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Pfaffenbichler, P., Emberger, G. and Shepherd, S. (2008) The integrated dynamic land use and transport model MARS. *Networks and Spatial Economics*, Online. ISSN 1566-113X

<https://doi.org/10.1007/s11067-007-9050-7>

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**Published paper**

Pfaffenbichler, P., Emberger, G., Shepherd, S. (2008) The Integrated Dynamic Land Use and Transport Model MARS. *Networks and Spatial Economics*. Online First: January 2008.

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# **THE INTEGRATED DYNAMIC LAND USE AND TRANSPORT MODEL MARS**

Paul Pfaffenbichler, Günter Emberger

Vienna University of Technology, Institute for Transport Planning and Traffic Engineering, Vienna,  
Austria

Simon Shepherd

Institute for Transport Studies, University of Leeds, Leeds, UK

Corresponding author:

Paul Pfaffenbichler

Vienna University of Technology, Institute for Transport Planning and Traffic Engineering  
Gußhausstraße 30/231  
A-1040 Vienna

E-mail address: [paul.pfaffenbichler@ivv.tuwien.ac.at](mailto:paul.pfaffenbichler@ivv.tuwien.ac.at)

Telephone: 0043 1 58 801 231 14

## **ABSTRACT**

Cities worldwide face problems like congestion or outward migration of businesses. The involved transport and land use interactions require innovative tools. The dynamic Land Use and Transport Interaction model MARS (Metropolitan Activity Relocation Simulator) is part of a structured decision making process. Cities are seen as self organizing systems. MARS uses Causal Loop Diagrams from Systems Dynamics to explain cause and effect relations. MARS has been benchmarked against other published models. A user friendly interface has been developed to support decision makers. Its usefulness was tested through workshops in Asia. This paper describes the basis, capabilities and uses of MARS.

**KEY WORDS:** land use, transport, dynamic modelling, decision making, public participation

## 1. INTRODUCTION

Urban regions today face serious problems caused by transport and land use developments. To deal with them decision makers need knowledge about strategies which can contribute to goals such as reducing road congestion, increasing quality of life, or how to ensure future economic prosperity. It is well known that transport and land use planning are strongly interrelated and play a key role in the solution of present and future problems. Obviously decision making processes concerning land use development are becoming more and more complex. On the one hand the number of involved stakeholders is increasing and on the other hand long term feedback effects have to be taken into account. To reduce the risk of inappropriate and publicly unacceptable decisions the use of state of the art decision support tools is essential. One of these tools, the **Metropolitan Activity Relocation Simulator MARS**, is presented here. MARS is a dynamic Land Use and Transport Interaction (LUTI) model.

The paper is structured as follows. Section 2 gives an overview of today's decision making context in European cities. To support this process a series of decision making support tools were developed during the past decades, a short description of these developments is given at the beginning of section 3. MARS which was designed specifically to support the decision makers at all steps of the decision making process (objective definitions, policy instrument identification, assessment of short and long term impacts and appraisal), is described in detail in this section using causal loop diagrams to explain the main cause and effect relationships employed within the model. This helps in providing the decision-makers with an understanding of the concepts underlying the model and so provides a transparent process.

Even though the model may be transparent and relatively easy to understand the credibility of any model is important to stakeholders. Section 0 describes how MARS was calibrated and validated using data for the Vienna model from 1981 to 2001. During our work with MARS and collaboration with decision makers it was realized that the use of MARS was becoming too complex for decision

makers. To overcome this problem a simpler, graphical user interface was designed and implemented taking into account the needs of the user. This user interface allowing an easy handling of the MARS LUTI model is introduced in section 5. Section 6 reflects upon experience of using the MARS graphical user interface in a series of workshops with decision makers in Thailand and Vietnam. Finally section 7 concludes with an outlook of future research needs and lists potential improvements of the software package.

## **2. DECISION MAKING PROCESS**

May et al. (2003), a decision makers guidebook, is one of the results of the EU funded research project PROSPECTS (Procedures for **R**ecommending **O**ptimal **S**ustainable **P**lanning of **E**uropean **C**ity **T**ransport **S**ystems; [www.ivv.tuwien.ac.at/projects/prospects.html](http://www.ivv.tuwien.ac.at/projects/prospects.html)). The results presented in May et al. (2003) are based on a survey in 60 European cities. Simplified the decision making process consists of the following four steps:

1. Identification of objectives / setting targets
2. Identification of available instruments and their combinations (strategies)
3. Assessing and appraising the outcome of the chosen instruments/strategies against the objectives/targets including identification of barriers to implementation
4. Have the objectives/targets been met?

If yes: appropriate strategy is found – implementation of the strategy

If no: go back to step 2

A clearly defined vision of the objectives is necessary to identify a goal orientated policy package (step 2). A set of key indicators is necessary to monitor the outcome of the suggested policy packages (step 3). Noise and air pollution, accident costs, present value of finance, fossil fuel consumption, etc. might be used as performance indicators. The MARS model environment allows the calculation of a wide range of such indicators. Users can choose the set of indicators which fit

the needs of their specific decision making context. MARS calculates the policy-dependent values for the key-indicators and hence allows the assessment and appraisal of the strategy (steps 3 and 4). The past decades have shown that no single transport policy instrument is able to solve all problems. Among others May and Roberts (1995) therefore have argued for an integrated approach. Three main sources of synergies are identified: complementary, financial support and public acceptance. For example, if parking fees and public transport frequency increases are combined the two instruments reinforce the effects on mode choice of each other. Furthermore it might not be possible to implement the costly improvement of public transport without the revenues from the parking charges. On the other hand the introduction of parking charges might be more acceptable to the public if the revenues are used to improve public transport. KonSult (2002) presents a comprehensive list of instruments including a description of the likely impacts of their combinations. The MARS model environment includes a predefined set of transport and land use policy instruments. This list comprises among others pedestrianisation, public transport policies, such as capacity changes or fare changes, policies for motorized transport, such as road capacity changes, road charges, parking charges, etc. and land use measures such as value capture tax. MARS allows in a user friendly way to select instruments, form policy packages (step 2) and predict their impacts on the key-indicators (step 3).

Today Cost-Benefit-Analyses (CBA) and Multi-Criteria-Analyses (MCA) are the most common appraisal methods. Both methods can be easily integrated into the MARS modelling environment (step 3), e.g. Vieira (2005) has used a MARS model of the city of Madrid in combination with a CBA. The MARS model of Edinburgh presented in Shepherd and Pfaffenbichler (2006) was combined with an MCA in the EU funded research project STEPS (Scenarios for the Transport system and Energy supply and their Potential effects; <http://www.steps-eu.com/>).

The run time of a typical MARS model is less than one minute for a 30 year simulation. Therefore the user is able to test a wide variety of different policy instrument values and/or combinations in

reasonable time. This allows the user to iterate between the steps 2 and 4 as long as it is necessary to meet the objectives/targets as defined in step 1. Additionally MARS can use formal optimization routines to maximize the welfare surplus of a CBA or the global social utility value of an MCA<sup>i</sup>.

### **3. LAND USE AND TRANSPORT MODEL MARS**

#### **3.1 General**

The first operational land-use model was presented by Lowry (1964). The early land use models drew heavily on analogies to physics, e.g. the law of gravity. Today most state-of-the-practice models have their foundation in random utility theory, which is based on the principle of utility maximization originating from micro-economics. Nevertheless Anas (1983) has shown that entropy or gravity models are equivalent to stochastic utility models<sup>ii</sup>. Another approach in state-of-the-practice land use modelling (e.g. the MUSSA model) is based on bid-choice theory (Martínez (1996), Martínez and Donoso (2001)). Typically, LUTI models combine at least two separate components: a land-use and a transport sub-model, which generate dynamic behaviour based on time lags between the two systems. State of the art models feature a modular structure, which entails a flexibility to include further aspects such as imperfect markets (David Simmonds Consultancy (1999)). However SACTRA (1998) raises concerns that LUTI models focus mainly on the redistribution of activities, neglecting aggregate effects, e.g. on employment, as overall economic activity is usually exogenously specified. Some of the most advanced European LUTI models are IRPUD (Wegener (1998) and Wegener (2004)), DELTA (Simmonds (1999) and Simmonds (2001)), MEPLAN (Echenique et al. (1990)), Urbansim (Waddell (2002)), MUSSA (Martínez (1996); Martínez and Donoso (2001)) and MARS (Pfaffenbichler (2003)).



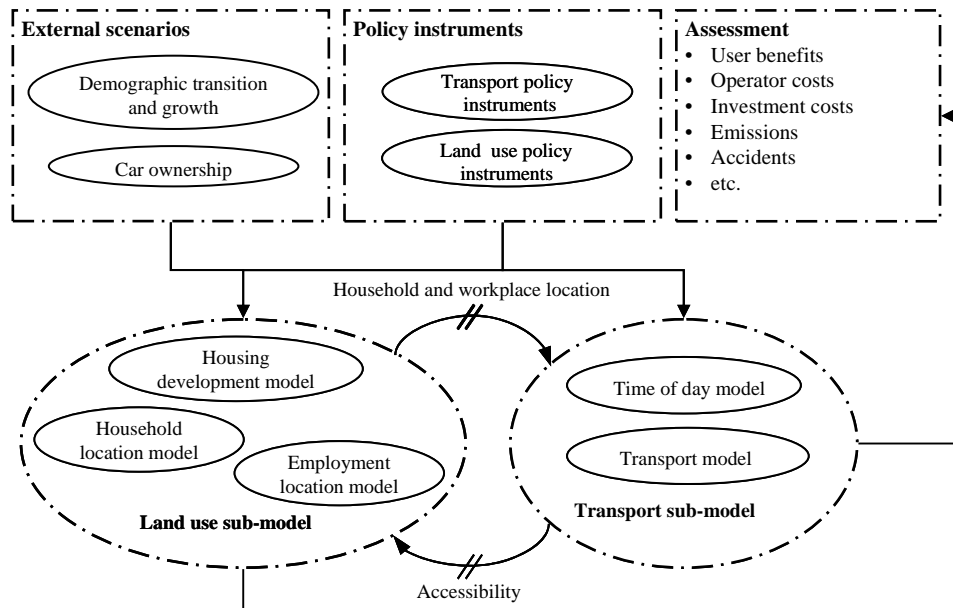
### 3.2 Structure of the MARS model

MARS is a dynamic Land Use and Transport Integrated (LUTI) model. The basic underlying hypothesis of MARS is that settlements and activities within them are self organizing systems. Therefore MARS is based on the principles of systems dynamics (Sterman (2000)) and synergetics (Haken (1983)). The development of MARS started some 10 years ago partly funded by a series of EU-research projects (OPTIMA, FATIMA, PROSPECTS, SPARKLE). To date MARS has been applied to seven European cities (Edinburgh - UK, Helsinki - FIN, Leeds - UK, Madrid -ESP, Oslo - NOR, Stockholm – S, and Vienna – A) and 3 Asian cities (Chiang Mai and Ubon Ratchathani in Thailand and Hanoi in Vietnam).

***The present version of MARS is implemented in Vensim®, a System Dynamics programming environment. This environment was designed specifically for dynamic problems, and is therefore an ideal tool to model dynamic processes. The MARS model includes a transport model which simulates the travel behaviour of the population related to their housing and workplace location, a housing development model, a household location choice model, a workplace development model, a workplace location choice model, as well as a fuel consumption and emission model. All these models are interconnected with each other and the major interrelations are shown in***

Figure 1. The sub-models are run iteratively over a period of time of 30 years. They are on the one hand linked by accessibility as output of the transport model and input into the land use model and on the other hand by the population and workplace distribution as output of the land use model and input into the transport model. Although the MARS model runs over a period of 30 years it is deterministic within each iteration and there are no random error terms included in any of the sub-

models. Indeed each model run is repeatable and there is no issue of path dependency. The results only change when a policy is changed at some point in time. In terms of transport policies which can be modelled, MARS was developed to investigate strategic level issues over a long time period. It is therefore an aggregate model. Most significantly it does not include the assignment stage (which is the most time consuming element of a LUTI model), instead it uses aggregate speed-flow relationships for each origin-destination movement. This limits the representation of policies to be at the corridor or area level so that typical policies tested would include corridor specific changes in capacity, road charges either per corridor or around a set of zones, area wide changes in public transport fares and frequencies or changes to fuel duties. In addition to these transport based policies the model is also able to simulate the impacts of changes in land use development policies or controls. The next section describes the main cause effect relations in a qualitative way which is useful when discussing modelling concepts with non-mathematicians. Some of the most relevant quantitative relations can be found in section 8 Appendix, however a comprehensive description of MARS can be found in Pfaffenbichler (2003).



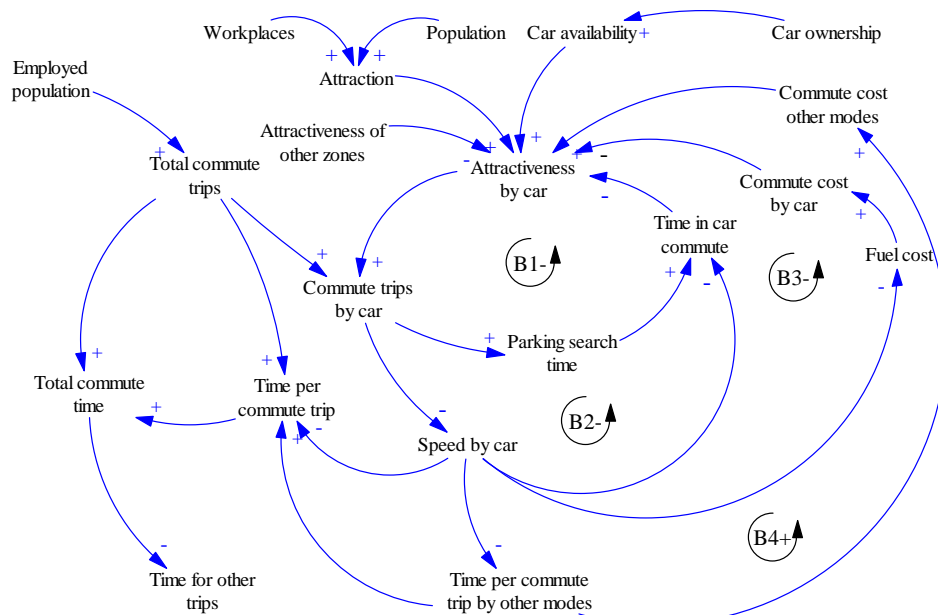
**Figure 1. Basic structure of the MARS sub-models**

### 3.3 Main cause effect relations

This section uses the Causal Loop Diagram (CLD) technique to explain two of the core sub-models of MARS namely the transport model and the land use development model<sup>iii</sup>. Figure 2 shows the CLD for the factors which affect the number of commute trips taken by car from one zone to another. From Figure 2 we start with loop B1 which is a balancing feedback loop, commute trips by car increase as the attractiveness by car (see equation 1 in section 8 Appendix) increases which in turn increases the search time for a parking space which then decreases the attractiveness of car use – hence the balancing nature of the loop. Loop B2 represents the effect of congestion – as trips by car increase speeds decrease, times increase and so attractiveness is decreased. Loop B3 shows the impact on fuel costs, in our urban case as speeds increase fuel consumption is decreased – again we have a balancing feedback.

Loop B4 represents the effect of congestion on other modes and is actually a reinforcing loop – as trips by car increase, speeds by car and public transport decrease which increases costs by other

modes and all other things equal would lead to a further increase in attractiveness by car. The other elements on Figure 2 show the key drivers of attractiveness by car for commuting. These include car availability, attractiveness of the zone relative to others which is driven by the number of workplaces and population. The employed population drives the total number of commute trips and within MARS the total time spent commuting influences the time left for other non-commute trips. Similar CLDs could be drawn for other modes and for non-commute trips as MARS works on a self-replicating principle applying the same gravity approach to all sub-models.

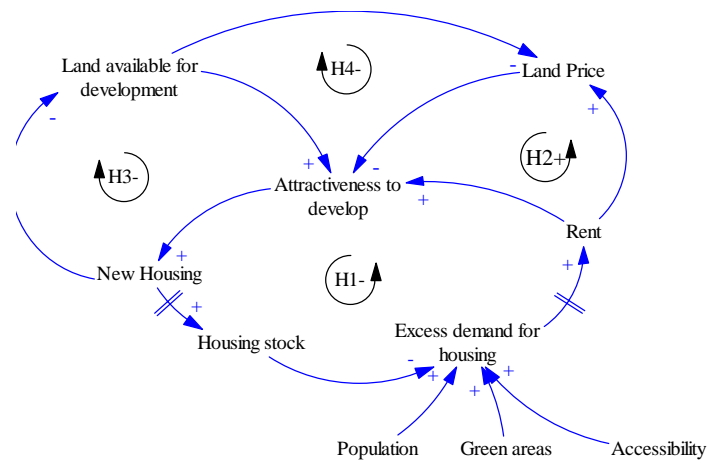


**Figure 2. CLD for the transport model – commute trips by car in MARS**

Figure 3 shows the CLD for the development of housing in MARS. Loop H1 is a balancing feedback loop which shows that the attractiveness to the developer to develop in a given zone is determined by the rent which can be achieved. The level of the rent is driven by the excess demand for housing which in turn is related to the housing stock and new housing developments. As new houses are developed the stock is increased which reduces the excess demand which then reduces the rent achievable which reduces the attractiveness to develop – hence we have a balancing loop.

Loop H2 is a reinforcing loop as new housing reduces the excess demand which reduces rent and hence land price which in turn makes development more attractive all other things being equal.

Loop H3 represents the restriction of land available for development as land available is reduced then the attractiveness to develop is reduced. Loop H4 extends H3 to represent the effect of land availability on land price. Finally the drivers of demand for housing are shown to be population, amount of green space and accessibility to activities from that zone (see also equations 2 and 3 in section 8 Appendix).



**Figure 3. CLD for development of housing in MARS**

## **4. MODEL TESTING**

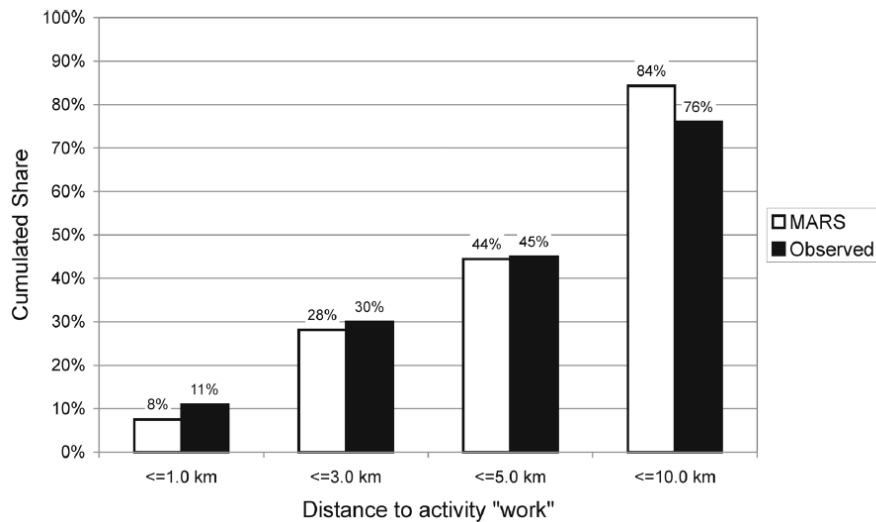
### **4.1 Theoretical background**

The common understanding of “calibration” and “validation” in transport modelling is that calibration is the estimation of certain model parameters to fit the model results to a set of observed data while validation is the process to assess the conformity between simulation results using the calibrated model and observed data. The data sets used in calibration and validation have to be different. Nevertheless Sterman (2000) argues that models neither can be verified nor validated. The word “verify” derives from the Latin *verus* – truth. Verify can be defined as establishing the truth, accuracy or reality of something. “Valid” can be defined as having a conclusion correctly derived from premises. Both interpretations imply being supported by objective truth. *By these definitions, no model can ever be verified or validated. Why? Because all models are wrong. ..., all models, mental or formal, are limited, simplified representations of the real world.* Sterman (2000) p. 846. Therefore the term “model testing” was chosen by Sterman (2000) to describe what others might call “model validation”.

### **4.2 Results of “model testing” for MARS**

To test the appropriateness of MARS a Vienna model with the base year 1981<sup>iv</sup> was set up and its results were compared to empirical data observed in the period 1981 to 2001 (Pfaffenbichler (2003)). As an example Figure 4 shows a comparison between the commuting distances as calculated by the MARS model and the resulting from the 1993 Vienna household survey (Socialdata (1993)). The regression coefficient  $R^2$  of a comparison between the commuting origin destination matrices from the 1991 census and the base year 1981 MARS model results is about 0.88 (0.92 for non motorized modes, 0.81 for public transport and 0.76 for car trips). The model testing exercise in Pfaffenbichler (2003) demonstrates that MARS is able to reproduce historic developments with a quality for strategic planning.

During the 1990's a charged area wide short term parking scheme was established in the central business district and the inner-city districts of Vienna. Before and after studies are available for the implementation of this policy instrument (Herry et al. (1994); Herry et al. (1996); Dorner A. et al. (1997)). The MARS model with the base year 1981 was used to predict the effects of the parking charging scheme. Table 1 compares the results of the simulation with the observed changes.



**Figure 4. Comparison of the cumulated share of commuting distances MARS; Pfaffenbichler (2003) – Observed data; Socialdata (1993)**

**Table 1. Comparison of observed and simulated effects on incoming car trips caused by the policy instrument parking charges**

Area	Implementation year	Observed changes	Simulated changes
Central business district	1993	-15%	-11%
Districts 6 to 9	1995	-26%	-24%

Source: Herry et al. (1994); Herry et al. (1996); Pfaffenbichler (2003)

### 4.3 Benchmarking

An extensive literature review was performed to benchmark the results of the MARS model testing against other models. Though many references stress the importance of model testing (e.g. Schnabel and Lohse (1997); Sterman (2000); Wegener (2003)) up to date only three references publishing model testing exercises have been found. The first one, Waddell (2002), concerns an UrbanSim model of Eugene-Springfield, Oregon. The model was calibrated with a 1994 database. A 1980 database was developed and the 1994 database became the observed target for comparison of simulation results. The second one, Hunt (1994), is about a MEPLAN based model of Naples, Italy. The Naples model calibrated for 1981 values was used to predict household locations in the year 1989. The third one, Martínez (1996), is the MUSSA model of Santiago City. It is likely that governments require some form of validations if they contract consultant work. Unfortunately it seems that these results are not in the public domain.

Table 2 compares the correlation between observed and simulated land use data of the UrbanSim model of Eugene-Springfield, the MUSSA model of Santiago City and the MARS model of Vienna. The correlation coefficients for the two models are of the same order of magnitude. A more stringent benchmark than the comparison of absolute values in a target year is the comparison of observed and simulated changes over a period of time. Figure 5 portrays this comparison for the UrbanSim model of Eugene-Springfield for households and employment. The graph shows the percentage of zones classified according to the size of the differences between the observed and simulated changes in households and employment between 1980 and 1994. Figure 6 shows a similar graph for the observed and simulated changes in the number of residents in Vienna between 1991 and 2001.



**Table 2. Correlation of simulated to observed values**

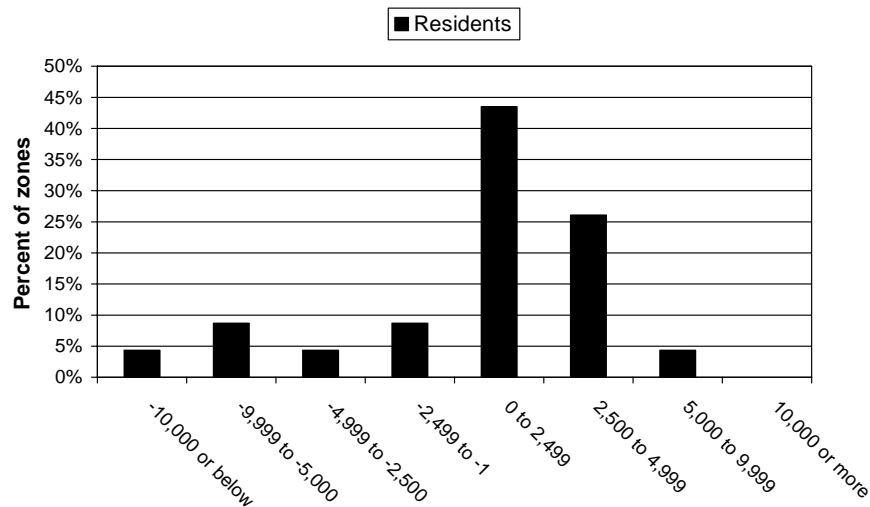
	UrbanSim, Eugene-Springfield	MUSSA, Santiago City	MARS, Vienna
Employment	0.865	0.74	
Population	0.929	0.75	0.983 (2001)
Housing units	0.927		0.995 (1998)
Land value	0.925		

Source: Waddell (2002); Martínez (1996); Pfaffenbichler (2003)



**Figure 5. Difference between simulated and observed 1980 to 1994 change by zone**

**UrbanSim, Eugene-Springfield; Waddell (2002)**



**Figure 6. Difference between simulated and observed 1991 to 2001 change by zone  
MARS, Vienna**

Within the model testing exercise it became clear that MARS significantly underestimates housing and population development in the districts North of the river Danube while it overestimates it in some Western districts. The municipality itself is still the biggest developer and owner of housing in Vienna. Housing development in Vienna therefore is often influenced by political rather than rational market economy principles. Several factors external to a land use transport model influence such decisions. This was the case in the districts 21 and 22 north of the river Danube. An area near the river Danube was dedicated to host a world exposition EXPO in 1995 (Strasser (2001)). However in 1991 a referendum stopped these plans. To save the investments already committed to new infrastructure, the city authorities decided to develop this area with housing and office buildings (Markowitsch (1995a); Markowitsch (1995b); Freihsl (1995)). This could explain the significant underestimation of housing development by MARS in the districts 21 and 22.

On the other hand an explanation for the overestimation of population in the Western districts could be attributed to the different age structure in the zones. There is a significant correlation between the share of elderly people in a zone and the overestimation of population development by MARS.

MARS currently does not model ageing of the population and household transition i.e. currently each resident leaving a zone makes living space available for another person. Obviously this is not true in the case of children growing up and leaving their families as well as for a partner in an elderly couple dying. To eliminate this shortcoming cohort models for population age groups and household types are currently under development.

## **5. USER INTERFACE**

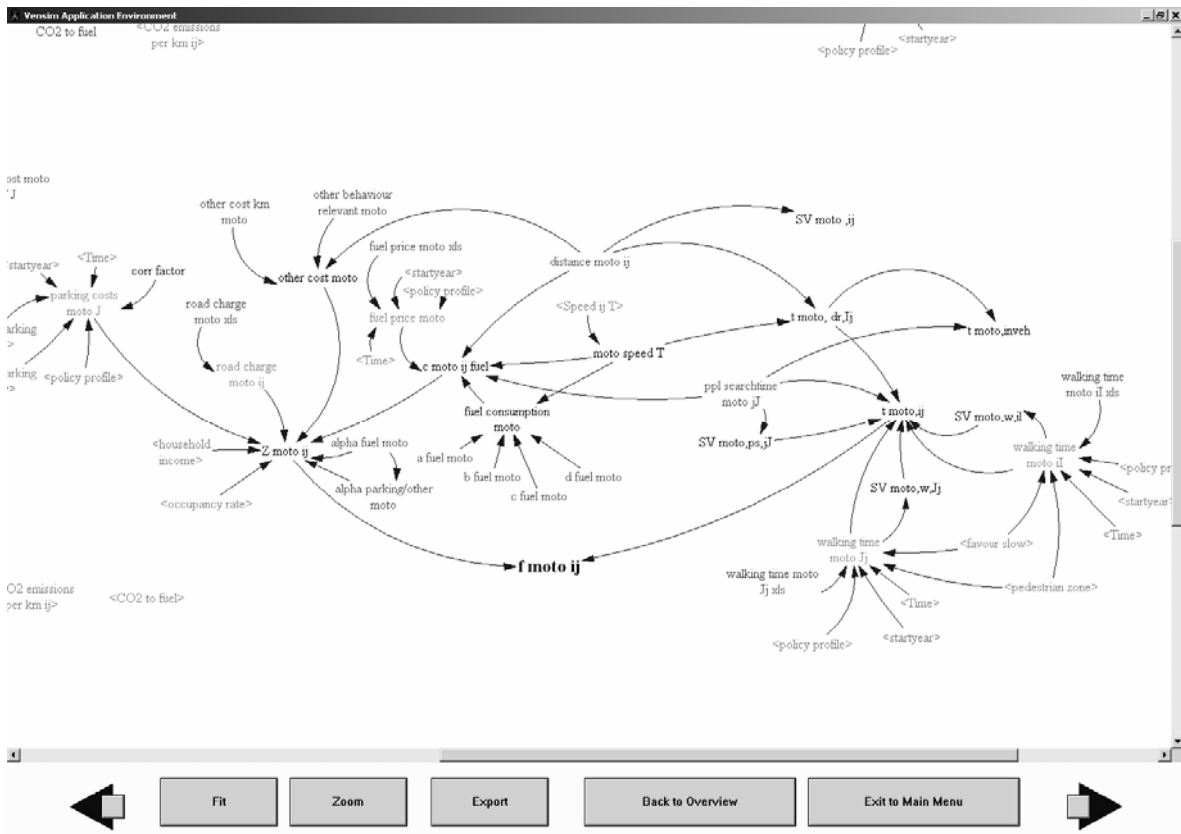
### **5.1 Purpose of the flight simulator**

*The goal of modeling, ..., is to build shared understanding that provides insight into the world and helps to solve important problems.... Experienced modelers likewise recognize that the goal is to help their clients make better decisions, decisions informed by the best available model.* Sterman (2000) p. 850. The MARS flight simulator is a graphical user interface which is designed to meet the needs of decision makers and other stakeholders in decision making processes. It enables non-modelling experts to test the effects of a wide range of transport and land use policy instruments for an underlying case study area. It supports decision makers to identify optimal policies in their local context and for their specific objectives. The purpose of the flight simulator user interface is in line with the above citation twofold: to allow the user to investigate the underlying cause-effect-relations in a qualitative way and to enable the user to test a wide range of policy instruments without the need to have experience in transport modelling. The following sections aim at demonstrating the added value generated by the use of the MARS flight simulator within different decision making processes and environments.

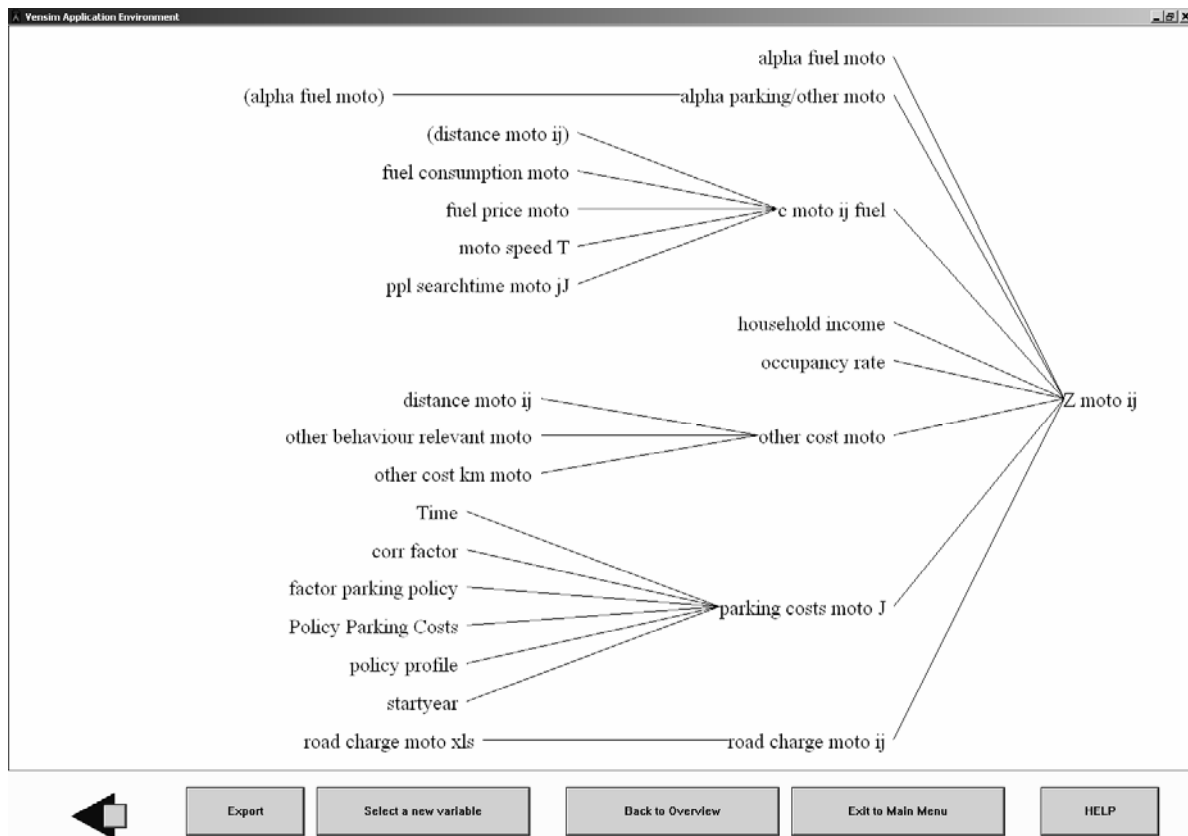
### **5.2 The model structure review tools**

Two different ways are offered to explore the model inherent cause-effect relations. The first one is the view tool. The user has the possibility to scroll through a range of views from the Vensim®

model. Figure 7 shows a sector of the view in which the subjective generalized costs for using the different modes are calculated. The generalized costs for using the mode motorcycle ( $f_{moto ij}$ ) depend on costs ( $Z_{moto ij}$ ) and travel times ( $t_{moto ij}$ ). The costs are a function of fuel and other costs and policy instruments such as parking costs or road charging. The time part of the generalized cost is made up of access to the parking place, driving and searching for a parking place. The second possibility to review the model structure is the “causes tree” tool. The user can select any variable used in the MARS model from a list. Figure 8 shows as an example the cause tree of the costs to use a motorcycle.



**Figure 7. MARS flight simulator view mode – generalized costs motorcycle, Hanoi model**



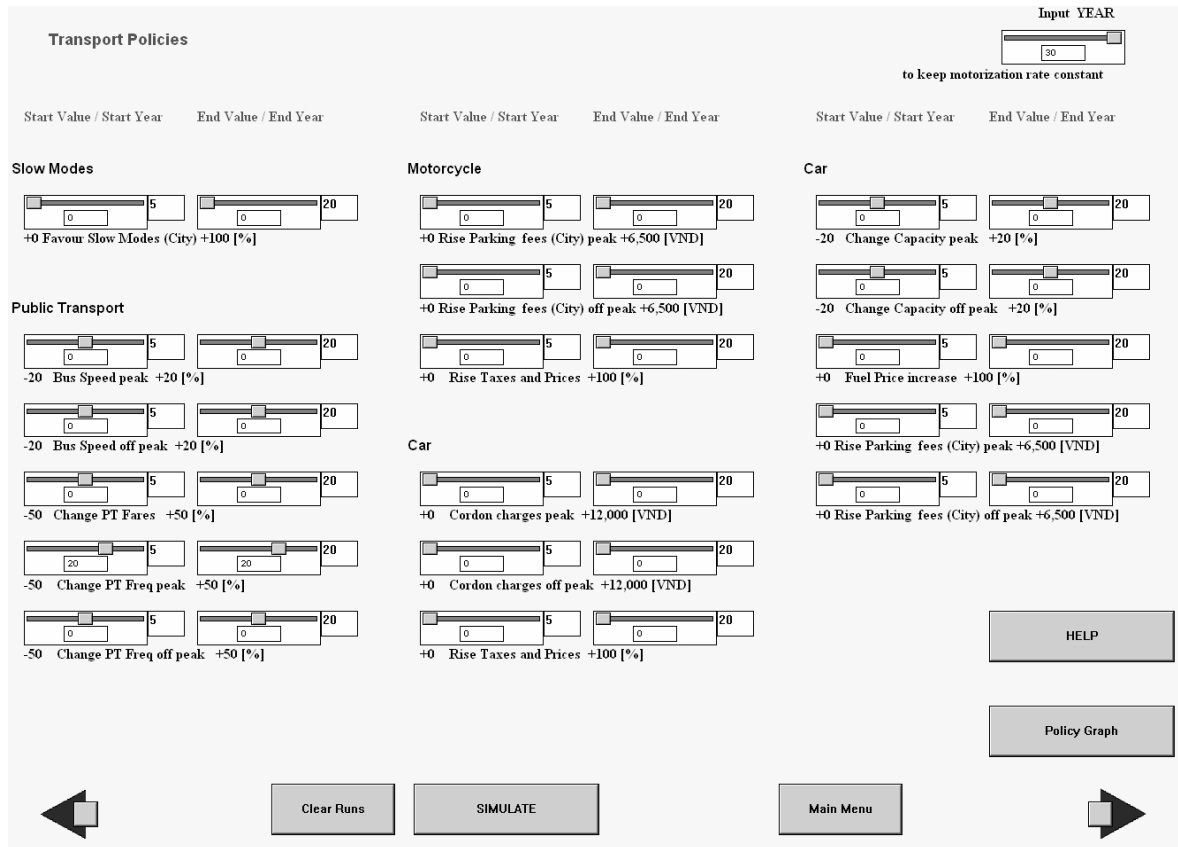
**Figure 8. MARS flight simulator cause tree tool – costs motorcycle use, Hanoi model**

### 5.3 The simulation tool

The core of the MARS flight simulator is the policy input screen (Figure 9). On this screen, all implemented transport policy instruments are represented with so-called “sliders”. For example in the upper left corner, there is a slider headed “slow modes”. Here the user has the possibility to test the impacts of a policy favouring the slow modes (pedestrianisation of the city centre zones). To set up a scenario the user can either pick up the slider with the mouse and move it to the desired numerical value or key in a target value in the box below the slider.

This has to be done for a start year (in this case for year 5 of the simulation as shown with the number on the right hand side of the slider) and for an end year (in the example year 20 of the simulation). After the end year, the level of the instrument stays constant for the rest of the

simulation period. Of course, it is also possible for the user to vary the values for the start and the end years between 0 and 30.

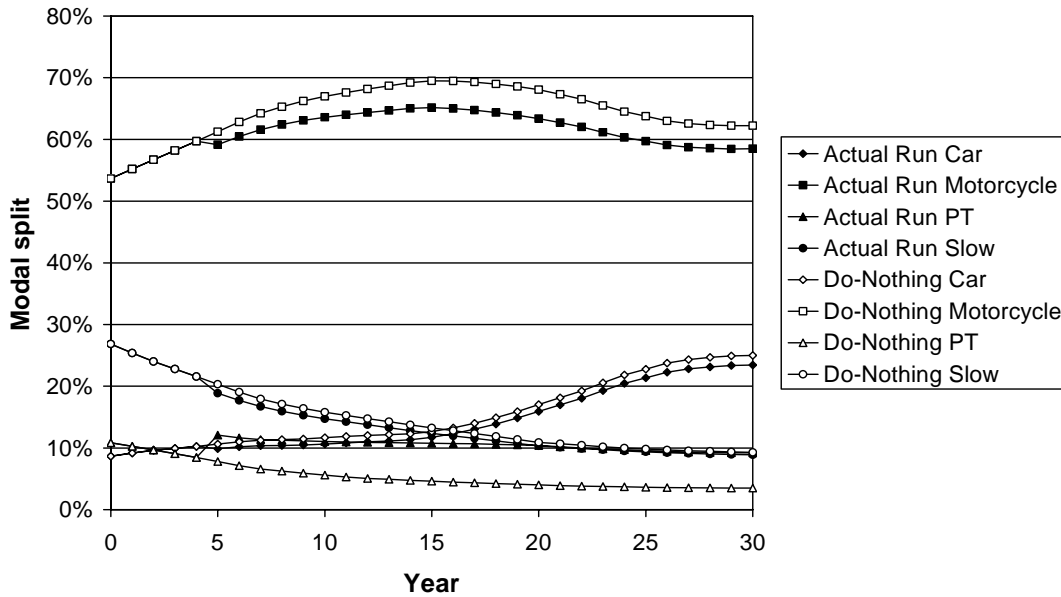


**Figure 9. MARS flight simulator– policy input, Hanoi model**

### 5.4 Output of results

The user of the MARS flight simulator has the possibility to either scroll through a set of predefined output indicators or to individually select any variable from a list. All results can be viewed within the MARS flight simulator as well as diagrams as in form of tables. Additionally the user has the possibility to export the results to the clipboard for further use in other software. **Error! Reference source not found.** shows the peak period modal share for two scenarios: do nothing and a public transport frequency increase by +20% in year 5 raising to +50% in year 20. The results have been

exported to the clipboard and then further processed in Microsoft Excel®. The increase in public transport frequency results in an increase of the share of public transport to about 10% in the long run. The majority of the additional public transport trips replaces former motorcycle trips.



**Figure 10. MARS flight simulator – output modal share peak period, Hanoi model**

## 6. EXPERIENCE WITH THE MARS FLIGHT SIMULATOR

The MARS flight simulator was used and tested within six training courses in Thailand and Viet Nam organized within the project SPARKLE. About 20 to 30 transport planning experts from ministries, municipalities and universities attended each of these three day workshops. On the last day the participants had the opportunity to use the MARS flight simulator software by themselves. Table 3 summarizes some of the tasks from the hands-on sessions in Ho Chi Minh city, Da Nang and Ha Noi. The first of these tasks will be used to explain the use of flight simulator and its relation to the decision making context as described in section 2 in more detail.

**Table 3. MARS flight simulator exercises SPARKLE training courses Vietnam**

Task	Results
The mayor of Hanoi has the objective to increase public transport use to a share of 10% in the year 2015. How much would you need to increase public transport frequency to achieve this target?	+25% by 2010
The public transport operator tells you that it is impossible to buy that much busses at one time. Is it possible to achieve the same target with gradually increasing public transport frequency from 2010 on?	0% by 2010, +48% by 2020
The national government is not willing to finance the investment in new busses. But the city has the authority over motorcycle parking charges. Which level of parking charges would be necessary to achieve the same target as above?	5200 Vietnamese Dong per stay from 2010 on
Etc.	

The target (step 1) was defined as having a public transport share of 10% in the peak period in 2015. Public transport frequency was selected as the policy instrument to achieve this goal (step 2). For solving such tasks the user has first to go to the flight simulator policy input view (Figure 9). The next step is to select the policy instrument values and corresponding implementation years. In the example shown in Figure 9 it was decided to increase public transport frequency during the peak period by 20% in year 5 (which is in this case study is 2010) and afterwards keep it at this level (+20% in the year 2025). After pressing the *simulate button* the user can navigate through the pre-prepared simulation output by pressing the arrow in the right lower corner (step 3). The target to have a share of public transport of 10% in 2015 was slightly missed (step 4). As the target was not met the user has to go back to step 2 and select a new policy instrument value. This has to be repeated until the target has been met. **Error! Reference source not found.** shows the result of



such a process. The target was met with an increase of public transport frequency by +20% in 2010 raising to +50% in 2025.

## **7. CONCLUSIONS**

This paper demonstrates the development and use of the MARS flight simulator. It explains why the model has been developed, the structure of the model and presents some results of an extensive testing process for a Vienna case study<sup>v</sup>. Finally we explain the recently developed flight simulator which provides a new real time functionality. Thus bringing strategic modelling into the hands of the decision-makers and planners. The flight simulator has been used in Thailand and Vietnam and has been shown to be a useful and simple to use tool.

Research work and development continues and the MARS model is currently being enhanced to represent over-crowding in public transport, improved representation of congestion in the inter-peak and the impact of parking capacity on search times. In addition new policies such as Quality Bus corridors, tele-working policy and smart measures such as company travel plans and marketing campaigns are being implemented for the UK models.

In addition the land use model is also being updated to incorporate the ageing process of the population and separating out the migration effect, by the use of cohorts. This will allow the analysis of the impact of ageing on trip generation and employment levels which will obviously affect resulting demand for car use.

Finally we are investigating the possibility of linking MARS with other models including assignment models, regional economic models, and EU level transport and energy models thus enabling research into regional and twin city issues along with interaction with policies coming down from National and EU levels.

## 8. APPENDIX

The following equations summarise the main quantitative relations used in the model MARS.

$$(1) A_{ij}^m = \frac{A_j}{r_{ij}^m} = \frac{A_j}{f(t_{ij}^m, c_{ij}^m)} = \frac{A_j}{\sum_k {}^kSV_{ij}^m * {}^k t_{ij}^m + \frac{1}{I_i * o_{ij}^m} * \sum_l \frac{{}^l c_{ij}^m}{\alpha}}$$

where,  $A_{ij}^m$  is the attractiveness to use the mode  $m$  for a trip from  $i$  to  $j$ ,  $A_j$  is the attracting force at destination  $j$  (number of work places for commuting trips, number of workplaces in the service sector for shopping trips, etc.),  ${}^k t_{ij}^m$  is the time of part  $k$  of the trip (walking to and from the parking place or public transport stop, waiting at the public transport stop, in-vehicle time, parking place searching time, etc.),  ${}^l c_{ij}^m$  are the costs of different types  $l$  (public transport fares, parking costs, road charge, fuel costs, etc.),  ${}^k SV_{ij}^m$  are subjective valuation functions taking into account the different perception of different parts  $k$  of the trip,  $I_i$  is the household income of a household living in zone  $i$ ,  $o_{ij}^m$  is the occupancy rate and  $\alpha$  is a parameter for the willingness to pay costs of type  $l$  (Walther et al. (1997)).

$$(2) dHH_i^t = dHH^t * \frac{e^{U_i^t}}{\sum_i e^{U_i^t}} = (dHH_e^t + dHH_m^t) * \frac{e^{f(acc_i^t, rent_i^t, rec_i^t)}}{\sum_i e^{f(acc_i^t, rent_i^t, rec_i^t)}}$$

where,  $dHH_i^t$  is the increment of households in zone  $i$  in year  $t$ ,  $dHH^t$  is the total demand for housing units in the study area in year  $t$ ,  $U_i$  is the utility to relocate to  $i$ ,  $dHH_e^t$  is the external demand for housing units from households willing to move into the study area,  $dHH_m^t$  is the demand for housing units from households willing to move within the study area,  $acc_i^t$  is the accessibility of zone  $i$  in year  $t$ ,  $rent_i^t$  is the rent or mortgage for a housing unit in zone  $i$  in year  $t$  and  $rec_i^t$  is the amount of recreational land at the location  $i$  in year  $t$ .

$$(3) dHU_i^t = dHU_i^{t,n} + dHU_i^{t,m} = dHU_p^{t-T} * f(lpr_i^{t-T}, rent_i^{t-T}) + dHH_m^t * \frac{e^{g(acc_i^t, rent_i^t, rec_i^t)}}{\sum_i e^{g(acc_i^t, rent_i^t, rec_i^t)}}$$

where,  $dHU_i^t$  is the supply with housing units on the market in zone  $i$  in year  $t$ ,  $dHU_i^{t,n}$  is the supply with new built housing units in zone  $i$  in year  $t$ ,  $dHU_i^{t,m}$  is the supply with housing units from households willing to relocate,  $lpr_i^{t-T}$  is the price of land in zone  $i$  in year  $t-T$ ,  $rent_i^{t-T}$  is the rent or mortgage in zone  $i$  in year  $t-T$ ,  $dHH_p^{t-T}$  is the total number of new housing units planned in the year  $t-T$ ,  $dHH_m^t$  is the number of households willing to move within the study area,  $acc_i^t$  is the accessibility of zone  $i$  in year  $t$ ,  $rent_i^t$  is the rent or mortgage for a housing unit in zone  $i$  in year  $t$  and  $rec_i^t$  is the amount of recreational land at the location  $i$  in year  $t$ .

Demand and supply of housing are not necessarily in equilibrium. If demand is higher than the supply then households are re-distributed to second or third best choices or have to postpone their wish to relocate. Households residing in the study area are served before households willing to relocate into the study area from outside. Furthermore this situation will stimulate developers to increase the number of planned housing units as well as increase rent. On the contrary over supply decreases the number of planned housing units as well as the rent.

## 9. REFERENCES

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<sup>i</sup> In previous versions of MARS different external optimisation algorithms have been employed. More details

concerning these procedures be found in Pfaffenbichler (2003) p. 181 ff. One of the advantages of the new software

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environment is that optimisation algorithms are readily available within Vensim®. These can be used in the calibration process as well as in the optimisation of policy strategies.

<sup>ii</sup> *“This paper shows that it is no longer reasonable or excusable to claim that entropy or gravity models are inherently less “behavioural” than stochastic utility models of discrete choice and multinomial logit in particular. The two approaches are two equivalent views of the same problem.”* Anas (1983) p. 22 f.

<sup>iii</sup> The qualitative method of CLD is used in this paper to describe the basic relations represented in the model MARS. Nevertheless it has to be stated that in the full model there exist quantitative formulations for each of the qualitative relations shown here.

<sup>iv</sup> The transport sub-model of MARS was calibrated to city wide modal split data and commuting trips by zone and mode (ÖSTZ (1985); Herry and Snizek (1993)). The land use sub-model was calibrated to data about changes in housing stock, number residents and number of workplaces by sector and zone in the period 1981 to 1991 (Magistratsabteilung 66 - Statistisches Amt (1990); Magistratsabteilung 66 - Statistisches Amt (1999); ÖSTZ (1984); ÖSTAT (1993)).

<sup>v</sup> The full results of the testing exercises can be found in Pfaffenbichler (2003).