatial policies analyzed in the test application are described in Table 7-1.

Table 7-1: Overview of alternative spatial policies for the city of Almere

Nr.	Name	Study area	Description
R1	Regulated market	Almere	Similar to regulated market under 6.2, housing construction plans for Almere of 60000 units in period 2000 – 2030
A1	Regulated market, plan 1	Almere	Housing construction plan of 75000 units for Almere in period 2000 – 2030, regulated market conditions
A2	Semi regulated market, plan 1	Almere	Housing construction plan of 75000 units in period 2000 – 2030, semi regulated market conditions
A3	Zoning policy	Almere and surrounding	Free market development policy for the city of Almere and strict zoning policies in the surrounding regions
A4	Free market	Almere	Free market policy for the whole of the Netherlands
A5	Regulated market, plan 1, high national housing construction	Almere	Housing construction plan of 75000 units for Almere in period 2000 – 2030, regulated market conditions, national housing construction restriction is 90000
A6	Semi Regulated market, plan 1, high national housing construction	Almere	Housing construction plan of 75000 units for Almere in period 2000 – 2030, semi regulated market conditions, national housing construction restriction is 90000
A7	Regulated market, plan 2	Almere	Housing construction plan of 30000 units for Almere in period 2000 – 2030, regulated market conditions

The population of the city of Almere in the year 2000 was 147,000; in the spatial plans of the Dutch government the population is foreseen to grow significantly. Key target of these test applications is to test the sensitivity of the impacts for various policy decisions. Three alternative residential construction plans are worked out, namely a high construction plan of 75 thousand houses, a medium plan of 60 thousand houses, as included in the reference case, and a low construction plan of 30 thousand houses. The variation in market regulation will illustrate how likely these plans can be realized under different market regimes. The zoning policy, part of the philosophy of the latest national note on spatial development “Nota Ruimte”, explores the spatial implications of different market regimes in different regions within the country. In the variants with a high national construction restriction, the limit has been increased from 76,000 houses a year to 90,000, which means a net increase of the housing stock of around 75,000 units a year.

7.1.1 Impacts on the spatial distribution of residents

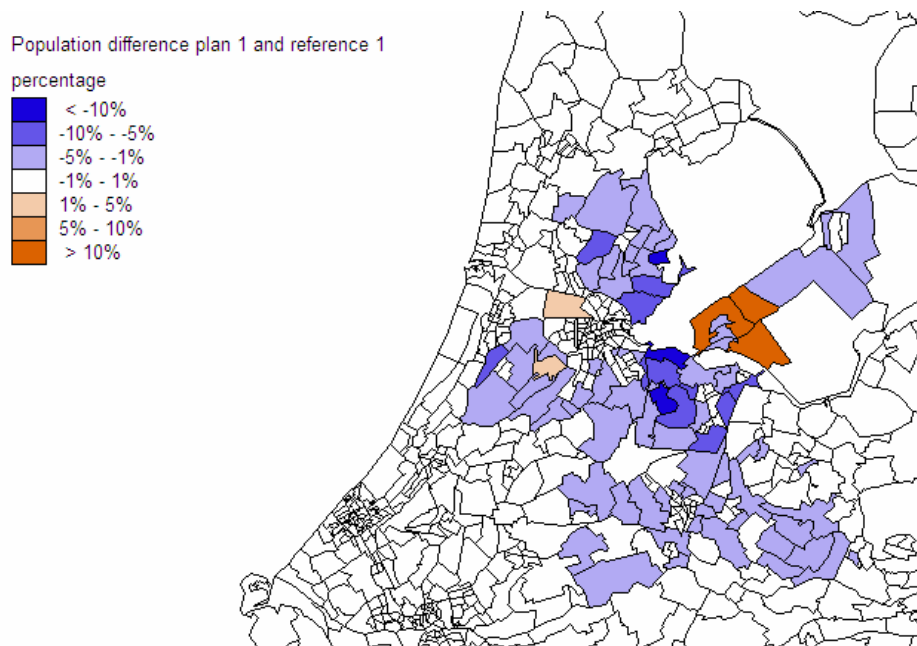
Table 7-2 shows the population projections for Almere for each of the variants. In all variants the 2000 population figures are forecasted to grow, but large differences exist in the forecasted growth figures between a modest growth of 40% population growth between 2000 and 2030 at the bottom end and a high growth of 126% at the top.

Table 7-2: Population forecasts 2000 – 2030 for Almere for different variants

Variant	2000	2010	2020	2030	Pop. Change 2000-2030 %
Regulated market	142762	190914	256946	262945	84
Regulated market, plan 1	142762	190889	266768	299423	110
Semi regulated market, plan 1	142762	186771	241000	264881	86
Zoning policy	142762	170134	192918	208573	46
Free market	142762	167805	186469	199828	40
Regulated market, plan 1, high national housing construction	142762	192528	269419	322987	126
Semi Regulated market, plan 1, high national housing construction	142762	187892	245838	281212	97
Regulated market, plan 2	142762	183254	207086	204626	43

The population forecasts in Table 7-2 show that a high growth scenario for Almere, similar to the reference plan of 60,000 houses or 75,000 houses in plan 1, can only be realized under regulated market conditions. The free market scenario illustrates that the market demand for Almere, as residential location is slightly lower than the small construction plan of 30,000 houses.

In Figure 7-1 a comparison of the high construction plan (75,000) with the reference (60,000) illustrates that Almere, as a development location mainly competes with other lower residential density areas around Amsterdam and Utrecht. In both variants the residential construction plans in the other regions remain restricted conform the reference case and the general market condition can be referred to as a market with supply shortages.

**Figure 7-1:** Impacts (in %) of high residential construction plan for Almere

In a free market variant, as shown in Table 7-3, a limited number of people decide to reside in Almere; alternative options in the region, both the region surrounding Almere and the wider region, are more preferred. Government regulation and construction plans are needed to develop Almere into a city of around 300,000 inhabitants.

Zoning policy can be considered as an alternative government policy to support the growth of Almere. In this variant the government restricts the developments in the regions surrounding Almere, -the COROP regions het Gooi en Vechtstreek, -Utrecht, - Amsterdam, - and the rest of the COROP Flevoland outside the municipality of Almere. Within the municipality of Almere a free market policy applies and housing construction can follow demand, only restricted by the availability of land. All other COROP regions in the Netherlands apply a free market policy as well.

The differences in effects between the zoning policy and a completely free market development on the population at a regional and local level are compared in Figure 7-2 and Figure 7-3. All regions with strict market regulations lose, as expected, a part of their market share to regions with a less restricted regime. The COROP region of Flevoland loses some of its population as well, because the sum of the gains of Almere and losses of other municipalities in Flevoland is negative.

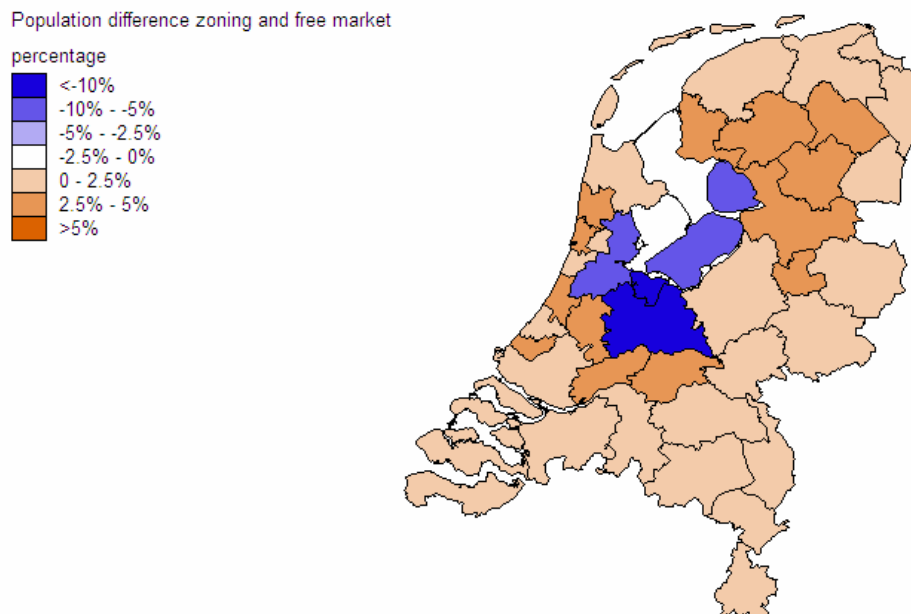


Figure 7-2: Population difference between zoning policy and free market policy for Almere at a regional level in 2030

In Figure 7-2 it is clear that the market freedom in Almere, and restrictions in the surrounding, result in a small growth of only 9,000 inhabitants. At the same time the COROP regions Amsterdam, Utrecht and het Gooi en Vechtstreek are facing a population reduction of almost 250,000 inhabitants resulting from the zoning policy. Most of these residents prefer to locate in other alternatives, like the Northern part of the province of North-Holland, the Northern Provinces or non-restricted regions within the Randstad area. This example illustrates the point that zoning policies can have far-reaching effects, even though the vast majority of household moves are over a short distance. Spatial overlapping of housing markets can explain this, for example, the housing market of the Northern Part of the Province of North Holland has an overlap

with the market of Amsterdam and the housing market of Almere has an overlap with Amsterdam as well.

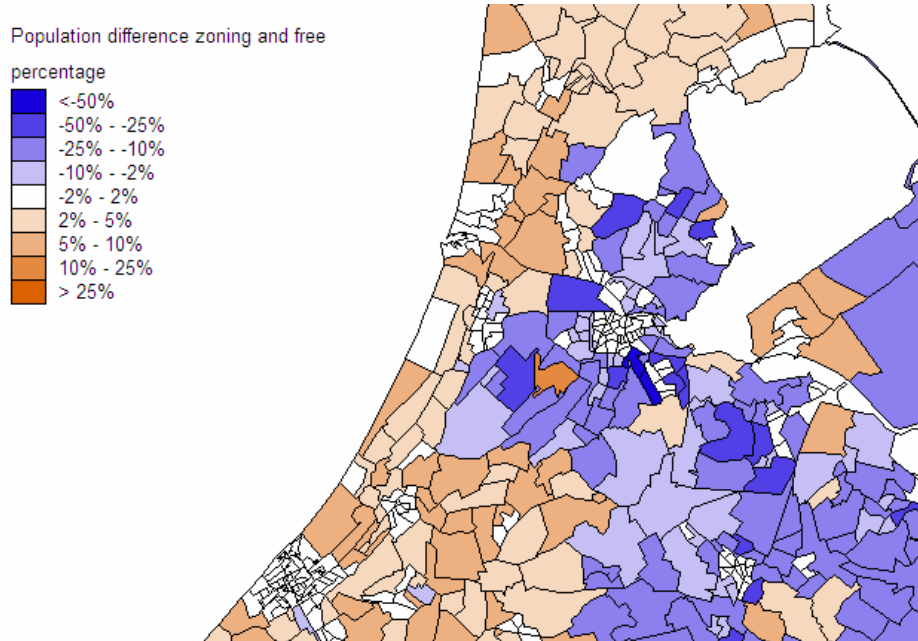


Figure 7-3: Population difference between zoning policy and free market policy for Almere at a local level in 2030

7.1.2 Impacts on spatial distribution of jobs

The effect of market regulations on the spatial distribution of jobs is indirect, similar to the test applications reported in Section 6.3. Several economic sectors are strongly affected by changes in populations, retail or government services. Other economic sectors such as business services respond more modestly to changes in the number of residents; they primarily respond indirectly to changes in the number of jobs in other economic sectors. The industry may show mixed results as this sector responds positively to an increased work force and negatively to increased pressure on land and related increases in land-prices.

A detailed discussion written by Bureau Louter about the effects on the economic sectors can be found in the publication “TIGRIS XL proeftoepassingen”. In this thesis a short overview of the changes is included in Table 7-3 to give a more comprehensive picture of the spatial changes in Almere and surrounding. The forecasts are presented at the regional level (the whole of Flevoland) to be consistent with the level of estimation of the model parameters.

Table 7-3: Overview changes in residents and jobs for Flevoland 2000-2030, jobs and residents (*1000)

Variant	Population 2000	Population 2030	Pop. Change 2000-2030 %	Jobs 2010	Jobs 2030	Job change 2000- 2030 %
Regulated market	317	545	72	116	204	76
Regulated market, plan 1	317	580	83	116	213	84
Semi regulated market, plan 1	317	530	67	116	200	73
Zoning polciy	317	422	33	116	172	49
Free market	317	446	41	116	178	54
Regulated market, plan 1, high national housing construction	317	613	93	116	222	92
Semi Regulated market, plan 1, high national housing construction	317	554	75	116	207	79
Regulated market, plan 2	317	490	54	116	189	64

The changes in jobs show a strong similarity with the changes in residents: an alternative with fewer resident results also in fewer jobs. However, the size of the changes differs: in low residential growth variants, the growth in jobs is significantly higher than in residents and for the high residential growth variants, job growth figures are of a similar magnitude. Several balancing forces in the modeling can explain this difference, such as congestion effects or increased pressure on land.

7.1.3 Policy and model observations

Several policy observations as well as observations about the modeling can be derived from the Almere case. The various test applications for Almere illustrate the capability of the model to generate alternative spatial developments and the effect of spatial policies on these developments. On this basis the model can be used to explore alternative future spatial developments and analyze the influence of alternative spatial policies. Through its link with the transport model the impacts of alternative spatial configuration on transport can be analyzed as well.

General conclusion for the future development of Almere is that the government ambitions are much higher than market demand; therefore realization of the medium and high growth ambition of 60 thousand or 75 thousand houses depends strongly on a strictly regulated land market regime. Under less restricted circumstances, as proposed in the Nota Ruimte (Ministerie van VROM, 2005), the low growth ambition of 30 houses seems to be more realistic. Even if a strict zoning policy in neighboring regions, such as COROP Amsterdam, COROP Utrecht and COROP Gooi en Vechtstreek, is applied, the growth of Almere is modest. This is caused by the competition of alternative locations in less restricted regions. Therefore the policy ambitions in the most recent physical plan for the Netherlands, the “Nota Ruimte”, which state targets of

high growth for Almere and less central steering for spatial developments, seem to be two conflicting policy goals.

7.2 Zuiderzeelijn application; an inter-regional transport measure

The TIGRIS XL model aims to operate at a national-, as well as the regional level, studying the effects of inter-regional transport measures and the impacts of large intra-regional infrastructure measures. The scale of the modeling does not support the analysis of urban infrastructure measures or small-scale infrastructure measures. In this section the structuring impacts of an inter-regional transport measure on the spatial distribution of jobs and residents is tested. The analysis focuses on the kind of effects and their order of magnitude; the present set-up lacks sufficient detail to be considered as a full-fledged policy evaluation study.

Inter-regional infrastructure measures are normally high profile measures involving massive investment. A highly debated infrastructure measure in the Netherlands is the so-called Zuiderzeelijn, a high-speed train connection between the more peripheral Northern-Provinces and the core of the Netherlands. Key argument advocating the infrastructure measure is that the connection will support the social-economic development of the Northern provinces, which have a lower economic performance than the core of the Netherlands (Elhorst et al., 2000). The inter-regional test application of the TIGRIS XL model will focus on this infrastructure measure; it has for the Netherlands, an unique characteristic of linking the core and periphery.

The expected positive indirect effects on the housing and employment market in the North are in this case the main desired effects of the infrastructure measure. The outcomes of the test applications will be analyzed at a regional level to see whether the measure is strengthening the Northern provinces and at an intra-regional level to see the nature of the effects at a more local level. The changes in number of residents and jobs will be used as performance indicators. All applications use the scenario settings as specified in Section 6.1 and the forecast period is in all cases 2000-2030. The test runs executed to study the impacts of the inter-regional transport measure are listed in Table 7-4.

Table 7-4: overview of test application to study Zuiderzeelijn impacts

Nr.	Name	Study area	Description
1	Zuiderzeelijn service level 1, regulated market	NL	Regulated market development conform section 6.3 and fastest variant
2	Zuiderzeelijn service level 2, regulated market	NL	Regulated market development conform section 6.3 and slower variant
3	Zuiderzeelijn service level 1, free market	NL	Free market development conform section 6.3 and fastest variant
4	Zuiderzeelijn service level 2, free market	NL	Free market development conform section 6.3 and slower variant

The Zuiderzeelijn train connection between Schiphol and Groningen consists, for service levels 1 and 2 respectively, of a more direct service, Schiphol - Amsterdam Zuid - Almere - Heerenveen – Groningen and a service with more stops on the way, Schiphol - Amsterdam Zuid - Almere - Lelystad - Emmeloord - Heerenveen - Drachten – Groningen. The travel time differences between service level 1 and 2 are significant as shown in Table 7-5. Both service variants are significant improvements to the existing train service with a travel time of 144 minutes.

Table 7-5: travel times for service level 1 and 2

Service level variants	Travel time Schiphol-Groningen, direct service	Travel time Schiphol-Groningen (Lelystad, Emmeloord, Drachten)
Service level 1	39 minutes	47 minutes
Service level 2	78 minutes	94 minutes

*) the travel time between Schiphol and Groningen depends on the type of train and infrastructure (service level 1 or 2) and the number of stops

For the analysis of the structuring impacts of transport measures it is necessary to isolate these effects. The reference conditions are different for the four test applications as specified in Table 7-4. The outcomes of application 1 and 2, transport measures under regulated land market conditions, are compared with the regulated land market run, without this transport measure, as reported in section 6.3. The outcomes of application 3 and 4, transport measures under free land market conditions, are compared with the free land market run, without this transport measure, as reported in section 6.3.

7.2.1 Impact on spatial distribution of residents

Table 7-6 presents the outcomes of the Zuiderzeelijn variants on the distribution of the residents over the Provinces in the Netherlands.

Table 7-6: changes in the distribution of residents over Provinces in NL

Province	LOS 1, regulated	LOS 2, regulated	LOS 1, free market	LOS 2, free market
Groningen	9598	4628	8432	3299
Friesland	1511	709	15686	8114
Drenthe	3155	-191	-498	-808
Overijssel	-1233	-412	-3700	-1308
Flevoland	-781	-800	1462	-2404
Gelderland	-2026	-802	-5074	-1559
Utrecht	-1815	-523	-3546	-1116
Noord-Holland	-1081	-234	-2224	-437
Zuid-Holland	-2452	-823	-3602	-1247
Zeeland	-534	-181	-870	-259
Noord-Brabant	-2499	-808	-4543	-1720
Limburg	-1829	-563	-1499	-536

For all four test applications the province of Groningen and Friesland are facing an increase in the number of residents. For Drenthe and Flevoland the results are mixed,

depending on the variant and all other provinces face a decrease in population. The mixed results for Drenthe and Flevoland can be explained as follows: in the Province of Flevoland the accessibility of Zuiderzeelijn station cities such as Almere and Lelystad increases as well as the number of residents in these cities. However the other municipalities in the Province of Flevoland are attracting less residents due to an increased competition of the Northern Provinces with a similar residential environment. Although the Province of Drenthe does not have a station of its own, it takes advantage of a slightly improved accessibility; on the other hand the larger improvements in accessibility in Friesland and Groningen change the competitive conditions between the Northern provinces resulting in a population decrease in Drenthe.

The population in the province of North Holland is decreasing, although the accessibility of this province increases. An important effect of the Zuiderzeelijn is that it enlarges the spatial scope of the housing and labor market of the city of Amsterdam towards the Northern Provinces. The location choice of households for the Northern provinces is therefore sometimes at the expense of the choice for a suburban location in for example the province of North Holland.

The changes in the spatial distribution of the residents for the Northern provinces are further detailed in Table 7-7 presenting the changes in residents at a COROP level. Highest growth for all variants can be observed in the COROP “Overige Groningen”, which includes the city of Groningen. Other high growth regions, like the COROP regions in Friesland and North Drenthe, are more sensitive to the land market condition. Under regulated land market conditions the growth in Friesland is minor reflecting housing shortages in the market, the region North Drenthe is chosen as an alternative location. Under free market conditions most of the growth will be realized in the COROP regions in Friesland, resulting from additional house construction in this area.

Table 7-7: change in number of residents for the COROP region within the three Northern-Provinces

COROP	LOS 1, regulated	LOS 2, regulated	LOS 1, free market	LOS 2, free market
Oost-Groningen	641	216	742	529
Delfzijl eo	-68	-263	76	-141
Overig Groningen	9025	4675	7614	2911
Noord-Friesland	489	299	2567	1684
Zuidwest-Friesland	376	130	5396	2496
Zuidoost-Friesland	646	280	7723	3934
Noord-Drenthe	4352	1388	1754	778
Zuidoost-Drenthe	-661	-110	-647	-172
Zuidwest-Drenthe	-536	-1469	-1605	-1414

The COROP regions without a station at the Zuiderzeelijn, having a smaller increase in accessibility, like COROP “Zuidoost-Drenthe” or “Zuidwest-Drenthe” are facing a decrease in population as a response to the improved competitive position of the other COROP regions within the Northern provinces. Figure 7-4 and Figure 7-5 present the changes in residents, for variant LOS 1 and free market, as an index and in absolute figures for all COROP regions within the Netherlands.

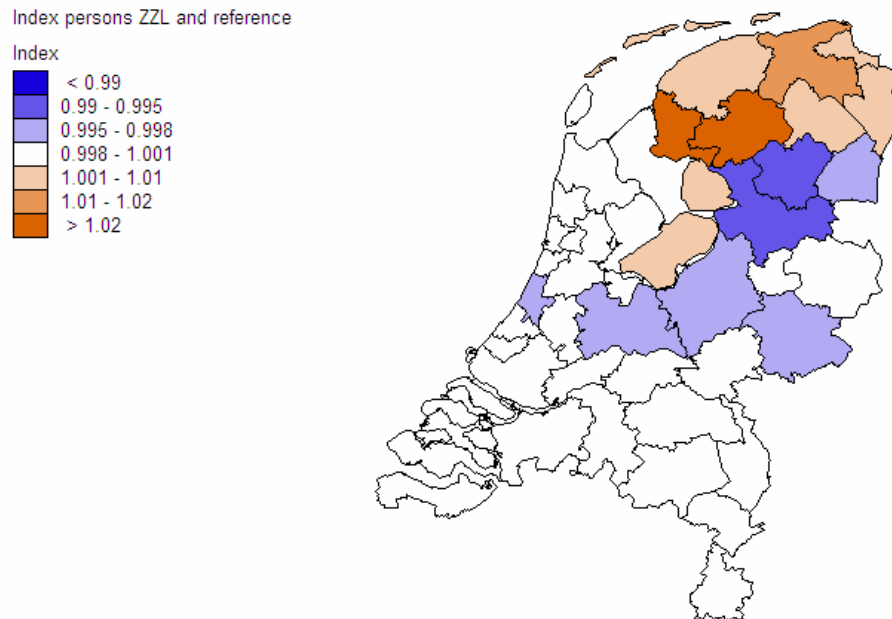


Figure 7-4: Index number of residents by COROP with and without Zuiderzeelijn project (LOS 1, free market) in 2030

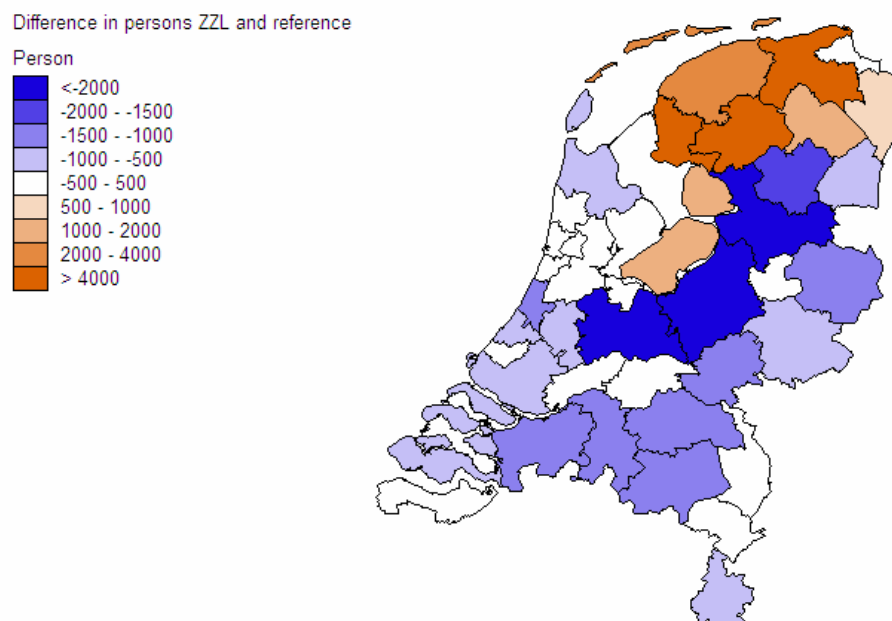


Figure 7-5: Change in residents by COROP with and without Zuiderzeelijn (LOS 1, free market) in 2030

For the same variant, LOS 1 and free market, the effects on the population size at an intra-regional level are presented in Figure 7-6. This map illustrates the effect of station locations or their direct surroundings. The impact of the transport measure on the Northern part of the country comprises a mixture of positive and negative effects on the population size at a local level. These mixed changes result from the complex effect of the infrastructure measure on the competitive conditions within the Northern region and between the Northern region and the rest of the country.

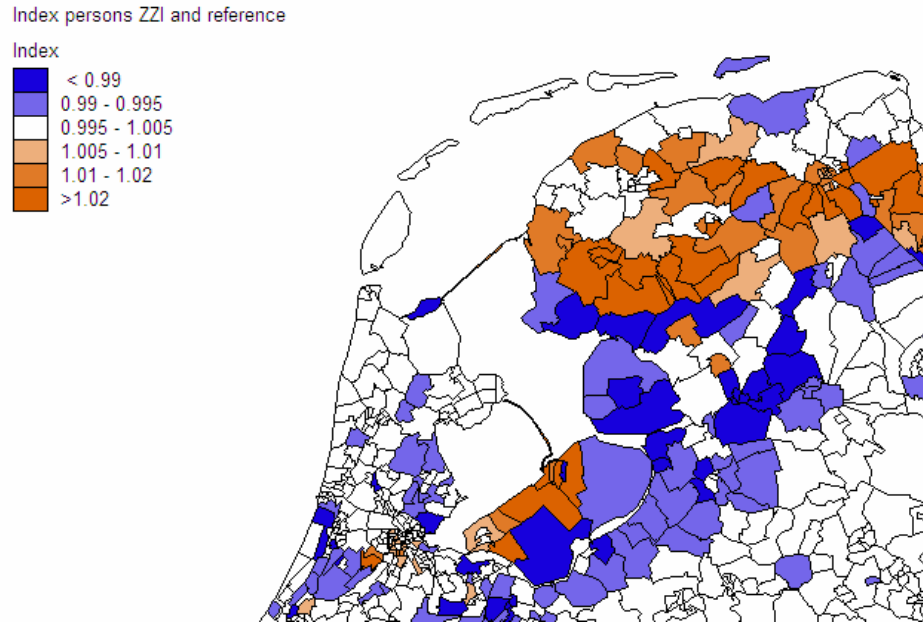


Figure 7-6: Index number of residents by zone with and without Zuiderzeelijn (LOS 1, free market) in 2030

7.2.2 Impact on spatial distribution of jobs

The impact of the high-speed train on the spatial distribution of jobs depends on a direct effect, job location choices responding to changes in travel conditions, and an indirect effect associated with the changes in distribution of the residents such as described above. It should be noted that the large differences in response between the economic sectors, as discussed in section 6.4 apply here as well. Strong responding sectors are industry and business services. Other sectors present a less strong but still positive effect for the Northern Provinces. Table 7-8 presents the results, shift in number of jobs by province, associated with the two ZZL level-of-service variants under different market conditions.

Table 7-8: changes in the number of jobs by Province

Province	LOS 1, regulated	LOS 2, regulated	LOS 1, free market	LOS 2, free market
Groningen	6247	3513	5528	2740
Friesland	3273	2090	7424	4289
Drenthe	938	7	-34	-165
Overijssel	-1293	-536	-2211	-902
Flevoland	1683	1558	1811	856
Gelderland	-1240	-777	-1620	-674
Utrecht	-822	-925	-850	73
Noord-Holland	-1774	-1109	-2619	-1882
Zuid-Holland	-3320	-2246	-2883	-1773
Zeeland	-278	-111	-325	-129
Noord-Brabant	-2529	-1504	-2826	-1670
Limburg	-843	41	-1384	-735

The results in Table 7-8 illustrate that the labor market is less sensitive, but not insensitive, to the land market regime. The labor market results are indirectly, through an alternative spatial dispersion of the residents, affected by changes in the land market regime. Both distributions, residents and jobs, present a higher growth under free market conditions in the Province of Friesland than under regulated conditions. Part of this additional growth in Friesland depends on a lower growth under free market conditions in the Province of Groningen. Under regulated market conditions Groningen benefits more strongly from existing housing vacancies and development plans. Furthermore housing supply limitations restrict the population and job growth in Friesland, especially in the southern part of the Province.

The changes in the distribution of jobs do not only occur at the spatial level of Provinces but at lower levels of spatial resolution as well. As stated before the effects of transport policies occur at a local level and the benefits and losses might differ significantly between region and cities within a Province. Table 7-9 presents the changes of the distribution of jobs for the COROP-regions within the Northern Provinces.

Table 7-9: changes in number of jobs by COROP-region in the three Northern-Provinces

COROP	LOS 1, regulated	LOS 2, regulated	LOS 1, free market	LOS 2, free market
Oost-Groningen	278	116	229	136
Delfzijl eo	91	-28	73	-27
Overig Groningen	5878	3425	5226	2631
Noord-Friesland	737	522	1524	1011
Zuidwest-Friesland	287	144	1584	738
Zuidoost-Friesland	2249	1424	4316	2540
Noord-Drenthe	1358	498	622	290
Zuidoost-Drenthe	-179	-39	-183	-57
Zuidwest-Drenthe	-241	-452	-473	-398

Table 7-9 shows that of all nine Northern COROP-regions almost all the benefits are allocated to only two COROP regions “Overige Groningen” and “Zuidoost Friesland”. These two COROP regions are connected directly to the ZZL service by the station of Groningen and Drachten. The other COROP regions within the Northern Provinces benefit of the transport improvement as well, however via an indirect connection. In these COROP regions the change in number of jobs is not always positive. Reason for this is that accessibility is a relative measure influencing the competitiveness between regions.

The ZLL Level of service 1 variants with the most radical improvement in travel time has, as expected, the strongest effect under both land market regimes. A comparison of the regulated and free market pattern for job changes by COROP illustrates the second order effect of population changes on the distribution of the jobs.

7.2.3 Conclusions Zuiderzeelijn case

The case study for the Zuiderzeelijn illustrates that the TIGRIS XL model calculates plausible results for the changes in the distribution of residents and jobs. The effects of the infrastructure measure for the Northern Provinces are small compared to the total population and number of jobs and autonomous developments in these Provinces. A comparison with the results in paragraph 6.3 shows that spatial policies are much more effective in influencing the spatial distribution of residents and jobs than transport policies.

In the case of project evaluation the indirect distribution effects need to be transferred into costs or benefits and compared with the costs of the project. This transfer is highly debatable, as standard figures are missing, and therefore not carried out in this research. However, the modest number of jobs transferred to these Northern Provinces and the high costs of the project (investment costs up to 8.5 billion Euro for the Maglev variant, Ecorys 2006) illustrate that these indirect distributions effects can be no more than a marginal additional benefit. The policy conclusion is that if the direct benefits of the project and costs are not close to break-even then the indirect distribution effects are unlikely to make the difference between break-even or not.

8 Conclusions and recommendations

8.1 General

Over the last decades it has become clear that the problems of a continued growth of transport in urbanized regions, such as congestion and environmental externalities, cannot be solved only by conventional transport measures. A broad strategy, incorporating a variety of policies affecting the urban/regional system and its interactions with transport, is needed to manage transport supply and demand, and realize regional development targets. In the Netherlands this recognition has resulted in an ongoing integration of land-use plans, as formulated in the national physical plans, and transport plans.

Over time a trend can be observed in many of the European countries towards standardized project evaluation procedures and methods. In first instance these evaluation methods have focused on estimating direct effects, defined as transport sector related effects, and external effects, such as environmental effects. The indirect effects, effects on non-transport markets, have been a continuous point of discussion and governments strive to integrate these effects as a standard element in the evaluation framework.

Integrated, multi-sector models have potential to support this integrated policy making- and evaluation practice. A joint modeling of land-use, transport and economy provides an analytical framework for a systematic evaluation of policy packages which combine transport- and land-use policies. Such modeling enables integrated policy packages to be tested through a transformation of policy measures into specific settings of model parameters and input data describing the system and the external scenarios. Physical effects or performance indicators, resulting from simulation of the system, need to be valued for use in the evaluation; this should provide a ranking of the proposed policy package with respect to the reference situation and alternative packages.

The research reported in this thesis has resulted in a number of observations and conclusions corresponding to:

- The objective of the research to improve the estimation of land-use effects resulting from transport policy measures, and with the specific aim to facilitate project evaluation;
- The operational target of the research to improve integrated model systems as tools in policy analysis.

The conclusions on the operational target to improve integrated models systems as tools in policy analysis are reported in Section 8.2. This section responds to existing gaps as identified in Section 1.5, as follows:

- To find a balance between the level of detail for each of the three relevant dimensions of space, time and sectors/actors;
- To realize a close integration with an advanced transport model;
- Estimate the key relationships on empirical data;
- To tailor the modeling set-up to the spatial regime and spatial structure in the Netherlands.

The conclusion on the land-use impacts of land-use and transport policies, corresponding to the objective of the research, are reported in Section 8.3. In Section 8.4 a bottom-up approach is explored to calculate, in a post-processing step, the generative production effects of transport measures resulting from agglomeration benefits. Such approach will bridge the gap between LUTI models and current project evaluation practice as it strengthen the capability of LUTI-models to address generative economic effects, while maintaining the strong points such as representation of dynamics, spatial detail and modular set-up.

8.2 Methodological lessons on integrated modeling

As stated above, two trends, the ongoing change towards integrated policy making and specification of land-use and economic effects in standardized evaluation procedures, have set new demands on the scope and output of the analytical framework. The OEI - evaluation framework in the Netherlands includes in its full scope a wide set of effects, both monetary and non-monetary. Established and mature transport models and procedures are available to calculate the direct benefits and environmental externalities. For the indirect benefits such mature level of procedures and models does not exist;

there is ongoing debate about the methodology, -model estimation, -required spatial level of detail, -time dynamics and scope of these models. Besides these differences there is an unified recognition of the need for quantitative information about the effects of transport measures on other regional markets such as the housing- and labor market and the production system, and that such quantification calls for an integral modeling of transport and regional development.

This research has focused on a contribution to the family of so-called LUTI models, a specific family of models, with many different members, focusing on the integrated modeling of land-use and transport. Because of the endogenous inclusion of land-use changes, these models cover a substantial part of the above-mentioned indirect effects. This section presents the main findings regarding the design of TIGRIS XL, a LUTI model tailored to the specific conditions in the Netherlands, addressing evaluation procedures, data availability and level of market regulation. Key conclusions/recommendations regarding the modeling are presented below:

Methodology

An important decision on methodology is to focus either on an equilibrium approach, explaining the land-use and transport system at a point in time, or to focus on a time evolving description of the changes within the system, following a dynamic system approach. Chapter 3 and 5 have argued the non-existence, at any moment in time, of a general equilibrium in the land-use and transport system, due to a variety of time lags and differences in speed of change for components of the system. A dynamic system approach is therefore preferred as it is much better capable of addressing these changes. The land-use changes are relatively small in nature compared to overall land-use, and a dynamic incremental approach is well suited to model small changes. A consequence of following a dynamic approach is that it is difficult to estimate indirect generative effects. Further in this Chapter a method is explored to improve the link between LUTI-models (following a dynamic system approach) and the standardized economic evaluation procedures in the Netherlands and UK (including indirect generative effects).

A dynamic system modeling approach, other than for a general equilibrium approach, gives flexibility to set-up a modular modeling system with a sequential treatment of the various modules. General equilibrium models have an integrated, closed format structure, often using an input-output framework to link the various components; all model components need to be calibrated/estimated simultaneously. A modular set-up enables to tailor individual components with available databases, without the restriction that all model components need to be represented in that one database. This flexible use of databases has proven to be very valuable during the design and development of the TIGRIS XL model. It further also facilitated the necessary flexibility towards existing databases and experts addressing specific components.

A further important modeling decision that needs to be made is how to address supply and demand, and their interaction. An important contribution of the present research is that several alternative land market regimes can be explored. The alternative spatial projections can vary from completely regulated, following supply planning of the government, to a free market regime, in which supply follows the location preferences of the residents. Chapter 6 illustrates the value of being capable to explore alternative spatial projections.

The full complexity of supply and demand interactions is only partly addressed in this research and some limitations need to be mentioned. In reality, supply and demand

interactions are not only influenced by households and government planning alone, other actors play an important role such as land-owners, project developers and investors. Secondly the demand preferences as measured in revealed preference data might be affected by other market conditions; this issue is discussed in more detail below in the topic model estimation.

Linkage with transport model - accessibility

The TIGRIS XL land-use model is linked with the National Model System (NMS), a passenger transport model for the Netherlands. The NMS is a discrete choice type of transport model based on micro-economic utility theory. With such a model it is possible to generate a logsum value, an aggregate value expressing the utility from multiple alternatives. Chapter 5 describes the use of utility-based accessibility indicators for the TIGRIS XL model. The utility-based indicators in TIGRIS XL include personal characteristics and preferences, besides characteristics of the transport and land use system, to capture observed heterogeneity across individuals. Including the individual component of accessibility means that more realistic accessibility indicators, namely accessibility indicators closer representing the specific activity pattern and preferences of the households or firms, can be included as explanatory variable in the estimation process of residential or firm location choices.

Model estimation

In most LUTI-models parameter values are based upon expert judgment or informal calibration procedures: observed and calculated data sets are matched without using statistical indicators such as model fit or parameter significance. Preferred modeling practice is to establish formally estimated location choice models for household location choice and firm location choice. In the Netherlands sufficient data is available to realize such a formal estimation of the relationships for the housing and labor market. For the TIGRIS XL model the model coefficients are formally estimated using available databases; this can be considered as an important contribution to an increased confidence in the model results. Important contributions of TIGRIS XL are in particular the use of advanced accessibility measures in combination with a wide set of other explanatory variables in the model estimation, and the estimation of specific models by household types and economic sectors (Chapter 5).

The functionality of TIGRIS XL which enables to vary the land planning regime is important to address policy decisions for this market but at the same time it puts challenges for model estimation; the parameters are estimated for a particular market regime and a different regime may affect model parameters. A future research challenge is to explore the use of stated preference data to account for location choice preferences under different, less restricted, market conditions. It should be noted that the effects generated with the TIGRIS XL model reflect the observed residential location choice preferences for the period 2000-2002 which are affected by the market conditions in this period. A description of the market conditions for the housing market in this period is complex as it constitutes a combination of free market processes, such as price settings in the private ownership market, mixed conditions in the private rent market, restrictions such as price caps, point system and protection of renting households, or other regulations in the public rent market, with arbitrary allocation systems.

At a more aggregated level, addressing all market segments, a mixture can be observed and the model coefficients are thus effected both by preferences of the households as well as planning restrictions by the government. Therefore in reality it might be that the

changes in land-use are more drastic under free market conditions than calculated in Chapter 6.

Spatial level of detail

In the international literature a distinction is often made between models operating at a regional level and inter-regional models. In regional models it is generally assumed that “hard” regional borders exist and important spatial markets, like the housing and labor market, are constraint by the regional boundaries. Such assumption can be realistic in a context of a big urban center surrounded by suburban areas and rural areas at a farther distance. However, in an area with a complex spatial structure with multiple centers and overlapping labor and housing market, such as for the Netherlands, identification of hard regional boundaries is not realistic.

In the present research, both the regional and inter-regional level, are integrated within one framework. Within the housing market module a nested structure has been used to address inter-regional moves and moves within the region. Different coefficients and explanatory variables have been tested at the different spatial scale levels. Based on this concept the modeling is capable of consistently analyzing regional and inter-regional transport plans. For application at other scale levels, for example the analysis of international- or urban infrastructure, additional research is needed as other explanatory variables and coefficient weights may be needed at these levels.

8.3 Land-use impacts of transport- and land-use policies

Tracing the effects of transport- and land-use policies on spatial development is a main issue of the present research. The drivers underlying the structuring impacts of transport on land-use vary by spatial scale level and a distinction can be made between intra-regional and inter-regional structuring effects of transport. Intra-regional structuring effects comprise household- or firms relocations, within the same housing- and labor market, resulting from changes in the transport system. Inter-regional relocation decisions may result from transport measures extending spatial markets over the regional boundaries or affecting the competitiveness of a region by improving its accessibility.

In this research the structuring effects have been studied by using various sources, such as:

- A literature review of the structuring effects as reported in Chapter 3. This review highlighted the complexity of empirically analyzing the influence of accessibility on land-use changes. It also pointed out that the size of the structuring effects of a specific measure is affected by the specific context of the study region, regarding its spatial structure and density, existing level of transport infrastructure, and spatial planning practice;
- Chapter 5 reports on a statistical estimation of the relationship between accessibility, and residential- and firm location choices. These relationships have been detailed for various socio-economic groups and economic sectors. Another strong point of the housing market estimation, compared to other studies, is the inclusion/testing of many explanatory variables;

- An isolated environment, based on the development of the TIGRIS XL model, has been used to calculate the structuring effects of various transport measures. Within the environment of such a model, of which the components have been empirically estimated, it is possible to overcome many of the complications observed by empirical analyses of the structuring effects on the total system. The model enables to compare, under different scenarios, the land-use pattern with and without a particular transport measure.

As specific contributions of the present study can be listed the use of empirically based relationships (survey data or time series data) for the influence of accessibility on residential- and job location choices, the incorporation of the regional and inter-regional level within one framework and the flexibility to analyze the effects for various levels of land market regulation by the government. Key restrictions of the research are that it does not include different dwelling types at the housing market, a modeling of commercial space at the labor market, and uses a representation of firms in the format of jobs as decision-making actors.

Structuring effects on residential location choice

The results of the empirical estimation in Chapter 5 show a significant, but modest, influence of accessibility on residential location choice. Demographic developments, neighborhood amenities and especially housing attributes seem to be more dominant explanatory variables. These findings are within the range of findings in the literature. The literature is unfortunately not rich enough to analyze the impacts of different research methods, for example Stated Preference versus Revealed Preference, or to draw final conclusions about how transferable findings are between different regions. However, literature highlights the big difference in the structuring role of the transport infrastructure between developed countries with a mature transport infrastructure, and developing countries with large deficiencies in their infrastructure.

Test runs with the TIGRIS XL system illustrate that large transport measures do have a significant but modest effect on the spatial distribution of residents. The tests also illustrate that such change in the distribution of residents has a significant secondary effect on the distribution of jobs as well. As mentioned, the context, spatial structure and network structure, has a large impact on the findings. For example, accessibility differences in the Netherlands (a rather homogenous network and spatial structure) are rather small compared to larger countries and therefore their expected impact on spatial structure is relatively low.

Another important feature of the Netherlands is that the housing market is strongly regulated. This feature influences the model estimation results and should be addressed when applying the model. In general it can be stated that an empirical analysis on accessibility, analysis conditions and choice of variables, necessarily has to deal with a significant amount of specific characteristics for the region.

The sensitivity analysis, as reported in Chapter 7, made clear that these changes are not instantaneous; it takes a long time before the full land-use impacts of a transport measure can be observed. The sensitivity analysis also illustrates that the structuring impact of transport on land-use depends on the spatial policy of the government. In a regulated market the actors are restricted in their options to take advantage of accessibility improvements. The structuring impacts are therefore higher under free market conditions than under regulated conditions.

More detailed conclusions of the present study on the role of accessibility in residential location choice are:

- The model estimation results suggest that accessibility is a significant variable in the Move/Stay choice. It is less likely that households are going to move away from a more accessible location than from a less accessible location. This finding confirms that households are more likely to move away from remote areas than from central areas;
- The model estimation results suggest that accessibility of a specific location is for many household types not a significant variable in their location choice. The findings confirm that demographic factors, neighborhood amenities and dwelling attributes are more important variables to explain residential location choices. The context of the Netherlands, as described above, strongly influences those findings;
- The model estimation results for the travel time variables, illustrate the important role of the transport system in defining the sizes of the housing market. Travel time variables are significant for all household types and therefore changes in the transport system will affect the size of the housing market and location preferences of the households. This effect is more predominant if the travel time between different types of residential environments is reduced;
- The level of land market regulation has a large impact on the role of accessibility in influencing residential location decision. In a strictly regulated land market it can only affect the location choice of households, and under conditions of scarcity in the housing market, the effects will be minimal. In a free land market changes in the transport system will affect the location of construction as well, and this will result in more substantial effects.

Structuring effects on jobs

The empirical literature on structuring effects of transport on the distribution of jobs is limited and the available sources show a wide range of results. Part of this variety might be explained because the structuring impacts on the distribution of jobs differ widely for the different economic sectors. Empirical analysis, without a detailing into economic sectors, can be expected to be highly influenced by the economic structure in a specific region.

Model estimations for the TIGRIS XL model show that manufacturing, logistics, other consumer services and especially business services are the most sensitive sectors for changes in accessibility. The sectors retail and government respond indirectly to changes in accessibility and are responding to changes in the number of residents. The effect of transport measures on the spatial distribution of residents will determine for these sectors the size of the effect.

The spatial scale level of the labor market estimation in TIGRIS XL is the municipality level. At this level demand forces seem to be dominant and it is assumed that job location demand will be facilitated by supply of commercial floor space or industrial land. However, it should be noted that in reality supply restrictions play a role at lower spatial scale levels. The findings discussed in this section are therefore valid at the municipality level. At this level the labor market module, and the size of its structuring effects, is less sensitive for the level of land market regulation by the government than

the housing market module. There is only a secondary effect, as explained above, following changes in residential land-use.

The TIGRIS XL test applications in Chapter 7 present structuring impacts on the spatial distribution of jobs, which are overall significantly bigger than the structuring impact of transport infrastructure on the spatial distribution of residents. However these effects can still be considered modest compared to total employment figures and autonomous changes (changes in the reference case). For the individual economic sectors it appears that especially business services respond relatively strongly to changes in accessibility.

Policy implications

The above summarized research findings have the following policy implications:

- The indirect distribution effects of transport infrastructure measures are relatively small compared to direct benefits and project costs. It can be concluded that if the direct benefits of the project and costs are not close to break-even than the indirect distribution effects are unlikely to make the difference between break-even or not. It should be noted that this conclusion is context specific and applies only to regions with a well developed infrastructure.
- Changes in the level of spatial regulation by the government result in significantly different spatial patterns (see Section 6.3). The long-term spatial pattern of transport demand is therefore uncertain and current practice in transport policy analysis could be improved from addressing this uncertainty.
- The ambition of the latest physical plan “Nota Ruimte” to use different spatial regimes, varying between “centrally controlled” and “freedom for regional authorities”, for different regions has important spatial impacts. In a small and high density country as the Netherlands spatial markets overlap and the spatial regime of a region affects not only neighboring regions but also more distant regions. The case study “Almere” (Section 7.1) illustrates that growth ambitions for this city are affected by a less centrally regulated market regime in more distant regions outside the urban core of the Netherlands.

Overall the research results indicate that annual land-use changes, and in particular the structuring impacts of transport on land-use, are small compared to existing patterns. Therefore at first one might consider ignoring these changes. However the long term character of these slow dynamics makes these land-use changes important. A change in land-use does have a very long-term influence on the urban and regional structure and can be considered as almost irreversible. This can be illustrated by observing the difficulties which, car-based low-density cities, have with formulating alternative transport strategies. Land-use developments are therefore a critical element of any long-term transport strategy.

8.4 Recommendations for future research

It appears from the review in Chapter 4 that worldwide the number of operational land-use and transport interaction models has increased significantly, and this trend seems to continue into the near future. It should further be noted that combined land-use and transport models are still in a very early phase compared with standard transport

models. This fact combined with ongoing urbanization and pressure on land, especially in fast rising economies, presents a fruitful environment for future development of land-use models in general and LUTI-models in particular. These favorable signs are however tempered by the lack of applications and contributions of LUTI-models to actual policy making.

This last point represents a real risk for future research funding and further development of LUTI-models. Application of LUTI-models has been hampered both by a lack of integration of the models with standard evaluation practices, and by a lack of empirically based confidence in the models. Integration with the standard evaluation practice in the Netherlands requires a distinction between direct effects, indirect distribution effects and indirect generative effects. LUTI-models are typically not capable of handling indirect generative effects. Both more fundamental research and experiences with pragmatic implementations addressing the indirect generative effects, are needed. A pragmatic direction to incorporate these indirect generative effects within the scope of the LUTI-models is explored as part of the present research (see further below).

A key focus in further research should be the exchange of knowledge and ideas between the community of spatial economists, heavily involved in new economic geography work, and the community of urban and transport modelers, heavily involved in micro-simulation and decision choices/rules of actors. Economic theory should be important in this research, but its' poor integration with space, time and non-economic spatial processes, should be overcome with a wider multi-disciplinary approach. Sub-sections 8.4.1 and 8.4.2 explore a bottom-up approach, to incorporate indirect generative effects within LUTI-models, by using the detailed spatial representation of LUTI-models to derive agglomeration effects, as well as other effects associated with the housing- and labor market.

8.4.1 LUTI models and agglomeration effects

It should be noted that at present there is no modeling approach (with an empirical basis) available which calculates all the indirect generative welfare effects as listed in Section 4.3. Most of the existing models are missing certain markets and in most cases the modeling of the relationships lacks an empirical basis. The situation for the TIGRIS XL model is as follows: the model describes the housing market and elements of the land- and labor market. The model does not describe the product market, knowledge spill-over, and international effects. An extension of the model with each of these elements would seem to be infeasible, largely because data of the required level of detail is not available, such as on the economic effects of knowledge spill-over or product differentiation.

An alternative way is to combine several effects in a single outcome indicator. The effect of transport and land-use changes can be estimated on this outcome indicator. The so-called agglomeration effect is generally used to indicate a combination of several generative effects; such as scale advantages, increasing variety of products, labor market matches and knowledge spill-over. An individual empirical estimation of each of those effects seems to be infeasible based on currently available data sources. However, an estimation of the more aggregated agglomeration or urbanization economies effect seems to be feasible. The TIGRIS XL model is capable of generating the variables determining agglomeration: the model simulates in sufficient detail the land-use changes and transport times affecting the size and density of urban areas. The

model needs further to be extended with functionality to link agglomeration changes with generative economic effects. Agglomeration effects are discussed in more detail below and an approach is explored to formulate agglomeration variables and a way to link these variables with economic performance.

The observation that economic activities are not homogeneously distributed in space is the starting point for the study of agglomeration effects. Both geographers and economists (Brakman et al 2001, Fujita et al 2000) conclude that processes causing agglomeration effects at different spatial scale levels are: scale advantages, monopolistic competition, economic attraction variables such as labor supply and clients, and disadvantages as transport costs, land prices and wages.

All these points are related to geographical proximity of activities; the basic principle of agglomeration for firms is proximity in multiple dimensions, these include:

- Backward linkages to suppliers and employees;
- Forward linkages to clients;
- Horizontal linkages to other firms in the same sector or firms in other sectors, knowledge spill-over etc.

The linkages for an individual firm depend on the characteristics of the firm, the spatial distribution of socio-economic activities and the performance of the transport system.

For the horizontal linkages several agglomeration hypotheses exist, varying from sector specific concentration as driver of economic growth (Marshall, 1890), or regional competition as driver of innovation and growth (Porter, 1990), and diversity as driver of growth (Jacobs, 1969). An extended overview on agglomeration, economic growth and innovation can be found in (Van Oort, 2002).

The performance of a firm depends on how good/efficient it can realize its linkages; therefore the proximity of relevant activities in agglomerations might result in a positive relationship between city size and productivity. There is substantial literature quantifying, at an aggregated level, the relationship between city size and productivity. An empirical study of Ciccone (2002) on agglomeration effects in Europe, for the countries of France, Germany, Italy, Spain and the UK, presents an estimated elasticity of 0.045 for average labor productivity with respect to employment density.

The literature on studies, using cross section data on cities, presents varying findings. These vary according to the extent to which researchers are able to control for quality of inputs – capital stock and the skill of the labor force-, and typically yield the result that doubling city size increases productivity by an amount in the range of 3-8%, i.e. an elasticity of productivity with respect to city size of between 0.04 and 0.11 (Venables 2003).

Some critical remarks can be made about the weaknesses or limitations of most of the empirical work in this field. Most of the studies operate at a macro level estimating the effects of agglomeration on the whole economy following a cross-section analysis on cities and regions within administrative boundaries. A first critical remark can be made about the aggregated level of the studies, as mentioned above the agglomeration effects differ strongly by firm. If data sources permit, such analysis should differentiate between economic sectors to address heterogeneities of firm behavior. Another issue, more complicated to address, is firm demography, a decomposition of firms into their phase in the life cycle is an important explanatory variable for economic growth, and

the impact of agglomeration forces (van Oort, 2002). Including this issue requires the use of micro data on firms.

Another weakness, certainly for transport policy analysis, is the use of fixed geographical area based on administrative city- or regional boundaries. This use of a fixed geographical area makes the agglomeration variables insensitive for the transport system. The use of a flexible agglomeration variable, not based on an administrative boundary but calculating spatial proximity is preferable for the purpose of this study. Such variable should include the level-of-service of the transport system, both from the perspective of developing adequate/realistic variables as from the perspective of linking transport measures through agglomeration variables with productivity.

As stated before, the hypotheses on a productivity relationship between degree of agglomeration, resulting from the different linkages, and productivity (GDP per employee), forms the basis foundation for the presented approach. This relationship can be quantified by a variable addressing the degree of agglomeration and an elasticity of productivity with respect to this degree of agglomeration. A state-of-the-art example of how such an effect can be quantified and related to policy making in the field of transport can be found in the UK Department for Transport note on “Transport, wider Economic benefits, and impacts on GDP” (DFT, 2005), and a more detailed description can be found in Graham (2005). It should be mentioned that the method and the results are specific for the UK situation, and rely on local data sources. It is believed that the concept is of value for other situations, such as the Dutch situation, as well.

The basic element of the concept is a two step approach in which transport affects the degree of agglomeration and agglomeration has an effect on productivity. In this way the causality problems of directly estimating the effects of transport infrastructure on productivity can be avoided. Furthermore the effects are project specific and the specific geographical location of a project does matter. The work of Graham (2005) applies this method and presents an empirical foundation for an economic sector specific relationship between agglomeration, expressed in a density variable, and additional productivity.

It is considered of particular value to apply this approach, in combination with the TIGRIS XL model, to address the changes in degree of agglomeration. The impact of transport measures on the agglomeration variable, e.g. density of residents or jobs, can be addressed at a detailed level by the TIGRIS XL model; this includes congestion and spatial distribution effects. The representative agglomeration variable can be a gravity type variable and, for example, depend on generalized travel cost from zone x to all jobs in all other zones. The variables can be sector specific and have different values at a zone or regional level; regional level variables can be aggregated from the lower zone level. An important advantage of using a detailed modeling is that the use of abstract administrative boundaries can be avoided.

It would be preferable to estimate the parameters for the effect of agglomeration on productivity at the level of individual firms and aggregate bottom-up from this micro level. Micro-level data enable to estimate agglomeration effects in combination with firm internal effects of increasing returns to scale. However micro-level estimation sets high demands on data sources and requires information for individual firms on production, labor and capital input, which may be unavailable for reasons of confidentiality. A second-best option, if available data sources would not support a micro-level analysis, is estimating the effect of agglomeration on productivity by sector

at a regional level. At this level it will not be possible to separate internal scale advantages, relating to size of firms, and external scale advantages like product differentiation or labor market matches.

In the work of Graham (2005) a micro database, called “Financial Analysis Made Easy”, has been used to estimate the coefficients by economic sector. The coefficients, describing the relationship between productivity and effective density (agglomeration variable), vary widely between economic sectors and the average elasticity of productivity with respect to effective density is 0.04 for manufacturing and 0.12 for services. The report emphasizes that more work on this subject is needed and in our view the first results are certainly encouraging to further elaborate and refine this approach. An example of a micro analysis in the Netherlands is the paper of de Bok et al. (2005), reporting on a micro level empirical estimation of the influence of agglomeration attributes, like sector –specific concentration or diversity, on the interregional firm relocations for four economic sectors. The underlying database does not facilitate an estimation of agglomeration attributes on productivity.

It can be concluded that the proposed method to calculate indirect generative welfare effects on the production market and labor market can be classified as a bottom-up approach by using the detailed spatial representation of the LUTI-models to derive agglomeration effects. It is a two-step procedure, which calculates in step one the effect of transport changes, and associated land-use changes on spatial proximity or level of agglomeration. In step two the effects on productivity, resulting from the changes in agglomeration, are calculated.

8.4.2 Welfare effects on the housing and land market

In the Dutch context both the housing and land-market are partly regulated and both markets face imperfections and externalities like regional imbalances in land and housing demand and supply, market regulations to protect scarce natural land resources, or social housing programs.

The most important land market imperfection in the Netherlands is that physical planning restrictions are imposed on a large scale to protect natural land or open spaces. The price effect on development sites is large; land prices for development sites can be tenfold or more than land prices for agricultural land. The net welfare effects at a national level do not automatically increase if the market regulation would become less strict (this means lower land prices for development sites), because the welfare effects depend on the right societal price setting for open space and/or natural land. A second issue, potentially resulting in additional welfare effects, is that the pressure on land and therefore the welfare contribution of open spaces and natural land is not equal in all regions. A transport project can result in a better match in population or labor distribution between regions with scarce land resources and regions with ample land resources. Such an effect can be described as an indirect external welfare effect and will vary strongly by location and type of transport project. This type of effect will here not be explored any further, but it is clear that a land-use model like TIGRIS XL can deliver valuable information for calculating such an effect.

On the housing market a transport measure can have an effect on the housing utility for residents living in a region affected by the transport measure. In a perfectly functioning housing market this effect will be passed on to the immobile factor namely through changes in the housing price accruing to the house/land owner. In TIGRIS XL a change in accessibility will result in a change in utility in the move/stay module; accessibility is

a significant explanatory variable in the move/stay choice function. For a large part of the housing market in the Netherlands, namely the private ownership market, the outcome is likely to be a passing on of the transport effect into the housing price as the market can be described as being largely a free market and the household residing in and owning the building are one. For the rental market the transport effects are not directly passed on into the price, since rent increases are to a large extent controlled by the government. In this case the transport effects will be passed on to the households residing in the affected houses in the rental market. In principle we suggest to ignore the additional welfare effects on households staying at their location, as transport changes do not solve imperfections in the housing market such as imbalances between supply and demand for land and houses.

A second effect is that a transport measure results in the relocation of households. The housing market module of the TIGRIS XL model simulates residential location choices through a discrete choice type of modeling. The model operates at a spatial detailed level of 1308 zones and the utility functions are household type specific. Six different types of households are distinguished to account for differences in residential location behavior. The discrete choice modeling of the housing market makes TIGRIS XL capable of addressing the increase in utility at the housing market resulting from a transport project by comparing the with project situation to the reference situation. For each case the household type specific utility needs to be calculated and then the results from individual households are aggregated to the zone level. At a national level the change in utility between project variants and the reference situation can be calculated for each household type. The changes in utility by household type need to be transformed into monetary values for each household type. For the household types, this information can be used to transform utility changes into monetary effects.

Once the utility changes have been converted into monetary values, the question should be asked whether these increases in welfare are an additional effect or just a passing on of the transport effect. As long as the indirect network effects or long-term transport effects are not included in the evaluation it seems straightforward: the effect can be included as an additional welfare effect. However, once the second order transport effects are correctly included in the evaluation there is a risk of double counting. Simply ignoring the effect under these circumstances does not seem to be correct as well, since the transport measure does not only increase the accessibility of location but it also widens the size of the housing markets. However it seems to be a reasonable assumption that, if these effects can be proven, that they will remain small. Several test applications with TIGRIS XL show that the number of people relocating as a response to transport measures is rather small.

More important is the question if current methods to transform transport effects in monetary terms account for increased housing utility. Following the concept that transport is a derived demand, and under assumption of a perfect housing market, the demand function for transport should include changes in housing utility as well. In a perfect housing market the change in housing utility or housing price, resulting from a transport measure, cannot be more than the calculated direct transport benefits. It is suggested here to perform an ex-post analysis to check the consistency between the direct transport benefits and changes in the housing prices. A significant change in the infrastructure and time series data on housing prices will be needed to analyze this. The analysis should be restricted to the private ownership segment of the housing market as

the assumption of a perfect market conforms best to reality for this segment of the housing market.

It can be concluded that the current level of knowledge on the indirect generative effects of transport changes on the housing market and land-market is insufficient to propose, at this stage, an approach for incorporating these effects within LUTI-models. An empirical research is suggested to analyze the assumption that the effects of a transport change on the housing market, under free housing market conditions, is fully captured in the calculation of the direct transport effects. Such research would consist of an ex-post analysis of the consistency between changes in housing prices, at the private market, after a major transport changes and the calculated direct transport benefits.

8.4.3 General recommendations for future research

The statistical estimation procedure has strongly supported the confidence in the TIGRIS XL model. Important future research challenges to further improve this confidence in the LUTI modeling field in general and the TIGRIS XL model in particular are:

- Performing a validation of model results on historical time series data;
- Improving land-use data in TIGRIS XL by a better integration with available GIS data bases on land-use and improved specification of supply characteristics;
- Use of Stated Preference data in addition to Revealed Preference data in the estimation of the housing market. This is especially of importance for the modeling of alternative market regimes; currently the responses are restricted by the estimation results based on the situation in 2000-2002;
- More detail in the modeling. This aspect covers both detail in space and supply features, such as housing types, as well as detail in the social-economic grouping. A micro simulation in the demographic and housing market module could result in a better integration of transitions, ageing for example, and housing market choices. The labor market module would benefit of the modeling of firms as decision makers instead of jobs. Also in this case a micro model could realize a better integration between demographic aspects of the firms and location choice behavior;
- Uncertainty in complex model systems simulating long-term developments. This includes insight in the uncertainty resulting from model specification issues, coefficient values and variable values. But it should also address strategies to optimize the use of this information in the policy making process (e.g. adaptive policy making concepts);
- Improved linkage of land-use and transport interaction models and environmental impact models. The environmental impacts of land-use and transport strategies have a high priority on the policy agenda. Land-use and transport interaction models can play an important role in this field, but there are still many challenges like differences in geographical detail or detail in features (e.g. land-use of parcels of land, type of car, etc).

- Most important of all is probably performing applications with the model. Not only to raise confidence in the modeling, but also to stimulate future research. In general each application results in new insights and research challenges to improve the modeling and its contribution to policy making.

References

- Abraham J. (1998), *A review of the MEPLAN modeling framework from a perspective of urban economics*, University of Calgary, Department of Civil Engineering, Research Report No. CE98-2
- Anas A. (1978), Dynamics of Urban Residential Growth, in *Journal of Urban Economics* 5, pp 66 – 87, Academic Press Inc.
- Anas A. (2001), Book review of “The spatial economy: Cities, Regions and International Trade” by M. Fujita, P. Krugman and A. Venables, in *Regional Science & Urban Economics* 31, pp 601-641
- Alonso W. (1964), *Location and land-use*, Cambridge, Harvard University Press
- Anderson L.G. and R.F. Settle (1979), *Benefit-Cost Analysis: a Practical Guide*, Lexington Books, Lexington, Toronto, Canada
- Aschauer D.A. (1989), Is public expenditure productive?, *Journal of Monetary Economics* 23, pp 177-200, Elsevier Science Publisher B.V. North-Holland
- Armstrong H. and Taylor J., *Regional economics and policy*, University of Lancaster, Phillip Allan publishers ltd., Oxford 1985
- AVV Transport Research Centre (2001), *TIGRIS 4.0*, Ministry of Transport, Public Works and Water Management, Rotterdam, The Netherlands
- Banister D. and J. Berechman (2000), *Transport investment and economic development*, UCL Press, London
- Bates J. (2000), History of demand modeling, in *Handbook of Transport Modelling*, D.A. Hensher and K.J. Button (eds.), Elsevier Science Ltd
- Ben-Akiva M., Bowman J.L. (1998), Integration of an activity-based model and a residential location model, *Urban Studies* 35 (7), 1131-1153
- Ben-Akiva M. and Lerman S.R. (1985), *Discrete choice analysis: Theory and application to travel demand*, Cambridge MIT press
- Berechman J. (1994), Urban and Regional economic impacts of transportation investment: a critical assessment and proposed methodology, *Transportation Research A*, Vol. 28, No. 4, pp 351 – 362
- Brakman, S., H Garretsen en C. Van Marrewijk (2001), *An introduction to geographical economics*, Cambridge: University Press
- Brent R.J. (2006), *Applied Cost-Benefit Analysis, second edition*, Fordham University, Edward Elgar Publishing, US
- Bristow A.L. and J. Nellthorp (2000), Transport project appraisal in the European Union, *Transport Policy* Volume 7, issue 1, pp 51-60

Bröcker, J., (2002), Passenger flows in CGE models for Transport Project Evaluation, *proceedings 42nd congress of the European Regional Science Association*, Dortmund, Germany

Bröcker, J., A. Kancs, C. Schürmann and M. Wegener (2002), *Deliverable 2: Methodology of the assessment of spatial economic impacts of transport projects and policies*, IASON project, project funded by the European Community under the "Competitive and Sustainable" growth programme

Bröcker, J., (2004), Computational general equilibrium analysis in transportation economics, in D. Hensher, J. Button, K. Haynes and P. Stopher (editors), *Handbook of Transport geography and spatial systems*, Elsevier publication

Broer P., R. de Mooij and R. Okker (1998), *Special: focus on CPB models, CPB models and their uses*, Centraal Planbureau report 1998/3, Den Haag, The Netherlands

Broersma L. and J. van Dijk (2001), Regional labour market dynamics in The Netherlands, *proceedings 41st congress of the European Regional Science Association*, Zagreb, Croatia

Bruinsma F.R. and P. Rietveld (1992), *De structurerende werking van infrastructuur: een state of the art review*, report prepared for projectbureau integrale verkeers- en vervoerstudies, The Hague, The Netherlands

Bruinsma F.R., S. Rienstra and P. Rietveld (1995), *De structurerende effecten van infrastructuur op interregional niveau langs verbindingssassen: een ondernemerssurvey*, in opdracht voor PbIVVS, Vakgroep Ruimtelijke Economie, Fakulteit der Economische Wetenschappen en Econometrie, Vrije Universiteit, Amsterdam, The Netherlands

CBS/CPB (1997) *Bevolking en arbeidsaanbod: drie scenario's tot 2020*, Sdu Uitgevers, Den Haag

Cheshire P. and S. Sheppard (1998), Estimating the demand for housing, land and neighborhood characteristics, in *Oxford Bulletin of Economics and Statistics*, 60, 3, pp 357-382

Ciccone A. (2002), Agglomeration effects in Europe, *European Economic Review*, 4, pp 213-227

Clarke W.A.V. and J. Onaka (1983), Life cycle and housing adjustment as explanation of residential mobility, in *Urban Studies*, vol. 20, pp. 47-57

Clarke W.A.V., M.C. Deurloo and F.M. Dieleman (1990), Household characteristics and tenure choice in the U.S. housing market, in *Journal of housing and built environment*, vol 5, No 3, pp 251-270

CPB (1990), *ATHENA een bedrijfstakkenmodel voor de Nederlandse economie*, monograph No. 30, Centraal Planbureau, The Hague, The Netherlands

CPB (1996), *Omgevingsscenario's Lange termijn verkenning 1995-2020*, Werkdocument no. 89, Centraal Planbureau, Den Haag

CPB, NEI (2000), *Evaluatie van grote infrastructuurprojecten, leidraad voor kosten – baten analyse*, Onderzoeksprogramma Economische Effecten Infrastructuur, The Hague, The Netherlands

- CPB (2003), *Workshop OEEI (2002), Twee jaar ervaring met OEEI – de discussie over indirecte effecten*, Erasmus congres centrum, Rotterdam, The Netherlands
- Dasgupta A.K. and D.W. Pearce (1972), *Cost Benefit Analysis*, The Macmillian Press Ltd., London
- Daly A.J. and S. Zachary (1976), Improved multiple choice models, in D.A. Hensher and M.Q. Dalvi (eds.), *Determinants of Travel choice*, Saxon House 1978; previously presented to PTRC Summer Annual Meeting, 1976
- De Bok M. and F.M. Sanders (2005), Firm relocation and accessibility of locations: Empirical results from the Netherlands, *Transportation Research Record*, Journal of the Transportation Research Board, No. 1902
- De Bok M. and F. van Oort (2005), Empirical evidence for accessibility and agglomeration factors in the relocation decisions of firms, *proceeding 45th ERSA congress*, Amsterdam
- De Brucker K., A. Verbeke and W. Winkelmanns (1998), *Sociaal-economisch evaluatie van overheidsinvesteringen in transportinfrastructuur*, Garant Uitgevers, Leuven, Belgium
- De la Barra, T. (1995), *TRANUS Integrated land use and transport modelling system*, internet publication Modelistica www.modelistica.com
- De la Barra, T. (1997), *Mathematical and aglorithmic structure of TRANUS*, internet publication Modelistica www.modelistica.com
- Department for Transport (2003), *Transport and development in the Thames Gateway Phase 2*, Regional Transport Division, London, UK
- Department for Transport (DfT, 2005), *Transport, Wider Economic Benefits, and Impacts on GDP*, website www.dft.gov.uk
- Dings J.M.W., B.A. Leurs and A.N. Bleijenberg (2000), *Economische beoordeling van grote infrastructuurprojecten, leren van internationale ervaringen*, Centrum voor energiebesparing en schone technologie, prepared for the Ministry of Economic affairs and Ministry of Transport, Water Management and Public Works, The Netherlands
- Dong X, M. E. Ben-Akiva, J.L. Bowman and J.L. Walker (2006), Moving from trip-based to activity based measures of accessibility, *Transportation Research Part A*, vol 40, 163-180
- Duin, van C., A . de Jong and R. Broekman (2006), *Regionale bevolkings- en allochtonenprognose 2005 – 2025*, Ruimtelijk planbureau/Centraal Bureau voor de Statistiek, Den Haag, The Netherlands
- ECORYS Nederland BV (2006), *KBA Openbaar vervoer-alternatieven Zuiderzeelijn – onderzoek in het kader structuurvisie*, studie in opdracht van Ministerie van Verkeer en Waterstaat, Projectorganisatie Zuiderzeelijn, Rotterdam, The Netherlands
- Elgar I., E.J. Miller (2005), A conceptual model of small office firm location, *proceedings 85th annual meeting of Transportation Research Board*, January 22-26, Washington

Elhorst J.P., T. Knaap, J. Oosterhaven, W.E. Romp, T.M. Stelder en E. Gerritsen (2000), *Ruimtelijk economische effecten van zes Zuiderzeelijn varianten*, Faculteit de Economische Wetenschappen, Universiteit van Groningen, The Netherlands

Environmental Protection Agency (EPA, 2000), *Projecting Land-Use Change: A Summary of Models for Assessing the Effects of Community Growth and Change on Land-Use Patterns*, Office of Research and Development, Washington, USA.

European Commission (1996), *European Sustainable Cities*, EU expert group on the Urban Environment, DG XI, Brussels, Belgium

European Commission (1997), *The EU compendium of Spatial Planning Systems and policies*, Regional Development Studies 28, Luxembourg, Office for Official Publications of the European Communities

European Conference of Ministers of Transport (ECMT, 2002), *Implementing sustainable urban travel policies – final report*, OECD publications service, Paris, France

European Environment Agency (1995), *Europe's Environment: The Dobbris Assessment*, Edited by Stanners David and Bourdeau Philippe, Copenhagen, Denmark

European Spatial Development Perspective (ESDP, 1999), *Towards balanced and sustainable development of the territory of the European Union*, Office for official publications of the European Communities, Luxembourg

European Spatial Planning Observation Network (ESPON, 2006), *Territory matters for competitiveness and cohesion, facts of regional diversity and potentials in Europe*, ESPON Synthesis report III, results by autumn 2006

Filarski R. (2004), *The rise and decline of transport systems, changes in a historical context*, AVV Transport Research Centre, Rotterdam, The Netherlands

Florax R.J.G.M and D. Plane (eds., 2004), *The brightest of dawns, 50 years of Regional Science*, *Papers in Regional Science: Journal of the Regional Science Association International*, volume 83, number 1

Forrester J.W. (1973), *Urban Dynamics*, Cambridge Massachusetts: The Massachusetts Institute of Technology Press, 1973

Fujita M. (1999), *Location and Space-economy at half a century: revisiting Professor Isard's dream on the general theory*, *the Annals of Regional Science*, volume 33, pp. 371-381, Springer-Verlag

Fujita M, P. Krugman and A. Venables (1999), *The spatial economy. Cities, regions and international trade*. Cambridge, Mass.: The MIT Press

Geurs K.T., J.R. Ritsema van Eck (2001), *Accessibility measures: review and applications, Evaluation of accessibility impacts of land-use transport scenarios, and related social and economic impacts*, RIVM report 408505 006, National Institute of Public Health and the Environment, The Netherlands

Geurs K.T. (2006), *Accessibility, land-use and transport, accessibility evaluation of land-use and transport developments and policy strategies*, PhD research thesis, University of Utrecht, published by Uitgeverij Eburon, Delft, The Netherlands

- Graham D.J. (2005), *Wider economic benefits of transport improvements: link between agglomeration and productivity, stage 1 report*, Centre for Transport Studies, Imperial College London
- Groen J., E. Koomen, M. Piek, J. Ritsema van Eck and A. Tisma, *Scenario's in kaart, Model- en ontwerpbenaderingen voor toekomstig ruimtegebruik*, Ruimtelijk Planbureau publication, NAI Uitgeverij, Rotterdam, The Netherlands
- Gunn H. (2004), *SCGE models: relevance and accessibility for use on the UK, with emphasis on implications for evaluation of transport investment*, Report to Department for Transport, London, UK
- Hague Consulting Group (2000), *Het Landelijk Model Systeem versie 7.0, deel D1*, in opdracht van Adviesdienst Verkeer en Vervoer, The Hague, The Netherlands
- Hansen W.G. (1959), How accessibility shapes land-use, *Journal of the American Institute of Planners*, volume 25, 73-76
- Hayashi Y. and H. Morisugi (2000), International comparison of background concept and methodology of transportation project appraisal, *Transport Policy*, volume 7, issue 1, pp 73-88
- Haughwout A.F. (2002), Public infrastructure investment, productivity and welfare in fixed geographic areas, *Journal of Public Economics*, volume 83, pp 405-428
- Heida H. and H. Gordijn (1985), PRIMOS huishoudensmodel, Ministerie van VROM, Den Haag, The Netherlands
- Heide H. (2003), PRIMOS 2003: Prognosemodel voor bevolking, huishoudens en woningbehoefte, Delft: ABF research, The Netherlands
- Hilbers H.D. and E.J. Verroen (1993), *Het beoordelen van de bereikbaarheid van locaties, definiering, maatstaven, toepassing en beleidsimplicaties*, rapport INRO-VVG 1993-09, rapport in opdracht van Projectbureau Integrale Verkeers- en Vervoersstudies, Delft, The Netherlands
- Hilferink M. and P. Rietveld (1999), Land-use scanner: An integrated GIS based model for long term projections of land-use in urban and rural areas, *Journal of Geographic Systems* 1 (2), pp 155-177
- Holtz-Eakin D. and A. Schwartz (1995), Infrastructure in a structural model of economic growth, *Regional Science and Urban Economics*, volume 25, pp 131-151
- Hoyt H.C. (1939), *Structure and Growth of Residential Neighborhoods in American Cities*, Washington, DC: Federal Housing Administration
- Hubacek K. and Bergh van den J.C.J.M., *The role of land in economic theory*, IR-02-037, International Institute for Applied System Analysis, Laxenburg, Austria
- Hubacek K. and J. Vazquez (2002), *The economics of land use change*, IR-02-015, International Institute for Applied System Analysis, Laxenburg, Austria
- Hunt J.D., D.S. Kriger and E.J. Miller (2005), Current operational urban land-use – transport modelling frameworks: a review, in *Transport Reviews*, Vol. 25, No. 3, pp 329-376

- Hupkes G. (1977), *Gasgeven of afremmen, toekomstscenario's voor ons vervoersysteem*, Kluwer uitgeverij, Deventer, The Netherlands
- Isard W. and T.E. Smith (1969), *General Theory: Social, Political, Economic, and Regional*, Cambridge Mass., MIT Press 1969
- Jacobs J., (1969), *The economy of cities*, New York: Vintage
- Jong, A. de, M. Alders, P. Feijten, P. Visser, I. Deerenberg, M. van Huis and D. Leering (2005), *Achtergronden en veronderstellingen bij het model PEARL: naar een nieuwe regionale bevolkings- en allochtonenprognose*, Ruimtelijk Planbureau/Centraal Bureau voor de Statistiek, NAI Uitgevers, Rotterdam, The Netherlands
- Jong, G.C. de, M. Clarke and J. Ryan, A comparison of residential choice models estimated for New York city and the Netherlands, paper presented at the 6th *International Conference on Travel Behavior*, IATB, Quebec, 1991
- Jong, G.C. de, A.J. Daly, M. Pieters and A.I.J.M. van der Hoorn (2005), The logsum as an evaluation measure; review of the literature and new results, *proceedings 45th European Regional Science Association Congress*, Amsterdam.
- Kendig H.L. (1984), Housing careers, life cycle and residential mobility: implications for the housing market, *Urban studies*, vol. 21, pp. 271-283
- Krugman P. (1991), *Geography and trade*, Cambridge MA: MIT press
- Kwan M. (1998), Space-time and integral measures of individual accessibility: a comparative analysis using a point based framework, *Geographical Analysis* 30 (3), 191-216
- Lamrani Y. (2004), *synthesis report: travel demand management*, Planning and Urban Mobility in Europe (PLUME) project for the EC, Key action: City of Tomorrow, task 3.1 (website: www.lutr.net)
- Lau, S.H.P. and Sin C.Y. (1997), Public Infrastructure and economic growth: time series properties and evidence, *Economic Record*, vol 73, pp 125-135
- Lee Jr. D.B. (2000), Methods for evaluation of transportation projects in the USA, *Transport Policy*, volume 7, issue 1, pp 41-50
- Louw E. And Y. Bontekoning (2004), The productivity of industrial land in the Netherlands, in *proceedings 44th congress of the European Regional Science Association*, Porto, Portugal
- Lowry I.S. (1963), *A Model of Metropolis*, RM-4035-RC, Santa Monica, CA: RAND Corporation
- Marcial Enchenique & Partners Ltd. et al. (2001), *The EUNET /SASI final report, socio-economic and spatial impacts of transport*, project funded by the European Commission under the transport RTD programme of the 4th Framework Programme
- Marshall A. (1890), *Principles of economics*, New York: Prometheus Books

- Marshall S. and Y. Lamrani (2003), *synthesis report: land-use planning measures*, Planning and Urban Mobility in Europe (PLUME) project for the EC, Key action: City of Tomorrow, task 3.1 (website: www.lutr.net)
- Marshall S. (2004), *synthesis report: infrastructure provision*, Planning and Urban Mobility in Europe (PLUME) project for the EC, Key action: City of Tomorrow, task 3.1 (website: www.lutr.net)
- Martens K. (1994), *Twintig jaar ruimtelijk mobiliteitsbeleid, Ontwikkelingen, achtergronden en gehanteerde veronderstellingen*, rapport nummer 12, Vakgroep Planologie, KU Nijmegen, The Netherlands
- Martínez F. (1996), MUSSA: A Land Use Model for Santiago City, *Transportation Research Record* 1552: Transportation Planning and Land Use at State, Regional and Local Levels, V.126
- McFadden, D. (1978), Modelling the choice of residential location, in *Spatial Interaction Theory and Residential Location*, A. Karlqvist, L. Lundqvist, F. Snickars and J. Weibull (eds), North-Holland, Amsterdam
- McFadden, D. (1981), Econometric models of probabilistic choice. in *Structural Analysis of Discrete Data with Econometric Applications*, C.F. Manski and D. McFadden, eds., MIT Press, Cambridge, MA, 198-272
- Meadows, D. H., D. Meadows and J. Randers (1972), *The limits to growth; a report of the Club of Rome's project on the predicament of mankind*, New York: New American Library 1972
- ME&P (2002), *LASER enhancement report*, prepared for DTLR, Cambridge
- Miller, E.J., Kriger, D.S., Hunt, J.D., (1998), *Integrated Urban Models for Simulation of Transit and Land-Use Policies*, Final report TCRP Web Document 9, University of Toronto.
- Miller H.J. (1991), Modelling accessibility using space-time prism concepts within geographical information systems, *International Journal of Geographical Information Systems*, volume 5, 287-301
- Mills J. and S. Zankvili (1997), Statistical inference via bootstrapping for measure of inequality, *Journal of Applied Econometrics* 12, pp 133-150
- Ministerie van VRO (1960), *Nota inzake de ruimtelijke ordening in Nederland*, Staatsuitgeverij 's-Gravenhage, The Netherlands
- Ministerie van VRO (1966), *Tweede nota over de ruimtelijke ordening in Nederland*, Staatsuitgeverij 's-Gravenhage, The Netherlands
- Ministerie van VROM (1988), *Vierde nota over de ruimtelijke ordening, deel d: regeringsbeslissing*. Tweede kamer 1988 – 1989, 20490, nrs. 9 – 10. 's-Gravenhage, The Netherlands
- Ministerie van VROM (2001), *Ruimte maken, ruimte delen. Vijfde Nota over de Ruimtelijke Ordening 2000/2020*, 's-Gravenhage, The Netherlands
- Ministerie van VROM (2005), *Nota Ruimte*, PKB deel 3, 's-Gravenhage

- Ministerie van Verkeer en Waterstaat (2004), *MIT/SNIP projectenboek, stand van zaken 2004*, www.verkeerenwaterstaat.nl
- Miyamoto, K. (1993), Development and applications of a land-use model based on random utility/rent-bidding analysis (RURBAN), *Thirteenth Pacific Regional Science Conference*, Whistler, British Columbia, Canada
- Moekel R., K. Spiekermann and M. Wegener (2003), Microsimulation of land use, *International journal of Urban Sciences*, 7 (1), pp 14 – 31, Institute of Urban Sciences
- Mokhtarian P.L. and C. Chen (2004), TTB or not TTB, that is the question: a review and analysis of the empirical literature on travel time (and money) budgets, in *Transportation Research Part A*, vol 38, pp 643-675
- Morisugi H. and Y. Hayashi (2000), Editorial, in *Transport Policy*, vol. 7, pp 1-2
- Mott MacDonald (2004), *LASER model use audit report*, report prepared for the Highways Agency, Winchester, UK
- Munasinghe M. (1993), *Environmental Economics and Sustainable Development*, World Bank Environment paper No. 3. World Bank, Washington, D.C.
- Munnell A.H. (1990), *How does public infrastructure affect regional economic performance?*, in Munnell (ed.), Conference series 34, pp 11-32, Federal Reserve Bank of Boston
- Naess P. (2003), Urban structures and travel behavior. Experiences from empirical research in Norway and Denmark, in *European Journal of Transport and Infrastructure Research*, Vol. 3, No. 2, pp. 155-178
- Newman P.W.G. and Kenworthy J.R. (1989), *Cities and automobile dependence. An international sourcebook*, Gower Technical, Aldershot
- Nijs T. de, G. Engelen, R. White, H. van Delden and I. Uljee (2001), *De leefomgevingsverkenner. Technische documentatie*, RIVM-rapport 408764 003, Bilthoven, The Netherlands
- NIROV/Ministerie van VROM (2006), <http://www.nieuwekaart.nl>
- OECD 2002, *Impact of transport infrastructure investment on Regional Development*, OECD publications, France
- OECD 2002, *Road travel demand, meeting the challenge*, OECD publications, ISBN 92-64-19755-977 2002 04 18 1P, France
- Oosterhaven J. and T. Knaap, *Spatial economic impacts of transport infrastructure investments*, Trans-talk thematic network, Brussels, November 2000, revised version March 2001
- Oosterhaven J., T Knaap, C. Ruigrok and Lori Tavasszy (2001), On the development of RAEM: the Dutch spatial general equilibrium model and its first application to a new railway link, in proceedings *41st Congress of the European Regional Science Association*, Zagreb, Croatia

- Oskamp A. (1997), *Local housing market simulations, a micro approach*, PhD research school NEHUR, Thesis publishers Amsterdam, The Netherlands
- Pagliara, F., Simmonds, D. (2001), *Calibration and implementation of residential location in land-use/transport interaction models*, PTRC-conference Cambridge 2001
- Pinkster F. and R. van Kempen (2002), *Leefstijlen & woonmilieuvoorkeuren*, Urban and Regional Research centre Utrecht, Faculteit Ruimtelijke Wetenschappen, Universiteit Utrecht, The Netherlands
- Porter M. (1990), *The competitive advantage of nations*, New York: Free Press
- PROPOLIS consortium (2004), *PROPOLIS Planning and research of policies for land use and transport for increasing urban sustainability*, project funded by the European Commission under the Energy, Environment and Sustainable development thematic programme of the fifth RTD framework programme
- Quinet E. (2000), Evaluation methodologies of transportation projects in France, *Transport Policy*, Volume 7, issue 1, pp 27 - 34
- RAND Europe (2003a), *Work streams 5&6: passenger and freight transport demand*, Sustainable Mobility Project, World Business Council for Sustainable Development, Leiden, The Netherlands
- RAND Europe (2003b), *Gebruikerswensen TIGRIS*, prepared for the Transportation Research Centre of the Netherlands Ministry of Transport, Public Works and Water Management
- RAND Europe, BureauLouter, Spiekermann & Wegener (2003c), *Functioneel ontwerp prototype TIGRIS XL*, prepared for the Transportation Research Centre of the Netherlands Ministry of Transport, Public Works and Water Management
- RAND Europe (2004a), *Versnellen LMS en Quad, TIGRIS XL – fase 2*, prepared for the Transportation Research Centre of the Netherlands Ministry of Transport, Public Works and Water Management
- RAND Europe (2004b), *Mobiliteitsanalyses Deltametropool*, prepared for the Transportation Research Centre of the Netherlands Ministry of Transport, Public Works and Water Management
- Ransijn M. and R. Vreeker (2001), Historische analyse van ruimtegebruik en ruimtelijk beleid in Nederland, in H.J. Scholten, R.J. van de Velde and J.A.M. Borsboom van Beurden (eds.), *Ruimtescanner: informatiesysteem voor de lange termijnverkenning van ruimtegebruik*, Netherlands Geographical Studies nr. 242, Utrecht, The Netherlands
- Rietveld P. 1989, Infrastructure and regional development, a survey of multiregional economic models, *The Annals of Regional Science*, 23 (4), pp 255 - 274
- Rietveld, P. and F. Bruinsma (1998), *Is transport infrastructure effective? Transport infrastructure and accessibility: impacts on the space economy*, Springer, Berlin
- Rietveld, P. and P. Nijkamp (1992), *Transport and regional development*, research-memorandum 1995-50, Free University, Amsterdam

- Rothengatter W. (2000), Evaluation of infrastucture investments in Germany, *Transport Policy*, volume 7, issue 1, pp17-25
- Rossi P.H. (1955), *Why families move; a study in the social psychology of urban residential mobility*, The Free Press, Glencoe, IL
- Rouwendaal J. and P. Rietveld (2000), *Welvaartsapsecten bij de evaluatie van infrastructuurprojecten*, Muconsult and Free University, prepared for the Ministry of Economic affairs and Ministry of Transport, Water Management and Public Works, The Netherlands
- RUG/SEO (2004), *Indirecte Effecten Infrastructuurprojecten, aanvulling op de leidraad OEI*, prepared for the Ministry of Economic affairs and Ministry of Transport, Water Management and Public Works, The Netherlands
- SACTRA (1999), *Transport and the economy*, Department of Transport and Regions, London, UK
- Salvini P. and E.J. Miller (2003), ILUTE: An operational prototype of a comprehensive Microsimulation model of urban systems, *proceedings 10th International Conference on Travel Behaviour Research*, Lucerne, Switzerland
- Sanders F.M, B. Zondag and R.J. Verhaeghe (1997), Projection of the urbanization pattern for the Jabotabek region, *Asian Urbanization conference*, London
- SCATTER consortium (2004), *The SCATTER project – sprawling cities and transport: from evaluation to recommendations*, project under the European Commission DG Research “Energy, Environment and Sustainable Development Programme”, Brussel, Belgium
- SCENES consortium (2000), *SCENES European Transport Forecasting and Appended Module: Technical description*, Deliverable D4, project funded by the European Commission under the transport RTD Programme of the 4th Framework Programme
- Scholten H.J., R.J. van de Velde and J.A.M. Borsboom-van Beurden (eds., 2001), *Ruimtescanner: informatiesysteem voor de lange termijn verkenning van ruimtegebruik*, Nederlandse Geografische Studies, Utrecht/Amsterdam, KNAG/VU, The Netherlands
- Schoemakers A. and A.I.J.M. van der Hoorn (2004), LUTI modelling in the Netherlands: experiences with TIGRIS and a framework for a new LUTI model, in *European Journal of Transport and Infrastructure Research*, No. 3, pp 315-332
- Simmonds, D.C. and Echenique, M. (DETR report, 1999b), *Review of land-use/transport interaction models*, London
- Simmonds, D.C. (1994), The ‘Martin Centre Model’ in practice: strengths and weaknesses, *Environment and Planning B: Planning and Design*, volume 21, pages 619-628
- Simmonds D.C. (1999a), The design of the Delta land-use modelling package, *Environment and Planning B: Planning and Design*, volume 26, pages 665-684.
- Simmonds D.C. (2005), *Alternative approaches to spatial modelling*, Conference on Economic Impacts of Changing Accessibility, Transport Research Institute, Napier University, Edinburgh, Scotland

- Simmonds D.C. and O. Feldman (2005), Land-use modeling with DELTA: update and experience, *proceedings Ninth International Conference on Computers in Urban Planning and Urban Management (CUPUM)*. Available at www.cupum.org.
- Sorber M. (2001), *Volgt werkgelegenheidde bevolking? Een ruimtelijk-econometrische causaliteits-studie*, paper gepresenteerd op de RSA-Nederlanddag, Intechnum, Woerden, The Netherlands
- Stead D and S. Marshall (2001), The relationship between Urban Form and Travel Patterns, An International Review and Evaluation, *European Journal of Transport and Infrastructure Research*, N0.2, pp. 113 – 141
- STEPs Consortium (2006), *Transport strategies under the scarcity of energy supply*, published by Buck Consultants International, The Hague, The Netherlands
- Still B.G. and D.C. Simmonds (1997), *Implementation of the DELTA/START model*, Institute for Transport Studies, The University of Leeds
- Tavassy L. and Gusta Rennes (2002), *Indirecte effecten in OEEI*, TNO INRO notitie, Delft, The Netherlands
- Tavassy L., M.J.P.M. Thissen, A.C. Muskens and J. Oosterhaven (2002), Pitfalls and solutions in the application of spatial computable general equilibrium models for transport appraisal, *proceedings 42nd congress of the European Regional Science Association*, Dortmund, Germany
- Thompson W.R. (1968), Internal and external factors in the development of urban economies, in H. Perloff and L.Wingo Jr.(red.), *Issues in Urban Economics*, John Hopkins Press, Baltimore
- Thissen M., P. van de Coevering and H. Hilbers (2006), *Wegen naar economische groei*, Ruimtelijke Planbureau publication, Rotterdam: NAI uitgeverij, The Netherlands
- Timmermans H. (2003), The saga of integrated land use – transport modeling: how many more dreams before we wake up?, Conference keynote paper, 10th *International Conference on Travel Behavior Research*, Lucerne, Switzerland
- Train K. (2003), *Discrete Choice Methods with Simulation*, University of California, Publisher: Cambridge University Press
- University of Washington & Parsons Brinckerhoff Quade & Douglas Inc. (1999), *Longitudinal Calibration of UrbanSim for Eugene-Springfield*, Transportation and Land Use Model Integration Program
- University of Washington, (2000), *UrbanSim Users Guide 0.9*, University of Washington Urban Simulation Project
- Van de Loop J.T.A. and G.C. de Jong, What is the best public transport system? An instrument to compare urban public transport systems using transporational, environmental and social criteria, in *Urban Transport and the Environment for the 21st century III*, Eds: L.J. Sucharow and G. Bidini, Computational Mechanics Publications, Southampton, UK

- Van Oort (2002), *Agglomeration, economic growth and innovation, spatial analysis of growth – and R&D externalities in the Netherlands*, PhD-thesis, book no. 260 of the Tinbergen Institute Research Series, Erasmus University, Rotterdam
- Van Wee G.P. and A.I.J.M. van der Hoorn (1996), Employment location as an instrument of transport policy in the Netherlands, fundamentals, instruments and effectiveness, in *Transport policy*, Vol. 3, No. 3, pp. 81-89
- Van Wee G.P. en K.T. Geurs (2002a), De rol van ruimtelijke ordening in het landelijke mobiliteitsbeleid, in *Mobiliteit en Beleid*, ed. Bruinsma, Dijk en Gorter, Koninklijke van Gorcum BV, Assen, The Netherlands
- Van Wee G.P. (2002b), Land-use and transport: research and policy challenges, in *Journal of Transport Geography*, Vol. 10, pp 259-271
- Van Wee G.P. and K. Maat (2003), Land-Use and Transport: a review and discussion of Dutch Research, in *European Journal of Transport and Infrastructure Research*, Vol. 3, No. 2, pp 199-218
- Venables A. and M. Gasiorek (1999), *The welfare implications of transport improvements in the presence of market failure*, report for the Standing Advisory Committee on Trunk Road Assessment, Department of the Environment, Transport and the Regions, London
- Venables A (2003), *Evaluating urban transport improvements: cost-benefit analysis in the presence of agglomeration*, UK Department for Transport
- Vermeulen W. and J.N. van Ommeren (2004), *Interaction of regional population and employment: identifying short-run and equilibrium adjustment effects*, Tinbergen discussion paper, TI 2004-083/3
- Vickerman R. (2000), Evaluation methodologies for transport projects in the United Kingdom, *Transport Policy*, volume 7, issue 1, pp 7-16
- Vickerman R. (2000), *Transport and Economic Growth*, working paper ITS-WP-00-11, Institute of Transport Studies, The Australian Key Centre in Transport Management, The University of Sydney, Australia
- von Thünen (1826), *Der isolierte Staat in Beziehung auf Landwirtschaft und National-ökonomie*, Perthes, Hamburg
- Voogd H. (1983), *Multi criteria Evaluation for Urban and Regional Planning*, Psion Ltd., London
- Vooren van de F.W.C.J. (1998), A policy oriented model about economy, mobility, infrastructure and other regional features, 8th WCTR, Belgium 1998, in: *World Transport Research*, vol. 4, Elsevier Science, pp. 43 - 56
- Vooren van de F.W.C.J. (1999), Beleidseffecten op mobiliteit en economie in ruimte en tijd, *proceedings Colloquium Vervoersplanologisch Speurwerk*, Amsterdam, The Netherlands
- Vooren van de F.W.C.J. (2001), *Regionale effectanalyse van infrastructuurprojecten*, research paper 2001-026, University of Antwerp

- Vooren van de F.W.C.J. (2004), Modelling transport in interaction with the economy, *Transportation Research Part E*, volume 40, pp 417 – 437
- VROM (2001), *Ruimte maken, ruimte delen, Vijfde Nota over de ruimtelijke ordening 2000/2020*, Rijksplanologische dienst, Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu, The Netherlands
- www.vrom.nl, *Vragenlijst WBO 2002*, Ministry of Physical Planning, Housing and Environment, The Netherlands, 2003
- Waddell, P., (2000) Towards a behavioral integration of land use and transportation modelling, *proceedings 9th International Association for Travel Behavior Research Conference*, Australia
- Waddell P. & Parsons Brinckerhoff Quade & Douglas Inc. (1998), *Development and Calibration of the Prototype Metropolitan Land Use Model*, Transportation and Land Use Model Integration Program Final Report on Phase II, April 1998.
- Waddell P. (2001), *Between Politics and Planning: UrbanSim as a Decision Support System for Metropolitan Planning*, in *Building urban planning support systems: combining information, models, visualization*, Center for Urban Policy Research
- Waddell P. (2002), UrbanSim: Modelling Urban Development for Land Use, Transportation and Environmental Planning, in the *Journal of the American Planning Association*. Vol 68, No 3, pp 297-314
- Weisbrod G., Ben-Akiva M., Lerman S. (1978), Tradeoffs in residential location decision: transportation versus other factors, *Transportation Policy and Decision-making*, V1, N1, published version 1980
- Wit J. de, H. van Gent (1996), *Economie en transport*, Uitgeverij Lemma BV, Utrecht, The Netherlands
- Wegener M. (1983), A simulation study of movement in the Dortmund housing market, *Tijdschrift voor Economische en Sociale Geography*, vol. 74, nr. 4, pp. 267 - 281
- Wegener M. (1994), Urban/regional models and planning cultures: lessons from cross-national modelling projects, *Environment and planning B: Planning and Design*, volume 21, pages 629-641
- Wegener M. and D. Bokemann (1998), *The SASI model: Model Structure*, Deliverable D8 of the EU project Socio-Economic and Spatial Impacts of Transport Infrastructure Investments and Transport System Improvements, 4th Frame Programme of the European Commission
- Wegener, M., Fürst, F. (1999), *Land-Use Transport Interaction: State of the Art*, IRPUD, Dortmund.
- Wegener, M., (1998a), *The IRPUD Model: Overview*, website of the Institute of Spatial Planning, University of Dortmund
- Wegener, M., (1998b), *The IRPUD Model: Ageing Submodel*, website of the Institute of Spatial Planning, University of Dortmund
- Wegener, M., (1998c), *The IRPUD Model: Housing Market Submodel*, website of the Institute of Spatial Planning, University of Dortmund

- Wegener, M., (1998d), *The IRPUD Model: Labour Market Submodel*, website of the Institute of Spatial Planning, University of Dortmund
- Wegener, M., (1998e), *The IRPUD Model: Private Construction Submodel*, website of the Institute of Spatial Planning, University of Dortmund
- Wegener, M., (1998f), *The IRPUD Model: Public Programmes Submodel*, website of the Institute of Spatial Planning, University of Dortmund
- Wegener, M., (1998g), *The IRPUD Model: Transport Submodel*, website of the Institute of Spatial Planning, University of Dortmund
- Wegener, M., (2004), Overview of land use transport models, in D. Hensher, J. Button, K. Haynes and P. Stopher (editors), *Handbook of Transport Geography and Spatial Systems*, Elsevier publication
- Wilson A.G. (1970), *Entropy in Urban and regional modeling*, London: Pion
- White M.J., (1999), Urban areas with decentralized employment: theory and empirical work, in *Handbook of Regional and Urban Economics, Volume III: Applied Urban Economic*, P. Cheshire and E.S. Mills (eds.), pp 1375-1412
- Williams I.N., (1994), A model of London and the South East, *Environment and Planning B: Planning and Design*, volume 21, pages 535-55
- Workshop OEEI (2002), *Twee jaar ervaring met OEEI – de discussie over indirecte effecten*, Erasmus congres centrum, Rotterdam, The Netherlands
- Wetenschappelijke Raad voor het Regeringsbeleid (WRR, 1998), *Ruimtelijke ontwikkelingspolitiek*, Sdu Uitgevers, Den Haag, The Netherlands
- Wetenschappelijke Raad voor het Regeringsbeleid (WRR, 2001), *Ruimte aan de stad*, Den Haag, The Netherlands
- WSP (2003), *Workshop on the modelling of household and employment location: final report*, report prepared for Department for Transport, ITEA Division, Cambridge, UK
- Zahavi Y (1974), *Travel time budgets and mobility in urban areas*, report FHWA PL-8183, Washington DC, US Department of Transportation
- Zondag B and M. Pieters (2001), *Literature review of Land-Use models*, prepared by RAND Europe for the Transportation Research Centre of the Netherlands Ministry of Transport, Public Works and Water Management, Leiden
- Zondag B. (2002), Modelling residential land-use in a joint framework of land-use, transport and economy, *proceedings 42nd Congress of the European Regional Science Association*, Dortmund, Germany
- Zondag B., M. Wegener and P. Louter (2005), *Literature study structuring impacts of transport*, RAND Europe note prepared for the Transport Research Centre of the Netherlands Ministry of Transport, Public Works and Water Management

Appendix A: Residential location choice modeling results by household type

Household type definition

In the residential location choice procedure the number of household types in TIGRIS XL has been aggregated from 335 household types (see paragraph 5.3), since it is not feasible to estimate so many different models, into 13 household types. The 13 household types differentiate on key household features for the housing market such as size, employed/unemployed, income and age. The first estimation results for the thirteen household types resulted in a further reduction into six types. Arguments to reduce the number of household types were large similarities between household types in estimation results or lack of observations in the WBO 2002 survey for a household type. Table A-1 presents how the thirteen household types were aggregated into six; the columns present the key features per household type.

Table A-1: overview of household types in housing market module

Six household types	Age head of household	Household size	Employed persons	Income category
A	<65	1	0	1,2,3
B	<65	1	1+	1
B	<65	1	1+	2,3
A	<65	2	0	1,2,3
C	<65	2	1+	1
C	<65	2	1+	2
D	<65	2	1+	3
A	<65	3+	0	1,2,3
C	<65	3+	1+	1
C	<65	3+	1+	2
D	<65	3+	1+	3
E	>65	1	0+	1,2,3
F	>65	2/3+	0+	1,2,3

Household type A: Non-employed households under 65

The model structure of household type A is a nested structure (see Figure 5-9) with three layers, which is confirmed by the estimation results of the two nest coefficients (both between 0 and 1). The TIGRIS XL model does not deal with elemental housing units as the level of choice, but is instead aggregating alternatives into zones. Therefore the coefficient for the variable vacant houses has been fixed at one as a size variable, to adjust the choice equation to account for the aggregate nature of the choice set. All other significant variables for household type A, time between origin and destination, price, services, neighborhood type have the expected sign of the parameter. Non-employed households under 65 have a positive coefficient for urban areas (NT1 and NT2), which correspond with the higher number of non-employed households in urban areas (e.g. students).

The utility of a zone is negatively affected by a high price. It was not possible to estimate a nested model for household type A inclusive a price variable (PriceM2_C) at a higher level, such model was rejected by a nest coefficient above 1.

Table A-2: Estimation results for household type A

Variable	Description	Coefficient	t-value
VacHo	Number of vacant houses	1.00	*
NestZ	Nest coefficient zone level	0.830	(13.7)
Nest	Nest coefficient corop level	0.662	(2.9)
Intrazon	Dummy Intrazonal	5.18	(5.1)
NT1	Neighborhood type 1, urban center	0.0086	(4.5)
NT2	Neighborhood type 2, urban area (non-center)	0.0037	(5.2)
Services	Services in zone	0.0024	(2.9)
PriceM2	Housing price per square meter	-5.1e ⁻⁵	(-2.8)
1_time	Travel time measure between origin and destination	-6.91	(-2.3)
logtime	Travel time measure between origin and destination	-1.45	(-5.1)
logcost	Travel cost measure between origin and destination	-0.778	(-4.3)
1_time_C	Travel time measure between origin and destination, regional variable	-74.8	(-3.0)
Logtime_C	Travel time measure between origin and destination, regional variable	-1.78	(-6.3)

*) Number of observations is 1277, Final log (L) is -4815, D.O.F. is 12 and Rho² is 0.475

**) * is fixed coefficient

***) The location variables such as NT1, NT2, Services, PriceM2 refer to the new location

A disadvantage is that household type A combines all incomes classes and household sizes, although the majority of the households in this class will fall into the low-income group. These two household characteristics are especially distinctive for the variables as type of neighborhood and average income in the zone reflecting the status of zone.

Household type B: Employed, one-person household under 65

The model structure of household type B is a nested structure (see Figure 5-9) with three layers, which is confirmed by the estimation results of the two nest coefficients (both between 0 and 1). An important difference between one-person households and larger households is the preference of small households for an urban environment (see coefficient for N1). The accessibility variable is significant and the parameter value is positive conform expectations. The accessibility indicator indicates that households of type B value good access to leisure activities as important.

Similar to household type A it was not possible to estimate a nested model for household type B including a price variable (PriceM2_C) at a higher level, such model led to a nest coefficient above 1. One PriceM2 variable was included at the zone level and the coefficient was negative as expected.

Table A-3: Estimation results for household type B

Variable	Description	Coefficient	t-value
VacHo	Number of vacant houses	1.00	*
NestZ	Nest coefficient zone level	0.882	(16.0)
Nest	Nest coefficient corop level	0.437	(4.4)
Intrazon	Dummy Intrazonal	7.38	(16.4)
NT1	Neighborhood type 1, urban center	0.0061	(6.2)
NT4	Neighborhood type 4, village	-0.0024	(-2.2)
Services	Services in zone	0.0018	(4.2)
Density	Residential density	0.0042	(3.7)
Acc_oth	Logsum for purpose other, accessibility indicator	1.69	(3.0)
PriceM2	Housing price per square meter	-4.6e ⁻⁵	(-6.3)
logtime	Travel time measure between origin and destination	-0.248	(-2.2)
l_cost	Travel cost measure between origin and destination	-0.860	(-3.4)
logcost	Travel cost measure between origin and destination	-2.16	(-16.3)
Logtime_C	Travel time measure between origin and destination, regional variable	-1.29	(-3.6)
l_cost_C	Travel cost measure between origin and destination, regional variable	-2.64	(-2.64)
Logcost_C	Travel cost measure between origin and destination, regional variable	-1.07	(-2.7)

*) Number of observations is 1909, Final log (L) is -7738, D.O.F. is 15 and Rho² is 0.435

Household type C: Employed, 2/3+ persons household under 65 with a low income

Income is the only differentiating characteristic between household type C and D, however this difference has a large impact on several parameters. The average housing price variable (PriceM2 and PriceM2_C) has a negative parameter for lower income households of type C both at as zonal and regional variable. Furthermore households with a low income are attracted to neighborhoods with a high percentage of medium and high-income households. This illustrates the wish of people to move upwards.

The parameters for residential densities seem to be connected to income as well. Low-income houses have a preference for residential areas with a higher density (houses/hectare). Although it would be expected that larger household have a preference for a more suburban /rural environment with low residential densities. An explanation is that households with a low income are not capable of realizing this preference.

Table A-4: Estimation results for household type C

Variable	Description	Coefficient	t-value
VacHo	Number of vacant houses	1.00	(*)
NestZ	Nest coefficient zone level	0.952	(17.9)
Nest	Nest coefficient corop level	0.671	(8.6)
Intrazon	Dummy Intrazonal	10.3	(22.0)
NT2	Neighborhood type 2, urban area (non-center)	-0.0017	(-2.5)
Services	Services in zone	0.0014	(2.3)
Density	Residential density	0.0025	(4.3)
PriceM2	Housing price per square meter	-6.7e ⁻⁵	(-5.2)
Inc_med	Percentage households with middle incomes	0.0936	(5.7)
Inc_high	Percentage households with high incomes	0.0170	(3.8)
logtime	Travel time measure between origin and destination	-0.301	(-4.4)
1_cost	Travel cost measure between origin and destination	-0.749	(-6.2)
logcost	Travel cost measure between origin and destination	-2.05	(-24.2)
PriceM2_C	Housing price per square meter regional variable	-1.5e ⁻⁴	(-3.5)
Logtime_C	Travel time measure between origin and destination, regional variable	-1.03	(-8.5)
Logcost_C	Travel cost measure between origin and destination, regional variable	-1.32	(-8.4)

*) Number of observations is 3883, Final log (L) is -12889, D.O.F. is 16 and Rho² is 0.538

The parameter values and t-values of the accessibility variables are insignificant, which does not confirm theoretical expectations (Hansen 1959, Alonso 1964). A possible explanation is that these household types have a preference for less accessible non-urban locations. In theory other variables, such as neighborhood type or housing prices, should address this preference and accessibility could still be positive and significant. An option is to extend the model with more detailed alternatives; a potential extension is the inclusion of dwelling types.

Household type D: Employed, 2/3+ persons household under 65 with a medium/high income

Like the previous household types a nested structure is used in the residential location choice modeling of type D. Other similarities are that the number of vacant houses are incorporated as size variable and that the intrazonal dummy plays an important role. The estimation results show furthermore that households of type D have a preference for a green urban or non-urban environment with low-density housing. This confirms the preference of larger households for a sub-urban location.

Table A-5: Estimation results for household type D

Variable	Description	Coefficient	t-value
VacHo	Number of vacant houses	1.00	(*)
NestZ	Nest coefficient zone level	0.916	(16.9)
Nest	Nest coefficient corop level	0.943	(11.8)
Intrazon	Dummy Intrazonal	10.3	(17.9)
NT2	Neighborhood type 2, urban area (non-center)	-0.0014	(-2.3)
Density	Residential density	-0.0062	(-3.5)
PriceM2	Housing price per square meter	-3.4e ⁻⁵	(-2.2)
Inc_med	Percentage households with middle incomes	0.0727	(4.1)
Inc_high	Percentage households with high incomes	0.0277	(4.4)
logtime	Travel time measure between origin and destination	-0.450	(-4.7)
logcost	Travel cost measure between origin and destination	-1.33	(-13.1)
Logcost_C	Travel cost measure between origin and destination, regional variable	-1.99	(-14.1)

*) Number of observations is 3740, Final log (L) is -14353, D.O.F. is 11 and Rho² is 0.465

Similar to household type C the accessibility variables are insignificant, which does not confirm theoretical expectations. A possible explanation is that these household types have a preference for less accessible non-urban locations. In theory other variables, such as neighborhood type or housing price, should address this preference and accessibility could still be positive and significant. Another argument is that accessibility differences are small in the Netherlands, due to its spatial structure and developed transport system, and consequently play a less important role in the location choice. An option is to extend the model with more detailed alternatives; a potential extension is the inclusion of dwelling types.

Household type E: One person household above 65

The nested model structure did not fit for household type E and a multi-nominal logit model has been used for this household type. The nested structure probably did not work because of the small number of interregional movements of this household type. In the model estimations the nested structure was rejected because the nest coefficient was not significant different from 1. Households of type E have a strong preference to move to a new dwelling within the same zone. The accessibility variable has an expected significant and positive parameter. Negative coefficients are found for the variables price per square meter and residential density reflecting the relatively low-income position of one person households above 65.

Table A-6: Estimation results for household type E

Variable	Description	Coefficient	t-value
VacHo	Number of vacant houses	1.00	*
Intrazon	Dummy Intrazonal	3.00	(9.3)
Density	Residential density	-0.0104	(-3.9)
Acc_tot	Logsum for all travel purposes, accessibility indicator	0.577	(2.7)
PriceM2	Housing price per square meter	-1.3e ⁻⁴	(-3.5)
Logtime	Travel time measure between origin and destination	-2.34	(-37.2)

*) Number of observations is 406, Final log (L) is -1190, D.O.F. is 5 and Rho² is 0.591

Household type F: 2/3+ persons household above 65

Results for household type F are quite similar to the results for household type E, both models are multi nominal logit models instead of nested logit models. The local zone (intrazone) variable is again very dominant and it illustrates that elderly don't want to make a new start in another environment. Differences between the two elderly household types exist in the preferences for local amenities and prices.

Table A-7: Estimation results for household type F

Variable	Description	Coefficient	t-value
VacHo	Number of vacant houses	1.00	*
Intrazon	Dummy Intrazonal	6.61	(6.4)
Services	Services in zone	0.0039	(3.5)
Acc_tot	Logsum for all travel purposes, accessibility indicator	0.148	(2.1)
Inc_med	Percentage households with middle incomes	0.230	(6.9)
l_time	Travel time measure between origin and destination	-16.0	(-6.6)
logtime	Travel time measure between origin and destination	-3.08	(-23.2)

*) Number of observations is 442, Final log (L) is -1309, D.O.F. is 6 and Rho^2 is 0.587

Appendix B: Structure of Labor market

The labor market module in TIGRSI XL has been developed by Bureau Louter (an expert consultant in the field of spatial economy). A description is included in this thesis as an essential component to explain the overall framework and functioning of other components. The labor market sub-model is structured as a hierarchical distribution model; it follows a two-step approach with a regional- and a local level. At the regional level the Labor market module predicts the number of jobs for seven economic sectors. Changes in the number of jobs for a region depend on changes in the number of jobs by sector at the national level, the so-called changes in economic structure, and on regional characteristics, here addressed as location factors. The location preferences of firms, in the regional labor market module, depend on the value of location variables and the parameter values. In the model the behavior of firms is modeled at the level of jobs. This simplification is similar to other LUTI-models like IRPUD, MEPLAN and DELTA.

The detail in economic sectors is important to address the large variety in preferences between economic sectors (see literature review). The economic sectors differ in their land-use, interaction with the population and in their response to changes in accessibility. The seven sectors in TIGRIS XL have been defined based on expected differences in behavior and on consistency with economic sector classifications used at the national level. The economic sectors in TIGRIS XL are:

- Agriculture
- Industry
- Logistics
- Retail
- Other consumer services
- Business services
- Government

For each of the sectors labor demand will be estimated at a municipality level; the following equation is applied:

$$\frac{E_{ge}(t) / E_{ge}(t-1)}{E_{NLe}(t) / E_{NLe}(t-1)} = \alpha_{xe} * LF_{xg}(t)$$

where $E_{ge}(t)$ is employment of municipality g , time t , and economic sector e . NL stands for the Netherlands. $LF_{xg}(t)$ is location factor x for municipality g at time t , e.g. population or accessibility. α_{xe} is the estimated model parameter for location factor x and economic sector e .

After a log transformation:

$$\ln E_{g,e}(t) = \ln E_{g,e}(t-1) + (\ln E_{NL,e}(t) - \ln E_{NL,e}(t-1)) + \ln \alpha_{0,e} + \alpha_{1,e} \ln LF_{g,1}(t) + \alpha_{2,e} \ln LF_{g,2}(t) + \dots \alpha_{n,e} \ln LF_{g,n}(t)$$

All parameter values $\alpha_{1,e}$ until $\alpha_{n,e}$ are sector specific. Some of the location factors or explanatory variables are output from other sub models of TIGRIS XL and their value will be endogenously influenced in the model. For example accessibility indicators link the transport market model and labor market model. These accessibility indicators are included as explanatory variables for different sectors; accessibility indicators in the labor market are a logsum measure for business travel, a mirrored logsum measure for commuting and an accessibility measure for freight transport.

The model parameters are estimated using time series data between 1986 and 2000. Key data sources are statistics about employed persons at a municipality level by sector from the national statistical office, and data about labor participation from the national statistical office at a regional level. The data has been corrected for changing administrative boundaries and changes in sector definitions.

The labor market model also calculates labor supply at a regional level. Changes in labor supply in a region depend on changes in the population, residents between 15 and 65 years, and the regional labor participation ratio. For each region a region specific participation ratio has been derived and this ratio includes historical and cultural factors influencing labor participation. The regional labor participation ratio is affected by national developments in labor participation and changes in regional employment. Due to data limitations it was not possible to estimate the effect of employment on labor participation.

The developments in employment by sector calculated at the municipality level are subdivided to the zonal level by simple allocation rules, based on population, industrial sites or office space. These allocation rules are sector specific. The model is not estimated at a zonal level and therefore it can only be used to model structuring effects of transport measures at a municipality level.

Model estimation results labor market

Table B-1 presents an overview of all location factors, which are significant for at least one economic sector. The explanatory variables in table B-1 are incorporated as location factors by economic sector.

Table B-1: Explanatory variables labor market module

Variable	Description
AcCom	Accessibility for commuting (logsums)
GrAcCom	Change in accessibility for commuting (logsums)
GrP	Population growth
AcFr	Accessibility for freight transport
AcBus	Accessibility for business transport (logsums)
GrAcBus	Change in accessibility for business transport (logsums)
Agglo	Agglomeration effects
Urban	Level of urbanization
Relsha_Sec	Relative share of sector in a zone compared to national average
Eur	Location within Europe, distance from economic centers

Several of the variables in table B-1 are correlated and cannot be used in combination to explain the location choice of an economic sector. In these cases for each economic sector the variable producing the best model fit has been selected.

There is no empirical model estimated for the sector agriculture and employment in this sector for a region will change proportionally to national changes in employment for agriculture. The reason for exclusion of agriculture is that high growth rates for employment in horticulture, a sub sector of agriculture, result in unrealistic parameter values.

Table B-2: Estimate parameter values and t-values (between brackets) by economic sector

Variable	Ind	Log	Retail	CS	BS	Gov
AcCom						
GrAcCom	0.374 (4.4)			0.254 (3.7)		
GrP		1.072 (3.9)	1.101 (10.3)			0.952 (9.5)
AcFr		0.3118 (2.7)				
AcBus						
GrAcBus					1.804 (6.4)	
Agglo		-0.004 (-2.0)	-0.003(-2.8)	-0.005 (-3.6)		
Urban	-0.017 (-6.5)					
Relsha_Sec	-0.012 (-2.2)	-0.021 (-4.7)	-0.021 (-3.3)		-0.012(-4.1)	-0.010 (-4.0)
Eur	0.031 (2.8)	0.034 (3.3)				
R ²	.79	.70	.86	.50	.62	.76

Economic sectors	
Ind	Industry
Log	Logistics
Ret	Retail sector
CS	Other consumer services
BS	Business Services
Gov	Government

The parameters, as presented in table B-2, have been estimated for the time period 1986-2000. Separate parameters have been estimated for shorter time periods, namely 1986-1993 and 1993-2000. The results are rather different for the two time periods and illustrate that the variables are rather time dependent. General macro-economic cycles and lifetime developments of economic activities have an important influence on parameter values. In TIGRIS XL parameter values estimated for the whole time period are included in the modeling. A first reason is that the projection period is rather long, normally at least 20 years, and several economic up- and downturns can be expected in such a period. If estimation results of a rather short period are used they might reflect only one specific economic condition. A second reason is that the model fit, part of the variance that is explained by the model, over the whole period is for all sectors higher than the model fit of the 1986-1993 estimation or the 1993-2000 period. This point illustrates that shorter time periods are more sensitive to coincidental developments.

The main conclusions from the labor market estimation are:

- Accessibility indicators have a significant influence on the regional distribution of employment in most economic sectors. The logsum variable for commuting has a significant and positive influence on employment in the industry or other consumer services. The logsum variable for business has a significant and positive influence on employment in business services. The freight transport accessibility indicator, generated from travel times by truck, has a positive influence on employment in the logistic sector. It can be concluded that changes in accessibility, through transport measures, will have a significant structuring effect on employment in most sectors.

- A higher level of urbanization negatively influences economic sectors with an extensive land-use. Growth of urban land-use in a region will result in higher pressure on land and higher land prices;
- Population development in a region is an important variable for service sectors such as retail and government services. These sectors do not respond on changes in accessibility but they respond only on population developments within the region itself. The regional scale of the model, which is often larger than the market area for most services, makes the developments in surrounding regions of less importance;
- The relative share of a sector within a region has for almost all economic sectors a significant and negative parameter value. This indicator expresses for a region the share of a sector in total regional employment compared to the share of this sector in total national employment. Arguments for this characteristic can be found in the economic filtering-down theory (Thompson 1968).

Appendix C: Determine realistic changes in accessibility indicators

The accessibility indicators for the housing and labor market generated by the NMS are, the following (see paragraph 5.2):

- Logsums by household type and purpose;
- Logsum business purpose;
- Reflected logsum commuting;
- Freight travel time, non peak travel time weighted by attraction variable;
- Travel time between location of origin and destination.

The effect of policy measures on accessibility indicators has been tested for the following policy measures:

- Changes over time resulting from social-economic developments. This has been analyzed for a NMS reference case (2000), the changes in accessibility indicators for runs with the 2010 and 2020 situation has been analyzed;
- Change in accessibility due to new transport infrastructure;
- Change in accessibility due to pricing policies like congestion pricing;
- Change in accessibility due to different land-use alternatives.

The analysis does not aim to present an overview of the impacts of all possible transport and land-use policies on accessibility. The aim is to develop insight into realistic changes in accessibility, resulting from transport and land-use policies, and magnitude of changes in accessibility

An analysis of development in accessibility in time, like comparing reference runs for 2010 and 2020 with base year 2000, include all these developments and it is not possible to isolate the effect of individual factors. In the policy runs several system components, like socio-economic and demographic figures at the national level, are kept constant among the sensitivity runs. In such restricted environment the influence of transport policy measures on the accessibility indicators can be analyzed.

The main findings of the test runs are summarized in Table C-1 and can be described, as follows:

- Additional road infrastructure, increased capacity as well as new roads, improves the logsum accessibility indicators as well as travel time indicators. The largest effects occurs in the zones nearby the additional infrastructure and the effects minimize with distance;
- Congestion pricing has a positive effect on travel time indicators and a negative effect on the logsum indicators at the national level; in those logsum indicators the

increase in utility, due to a decrease in travel time, is out-weighted by a decrease in utility due to higher travel costs;

- Alternative land-use policies result in a modest positive local effect on travel time and logsum indicators. The logsum indicator increases in the zones surrounding the new residential location due to additional traffic attraction. However travel times in the surroundings of the location will increase due to additional traffic demand. In the logsum indicator the change in utility due to additional opportunities seems to be dominant over the change in utility due to changes in travel time.

The table presents the bandwidth of changes in accessibility indicators based on the performed test runs with the NMS. The bandwidth is presented by type of policy measure and presents the maximum observed change in the value of the accessibility indicator for an individual zone.

Table C-1: Changes in accessibility indicators for different policy options

Accessibility indicator	Reference development (2020-2000)	Infrastructure policy	Road policy	Pricing	Land-use policy
Logsum (move/stay)	0.0% - 5.0%	0.0% - 1.0%	- 3.0% - 0%		0.0% - 0.5%
Logsum (household type A)	0.0% - 10.0%	0.0% - 0.5%	- 2.0% - 0%		0.0% - 0.5%
Logsum (household type D)	0.0% - 4.0%	0.0% - 1.0%	- 3.0% - 0%		0.0% - 0.5%
Travel Time	0.0% - 4.0%	0.0% - 7.0%	0.0% - 5.0%		0.0% - 0.5%
Logsum (business)	0.0% - 2.0%	0.0% - 0.5%	- 0.5% - 0%		0.0% - 0.5%
Logsum (commuting)	0.0% - 4.0%	0.0% - 0.5%	- 2.0% - 0%		0.0% - 0.5%
Freight travel time	0.0% - 3.0%	0.0% - 6.0%	0.0% - 3.0%		0.0% - 0.5%

*) It should be noted that for the logsums indicators the bandwidth is by NMS zone and for the travel time indicators it is by origin-destination relationship.

The table shows that the level of infrastructure development and pricing policies has a larger effect on accessibility than land-use policies. However, land-use policies can still have a significant local effect on accessibility. The effects on “logsum” indicators are small, because of the logarithmic scale. Another issue is that logsum indicators incorporate social-economic, spatial as well as transport factors; a transport policy affects only one of these factors and the other factors are unchanged between the policy and reference run. The changes in accessibility indicators as implemented in the sensitivity runs of step 2 are based upon the findings in this table.

Summary

Joint modeling of land-use, transport and economy

Barry Zondag

Over the last decades it has become clear that the problems of an ongoing growth of transport in urbanized regions, such as congestion and environmental externalities, cannot be solved by conventional transport measures alone. There is widespread agreement that in order to bring about sustainable travel in urban areas, integrated policy packages – comprising a cross-sector mix of regulatory-, pricing-, and technological measures among others - are needed to send the right signals to both supply and demand elements in the urban land use and transport markets (ECMT, 2002). Successful implementation of these policy packages depends, among others, on a sufficient integration of land-use- and transport planning.

The present research aims to improve the estimation of transport and land-use effects of transport- and land use policies; this contributes to the ongoing effort in the Netherlands to improve policy making in the field of transport infrastructure by incorporating land-use and other indirect economic effects of transport measures in the evaluation of these measures. An integrated modeling, complementary to classical transport modeling, making land-use projections endogenous is needed to calculate a wide set of evaluation indicators for the evaluation of multi-sector policy packages. It should be noted that for many outcome indicators a substantial post-processing is needed. However, many of these indicators are related to changes in land-use and transport and the integrated land-use and transport model delivers intermediate input for these indicators. The body of this thesis research comprises the development of the integrated land-use and transport model “TIGRIS XL”: this model has been applied to calculate the effects of land-use and transport policies on the spatial distribution of residents and jobs.

Modeling

The operational target of this research is to improve the analytical tools required to perform an analysis of the impacts of integrated land-use and transport strategies on transport, land-use and the regional economy. The call for such integrated modeling is not new; models have been developed in the context of different disciplines, such as spatial economy, urban planning, transportation and geography, with an approach geared to the particular discipline. The use of these models in practice has been limited: many efforts have never passed the research and development phase. Developing an integrated model is a highly complex matter requiring to assess and balance theoretical soundness, data availability, integration in the policy-making process and practical issues as computation time. This thesis makes the following contributions:

Model structure: The art of modeling the urban or regional system is to model the three dimensions, space, time, and sectors/actors, in a balanced way. Each of these dimension has influence on the type and size of the interactions and therefore on the modeling results. Key observations affecting the structure of the modeling are that:

- A general theory, conceptualizing the development of “human society” in time and space, does not exist. In the absence of a general theory the next best approach to an integrated assessment of inter-related space-transport-economy effects is to combine elements of several theories and methods;
- The research has argued the non-existence of a general equilibrium in the land-use and transport system at any moment in time, due to a variety of time lags and differences in speed of change for components of the system.

An incremental systems approach, with a modular structure linking the various components, is therefore considered the best approach to model this system. Such approach enables to analyze and estimate specific relationships based upon available data sources for that sector. Furthermore this approach is flexible towards time dynamics and level of spatial detail. A review of the family of Land-use and transport interaction (LUTI) models and alternative approaches shows that LUTI-models are most suited to simulate the urban or regional system in the proposed way.

Linkage with transport model – accessibility indicators: The TIGRIS XL land-use model is linked with the National Model System (NMS), a passenger transport model for the Netherlands. The NMS is a discrete choice type of transport model based on micro-economic utility theory. With such a model it is possible to generate a logsum value, an aggregate value expressing the utility from multiple alternatives. The TIGRIS XL model uses these utility-based accessibility indicators. The utility-based indicators in TIGRIS XL include personal characteristics and preferences, besides characteristics of the transport and land use system, to capture observed heterogeneity across individuals. Including the individual component of accessibility means that more realistic accessibility indicators, namely accessibility indicators closer representing the specific activity pattern and preferences of the households or firms, can be included as explanatory variable in the estimation process of residential or firm location choices.

Model Estimation: In most LUTI-models parameter values are based upon expert judgment or informal calibration procedures: observed and calculated data sets are matched without using statistical indicators such as model fit or parameter significance. For the residential location choice module (and job location choice module) of the TIGRIS XL the coefficients are formally estimated using available databases; this can be considered as an important contribution. Advantage compared to informal calibration procedures is that the significance and size of the coefficients for the explanatory variables is statistically determined. Furthermore, it is possible to compare the overall fit of alternative model specifications. Separate models have been estimated for different household types (or economic sectors); in each model the influence of accessibility has been estimated among many other explanatory variables.

Land market regimes An important contribution of the present research is that several alternative land market regimes can be explored within the LUTI modeling. The alternative spatial projections can vary from completely regulated, following supply planning of the government, to a free market regime, in which supply follows the location preferences of the residents.

Spatial level of detail In the international literature a distinction is often made between models operating at a regional level and inter-regional models. In regional models it is generally assumed that “hard” regional borders exist and important spatial markets, like the housing and labor market, are constrained by the regional boundaries. However, in an area with a complex spatial structure with multiple centers and overlapping labor and housing market, such as for the Netherlands, identification of hard regional boundaries is not realistic. In the present research, both the regional and inter-regional level, are integrated within one framework. Within the housing market module a nested structure has been used to address inter-regional moves and moves within the region. Different coefficients and explanatory variables have been tested at the different spatial scale levels. Based on this concept the modeling is capable of consistently analyzing regional and inter-regional transport plans.

Indirect generative effects: A consequence of following a dynamic approach is that it is difficult to model indirect generative effects, resulting from comparing the equilibrium situation with and without the project. In the present research a bottom-up approach is proposed to calculate indirect generative welfare effects resulting from agglomeration effects. It uses the detailed spatial representation of the LUTI-models to derive agglomeration effects. In the next step the effects on productivity resulting from the changes in agglomeration are calculated.

Findings on land-use impacts of transport- and land-use policies

In this research the land-use effects have been studied by using various sources, such as:

- A literature review of the structuring effects;
- A statistical estimation of the relationship between accessibility, and residential- and job location choices;
- A model (TIGRIS XL) has been used to calculate the land-use effects of land-use and transport policies.

As specific contributions of the present study can be listed the use of empirical based relationships (survey data or time series data) for the influence of accessibility on residential- and job location choices, the incorporation of the regional and inter-regional level within one framework and the flexibility to analyze the effects for various levels of land market regulation by the government.

Structuring effects on residential location choice

The results of the empirical estimation show a significant, but modest, positive influence of accessibility on residential location choice. The model estimation results suggest that accessibility is a significant variable in the Move/Stay choice. It is less likely that households are going to move away from a more accessible location than from a less accessible location. However, the residential location choice estimation results suggest that accessibility of a specific location is for many household types not a significant variable in their location choice. Demographic developments, neighborhood amenities and especially housing attributes seem to be more dominant explanatory variables. The high weight for the travel time variables, between old en new residential location, illustrates the important role of the transport system in defining the spatial size of the housing market.

Test runs with the TIGRIS XL system illustrate that large transport measures do have a significant but small effects on the spatial distribution of residents. The tests also illustrate that such change in the distribution of residents has a significant secondary effect on the distribution of jobs as well. An important feature of the Netherlands is that the housing market is strongly regulated. This feature influences the model estimation results and should be addressed when applying the model. In general it can be stated that an empirical analysis on accessibility, analysis conditions and choice of variables, necessarily has to deal with a significant amount of specific characteristics for the region.

The sensitivity analysis with the TIGRIS XL model made clear that these changes are not instantaneous; it takes a long time before the full land-use impacts of a transport measure can be observed. The sensitivity analysis also illustrates that the structuring impact of transport on land-use depends on the spatial policy of the government. In a regulated market the actors are restricted in their options to take advantage of accessibility improvements. The structuring impacts are therefore higher under free market conditions than under regulated conditions. Finally it should be noted that the literature highlights the big difference in the structuring role of the transport infrastructure between developed countries with a mature transport infrastructure, and developing countries with large deficiencies in their infrastructure. Therefore the transferability of the results is limited.

Structuring effects on jobs

The empirical literature on structuring effects of transport on the distribution of jobs is limited and the available sources show a wide range of results. Part of this variety might be explained because the structuring impacts on the distribution of jobs differ widely for the different economic sectors. Empirical analysis, without a detailing into economic sectors, can be expected to be highly influenced by the economic structure in a specific region.

Model estimations for the TIGRIS XL model show that manufacturing, logistics, other consumer services and especially business services are the most sensitive sectors for changes in accessibility. The sectors retail and government respond indirectly to changes in accessibility and are responding to changes in the number of residents. The effect of transport measures on the spatial distribution of residents will determine for these sectors the size of the effect.

The spatial scale level of the labor market estimation in TIGRIS XL is the municipality level. At this level demand forces seem to be dominant and it is assumed that job location demand will be facilitated by supply of commercial floor space or industrial land. However, it should be noted that in reality supply restrictions play a role at lower spatial scale levels. The findings discussed in this section are therefore valid at the municipality level. At this level the labor market module, and the size of its structuring effects, is less sensitive for the level of land market regulation by the government than the housing market module. There is only a secondary effect, as explained above, following changes in residential land-use.

The TIGRIS XL test applications present structuring impacts on the spatial distribution of jobs, which are overall significantly bigger than the structuring impact on the spatial distribution of residents. However these effects can still be considered modest compared to total employment figures and autonomous changes (changes in the reference case).

For the individual economic sectors it appears that especially business services respond relatively strongly to changes in accessibility.

Policy implications

The research findings have the following policy implications:

- The indirect distribution effects of transport infrastructure measures are relatively small compared to direct benefits and project costs. It can be concluded that if the direct benefits of the project and costs are not close to break-even than the indirect distribution effects are unlikely to make the difference between break-even or not. It should be noted that this conclusion is context specific and applies only to regions with a well developed infrastructure.
- Changes in the level of spatial regulation by the government result in significantly different spatial patterns. The long-term spatial pattern of transport demand is therefore uncertain and current practice in transport policy analysis could be improved from addressing this uncertainty.
- The ambition of the latest physical plan “Nota Ruimte” to use different spatial regimes, varying between “centrally controlled” and “freedom for regional authorities”, for different regions has important spatial impacts. In a small and high density country as the Netherlands spatial markets overlap and the spatial regime of a region affects not only neighboring regions but also more distant regions. The case study “Almere” illustrates that growth ambitions for this city are affected by a less centrally regulated market regime in more distant regions outside the urban core of the Netherlands.

Overall the research results indicate that annual land-use changes, and in particular the structuring impacts of transport on land-use, are small compared to existing patterns. Therefore at first one might consider ignoring these changes. However the long term character of these slow dynamics makes these land-use changes important. A change in land-use does have a very long-term influence on the urban and regional structure and can be considered as almost irreversible. This can be illustrated by observing the difficulties which, car-based low-density cities, have with formulating alternative transport strategies. Land-use developments are therefore a critical element of any long-term transport strategy.

Samenvatting

Integraal modelleren van grondgebruik, transport en economie

Barry Zondag

Het is tegenwoordig een breed gedragen opvatting dat de problemen van een nog steeds groeiende transportvraag in stedelijke gebieden, zoals congestie of luchtkwaliteit, niet opgelost kunnen worden door het enkel nemen van traditionele transportmaatregelen zoals het investeren in infrastructuur. Om een duurzame vorm van mobiliteit te realiseren in stedelijke gebieden is een integraal pakket aan beleidsmaatregelen nodig bestaande uit een multidisciplinaire mix van regulering-, grondgebruik-, prijs-, technologie- en infrastructuur maatregelen. Hierbij wordt beoogd zowel de vraag als het aanbod op de transportmarkt te beïnvloeden, alsook op andere ruimtelijke markten, zoals de woningmarkt en arbeidsmarkt, welke op hun beurt transport in hoge mate beïnvloeden. Een succesvolle invoering van deze integrale maatregelpakketten hangt mede af van een voldoende mate van integratie tussen ruimtelijke- en transportplanning.

Het doel van dit onderzoek is het verbeteren van de bepaling van de transport- en grondgebruikseffecten van integrale ruimte en transport strategieën. Dit onderzoek draagt bij aan de inspanningen in Nederland om de evaluatie van infrastructuurinvesteringen te verbeteren; dit gebeurt hoofdzakelijk door het meenemen van de indirecte effecten van transport infrastructuurinvesteringen op andere ruimtelijke markten zoals de grondmarkt, woningmarkt en arbeidsmarkt. Een integraal grondgebruik en transport model, in aanvulling op de conventionele transportmodellen, is nodig voor het berekenen van de transport- en grondgebruikseffecten van een integraal pakket aan beleidsmaatregelen.

Met een integraal model kunnen combinaties van ruimte- en transportmaatregelen worden beoordeeld op basis van een brede set aan beleidsindicatoren. Bij het toepassen van een integraal model worden de beleidsindicatoren beïnvloed door zowel veranderingen in transport als in grondgebruik (b.v. geluidoverlast, bereikbaarheid, etc.). Kern van dit onderzoek bestaat uit de ontwikkeling van het integrale grondgebruik en transport model “TIGRIS XL”.

Modelleren

Het doel van dit onderzoek, namelijk het verbeteren van de analytische instrumenten voor het berekenen van de effecten van ruimtelijk- en transportbeleid op transport, grondgebruik en de regionale economie, is niet nieuw. In het verleden zijn diverse

integrale modellen ontwikkeld, vanuit verschillende academische disciplines, zoals ruimtelijke economie, stedelijke planning, verkeerskunde en geografie. Het gebruik van deze modellen in de praktijk is echter beperkt, veelal zijn de modellen blijven steken in de onderzoek- en/of ontwikkelingsfase. Een mogelijke reden hiervoor is dat het ontwikkelen van een integraal model erg complex is en er veel verschillende eisen bestaan voordat een model in de praktijk gebruikt zal worden. De complexiteit bestaat uit het beoordelen en gericht inzetten van theoretische kennis, data beschikbaarheid, integratie van het modelinstrument in de beleidspraktijk en het hanteren van grote gegevensbestanden en complexe modelstructuur (computerkennis). Het moge duidelijk zijn dat er op het gebied van integraal modelleren nog vele uitdagingen en mogelijke invullingen zijn; deze dissertatie levert op de volgende onderdelen een bijdrage:

Modelstructuur: Een belangrijke uitdaging bij het modelleren van het stedelijke of regionale systeem is het afstemmen van de drie dimensies van het systeem, tijd, ruimte en sectoren/actoren in het model. Elk van deze dimensies heeft een belangrijke invloed op de resultaten, zo ontwikkelen de grondgebruikseffecten van een transportmaatregel zich over een zeker tijdsinterval, zijn deze ruimtelijke sterk afhankelijk van de locatie van de maatregel, en kunnen de effecten sterk verschillen tussen economische sectoren of huishoudtypen. Andere observaties met een belangrijke invloed op de structuur van het model zijn:

- Een algemene theorie, welke de ontwikkeling van het stedelijke of regionale systeem beschrijft in tijd en ruimte, bestaat niet. Het heeft dan ook de voorkeur om terug te vallen op een combinatie van elementen uit verschillende theorieën en methoden, boven het gebruiken van één theorie welk maar een beperkt deel van het systeem verklaart;
- Dit onderzoek beargumenteert het ontbreken van een algemeen evenwicht in het grondgebruik en transportsysteem op een willekeurig tijdstip. Dit komt door de vele verschillende reactietijden van componenten in het systeem.

De meest geschikte wijze van modelleren is volgens dit onderzoek een systeem dynamische benadering met een losse modulaire structuur waarbij de verschillende componenten in de tijd worden verbonden. Een modulaire structuur maakt het mogelijk om per component de meest geschikte modelleringmethode, mede afhankelijk van de beschikbare data, te kiezen. Ruimtelijk detail wordt gewaarborgd door de te gebruiken methoden af te stemmen op de aanwezige ruimtelijke databestanden. De stapsgewijze, op verandering gerichte aanpak, maakt het model flexibel voor het modelleren van de tijdsdimensie. De hier voorgestelde modelleringaanpak kan het beste geplaatst worden binnen de familie van grondgebruik en transport interactiemodellen.

Koppeling met het transportmodel – bereikbaarheidsindicatoren: Het TIGRIS XL grondgebruik model is gekoppeld aan het Landelijk Model Systeem (LMS), een personen transportmodel voor Nederland. Het LMS gebruikt de discrete keuze methode en is gefundeerd in de micro-economische maximale nuttheorie. Met dergelijk model is het mogelijk om zogenoemde “logsum” bereikbaarheidsindicatoren te genereren, welke het geaggregeerde nut weergegeven van meerdere alternatieven (o.a. bestemmingen, vervoerwijzen). De logsum bereikbaarheidsindicatoren zijn verplaatsing specifiek en per persoonstype hangen de bereikbaarheidsindicatoren af van het activiteitenpatroon. Het mee laten wegen van het activiteitenpatroon (aantal verplaatsingen naar motief) per persoonstype maakt dat meer toegesneden bereikbaarheidsindicatoren worden gebruikt

voor de verschillende huishoudtypen (persoontypen maken via fracties deel uitmaken van huishoudtypen) in de woonlocatiekeuze module van TIGRIS XL.

Model schattingen: In veel grondgebruik en transport interactiemodellen zijn de waarden van de coëfficiënten gebaseerd op expertkennis of informele calibratieprocedures. Bij informele calibratieprocedures wordt het model afgestemd op waargenomen data zonder het gebruik van statistische kwaliteitsindicatoren voor de fitting van het gehele model en het teken en waarde van de coëfficiënten. De woonlocatiekeuze module (evenals arbeidsplaats locatie module) in TIGRIS XL zijn formeel geschat op basis van respectievelijk een maximum likelihood schatting en een minimale kwadraten schatting. Het voordeel ten opzichte van een informele procedure is dat het teken, waarde en significantie van de coëfficiënten voor de variabelen statistisch is getoetst. Daarnaast is het mogelijk om alternatieve modellen te vergelijken op basis van statistische waarden voor de fit van het model. Huishoudtype (of economische sector) specifieke submodellen zijn geschat, waarbij in elk model bereikbaarheidsvariabelen zijn meegenomen in combinatie met een uitgebreide set aan andere relevante variabelen.

Ruimtelijke planning regime: Een bijdrage van dit onderzoek is dat de gevolgen van alternatieve ruimtelijke planning regimes op het grondgebruik kunnen worden verkend. In de modellering kan het ruimtelijke regime variëren van een sterk gereguleerde planning, waarbij de woningbouwlocaties worden gepland door de centrale overheid, tot een vrije markt regime waarbij de woningbouwlocaties afhangen van de woningvraag op basis van de locatievoorkeuren van de huishoudens.

Ruimtelijk detail niveau: In de internationale literatuur wordt vaak een onderscheid gemaakt tussen interregionale – en regionale ruimtelijke modellen. De regionale of stedelijke modellen gebruiken vaak als aanname dat de regionale grenzen hard zijn en dat belangrijke ruimtelijke markten, zoals de woningmarkt of arbeidsmarkt, hierdoor begrensd worden. Echter in de complexe ruimtelijke context van Nederland, met meerdere economische centra op korte afstand en overlappende arbeid- en woningmarkten, is het gebruiken van harde regionale grenzen een onrealistische aanname. In dit onderzoek wordt geheel Nederland gemodelleerd en omvat het model zowel het regionale als inter-regionale niveau. Zo heeft de woningmarkt module een geneste structuur waarbij er een verschil gemaakt wordt tussen verplaatsingen binnen en buiten de regio.

Indirecte generatieve effecten: De dynamische structuur van het model en het ontbreken van een algemeen evenwicht maakt het moeilijk om de indirecte generatieve effecten te bepalen, deze resulteren immers uit het vergelijken van de evenwichtsituatie met en zonder project. Dit onderzoek stelt een “bottom-up” benadering voor het berekenen van agglomeratie effecten, waarin meerdere indirecte generatieve effecten worden samengebracht. De methode bestaat uit twee stappen: in stap 1 wordt het ruimtelijke detail van grondgebruik en transport interactiemodellen gebruikt voor het bepalen van de veranderingen in de agglomeratievariabele. In de tweede stap wordt het productiviteitseffect bepaald van de verandering in de agglomeratievariabele.

Grondgebruikeffecten¹³ van ruimtelijke – en transportmaatregelen

In dit onderzoek is de analyse van de grondgebruikeffecten van ruimtelijke- en transportmaatregelen gebaseerd op verscheidende bronnen, namelijk:

- Een literatuurstudie naar de structurerende effecten;
- Statistische schattingen voor de relatie tussen bereikbaarheid en de ruimtelijke distributie van bewoners en arbeidsplaatsen;
- Toepassen van een grondgebruik en transport inter-actie model (TIGRIS XL) voor het berekenen van de grondgebruikeffecten van ruimtelijke- en transportmaatregelen.

Specifieke bijdragen van dit onderzoek zijn het gebruik van een model waarin de relaties tussen grondgebruik en transport statistisch zijn bepaald, het integreren van het interregionale en regionale schaalniveau in een raamwerk, en de mogelijkheid om de effecten te analyseren voor verschillende vormen van ruimtelijke marktregulering door de overheid.

Structurerende effecten op de ruimtelijke distributie van bewoners

De schattingsresultaten, op basis van enquête data geven aan dat bereikbaarheid een statistisch significante maar geringe rol speelt, in de locatiekeuze van huishoudens. Transport speelt vooral een rol via reistijd en –kosten tussen de oude en nieuwe locatie, dit geeft de belangrijke rol aan die transport speelt in het bepalen van de omvang van de ruimtelijke markten. Op basis van de schattingen blijkt dat de invloed van transport op de woonlocatiekeuze via de specifieke bereikbaarheid van een locatie gering is en voor sommige huishoudtypen zelfs statistisch niet significant. Demografische ontwikkelingen, wijk- en woningkenmerken zijn dominantere verklarende variabelen in de woonlocatiekeuze dan bereikbaarheid. Daarnaast speelt bereikbaarheid ook nog een geringe rol in de verhuisbeslissing, doordat huishoudens eerder geneigd zijn om van slecht bereikbare locatie te verhuizen, dan van een goed bereikbare locatie.

Met het TIGRIS XL model zijn testberekeningen gemaakt waaruit blijkt dat de verwachte ruimtelijke distributie effecten van omvangrijke infrastructuurprojecten in Nederland gering zijn. Het valt hierbij op dat de ruimtelijke distributie effecten elkaar beïnvloeden door de tijd, een verandering in de ruimtelijke verdeling van de bevolking door de maatregel werkt in de tijd door op de ruimtelijke verdeling van de arbeidsplaatsen en vice versa. De specifieke ruimtelijke situatie in Nederland, met een relatief sterk gereguleerde markt, is ook van invloed op de resultaten. Dit geldt zowel voor de schattingsresultaten als voor toepassingresultaten, beide zijn afhankelijk van het marktregime. Gevoeligheidstesten met het TIGRIS XL model geven aan dat de structurerende effecten groter in omvang zijn onder een vrije dan onder een gereguleerde markt (waarbij geen flankerend beleid werd verondersteld). In een gereguleerde markt kunnen de huishoudens, door het ontbreken van aanbod aan vacante woningen, vaak niet profiteren van bereikbaarheidsverbeteringen. De gevoeligheidstesten gaven verder aan dat de structurerende effecten langzaam ontstaan in de tijd en de volledige effecten van een infrastuctuurmaatregel zijn pas op de lange termijn na de gemaakte infrastructuurmaatregel te zien.

¹³ Onder grondgebruikeffecten worden hier wijdere effecten bedoeld dan alleen de veranderingen in het grondgebruik, en onder de grondgebruikeffecten worden ook de verandering in de ruimtelijke distributie van bewoners en arbeidsplaatsen bedoeld.

Bovenstaande bevindingen geven aan dat de analyse van de invloed van bereikbaarheid op de ruimtelijke distributie van bewoners afgestemd moet op de regionale context. Zo beschrijft de literatuur bijvoorbeeld een groot verschil in structurerende effecten van transportinfrastructuur tussen ontwikkelde landen, met een omvangrijke bestaande infrastructuur, en ontwikkelingslanden met een zeer beperkte huidige transportinfrastructuur. Dit geeft aan dat de overdraagbaarheid van de in dit onderzoek gevonden resultaten beperkt is en sterk afhangt van de context.

Structurerende effecten op de ruimtelijke distributie van arbeidsplaatsen

De empirische literatuur, welke de structurerende effecten van transport op de ruimtelijke verdeling van arbeidsplaatsen beschrijft, is beperkt en kenmerkt zich door de diversiteit van de resultaten. Een deel van deze variatie kan waarschijnlijk verklaard worden doordat economische sectoren verschillend reageren op bereikbaarheidsveranderingen, zo zullen de resultaten van een empirische analyse, zonder uitsplitsing naar sectoren, sterk beïnvloed worden door de economische structuur in een regio. Modelschattingen, gemaakt door Bureau Louter, voor TIGRIS XL geven aan dat de economische sectoren industrie, logistiek, overige consumenten diensten en de zakelijke dienstverlening, het meest gevoelig zijn voor veranderingen in de bereikbaarheid. De economische sectoren detailhandel en overheid worden indirect beïnvloed door bereikbaarheidsveranderingen via een verandering in de bevolkingomvang.

De relaties voor de arbeidsmarkt in TIGRIS XL zijn geschat op gemeenteniveau, waarbij de aanname is gemaakt, gebaseerd op observaties van de ruimtelijke ontwikkelingen in Nederland, dat op dit niveau de vraag dominant is. Het aanbod aan kantooroppervlak en bedrijventerreinen speelt op een binnenstedelijk niveau een rol. Testberekeningen met het TIGRIS XL model geven aan dat de invloed van bereikbaarheid op de ruimtelijke verdeling van arbeidsplaatsen bescheiden is in omvang, zeker indien dit wordt afgezet tegen huidige totalen per regio of de autonome verandering (tussen basis en toekomstjaar in de referentieberekening). Wel zijn de effecten op de arbeidsplaatsen iets groter dan bij de bewoners.

Implicaties voor beleid

Op basis van de onderzoekresultaten kunnen de volgende implicaties voor het ruimtelijke- en transportbeleid gemaakt worden:

- De indirecte verdeel-effecten van transport infrastructuurmaatregelen zijn in regio's met een al goed ontwikkelde infrastructuur relatief beperkt ten op zichte van de directe effecten en projectkosten. Bij dergelijke projecten, met naar verwachting beperkte indirect effecten, kan op basis van de directe effecten een eerste schifting worden gemaakt tussen kansrijke en niet kansrijke projecten. Indien het gat tussen de kosten en baten op basis van de directe effecten nog erg groot is dan is het onwaarschijnlijk dat de indirecte effecten dit beeld zullen laten omslaan;
- De toekomstige ruimtelijke distributie van activiteiten hangt, naast sociaal - economische scenario ontwikkelingen, mede af van de mate van regulering van de ruimtelijke ontwikkeling door de overheid. De lange termijn distributie van activiteiten, en daarmee de ruimtelijke verdeling van de transportvraag, is dan ook onzeker en de huidige praktijk in het transportbeleid kan verbeterd worden door het meenemen van deze onzekerheid;
- De "Nota Ruimte" heeft als ambitie om een regio specifieke strategie te volgen waarin regio's alleen aan basiseisen hoeven te voldaan, een centrale strategie

blijft alleen gelden voor gebieden met een nationaal belang. In een klein land met een hoge dichtheid aan activiteiten zoals Nederland bestaan er geen geïsoleerde woning- en arbeidsmarkten, maar wordt het beeld bepaald door elkaar overlappende markten. Bij een dergelijke ruimtelijke structuur is het voeren van gedifferentieerd beleid zeer complex, daar het ruimtelijke beleid in een regio een invloed heeft op andere regio's zelfs over grotere afstand. Zo geeft de Almere toepassing aan dat de groei ambitie van deze stad sterk kan worden beïnvloed door minder centrale sturing in andere regio's buiten de Randstad.

Tot slot kan opgemerkt worden dat de jaarlijkse veranderingen in het grondgebruik gering zijn, al helemaal de grondgebruik veranderingen ten gevolgen van transportbeleid, in vergelijking met het bestaande ruimtelijke patroon. Dit kenmerk van het langzaam veranderen door de tijd is echter ook de belangrijkste eigenschap waarom het zinvol is om deze veranderingen mee te nemen in de beleidsvoorbereiding. Een verandering in het grondgebruik heeft een lange termijn invloed op het regionale grondgebruik en transportsysteem en is zeer moeizaam weer te veranderen. Een voorbeeld hiervan zijn de problemen bij het introduceren van openbaar vervoer in steden met een lage dichtheid. Om deze problemen te vermijden dienen grondgebruik ontwikkelingen een integraal onderdeel te vormen van een lange termijn transport strategie.

About the Author

Barry Zondag was born on the 5th of April 1973 in Medemblik. In 1997 he graduated with a master's degree in Civil Engineer from Delft University of Technology with a major in infrastructure planning. In his career Barry has balanced between academic research and practical consultancy. He has worked on issues related to transport planning, spatial planning and policy analysis. Barry has been part-time affiliated with Delft University of Technology, department of Transport and Planning, during his PhD research on joint modelling of land-use, transport and economy.

In his work for DEMIS, Hague Consulting Group and RAND Europe, he has participated in- and led projects on passenger and freight transport in an urban, national and European context. He has particularly specialised in the field of integrative land-use and transport modelling; he is the principal developer of the TIGRIS XL model, a new land-use and transport model for the Netherlands. He currently is a senior analyst at Significance, a firm specialising in quantitative analyses to transport and logistics; this recently (2007) founded firm is owned by NEA and former RAND Europe (Leiden) staff.

TRAIL Thesis Series

A series of The Netherlands TRAIL Research School for theses on transport, infrastructure and logistics.

Nat, C.G.J.M., van der, *A Knowledge-based Concept Exploration Model for Submarine Design*, T99/1, March 1999, TRAIL Thesis Series, Delft University Press, The Netherlands

Westrenen, F.C., van, *The Maritime Pilot at Work: Evaluation and Use of a Time-to-boundary Model of Mental Workload in Human-machine Systems*, T99/2, May 1999, TRAIL Thesis Series, Eburon, The Netherlands

Veenstra, A.W., *Quantitative Analysis of Shipping Markets*, T99/3, April 1999, TRAIL Thesis Series, Delft University Press, The Netherlands

Minderhoud, M.M., *Supported Driving: Impacts on Motorway Traffic Flow*, T99/4, July 1999, TRAIL Thesis Series, Delft University Press, The Netherlands

Hoogendoorn, S.P., *Multiclass Continuum Modelling of Multilane Traffic Flow*, T99/5, September 1999, TRAIL Thesis Series, Delft University Press, The Netherlands

Hoedemaeker, M., *Driving with Intelligent Vehicles: Driving Behaviour with Adaptive Cruise Control and the Acceptance by Individual Drivers*, T99/6, November 1999, TRAIL Thesis Series, Delft University Press, The Netherlands

Marchau, V.A.W.J., *Technology Assessment of Automated Vehicle Guidance - Prospects for Automated Driving Implementation*, T2000/1, January 2000, TRAIL Thesis Series, Delft University Press, The Netherlands

Subiono, *On Classes of Min-max-plus Systems and their Applications*, T2000/2, June 2000, TRAIL Thesis Series, Delft University Press, The Netherlands

Meer, J.R., van, *Operational Control of Internal Transport*, T2000/5, September 2000, TRAIL Thesis Series, Delft University Press, The Netherlands

Bliemer, M.C.J., *Analytical Dynamic Traffic Assignment with Interacting User-Classes: Theoretical Advances and Applications using a Variational Inequality Approach*, T2001/1, January 2001, TRAIL Thesis Series, Delft University Press, The Netherlands

Muilerman, G.J., *Time-based logistics: An analysis of the relevance, causes and impacts*, T2001/2, April 2001, TRAIL Thesis Series, Delft University Press, The Netherlands

Roodbergen, K.J., *Layout and Routing Methods for Warehouses*, T2001/3, May 2001, TRAIL Thesis Series, The Netherlands

Willems, J.K.C.A.S., *Bundeling van infrastructuur, theoretische en praktische waarde van een ruimtelijk inrichtingsconcept*, T2001/4, June 2001, TRAIL Thesis Series, Delft University Press, The Netherlands

Binsbergen, A.J., van, J.G.S.N. Visser, *Innovation Steps towards Efficient Goods Distribution Systems for Urban Areas*, T2001/5, May 2001, TRAIL Thesis Series, Delft University Press, The Netherlands

Rosmuller, N., *Safety analysis of Transport Corridors*, T2001/6, June 2001, TRAIL Thesis Series, Delft University Press, The Netherlands

Schaafsma, A., *Dynamisch Railverkeersmanagement, besturingsconcept voor railverkeer op basis van het Lagenmodel Verkeer en Vervoer*, T2001/7, October 2001, TRAIL Thesis Series, Delft University Press, The Netherlands

Bockstael-Blok, W., *Chains and Networks in Multimodal Passenger Transport. Exploring a design approach*, T2001/8, December 2001, TRAIL Thesis Series, Delft University Press, The Netherlands

Wolters, M.J.J., *The Business of Modularity and the Modularity of Business*, T2002/1, February 2002, TRAIL Thesis Series, The Netherlands

Vis, F.A., *Planning and Control Concepts for Material Handling Systems*, T2002/2, May 2002, TRAIL Thesis Series, The Netherlands

Koppius, O.R., *Information Architecture and Electronic Market Performance*, T2002/3, May 2002, TRAIL Thesis Series, The Netherlands

Veeneman, W.W., *Mind the Gap; Bridging Theories and Practice for the Organisation of Metropolitan Public Transport*, T2002/4, June 2002, TRAIL Thesis Series, Delft University Press, The Netherlands

Nes, R. van, *Design of multimodal transport networks, a hierarchical approach*, T2002/5, September 2002, TRAIL Thesis Series, Delft University Press, The Netherlands

Pol, P.M.J., *A Renaissance of Stations, Railways and Cities, Economic Effects, Development Strategies and Organisational Issues of European High-Speed-Train Stations*, T2002/6, October 2002, TRAIL Thesis Series, Delft University Press, The Netherlands

Runhaar, H., *Freight transport: at any price? Effects of transport costs on book and newspaper supply chains in the Netherlands*, T2002/7, December 2002, TRAIL Thesis Series, Delft University Press, The Netherlands

Spek, S.C., van der, *Connectors. The Way beyond Transferring*, T2003/1, February 2003, TRAIL Thesis Series, Delft University Press, The Netherlands

Lindeijer, D.G., *Controlling Automated Traffic Agents*, T2003/2, February 2003, TRAIL Thesis Series, Eburon, The Netherlands

Riet, O.A.W.T., van de, *Policy Analysis in Multi-Actor Policy Settings. Navigating Between Negotiated Nonsense and Useless Knowledge*, T2003/3, March 2003, TRAIL Thesis Series, Eburon, The Netherlands

Reeven, P.A., van, *Competition in Scheduled Transport*, T2003/4, April 2003, TRAIL Thesis Series, Eburon, The Netherlands

Peeters, L.W.P., *Cyclic Railway Timetable Optimization*, T2003/5, June 2003, TRAIL Thesis Series, The Netherlands

Soto Y Koelemeijer, G., *On the behaviour of classes of min-max-plus systems*, T2003/6, September 2003, TRAIL Thesis Series, The Netherlands

Lindveld, Ch..D.R., *Dynamic O-D matrix estimation: a behavioural approach*, T2003/7, September 2003, TRAIL Thesis Series, Eburon, The Netherlands

Weerdt, de M.M., *Plan Merging in Multi-Agent Systems*, T2003/8, December 2003, TRAIL Thesis Series, The Netherlands

Langen, de P.W., *The Performance of Seaport Clusters*, T2004/1, January 2004, TRAIL Thesis Series, The Netherlands

Hegyi, A., *Model Predictive Control for Integrating Traffic Control Measures*, T2004/2, February 2004, TRAIL Thesis Series, The Netherlands

Lint, van, J.W.C., *Reliable Travel Time Prediction for Freeways*, T2004/3, June 2004, TRAIL Thesis Series, The Netherlands

Tabibi, M., *Design and Control of Automated Truck Traffic at Motorway Ramps*, T2004/4, July 2004, TRAIL Thesis Series, The Netherlands

Verduijn, T. M., *Dynamism in Supply Networks: Actor switching in a turbulent business environment*, T2004/5, September 2004, TRAIL Thesis Series, The Netherlands

Daamen, W., *Modelling Passenger Flows in Public Transport Facilities*, T2004/6, September 2004, TRAIL Thesis Series, The Netherlands

Zoeteman, A., *Railway Design and Maintenance from a Life-Cycle Cost Perspective: A Decision-Support Approach*, T2004/7, November 2004, TRAIL Thesis Series, The Netherlands

Bos, D.M., *Changing Seats: A Behavioural Analysis of P&R Use*, T2004/8, November 2004, TRAIL Thesis Series, The Netherlands

Versteegt, C., *Holonic Control For Large Scale Automated Logistic Systems*, T2004/9, December 2004, TRAIL Thesis Series, The Netherlands

Wees, K.A.P.C. van, *Intelligente voertuigen, veiligheidsregulering en aansprakelijkheid. Een onderzoek naar juridische aspecten van Advanced Driver Assistance Systems in het wegverkeer*, T2004/10, December 2004, TRAIL Thesis Series, The Netherlands

Tampère, C.M.J., *Human-Kinetic Multiclass Traffic Flow Theory and Modelling: With Application to Advanced Driver Assistance Systems in Congestion*, T2004/11, December 2004, TRAIL Thesis Series, The Netherlands

Rooij, R.M., *The Mobile City. The planning and design of the Network City from a mobility point of view*, T2005/1, February 2005, TRAIL Thesis Series, The Netherlands

Le-Anh, T., *Intelligent Control of Vehicle-Based Internal Transport Systems*, T2005/2, April 2005, TRAIL Thesis Series, The Netherlands

Zuidgeest, M.H.P., *Sustainable Urban Transport Development: a Dynamic Optimization Approach*, T2005/3, April 2005, TRAIL Thesis Series, The Netherlands

- Hoogendoorn-Lanser, S., *Modelling Travel Behaviour in Multimodal Networks*, T2005/4, May 2005, TRAIL Thesis Series, The Netherlands
- Dekker, S., *Port Investment – Towards an integrated planning of port capacity*, T2005/5, June 2005, TRAIL Thesis Series, The Netherlands
- Koolstra, K., *Transport Infrastructure Slot Allocation*, T2005/6, June 2005, TRAIL Thesis Series, The Netherlands
- Vromans, M., *Reliability of Railway Systems*, T2005/7, July 2005, TRAIL Thesis Series, The Netherlands
- Oosten, W., *Ruimte voor een democratische rechtsstaat. Geschakelde sturing bij ruimtelijke investeringen*, T2005/8, September 2005, TRAIL Thesis Series, Sociotext, The Netherlands
- Le-Duc, T., *Design and control of efficient order picking*, T2005/9, September 2005, TRAIL Thesis Series, The Netherlands
- Goverde, R., *Punctuality of Railway Operations and Timetable Stability Analysis*, T2005/10, October 2005, TRAIL Thesis Series, The Netherlands
- Kager, R.M., *Design and implementation of a method for the synthesis of travel diary data*, T2005/11, October 2005, TRAIL Thesis Series, The Netherlands
- Boer, C., *Distributed Simulation in Industry*, T2005/12, October 2005, TRAIL Thesis Series, The Netherlands
- Pielage, B.A., *Conceptual Design of Automated Freight Transport Systems*, T2005/14, November 2005, TRAIL Thesis Series, The Netherlands
- Groothedde, B., *Collaborative Logistics and Transportation Networks, a modeling approach to network design*, T2005/15, November 2005, TRAIL Thesis Series, The Netherlands
- Valk, J.M., *Coordination among Autonomous Planners*, T2005/16, December 2005, TRAIL Thesis Series, The Netherlands
- Krogt, R.P.J. van der, *Plan Repair in Single-Agent and Multi-Agent Systems*, T2005/17, December 2005, TRAIL Thesis Series, The Netherlands
- Bontekoning, Y.M., *Hub exchange operations in intermodal hub-and-spoke networks. A performance comparison of four types of rail-rail exchange facilities*, T2006/1, February 2006, TRAIL Thesis Series, The Netherlands
- Lentink, R., *Algorithmic Decision Support for Shunt Planning*, T2006/2, February 2006, TRAIL Thesis Series, The Netherlands
- Ngoduy, D., *Macroscopic Discontinuity Modeling for Multiclass Multilane Traffic Flow Operations*, T2006/3, April 2006, TRAIL Thesis Series, The Netherlands
- Vanderschuren, M.J.W.A., *Intelligent Transport Systems for South Africa. Impact assessment through microscopic simulation in the South African context*, T2006/4, August 2006, TRAIL Thesis Series, The Netherlands
- Ongkittikul, S., *Innovation and Regulatory Reform in Public Transport*, T2006/5, September 2006, TRAIL Thesis Series, The Netherlands

Yuan, J., *Stochastic Modelling of Train Delays and Delay Propagation in Stations*, T2006/6, October 2006, TRAIL Thesis Series, The Netherlands

Viti, F., *The Dynamics and the Uncertainty of Delays at Signals*, T2006/7, November 2006, TRAIL Thesis Series, The Netherlands

Huisken, G., *Inter-Urban Short-Term Traffic Congestion Prediction*, T2006/8, December 2006, TRAIL Thesis Series, The Netherlands

Feijter, R. de, *Controlling High Speed Automated Transport Network Operations*, T2006/9, December 2006, TRAIL Thesis Series, The Netherlands

Makoriwa, C., *Performance of Traffic Networks. A mosaic of measures*, T2006/10, December 2006, TRAIL Thesis Series, The Netherlands

Miska, M., *Microscopic Online Simulation for Real time Traffic Management*, T2007/1, January 2007, TRAIL Thesis Series, The Netherlands

Chorus, C., *Traveler Response to Information*, T2007/2, February 2007, TRAIL Thesis Series, The Netherlands

Weijermars, W.A.M., *Analysis of Urban Traffic Patterns Using Clustering*, T2007/3, April 2007, TRAIL Thesis Series, The Netherlands

Zondag, B., *Joint Modeling of Land-use, Transport and Economy*, T2007/4, April 2007, TRAIL Thesis Series, The Netherlands