

# **NATIONAL SCALE LAND-USE AND TRANSPORT MODELLING: THE MARS AUSTRIA MODEL**

Reinhard Haller  
Vienna University of Technology,  
Institute for Transport Planning and Traffic Engineering  
Günter Emberger  
Vienna University of Technology,  
Institute for Transport Planning and Traffic Engineering  
Paul Pfaffenbichler  
Vienna University of Technology,  
Institute for Transport Planning and Traffic Engineering

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## **1. INTRODUCTION**

The notion that transport and land-use are strongly interrelated is accepted common knowledge. As a result, a series of land-use and transport interaction (LUTI) models have been developed in the past decades. Today, the approach has reached a stage of maturity in theoretical and methodological terms and was implemented in a number of operational models (Wegener 2004).

In this context, it is remarkable that most of these models concern cities or urban agglomerations. This is understandable as transport and land-use related problems, such as congestion, various forms of pollution, scarcity of natural land, etc. are most apparent in densely populated, busy urban areas. However, neither a theoretical point of view nor empirical evidence suggest that land-use/transport interactions are absent in rural (and/or remote) areas. On the contrary, many of them have been subject both to significant transport infrastructure construction and to considerable migration processes.

Second, it seems that most urban models are relatively custom-tailored implementations for specific urban case studies, sometimes only loosely related to more generic modelling environments. This raises the question of generality of LUTI models. The fact that it is hard to compare such specific implementations complicates benchmarking of different models. A sound model comparison would basically require the implementation of multiple models for the same region. To our knowledge, such an exercise has been carried out only once, comparing policy prescriptions from DELTA, TPM and MARS models of Leeds, UK (May et al. 2005).

To tackle the two research themes outlined above, namely the application of LUTI modelling to rural areas and an investigation of the generality of the LUTI modelling approach, we set up a nation-wide version of the existing urban LUTI model MARS (Pfaffenbichler 2003) for Austria.

Work on the model is currently still under progress; thus we have to restrict the presentation to some current experiences made in the model setup rather than giving conclusive answers to the research questions outlined above.

## 2. THE MARS MODEL

### 2.1. Introduction

The MARS model is a dynamic land-use/transport interaction (LUTI) model. MARS is based on the principles of synergetics (Haken 1983) and implemented as a systems dynamics model (Sterman 2000). To date, MARS has been applied to seven European cities (Edinburgh, Helsinki, Leeds, Madrid, Oslo, Stockholm and Vienna) and 3 Asian cities (Chiang Mai and Ubon Ratchathani, Thailand; Hanoi, Vietnam). The present version of MARS is implemented in Vensim®, a widely used system dynamics programming environment.

The model description in this paper will focus on overall model structure and some specific modules relevant for the issues addressed in this paper. For a more comprehensive presentation, we refer the reader to Pfaffenbichler (2003).

### 2.2. Model structure

The MARS model consists of sub models which simulate passenger transport, housing development, household migration and workplace migration; additionally accounting modules calculate assessment indicators and pollutant emissions. The overall structure of the model is shown in figure 1. The main link between the transport and the location choice model are accessibilities, which are passed on from the transport model to the location choice models, and the spatial distribution of households and employment which are input from the location models to the transport model.

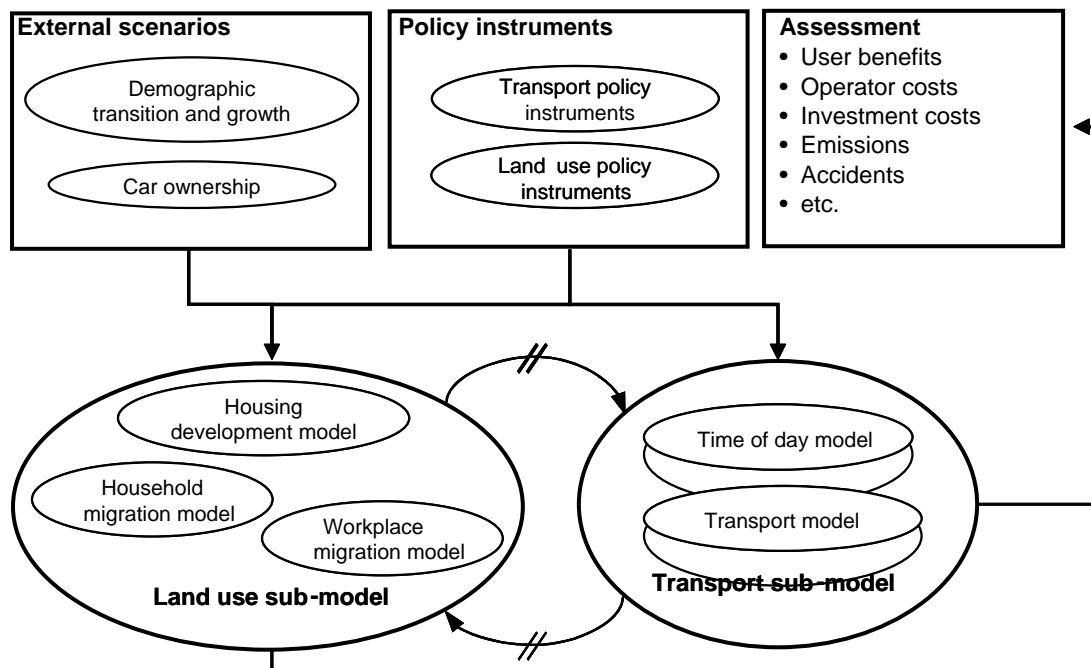


Figure 1 Overall structure of the MARS model

### **2.3. The transport sub model**

The transport model in MARS simulates passenger transport and comprises trip generation, trip distribution and modal choice, i.e. the first three steps of the classical four step transport model. Trip generation and modal split are calculated simultaneously by a gravity (entropy maximising) type model.

The modes in the model are slow, car, public transport (rail) and public transport (bus). The slow mode comprises the non-motorized modes walking and cycling. Due to the zone size in Austria model, this mode is almost exclusively relevant for intra-zonal trips (except for inter-zonal trips in Vienna where model zones represent municipal districts).

### **2.4. The land-use sub model and its modules**

The land-use sub model consists of location (household and workplaces) and a development module (housing only). The location modules simulate migration of households (residents) and workplaces. For housing, the development of housing units is explicitly modelled, whereas we assume that businesses develop their own premises. Therefore, residential migration is constrained by the availability of housing units, while workplace migration may be subject to a land shortage. In the rest of this section we present the household migration model in some more detail.

Figure 2 shows the structure of the residential migration module as a causal loop diagram. The total number of residents migrating in the case study in each period is determined based on the average time a residents lives at a given location. This gives a pool of residents moving out and a pool of residents moving in; to the latter an exogenously given overall population growth in the case study area is added. These two pools are allocated to model zones based on their relative attractiveness for migration. The allocation is implemented as a LOGIT model.

The relative attractiveness of a zone for potential migrants considers living costs, quality of life and the zone's potential for activity participation. Living costs are approximated by housing rents (in Euros per m<sup>2</sup> and month); housing costs constitute a major source for living cost differentials. Unused green land (as a share of total zone area) is used as a proxy for the living quality of a zone. Accessibility, formulated as potential to reach workplaces and shopping opportunities, represents the zone's potential for activity participation.

Migration to a zone is constrained by the availability of housing units (flats). Residents desiring to move to zones with excess demand are transferred to the pool of in-migrants of the subsequent period.

The workplace migration sub model has a very similar structure. However, the attractiveness to move in/move out considers different factors: accessibility, available building land and land prices (as mentioned before, we assume that businesses develop their own premises).

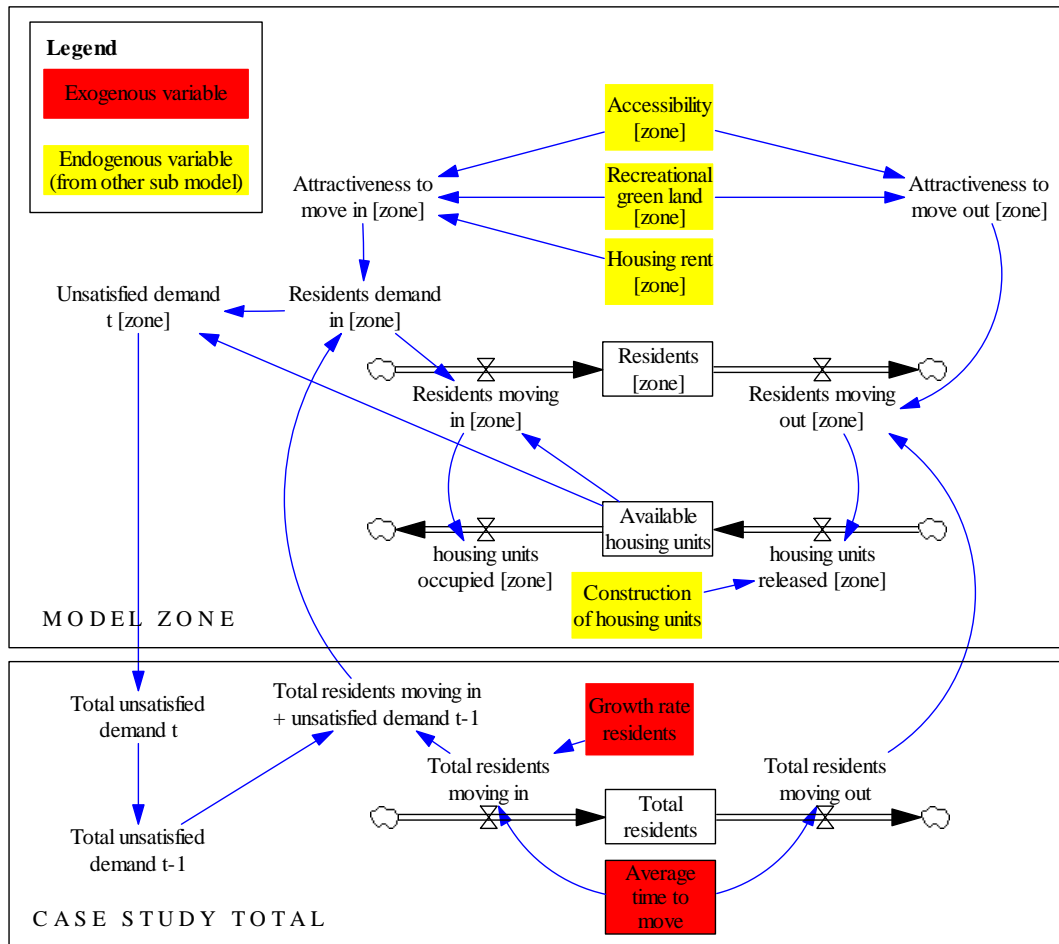


Figure 2 Causal loop diagram of the residential migration sub model in MARS

### 3. APPLICATION OF THE MODEL TO AUSTRIA ('MARS AUSTRIA')

#### 3.1. Study area and model zones

The study area comprises the whole territory of Austria; foreign zones are not included at the moment but will be added in later stages to capture cross-border migration. The description below focuses on the implications of the case study layout for land-use modelling and leaves aside transport model related issues for reasons of brevity.

The model comprises 121 model zones which are based on the district subdivisions ('politische Bezirke') of Austria plus the 23 municipal districts of Vienna. A first attractive feature of the district structure for land-use/transport modelling is that it includes fifteen so-called 'independent cities' (Statutarstädte) which are administratively separated from their hinterland districts. Thus, it is possible to represent core-periphery interactions (such as commuting flows and urban sprawl) for these districts in the model. Second, for many statistics, the district level is the most detailed level for which data are available. Third, the number of districts (121) is a good compromise from a technical point of view in that it keeps calculation time of the system

dynamics model within a reasonable limit<sup>1</sup> and still permits to carry out econometrical analyses (e.g. for parameter estimation).

Two features of the case study area, and the zoning scheme applied to it, distinguish our model from other LUTI modelling case studies: First, the model zones are very heterogeneous amongst each other. It comprises highly urbanized, service sector-oriented zones with highly positive commuting balance; sparsely populated zones with significant agricultural production and high out-commuting rates; mountainous regions influenced by tourism where settlement areas are concentrated in and constrained by alpine valleys to name just a few examples. All in all, diversity is much greater than in the usual urban agglomeration models, which constitutes a major challenge for LUTI modelling, (e.g. in relation to the different motives underlying migration decisions.) Table 1 presents some aggregate data on the zones.

Indicator	Population	Population density (inhabitants/km <sup>2</sup> )	Total workplaces	Share of service sector employment (%)
Total	7,795,786	–	2,933,438	–
Minimum	1,696	20	522	41%
Maximum	237,810	25,345	145,137	91%
Average	64,428	93	24,243	64%
Indicator	Total area (km <sup>2</sup> )	Undeveloped area (% of total area)	Land price (Euros/m <sup>2</sup> )	Housing rent (Euros/m <sup>2</sup> /month)
Total	83,859	–	–	–
Minimum	1	7%	14	1.63
Maximum	3,270	98%	577	4.02
Average	693	89%	204	2.60

*Table 1 Overview over key indicators for the case study area and the model zones. Source: authors' calculations from various sources*

Second, as the case study covers the entire Austrian territory, it is apparent the model area is polycentric and, additionally, comprises several levels of central places. Figure 3 illustrates this structure based on commuting patterns in 1991; several of these catchment areas are distinguished into core and peripheral areas by the zoning scheme as outlined above.

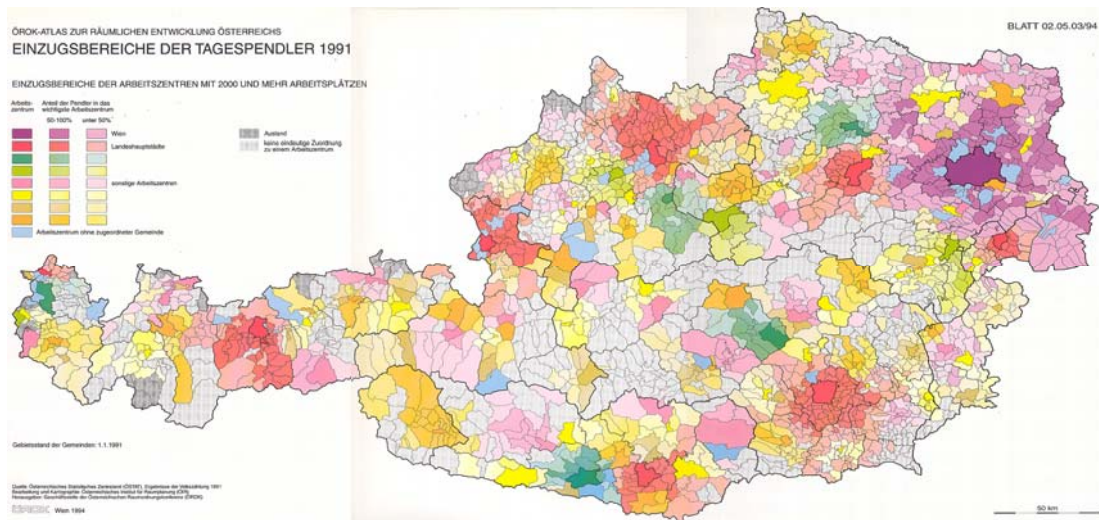


Figure 3 Employment centres and commuting catchment areas 1991 (colours indicate employment centres; darker colours higher out-commuter shares) Source: ÖROK (1994)

## 4. FIRST RESULTS FROM MODEL CALIBRATION AND TESTING

Model calibration and testing are currently work in progress. This section therefore presents some first insights gained from first model runs with a partially calibrated model; uncalibrated parameters are taken from a model developed for Vienna by Pfaffenbichler (2003).

### 4.1. Approach to model calibration and testing

As model calibration and testing are important issues in model setup, we briefly define these concepts based on Ortúzar and Willumsen (1994). Model calibration consists in finding parameter values that optimize the goodness of fit between model outputs and observed data. Model validation is a related but not an identical concept. It consists in comparing model predictions with observed data based on a dataset not used in calibration. However, in line with Sterman (2000), we prefer the term model testing instead of validation, as model “validation” in the strict sense of the word is impossible as a matter of principle.

The transport sub model of MARS models transport flows within a time period. Model calibration is thus carried out on a cross-sectional basis to improve model fit in a base year. By contrast, the land-use sub models simulates changes from one time step to another which requires calibration to changes in observed land-use.

Contrary to our initial intentions, which aimed for very long-time model setup, calibration and validation, we had to restrict the analysis to the period from 1991 to 2001 (1995 for employment) for data availability reasons in a first step.<sup>2</sup>

The MARS model has recently been migrated to the Vensim system dynamics environment which offers extensive optimization functionalities, amongst others things, for calibration purposes.<sup>3</sup> We applied this automated calibration

both to the transport and land-use sub models, however with varying success (see below).

## 4.2. Transport model

The transport model was calibrated against commuter data from the 1991 population census of Statistik Austria (1995). The goodness of fit for trip numbers per zone is reasonable for a strategic model without route choice (see figure 4 illustrating model fit for the number of incoming trips by zone). The model fit for modal shares is less satisfying for the time being.

A potentially useful extension of the transport model is to consider several distance bands for intra-zonal transport, as the zone size has increased considerably relative to the urban MARS models. However, calibration of and improvements to the transport model were not tackled in depth so far, as the focus in this study is on land-use sub modelling.

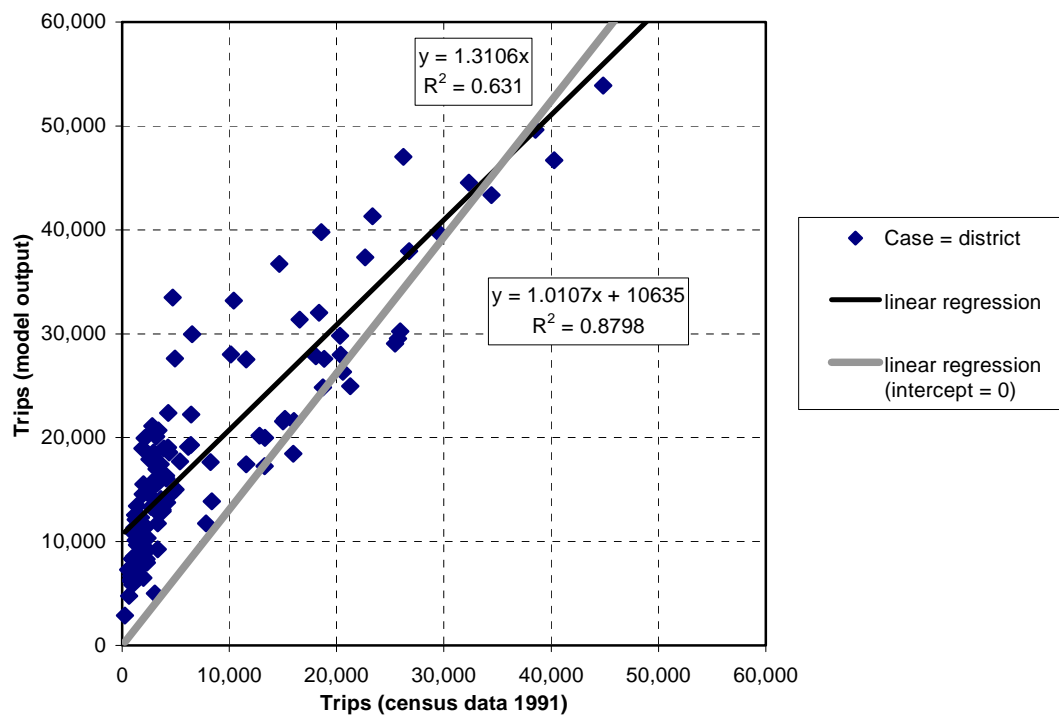


Figure 4 Number of incoming trips by zone 1991, all modes: model output versus census data. Sources: Statistik Austria (1995) and authors' calculations

## 4.3. Residential migration

In order to assess model output we briefly summarize domestic migration trends in Austria in the period 1991 to 2001. Overall, domestic migration was clearly dominated by a suburbanization process (figure 5): while the country's main cities (including all cities over 100,000 population: Vienna, Graz, Linz, Innsbruck and Salzburg) experience population losses, their hinterlands gain population, in some instances at substantial rates. A more localized and moderate shrinking/stagnation process affects some remote districts in the North (on the border to the Czech Republic) and Southeast (on the border to

Slovenia and Hungary). Finally, a series of districts in the province of Styria incur significant population losses; these old industrial districts struggle with poor employment opportunities as a consequence of structural economic change. Most other districts see slight population gains in line with Austria's overall population growth in the period (from 7,796,000 in 1991 to 8,033,000 in 2001 or 0.3 % per year).

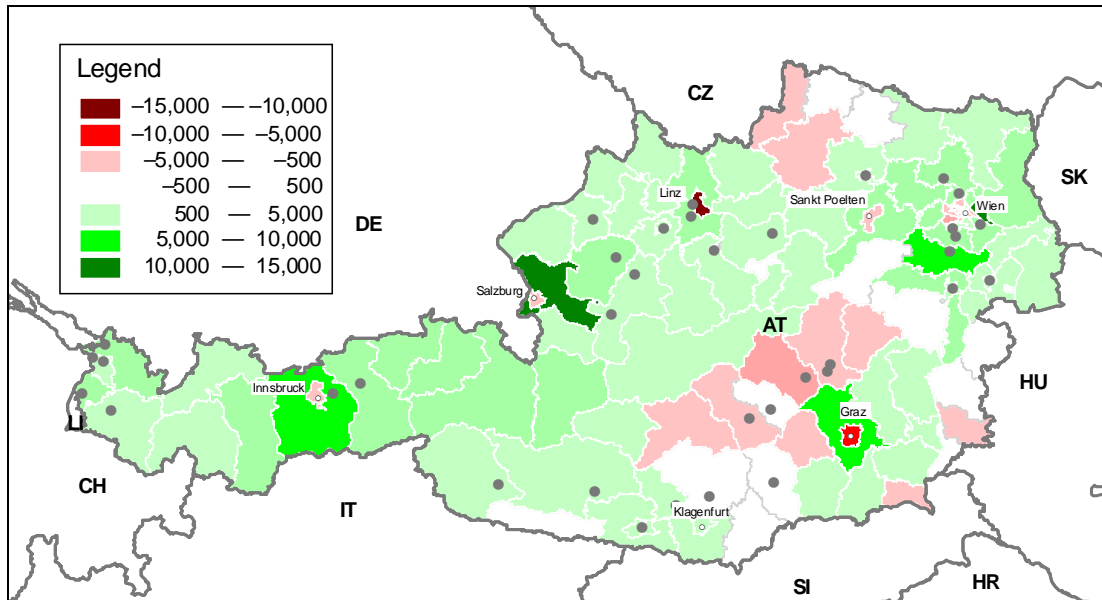


Figure 5 Actual change in population by district 1991–2001 (data). Source: Statistik Austria (2002)

The simulation results from the MARS model present a somewhat different picture (figure 6). In line with the observed development, the model predicts migration losses for the main cities. However, the corresponding hinterlands are negatively affected in the model as well, even though to a lesser extent.

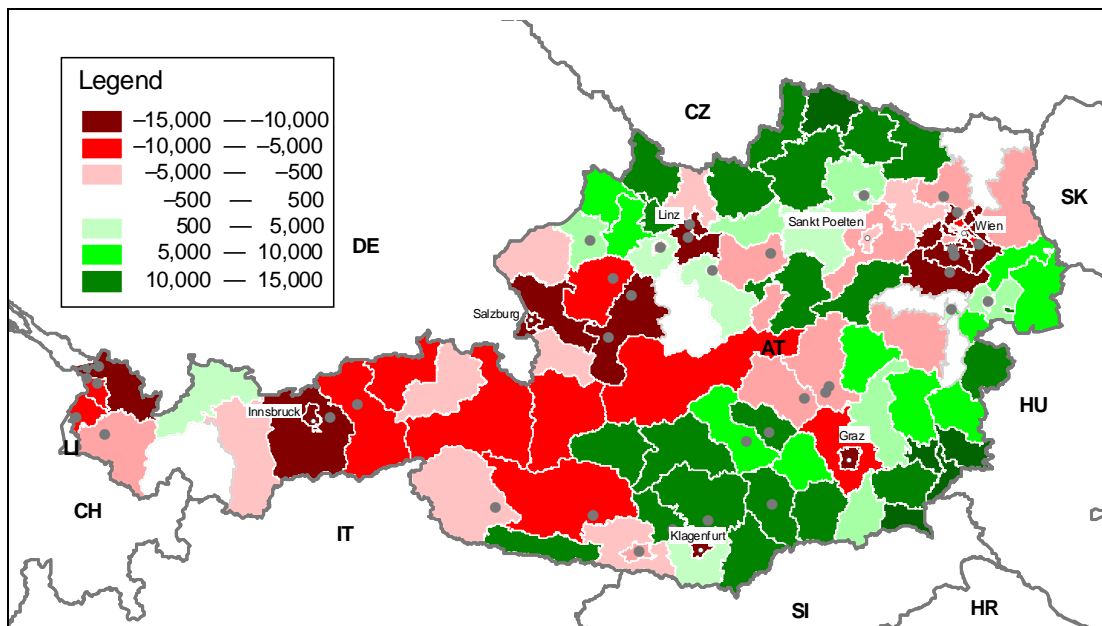


Figure 6 Simulated change in population by district 1991–2001. Source: authors' calculations



Remarkably, in the model another superimposed trend stands out: districts in the western and central districts generally loose population, districts in the Northeast and Southeast gain population.

It appears that this west-east migration in the model is mainly driven by land prices and housing costs. The topography of Austria's western provinces is dominated by the Alps; building land is scarce in many places and tourism raises the demand on land markets which means that land prices and housing rents are considerable higher there. Figure 7 plots population change from 1991 to 2001 by district against average housing rents 1991 in terms of model output and actual data. It is obvious that migration in the model results is driven to a significant extent by rent differentials. A simple linear regression shows unequivocally that in the simulated results population change is negatively related to the average housing rent.<sup>4</sup> By contrast, the correlation between housing rent and population change is absent when looking at the observed population development in the period 1991–2001.

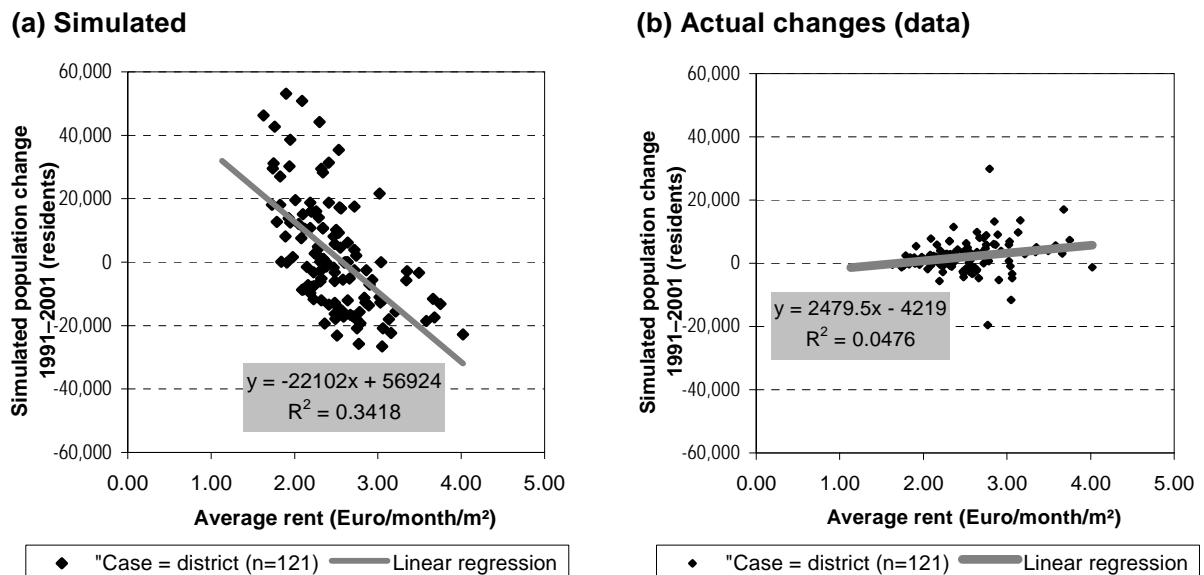


Figure 7 Scatterplot of average rent 1991 versus population change 1991–2001: (a) model simulation; (b) actual population change. Sources: Statistik Austria (2002), authors' calculations

#### 4.4. Workplace migration

Similar problems as encountered with the outputs of the household location model affect the simulation of workplace location. Essentially, an over-dependence on land prices seems to be at the root of an underestimation of workplaces in the Western districts while overestimating employment development in the East and South of Austria. Figure 8 shows the deviation of the simulated number of workplaces from the observed number of workplaces based on a simulation for the 5-year period from 1991 to 1995. As the pattern of deviations is very similar to the household migration model, we do not go into detail here.

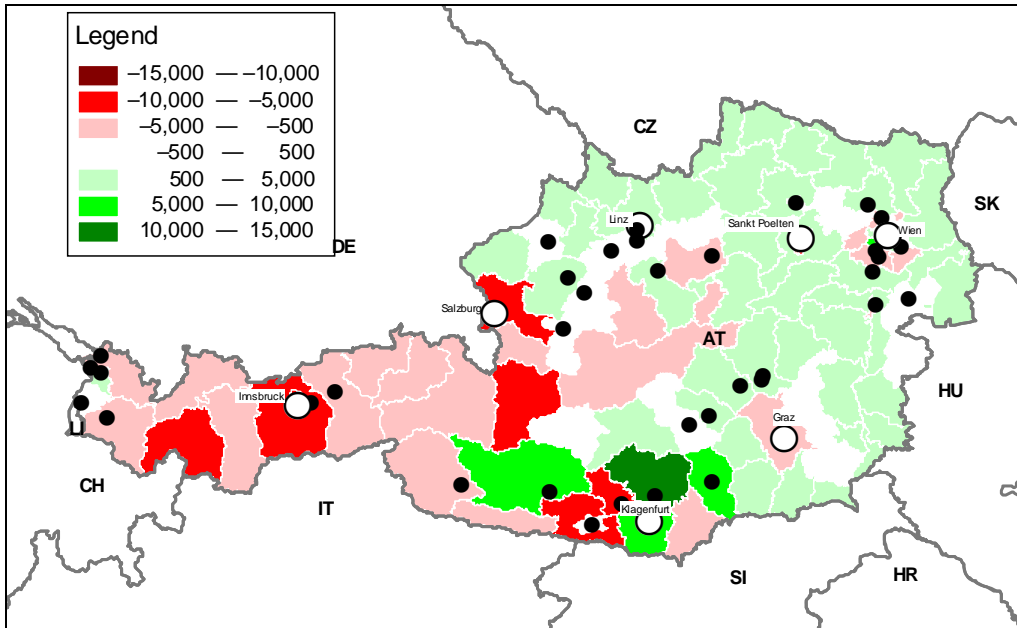


Figure 8 Change in total employment per district 1991–1995: deviation of model output from data (red = underestimation, green = overestimation)

An attempt was made to improve model fit of the workplace migration model using the optimization functionality of Vensim. Figure 9 shows, however, that the goodness of fit between simulation output and data was not improved. Additionally, we encountered problems with running time. As a single, partial (workplace location model only) model run for 5 years takes about 10 minutes, the optimizing algorithms has severe difficulties to compute a necessarily high number of model runs and the software becomes unstable.

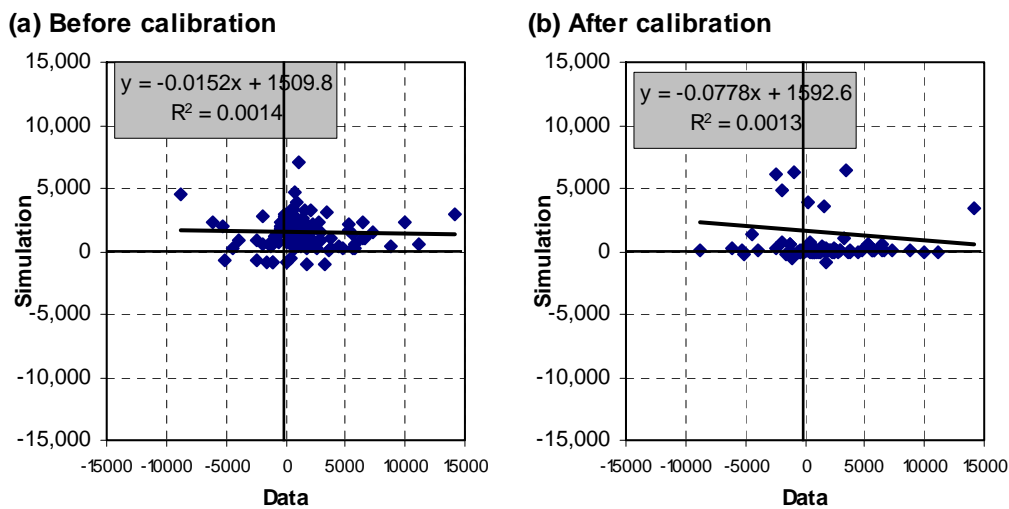


Figure 9 Employment model output fit to data 1995 for a 1991 to 1995 simulation run (a) before calibration and (b) after partial calibration of the workplace location model

## 5. DIRECTIONS OF CURRENT AND FUTURE RESEARCH

The initially envisioned approach to the implementation of a MARS model of Austria (1. calibrating to model to a decade; 2. validating it for the next) was hampered by problems encountered in the first step.

In line with the methodological system dynamics literature, which points out the danger of false confidence in structurally inadequate models due to automated calibration routines (Oliva 2003), we will revise the model structure before resuming model calibration.

An ad-hoc review of the model results helped to identify possible sources of model shortcomings. However, in order to make the model development process more systematic, an interesting option is to apply more formal model structure analysis to identify the causes of model behaviour. The system dynamics models literature essentially proposes two methods, pathway participation metrics and loop eigenvalue elasticity analysis (Güneralp 2006).

The analysis of preliminary simulation results revealed two main shortcomings of the current household location sub model. First, it “pools” migration flows for the entire case study area which essentially makes it impossible to track the origins and destinations of migration flows. Second, it does not reflect the empirical observation that most migration flows take place at short distances.

A first improvement to the household migration model will therefore be to model migration flows by origin-destination pairs. This can be done on the basis of a gravity approach without major methodological problems. This will allow to cross-check migration flows in the model with observed migration patterns. Migration data show that domestic migration is mostly limited to short distances: in 2002 a majority of 56 % of domestic migrants moved within the same commune; only 29 % changed the district of their residence, 13 % moved to an other of the nine Austrian provinces (Statistik Austria 2005).

Secondly, accounting for the costs of migration improves foundation of the model in migration theory. Current (economic) theories of migration put forward a series of causes for migration. The most important ones are real wage differences, unemployment rate differentials, the presence of localized (private and public) goods, the risk aversion of (potential) migrants and the monetary and social costs related to migration (Bode and Zwing 1998; Ghatak et al. 1996). Out of these theoretically posited causes, the current MARS model only accounts for localized goods in the form of housing rents, availability of green land and accessibility. Considering distance-dependent migration cost in the model thus improves the theoretical underpinnings of the model and is an elegant way to account for the observed spatial scope migration patterns. It is apparent that the cost associated with short distance migration (e.g. within the same municipality) is lower than that of long distance migration, especially in the case of social costs (e.g. because social network can be maintained).

Research will also be devoted to the way quality of life is considered in the model. The proxy currently used (the share of green land within a zone), is highly endogenous in a land-use/transport model and obviously stems from the urban origins of the model. However, its appropriateness is questionable in rural contexts. The literature suggests various methods and indicators to measure local quality of life (e.g. Audit Commission (2005), Rehdanz and Maddison (2007)). We will use the literature to improve the indicators

considered in MARS. In any event, the indicator should retain a certain degree of endogeneity in the model.

As to the workplace migration model, the model will be put on a zone-by-zone footing in the same way as household migration. Concrete further improvements are not decided upon at the moment but could include a more detailed sectoral disaggregation than the current two sectors (production and services) or a differentiation according to business size (number of workplaces).

## **6. CONCLUDING REMARKS**

This paper presents experiences made in the setup of a national land-use/transportation interaction model for Austria. The ultimate objective of the exercise is to test how LUTI modelling can be applied in rural contexts and to assess the generality of an urban LUTI model at a higher spatial level. This claim cannot be fully met at the current stage but first tentative conclusions are drawn for the MARS model.

We identified two concrete conceptual shortcomings of the model for national scale applications. First, migrations flows are treated in a too aggregate way ('pooling' of migrants over the case study) and, second, the costs of migration are neglected in the model whereas they play a central role in migration theory.

Even though the model results are clearly not satisfying at the moment, we conclude that implementing LUTI models higher spatial scales does have the potential to raise their generality and theoretical underpinning, which may in the end also benefit urban models. Moreover the exercise points out the iterative approach to model building emphasized so often in the system dynamics literature (Sterman 2000). In this spirit, the research directions outlined in this paper are only the first step to tackle the initial research questions.

## 7. NOTES

<sup>1</sup> Model running time, generally not as much an issue for system dynamics models as for equilibrium models, becomes relevant when a high number of models runs is required in order to carry out automated optimization routines. Automated optimization is used for calibration/parameter estimation and policy optimization purposes.

<sup>2</sup> The most important problem encountered was a change in the classification system for economic activities in the 1990s. The former Austrian classification “Betriebssystematik 1968” was replaced by the Austrian version of the NACE classification system (ÖNACE 1995). This break prevented the calculation of employment time series even at the very aggregate two sector disaggregation of MARS.

<sup>3</sup> The other major application of optimization in system dynamic models is policy optimization. Contrary to equilibrium models, optimization is not necessary for “normal” model runs in system dynamics models.

<sup>4</sup> The goodness of fit ( $R^2 = 0.34$ ) indicates that while housing rents exert a dominant influence on the simulation results, it is of course not the only one considered in the model.

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