A system dynamics approach to land use transport interaction modelling: the strategic model MARS and its application

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Abstract

Land use transport interaction models have been developed in various forms dating back to the early 1960s. They have moved from spatial interaction models or statistical models through econometric models to micro-simulation, cell-based automata and agent-based models. There has been a move towards more detail in representing space and individual behaviour. This paper presents an alternative approach which uses an intentionally developed strategic high-level model. Nevertheless this model still delivers comparable levels of statistical fit in terms of validation but is easy to present to decision makers and planners. The paper introduces the concepts behind the MARS model, deals with validation and transferability between cities and provides example applications. Copyright © 2010 John Wiley & Sons, Ltd.

Introduction

Urbanization, economic development and increasing standards of living have over the last century generated pressures for more and more urban transport. Now, however, the political pressures are changing: the qualities of the urban environment, social inclusion and access for all have to be addressed in parallel with pressures for more transport generated by economic development. The challenges that city leaders, business and the managers of urban transport systems now face are becoming much more complex. Historically, citizens and businesses have enlarged the geographical scope of their activities through increasing travel speed. Space has been bought by speed and speed by energy and concrete. This is not an option in the years to come, as energy constraints and climate change gradually make themselves felt. Politics, policy and action that can transform urban transport into more sustainable and resilient modes are called for.

One methodology to cope with this complexity are the so called land use transport interaction (LUTI) models, which are designed to predict the interactions between economic development and transport demand and vice versa. One of the first operational land use models 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. 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 LUTI models are IRPUD (Wegener, 1998), DELTA (Simmonds, 1999, 2001), MEPLAN (Echenique et al., 1990), Urbansim (Waddell, 2002), MUSSA (Martínez, 1996; Martínez and Donoso, 2001) and MARS (Pfaffenbichler, 2003, Pfaffenbichler et al., 2008). More recent developments have seen a move towards more detail with micro-simulation or agent-based models such as ILUTE (Salvini and Miller, 2005), or cell-based representations of land use (Lau and Kam, 2005), where transition probabilities are used to update land use over time. For a good overview of the models and their history, the reader is referred to Iacono et al. (2008), who give a chronological development and classification of LUTI models.

One distinctive feature of this interrelation between transport and land use is that changes within these two systems occur at significantly different speed. Whereas transport users respond relatively quickly to changes in the transport system, the land use system is characterized by a considerable degree of inertia, mainly due to the fact that land use systems are embodied in physical structures such as buildings and infrastructure. Despite this, most LUTI models follow the traditional approach to transport modelling, i.e. the notion of equilibrium. Equilibrium-based models forecast changes in transportation and land use 20 or 30 years hence with no connection from the current conditions to those future projections. The pathway to the future state is unknown. Exceptions to this include IRPUD, DELTA and MARS.

While DELTA, IRPUD, Urbansim and agent-based models have gone down the route of using more detailed models, the MARS model has been built at a more aggregate or strategic level. The aim was to make the model quick and easy to use while being easily understood by decision makers rather than a black box. MARS was therefore built using a system dynamics (SD) approach, basing the model on causal loop diagrams and evidence from Austria in the first instance. The model is now being used in many EU research projects and models exist for 18 countries and one country (Austria) around the world.

**Which questions can LUTI models answer?**

LUTI models are designed to predict the “most likely” development paths of land use for a given region over time. LUTI models can be used to assess the impacts of exogenously given transport and land use policies such as the implementation of significant urban transport infrastructure (e.g. subway systems, ring road constructions), new housing/business developments, changes in public transport provision and or fares, changes in the costs of private travel, e.g. road user charging around the city centre, parking charges, etc. They can also be used to investigate exogenously given socio-demographic developments (population growth, migration) and economic scenarios (economic growth/decline, changes in oil prices, etc.).
Typical questions asked by decision makers are therefore: What will be the impact of, for example, a cordon charge around the city centre on the economic development of a city as whole? What will be the impact on CO₂ emissions? Will this result in urban sprawl or densification? Who will be the winners and losers of such a transport policy and can the losers be compensated in some way?

Why system dynamics

As mentioned above, transport and land use systems are highly interrelated and influenced by each other. Feedbacks and time lags occur in these systems nearly everywhere. Wegener (1994) sets out the arguments behind an ideal urban model and identifies eight subsystems ordered by the speed with which they change from immediate (goods transport, travel), fast (employment, population), medium speed (workplaces, housing) to slow change (networks, land use). SD is designed to handle this kind of complexity in an intuitively understandable way. In the transport sector cars, roads and public transport supply are clearly identifiable as stocks, whereas road and public transport construction processes and car ownership changes can be seen as flows. On the land use side population, workplaces, housing units and land can be interpreted as stocks, whereas the changes in these stocks (population growth/decline, workplace developments, construction/demolition of housing units, etc.) can be interpreted as flows. All these stock and flow relations have their own reaction speed and therefore it is important to take their individual time lags into account. Additionally, these stocks and flows depend on each other, so modelling the feedbacks between these entities is essential. In SD methodology two key elements in modelling are combined and made explicit for the reader of such a kind of model, i.e. the structure of the modelled system (qualitative part) and the parameters of the modelled system (quantitative part).

The aim of this paper is to describe the MARS model and give an example of its application in terms more relevant to the SD community rather than the transport community. The following sections outline the basis for the MARS model structure using qualitative causal loop diagrams, with an example of the empirical evidence to back up the selected structure. The authors then move on to describe the quantitative model for some aspects of the model (for a detailed description see Pfaffenbichler, 2008). The issues of transferability and validation of the model are dealt with through an application to the city of Leeds in the U.K. An example for a typical model use is shown in the form of the representation of a trolley bus scheme in Leeds followed by the use of MARS in a training context in Asia. These latter sections demonstrate the easy-to-use interface and outputs which are built-in design elements of MARS.

MARS: Metropolitan Activity Relocation Simulator

MARS is a dynamic land use and transport integrated model. The basic underlying hypothesis of MARS is that settlements and activities within them are self-organizing systems. MARS is based on the principles of SD (Sterman, 2000) and synergetics (Haken, 1983). The development of MARS started some 10 years ago, partly funded by a series of EU research projects. The present version of MARS is implemented in Vensim®, an
SD programming environment. MARS is capable of analysing policy combinations at the city/regional level and assessing their impacts over a 30-year planning period. The MARS model consists of a transport and land use element and can be divided into a series of sub-models as follows and as shown in Figure 1.

1. Scenario input module
2. Policy input module
3. Transport model
   (a) Commuting trips sub-model
   (b) Other trips sub-model
4. Land use model
   (a) Housing development sub-model
   (b) Housing relocation sub-model
   (c) Workplace development and relocation sub-model
5. Fleet composition and emission module
6. Evaluation and assessment module
7. Output representation modules (AniMap, Vensim graphs, Venapp)

Each of the modules is now described in brief with more detail given for the transport and land use modules, which are the main elements of the MARS model.
Scenario input module

The scenario input module is where trends within the case study region are defined by the user. It can be used to alter, for example, the population growth assumptions or the economic development forecasts during the simulation. In other words, the scenario input module is used to steer global parameters of different scenarios to be tested with the MARS software.

Policy input module

The purpose of the policy input module is to handle policy profiles over time of certain policy instruments. Within this sub-module users can specify the start and end point and the start and end level of any policy instrument implemented in MARS. For example, it is possible to test the impacts of increasing “Public transport fare levels” starting in simulation year 3, with a start value of +20 percent. Increasing the public transport fare linearly to 50 percent in simulation year 12 and keep it constant at +50 percent until the end year of the simulation. With this module it is possible to specify these kinds of policy profiles for many policy instruments simultaneously. This enables us to test and assess the impacts (synergy effects) of policy combinations over time. Depending on the underlying case studies, more than 15 different policy instruments can be combined in one single simulation run with selections presented to the user in an easy-to-use flight simulator.

Transport model

The transport model in MARS simulates passenger transport and comprises trip generation, trip distribution and mode choice. In the trip generation part of MARS the number of trips starting or ending in a particular zone are calculated. The trip distribution allocates the total number of trips to all origin–destination (OD) pairs and the mode choice distributes the trips to the different means of transport, normally specified as percentage share. These described elements are the first three steps of the classical transport model (Ortúzar and Willumsen, 1994). Trip generation, trip distribution and mode choice are calculated simultaneously by a gravity (entropy-maximizing) type model. The modes considered in MARS are slow, car, public transport (bus) and public transport (rail). The slow mode represents the non-motorized modes walking and cycling.

The final output of a single simulation step of the transport model consists of average travel speed, trip length distribution, average costs, number of trips per means of transport per OD pair for the two trip purposes “commuting” and “other” for the time periods peak and off-peak. This information will then be combined to form a so-called general accessibility measure and passed on to the land use model part of MARS.

In order to explain the model concepts clearly to clients (ranging from local planners, other academics to local politicians) causal loop diagrams (CLD) were developed. This was done for both the transport and land use development sub-models. Figure 2 shows the CLD for the factors which affect the number of commute trips taken by car from one zone to another. Starting with the balancing feedback loop B1, commute trips by car increase as the attractiveness by car 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.

**Land use sub-model**

The land use model simulates the development of new housing or workplace developments within the different zones. It uses the principle of competing markets between these two distinct land uses and takes constraints such as available land into consideration (Pfaffenbichler, 2008).

The residential model is split into two sub-models: the housing development part, driven by developers (supply side); and the housing location choice part of the population (demand side).

For the workplace sector the decision process where to invest and construct new developments is made by the enterprises themselves based on the accessibility information stemming from the transport model taking into consideration the market
forces within the zones. Therefore a simplified combined development (supply) and relocation (demand) model approach is implemented in MARS. The final output of a single simulation step of this land use model is the forecast population and workplace distribution.

Housing development and location sub-models
Figure 3 shows the CLD for the development of housing and the interaction with location choice of residents in MARS. Starting with the development of housing, 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—resulting in a balancing loop. Loop H2 is a reinforcing loop as new housing reduces the excess demand, which reduces rent and

Fig. 3. CLD for development of housing in MARS

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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.

The housing development loops are linked to the residents' location choice. First, the main elements considered to influence the choice of location are rent, accessibility and area quality. As area quality is difficult to measure it is normal to take some kind of proxy for quality. In the first model of Vienna the amount of green space in a district was seen to be a good proxy (Pfaffenbichler, 2008). However for the Leeds model this was not the case and, as will be seen later, average income was used as a proxy for area quality. The main loops in the residential choice are M1, which is a balancing feedback loop—as more people move in, excess demand increases, which increases rent, which then reduces attractiveness to move in; M2 is also a balancing loop, which shows that as the number of residents increases in a zone, then congestion out of that zone increases, which reduces accessibility to workplaces and so reduces attractiveness to move in.

Loop M3 is a positive feedback loop which simply shows that as the number of residents increases in a zone then the potential for moving out also increases (set as 10 percent of residents per year in the simplest case). This increases the pool of potential movers, which also includes growth in population (which could come from natural growth or in-migration and is taken from an exogenous forecast per annum). Loop M4 is a positive feedback loop which extends H1: as more people move in this increases excess demand, which increases rent and so increases attractiveness to develop, which in turn increases the housing stock. Here it should be noted that housing stock available can limit the number of people allowed to move into a zone as any excess demand is reallocated to other zones. This process reflects reality, where excess demand must be taken up elsewhere if the capacity for residential occupation is reached in any one time period. A detailed description of how this is implemented in MARS is given in Mayer-thaler et al. (2009a,b).

Workplace relocation sub-module
In MARS two different approaches to model the workplace relocation are implemented (Pfaffenbichler, 2008). New developments of workplaces are driven by the exogenously given economic growth rate. Depending on the availability of developable land, land price and the accessibility stemming from the transport model, a gravity-based approach (formally equivalent to a logit model) is implemented in MARS to distribute the workplaces between the individual zones. Secondly, to enable a decrease in certain zones a "death" of business can be foreseen. This parameter has to be estimated through empirical analyses—if used in the simulation it enables the model to re-create the real changes seen from former industrial dominated zones into mainly residential zones.

Fleet composition and emission model
The emission/fleet composition module is used to translate vehicle km and speed calculated in the MARS transport module into air pollution emissions such as NO\textsubscript{x} and CO\textsubscript{2}. The model comprises forecasts of the fleet composition developments for different regions (Europe, Asia). These are taken from the higher-level models POLES and ASTRA, which simulate world energy markets and transport for the EU respectively. See
Shepherd et al. (2008) for a fuller description of how this is implemented and what effects technological developments have regarding future greenhouse gas emissions.

**Evaluation and assessment module**

Within the MARS model a series of output indicators are calculated: among others, modal split shares per means of transport, population distribution, fuel consumption, average travel times per means of transport, travel time savings, accidents costs and CO₂ emissions. These indicators can be depicted as overall values over time (for each year), or by means of transport, by means of trip purpose, by time of day (peak and off-peak), and some of them can also be displayed regarding their development over space and time using the dynamic geographic information system (GIS) tool AniMap, which was developed specifically for use with MARS. Examples of both types of output are contained in the application of MARS examples below.

**Technical specification of the model**

The MARS model used for one of the most recent case studies of the city of Leeds has nearly 750 variables. The model includes 10 different subscripts. The depth of the subscripts ranges from 2 (e.g. time of the day or trip purpose) to 33 (number of zones). The highest number of subscripts for a variable is 8712. The size of the model (.mdl) is about 340 kB. The size of the output (.vdf) is about 33 MB. The platform for the input data is MS Excel®. The runtime of the Leeds model is about 30 s.

**Implementation of the land use elements**

As the model is too large to detail in full, the authors concentrate here on the development of land for residential purposes and the location choice model. The choice model used for the Leeds version of MARS is a traditional logit model where the number of people moving in to zone \( j \) from zone \( i \) is:

\[
N_{ij}^p(t) = P_i(t) \cdot \frac{\exp(a \cdot \text{Acc}_j + b \cdot \text{Inc}_j + c \cdot R_j)}{\sum_j \exp(a \cdot \text{Acc}_j + b \cdot \text{Inc}_j + c \cdot R_j)}
\]  

where \( P_i(t) \) is the potential of moving residents made up from exogenous growth and internal movers for zone \( i \) at time \( t \) (note this is actually done on a matrix basis but is easier to understand at the zone level); \( \text{Acc}_j \) is the accessibility to workplaces from zone \( j \) relative to all other zones; \( \text{Inc}_j \) is the average income of the population within zone \( j \) relative to all other zones; \( R_j \) is the rent/housing costs in zone \( j \) relative to all other zones; and \( a, b, c \) are parameters to be calibrated (see later).

Implementing the causal loop structure of Figure 3 above requires more than one view and many intermediate variables. Figure 4 shows the view “residents” from the general model which deals with the residential choice model. The upper left corner contains the implementation of the choice model (though with a general structure to allow for differences between applications). Feeding down from the “residents potential
Fig. 4. View of the residential choice model as implemented in VENSIM
i(j,t) it is possible to see where the reallocation of any excess demand takes place. This allocation process checks whether demand exceeds supply and if so it sets attractiveness to zero in those zones and the excess demand is redistributed among the remaining zones. This is done using a fixed number of two iterations. If there is still unsatisfied demand this is added as additional demand/growth in the next iteration \( t \).

The middle section provides a general structure for the move-out model, which in its simplest form can be driven by a constant average time spent in a zone for all zones and in its more complex form the time spent can vary with cost, income, living space and share of owner occupiers. To calibrate this side of the model requires a lot of data. For the Leeds model simply an average time spent in a zone equal to 10 years was used. This implies that 10 percent of the residents are potential movers at each time step.

### Model validation/calibration

Apart from structure of the model, validation is important in providing credible forecasts of transport and land use polices. A full calibration of both transport and land use responses was conducted for the first MARS model of Vienna (see Pfaffenbichler, 2003, 2008). However, the question of transferability of coefficients arises when setting up a new model. This section briefly describes the calibration of the Leeds model. Leeds is a city in the north of England and the metropolitan area has a population exceeding 700,000. As MARS is a strategic model, the zoning system is based on administrative boundaries (33 electoral wards in the case of Leeds). This allows the model to be specified on census data from 2001 and associated travel surveys.

Regarding the transport side of the model, recent work for the UK Department for Transport has seen a link formed between the more traditional network assignment model SATURN (Van Vliet, 1982) and the MARS model. In this way the travel times between each OD pair and the so-called cost/supply functions are compatible with a much more detailed network model (see Shepherd et al., 2010, for details).

As MARS uses trip generation and a joint distribution and mode choice model at the ward level in the case of Leeds, a comparison was made between the base year commute trips by car produced by MARS against the 2001 census data. In order to calibrate the mode share the relative subjective values between each mode at the area level are adjusted. While this calibrates to the aggregate mode share, the parameters associated with each element of generalized cost between each mode for each OD pair control the OD-specific mode share. These coefficients have been transferred directly from the Vienna model and are based on a study by Walther (Walther 1973, 1991; Walther et al., 1997).

The statistics demonstrate that the journey to work by car trips originating from within a zone/ward was closely aligned with the MARS model as shown in Figure 5 (with an \( R^2 \) value of 0.896). This demonstrates the validity of the basic mode choice for trips to work that are based on base year costs (which now include the SATURN compatible results). This gives some credence to the belief that the Walther study is transferable across at least the EU in terms of mode choice behaviour, though further research would be needed to confirm this.

In order to calibrate the residential location model it is desirable to use three sets of data as in the Vienna case study, where data from 1981 to 1991 were used to calibrate
the response coefficients and then these were validated against the modelled projection from 1991 to 2001 (see Pfaffenbichler, 2008). In this case a regression approach was used to estimate the response coefficients used in the logit model for residential choice.

In the case of Leeds the data were not readily available so a compromise had to be made. It was decided to calibrate the response coefficients to accessibility, average income and rent using the automated calibration feature supplied in VENSIM. Population data for the Leeds wards for both 2001 and for 2007 were obtained from the Office for National Statistics, which enabled the response coefficients to be calibrated to best match the predicted growth between these years.

The calibration option supplied with VENSIM allows for the payoff function to be supplied in .vdf format. The constant parameters/coefficients $a$, $b$ and $c$ from Eq. (1) above were varied during the iterative process. Table 1 shows the final coefficients found after 146 simulations with payoff_value set to 4.

Although an offline regression approach could have been used, as was done for Vienna, it was thought that this automated approach was easier to implement and able to incorporate some of the constraints such as reallocation of residents within the year, as demand exceeds supply in particular zones until development has occurred. In terms of the coefficients all are of the correct sign in that an increase in accessibility relative to other zones would increase the attractiveness of moving into that zone; similarly an increase in rent would reduce attractiveness and the higher income zones are by sign more attractive than others. The payoff_value being set to 4 also reports the 95 percent confidence intervals for each parameter and, as can be seen from the table, the coefficients are determined within tight confidence intervals.
Table 1. Coefficients found by calibration option in VENSIM

<table>
<thead>
<tr>
<th>Sensitivity = payoff_value = 4</th>
<th>Applied to</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.343967 &lt;= “a” = 0.344949 &lt;= 0.344961</td>
<td>Accessibility, Acc_j</td>
</tr>
<tr>
<td>-0.611121 &lt;= “b” = -0.611079 &lt;= -0.611054</td>
<td>Rent, R_j</td>
</tr>
<tr>
<td>5.04014 &lt;= “c” = 5.13929 &lt;= 5.14755</td>
<td>Average income, Inc_j</td>
</tr>
</tbody>
</table>

Figure 6 shows the modelled growth by zone versus the actual growth—note that these data returned an \( R^2 \) value of 0.9075, which compares very well with other model calibration attempts in this field; see, for example, Waddell (2002), where the UrbanSim model returned an \( R^2 \) value of 0.919 for population changes over a period of 15 years for Eugene–Springfield, Oregon.

**MARS application types**

Since MARS is a very flexible tool it can be used for different application types, such as:

- Scenario testing
- Policy optimization
- Decision maker training
Here a simple example application of the Leeds model is presented in which a new corridor-based policy is introduced. The use of MARS in a training context with practitioners in Thailand and Vietnam is then described.

**Scenario testing: Leeds trolley bus scheme**

In an example to demonstrate a scenario test a simple representation of the Leeds trolley bus scheme was developed (www.insideyorks.co.uk/tbus/index.html; www.ngtmetro.com/About/). It was assumed that the zones City and Holbeck, Kirkstall, Headingley, University, Hunslet, Weetwood, Rothwell and Cookridge would be affected by the bus scheme modelled with MARS (Figure 7). All instruments are defined to be applied in the corridors defined by the aforementioned zones. The start and end years are arbitrarily set at years 5 and 30, respectively, for all instruments.

Figure 8 shows the policy instrument settings (set with a flight simulator view) which directly affect the mode bus. Bus lanes are assumed to be effective during peak and off-peak periods on 10–50 percent of the bus network in the corridor. It is assumed that the bus scheme is of high quality and hence results in a positive effect worth a fare rebate of 20 euro cents in both the peak and the off-peak periods. It is assumed that the bus lanes reduce the circulation time to such an extent that a 25 percent increase in frequency is possible without additional operation costs. It is also assumed that in the
corridor the bus lanes reduce the road capacity for private cars by 20 percent and the number of on-street parking places by 10 percent.

As this is a corridor application it is useful to present results to decision makers using GIS. The output interface AniMap, which is directly linked to the model MARS, is a dynamic GIS software developed specifically for use with MARS (Emberger and Riedl, 2007). Time series data such as the modal share at origin zones produced by MARS runs are automatically passed to Animap. Animap allows us to analyse the outcome of a single scenario or to compare the outcomes of different scenarios, e.g. a do-nothing and a do-something scenario. Figure 9 shows an example of the development of population in year 30 comparing the trolley bus scheme with the do-nothing scenario. From this representation it is easy to demonstrate how residents have relocated slowly over time, moving towards the corridors which are now better served by public transport. For example, by year 30 there are 3.8% more residents in the central ward than in the do-nothing case.

**Decision maker training**

To be able to use the MARS model in a training environment with real decision makers, MARS was extended to include a so-called “flight simulator” or graphical user interface using VENAPP. In this mode MARS can be controlled by a user through a graphical user interface. When using this tool the user will first see a case study specific introduction screen (Figure 10(a)), in which key information regarding the case study city is presented. On the next screen (Figure 10(b)) the user can choose between the model exploration tool, where they can learn more regarding the underlying model assumptions (Figure 10(c)), and how the different model parts are interconnected. On the other hand, the user can select the simulation input screen (Figure 10(d)), where they are able to set up different policy combinations using simple slider tools. After finishing the
Fig. 9. Example of AniMap output for the trolley bus scheme: residential location year
Fig. 10. MARS flight simulator screenshots and hands on experience: (a) Introduction; (b) main menu; (c) model exploration; (e) output; (f) exercises in Ho Chi Minh City, March 2006
process of setting up a certain policy combination the user can invoke a simulation run (the calculation for a 30-year period lasts around 1 min on a standard PC; this is much faster than traditional LUTI models, which can take many hours) and compare the results against a base run or a former simulation run (Figure 10(e)). The results are presented either as developments over time or by using AniMap to display the developments over space and time simultaneously.

By setting up mock-up exercises for users such as meeting targets for CO₂ reduction or increases in public transport share, users can try to find policy combinations which deliver the required results.

In several workshops held in Austria, Thailand, Vietnam, Laos and Brazil the MARS flight simulator was used successfully (see figure 10f). The feedback received from seminar participants was all positive in nature. Statements such as “I have never thought that this land use transport system is that complex!” or “I haven’t realized before using MARS that there are so many reinforcing and balancing loops working simultaneously!” showed us that a successful learning process took place. From this kind of feedback the conclusion could be drawn that this kind of hands-on experience with a LUTI model is very useful to increase the understanding of experts, transport planners, city planners and decision makers regarding the complexity they have to deal with in their day-to-day work.

Summary

As can be seen, the MARS model is a complex land use transport interaction model. It is fully implemented in VENSIM, which enables us to use the model for different purposes such as case study investigations, for policy optimization and for teaching activities. The model structure is complex, but still understandable for laymen.

As mentioned, MARS was developed over a time period of more than 10 years and has been calibrated to both empirical data and, as shown above, contains mode choice parameters which appear to be transferable, within Europe at least. The model framework can be easily adapted to suit the needs of a particular city and, as shown for Leeds, the VENSIM calibration facilities proved useful in calibrating the land use coefficients for residential location. The simulation of transport and land use interaction over a 30-year period in combination with the dynamic GIS application AniMap enables the user to evaluate visually spatial developments such as concentration and de-concentration and so provides a deeper understanding of slow processes in the land use transportation system.

MARS has undergone, as all models, a process of going into more and more detail. There were requests to add more household groups, more trip purposes, more means of transport, apply more and smaller zones, etc. These wishes were only partially fulfilled, because the developers wanted to avoid or minimize the related problems of detail, such as data mining for setting up a model, run time of simulations, and at the end of simulation the resulting information overflow. Furthermore, we have shown that at the typical level of analysis of transport planners MARS compares well with much more detailed approaches in terms of validation statistics.

MARS, as it stands, is a useful tool where planners can relatively easily test and identify the impacts of different policy instrument combinations; they can learn how
things are related to each other, identify synergies and contradictions and they can learn about time lags in inert complex systems such as transport and land use systems. It can be thought of as a strategic model which is useful for early analysis of options, with advantages of short set-up and quick run time with automated presentation, which proves useful for interaction with decision makers and for training of planners. MARS is therefore a complement to more detailed level models rather than a replacement, but one which can provide quick answers—something which other models cannot achieve currently.

Notes

1. Gateshead, Leeds, Edinburgh (GBR), Oslo, Trondheim (NOR), Helsinki (FIN), Vienna, Salzburg, Eisenstadt, Austria (AUT), Madrid (ESP), Stockholm (SWE), Ho Chi Minh City, Hanoi (VIN), Chiang Mai (THA), Ubon Ratchantani (THA), Washington DC (USA), Porto Alegre (BRA), Bari (ITA).
2. In some MARS applications motorcycles are treated as a separate means of transport.
3. The general accessibility measure used in MARS is a weighted sum of workplaces and potential customers that can be reached from a given location. The travel times between the location and the workplaces and potential customers are used as weighting factors. A detailed description is given in Pfaffenbichler (2008, p. 81).
4. Number of zones origin \times\text{number of zones destination} \times \text{time of day} \times \text{modes of transport} = 33 \times 33 \times 2 \times 4 = 8712.
6. We used the neighbourhood statistics website (http://neighbourhood.statistics.gov.uk/), which contains the 2001 census data, to obtain the mode of travel to work (uv39) for the resident population.
7. Website: www.statistics.gov.uk/sape.
8. It should be noted that all assumptions are our own and used here merely to display the new functionality of the model. Leeds City Council or METRO have not been involved in this application and the results are by no means intended to be used to assess the scheme proper.

Biographies

Dr. Paul Pfaffenbichler holds a MsC in Mechanical Engineering and gained his doctorate in Civil Engineering in 2003 developing the dynamic land use and transport interaction model MARS. He is working in the field of transport planning and traffic engineering since 1997. In 2004–2005 he spent a year as visiting professor at the Transport Research Center of the Universidad Politécnica de Madrid. Large part of his lecturing and research activities utilize the principles and methods of Systems Dynamics. His current research focus is on electric mobility and modeling the development of car fleets with alternative propulsion technologies.

Dr. Emberger holds a MSc in Computer Science and Business Administration and a doctorate in Social and Economic Sciences. He works in transport planning since 1990. He was a research fellow at the ITS, University of Leeds for 2 years. Since 2007 he is Professor for Transport Planning.
Planning at Vienna University of Technology. Dr. Emberger has experience in travel demand modelling, behavioural analyses, design and implementation of transport models, traffic safety, environmental impacts assessment, public transport planning applying the System dynamics methodology. He was involved in several national and international research projects (FP4 to FP7) dealing with sustainable transport strategies in Europe and Asia.

Dr Simon Shepherd Short Bio At the Institute for Transport Studies since 1989, he gained his doctorate in 1994 applying state-space methods to the problem of traffic responsive signal control in over-saturated conditions. His expertise lies in modelling and policy optimisation ranging from detailed simulation models through assignment to strategic land use transport models. Recently he has focussed on optimisation of road user charging schemes and is currently working on aspects of competition between cities. He has applied system dynamics approaches to the transport sector, looking at toll competition between private operators; take up of electric vehicles and strategic modelling where he has been involved in the development of MARS for the last ten years. He is currently involved in an EU research programme to support them in defining a feasible research and policy strategy for green house gas reductions in transport.

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