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Modelling automated technologies within a strategic transport model

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1 ABSTRACT

There is renewed interest in Europe in the potential role of new automated technologies for urban transport. These systems include cybercars, personal rapid transit (PRT), automated or high-technology buses, and dual mode vehicles. Assessing the contribution of such systems when applied extensively in an urban area is challenging. This paper describes how each of the technologies was represented in a systems dynamics model (MARS) using a case study of Vienna (AU). The unique supply characteristics need to be encapsulated, and the technologies need to be assessed when operating in conjunction with a range of other policy instruments. The scale of the applications ranges from small feeder systems, through PRT networks to automated bus corridor applications, and finally area wide effects of implementing dual mode vehicles within the fleet. The paper describes how we dealt with the inclusion of such variations in scale and reports on initial results.

2 INTRODUCTION

As part of the CityMobil project (http://www.citymobil-project.eu/), strategic modelling work is being undertaken to investigate the long-term impacts of the city-wide implementation of new automated technologies. To do this, a number of predictive tests using a fixed set of context and passenger applications will be undertaken for each of the four case study cities: Madrid, Trondheim, Gateshead and Vienna. The applications will be modelled over a 30 year period with 2005 as the base year. These tests will be conducted using a dynamic land use-transport interation model, MARS.

This paper starts by outlining the new automated transport modes and their applications in MARS. The MARS model is then described, concentrating on the causal loop diagram technique on which the model is constructed. The incorporation of the new technologies in the model is discussed, including a description of the 'tipping point' tests that have been used to determine an appropriate level for the new modes' supply characteristics, such as access/egress time, fares and headways. Using the Vienna case study, example schemes of the new modes are outlined and the initial results of a selection of predictive tests discussed.

3 NEW TECHNOLOGIES PASSENGER APPLICATIONS

The new technologies to be modelled in MARS include cybercars, PRT, automated buses and dual mode vehicles. The specifications of individual modes can vary between different types of systems, so the specifications in this paper will not apply to all modes, but to those used as a basis for the MARS modelling work. The supply characteristics such as fares, changing times and access/egress time are determined using the 'tipping point' tests, described in more detail in section 3.4. The following passenger applications using the automated modes are based on those reported in Ruberti et al (2007). The types of applications modelled will be common across all four cities, though the individual schemes will vary between cities due to variations in size, geography and existing road and transport networks.

Figure 2-1 shows the type of cybercar to be used in the modelling work, based on the ParkShuttle system operating in Rotterdam (http://connectedcities.eu/guide/parkshuttle.html). The vehicles run on a lane segregated from other traffic at a maximum speed of 40kph, with a maximum capacity of 20 passengers. The fully automated vehicles can operate without a driver (the assumption to be used in the modelling) and have a battery powered energy supply. Two types of cybercar schemes will be modelled in MARS. The first will be an innercity network linking key facilities such as existing transport interchanges, universities and hospitals. The second will include several suburban feeder systems linking low density residential areas to existing high quality public transport systems.

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Figure 2-1: Cybercar


Figure 2-2: Prototype of ULTra PRT system

Figure 2-2 features the ULTra PRT system, which operates on a segregated guideway at a maximum speed of 40kph. The vehicles have a maximum capacity of 4 passengers, are automatically controlled and battery powered. This is a demand responsive mode in which passengers at the off line PRT station 'summon' a vehicle to take just them or their party to the requested destination. A city wide PRT network that mirrors the cybercar network will be modelled in MARS to enable comparison between the two modes.

Automated buses are similar to regular buses in terms of appearance and specifications, but are able to run automatically, without a driver on guideways. The two automated bus applications to be modelled in MARS include running on several major routes from the suburbs to the city centre, and at least one route linking the city centre to a major facility, such as an airport or out-of-town shopping centre.

Dual mode vehicles are similar in appearance and specification to regular cars, with the main difference being that they can be either operated by a driver or fully automated. These vehicles are equipped with advanced driver assistance systems including automated cruise control, parking assistance and ISA (Intelligent Speed Adaptation). For the purposes of the modelling work reported here, it is assumed that these vehicles will travel on mixed roads and will therefore have a driver. As such, the main difference from a regular car will be the use of automated systems enabling vehicles to maintain a constant distance from the vehicle infront, thus decreasing headway distance and consequently increasing road capacity. These vehicles will be modelled to cover the whole road network at all times of day. The penetration level will start at 1% in year 10 (2015), rising to 40% by year 30 (2035). This is equivalent to an increase of 8% in capacity over the 30 year modelling period.

4 MARS MODEL

4.1 Introduction

The strategic modelling of the new technologies transport schemes in four case study cities will be undertaken using MARS (Pfaffenbichler (2003)). 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 organising systems. 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. To date MARS has been applied to ten European cities (Bari, Edinburgh, Gateshead, Helsinki, Leeds, Madrid, Oslo, Stockholm, Trondheim and Vienna) and three 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.

MARS 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, and a fuel consumption and emission model. All these models are interconnected with each other and the major interrelations of the core land use and transport model are shown in Figure 3-1. The sub-models are run iteratively over a period of time of 30 years. They are linked on the one hand 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.

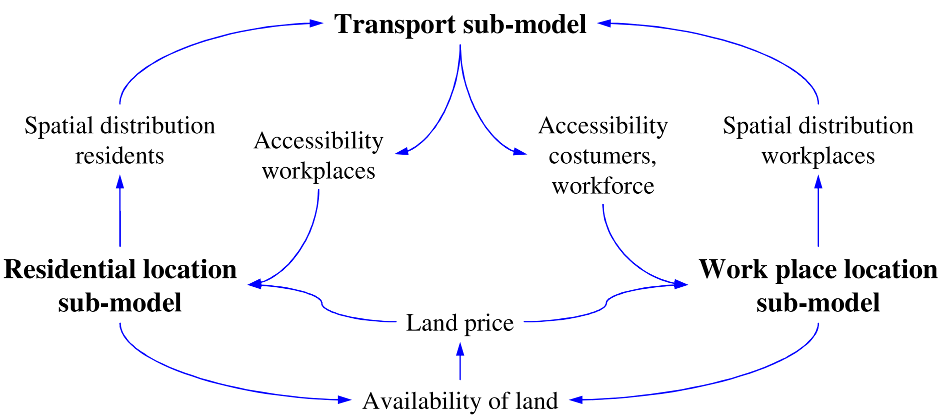

Figure 3-1: Basic structure of the MARS sub-models

4.2 Main cause effect relations

To help explain the model to users and stakeholders MARS is built using the Causal Loop Diagram (CLD) technique. Figure 3-2 shows the CLD for the factors which affect the number of commute trips taken by car from one zone to another. From Figure 3-2 we start with loop B1 which is a balancing feedback loop, 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 show 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 in Figure 3-2 show the key drivers of attractiveness by car for commuting. These include car availability and 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.

It is this simple causal loop structure and user friendly software environment which helps improve the transparency of the modelling approaches used.

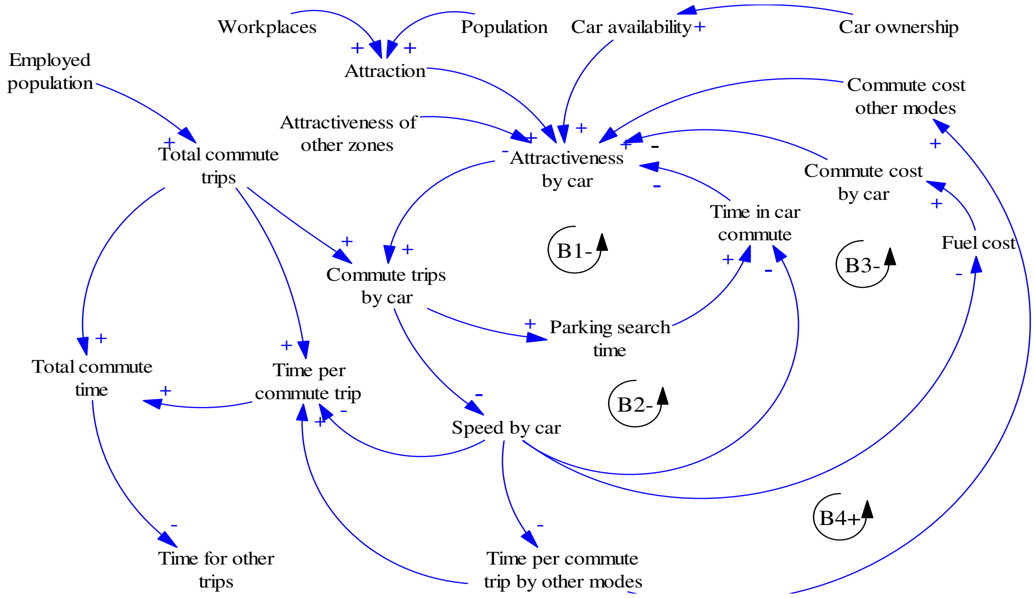

Figure 3-2: CLD for the transport model – commute trips by car in MARS

4.3 The residential location sub-model

The residential location sub-model was recently modified. The structure of this sub-model is shown in Figure 3-3. The moving out model now calculates the average time living at a location rather than the number of households willing to move out. This average time spent living at the same location depends on the relative costs of housing, household income, living space per housing unit and share of owner occupied housing (Equation 1 and upper middle part of Figure 3-3). Furthermore the moving in model was changed from distributing a number of housholds to a vector of locations to distributing a vector of households willing to move to a matrix of household movements (Equation 2 and upper left part of Figure 3-3). The moving in sub-model is doubly constrained. Excess demand for housing is redistributed within a fixed number of three ierations to zones with excess supply. See left lower part of Figure 3-3.

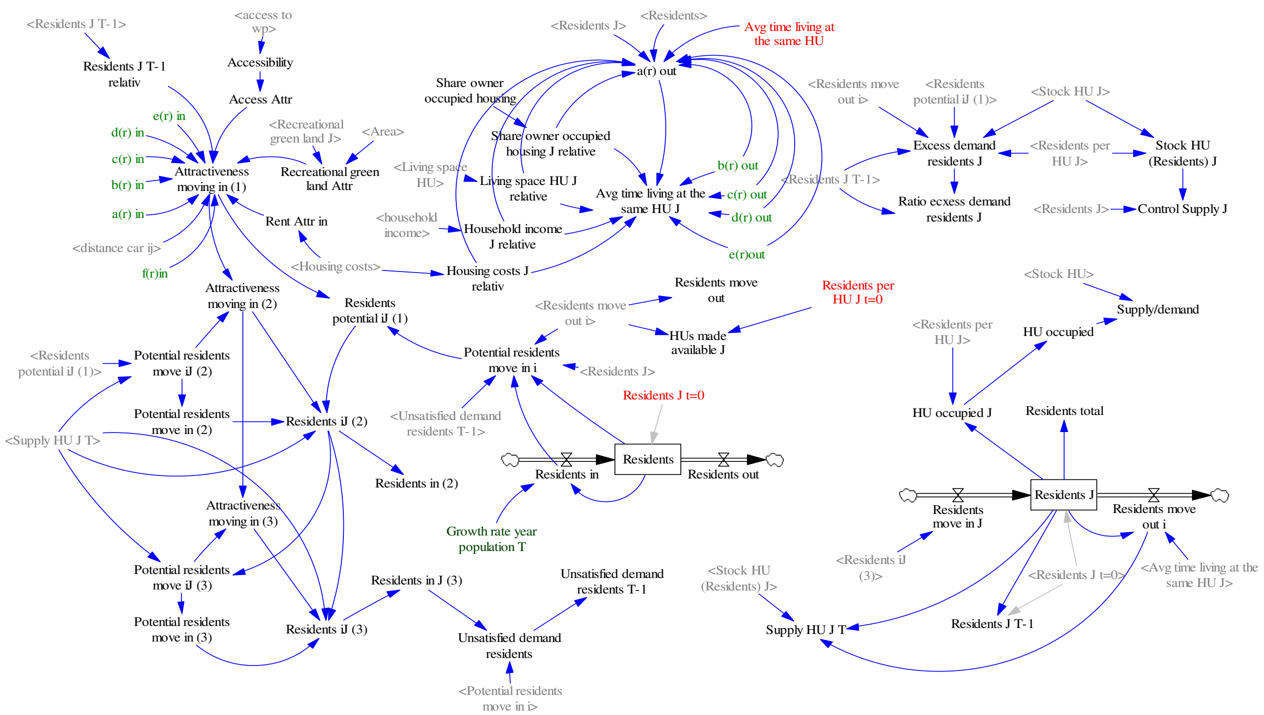

Figure 3-3: The houshold location sub-model of MARS

$$N_i = a + b * \frac{C_i}{\overline{C}} + c * \frac{I_i}{\overline{I}} + d * \frac{S_i}{\overline{S}} + e * \frac{O_i}{\overline{O}}$$

Equation 1 : Number of years a household stays at the same location

Legend:

N_i .... Number of years a households stays at the same location

a, b, c, d, e .... Parameters calibrated from a regression model

C_i .... Costs of housing in zone i (€/m²)

$\overline{C}$ .... Average costs of housing in the case study area (€/m²)

I_i .... Household income in zone i (€/month)

$\overline{I}$ .... Average household income in the case study area (€/month)

S_i .... Living space per housing unit in zone i (m²)

$\overline{S}$ .... Average living space per housing unit in the case study area (m²)

O_i .... Share of owner occupied housing in zone i (%)

$\overline{O}$ .... Average share of owner occupied housing in the case study area (%)

$$U_{ij} = \left[a * \left(\frac{R_j}{\overline{R}} - 1 \right) + 1 \right] * \frac{f}{d_{ij}} * e^{b * \frac{A_j}{\overline{A}} + c * \left(\frac{G_j}{\overline{G}} \right)^2 + d * \frac{G_j}{\overline{G}} + e * \frac{C_j}{\overline{C}}}$$

Equation 2 : Utility of moving from zone i to zone j

Legend:

U_{ij} .... Utility for a household moving from zone i to zone j

a, b, c, d, e, f .... Parameters calibrated from a regression model

R_j .... Number of residents living in zone j

$\overline{R}$ .... Average number of residents living in a zone

d_{ij} .... Distance from zone i to zone j

A_j .... Accessibility of zone j

$\overline{A}$ .... Average accessibility of zones

G_j .... Share of recreational green land in zone j (%)

$\overline{G}$ .... Average share of recreational green land (%)

C_i .... Costs of housing in zone i (€/m²)

$\overline{C}$ .... Average costs of housing in the case study area (€/m²)

4.4 Incorporating new public transport technologies

MARS models the mode choice between public transport, private car and slow modes via the concept of friction factors, which reflect the impedance of travelling between each origin-destination pair for each mode. For example, a trip by public transport consists of the following individual (cost) parts:

1. Average walking time to the next pt stop origin zone
2. Average waiting time for the pt service origin zone
3. In vehicle time (OD)
4. Changing time (OD pair dependent)
5. Egress time destination, and
6. Fare costs

For all time related parts of such a public transport trip so called subjective time valuation factors are applied to express the part specific discomfort while money costs are converted into time values as shown in Equation 3.

$$f\left(t_{ijPT}\right) = t_{W,to,i} * SV_{W,to} + t_{W,i} * SV_W + \sum t_{DR,ij} + \sum t_{Ch,ij} * SV_{Ch} + t_{W,from,j} * SV_{W,from} + R_{C,ij}$$

Equation 3 : Friction factor elements for a public transport trip

Legend:

$t_{W,to,i}$ Walking time from source i to public transport stop in zone i

$SV_{W,to}$ Subjective valuation factor walking time from source to public transport stop

$t_{W,i}$ Waiting time at public transport stop i

SV_W Subjective valuation factor waiting time at public transport stop

$t_{DR,ij}$ Total driving time from source i to destination j

$t_{Ch,ij}$ Total changing time from source i to destination j

SV_{Ch} Subjective valuation factor changing time

$t_{W,from,j}$ Walking time from public transport stop to destination

$SV_{W,from}$ Subjective valuation factor walking time from public transport stop to destination

$R_{C,ij}$ Impedance from costs travelling from i to j

$$R_{Cij} = \frac{C_{PTij}}{\alpha * Inc_{HH}}$$

Equation 4 : Fare cost part of the impedance to travel

α Factor for willingness to pay (=0.17)

Inc_{HH} Household income per minute

Each of these parts is perceived and valued differently by the user. MARS uses perceived values derived by Walther et al., (1997) who define separate friction factors for the public transport modes bus, tramway and rail, as well as for car. MARS makes a distinction whether public transport is separated from individual road traffic or not.

To include a new technology such as high technology buses, cyber cars as feeders to major public transport routes, or PRT systems, we have to characterise the supply factors such as average speeds, access/egress times, headways, fares and changing times. Despite MARS being a highly aggregate model it is important to consider the schemes to be modelled at a reasonable level of detail and to work up to the aggregate changes in these supply side characteristics as is demonstrated in the following case study for Vienna.

How to model a new technology will depend on whether or not the new technology will be perceived as a completely new mode or as similar to an existing mode (as might be the case for high technology buses). This will determine which of the subjective valuation factors should be applied in the first instance. In parallel we have conducted a stated preference survey to obtain valuations for each of the new technologies but these values were not available of time of writing.

As an example when implementing a cyber car feeder system we now replace the points 1+2 of the above list with

1. Average walking time to a cyber car boarding point in the origin zone
2. Average waiting time for the cyber car
3. In vehicle time cyber car
4. Cyber car fare (if present)
5. Average walking from cyber car stop to pt stop in the origin zone
6. Average waiting time for pt origin zone

The rest of the trip is treated in the same way as a "normal" pt trip presented in the friction formula.

As can be imagined, depending on the design of the feeder system there must exist a tipping point or minimal walking time below which a Cyber Car system is not sensible to implement, since the generalised cost of walking will be lower than the usage of a Cyber Car. On the other hand, above this threshold value an implementation of a CC system as a feeder system for public transport may be a good idea.

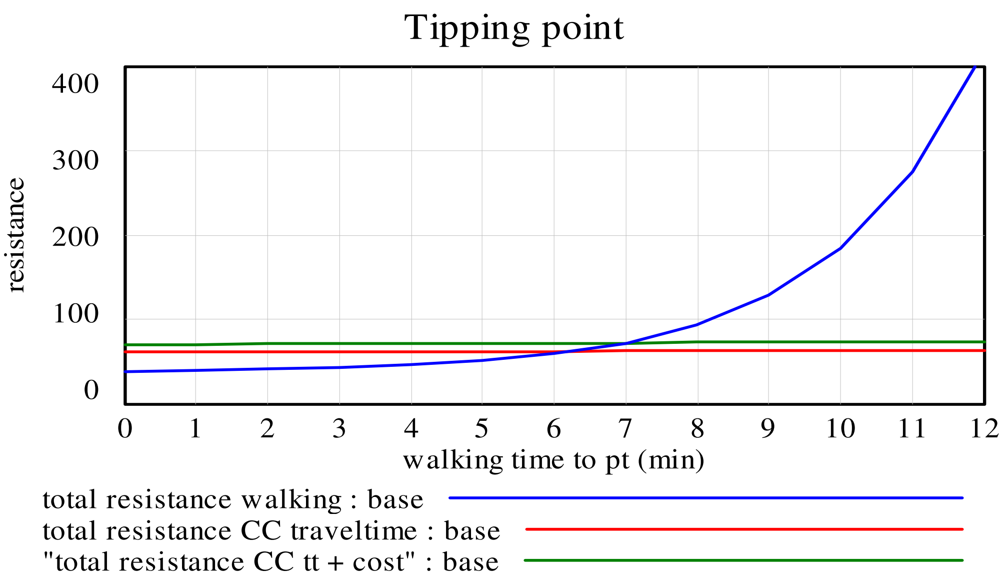

Figure 3-4 : Variation in walking time to pt stop and its impacts on transport resistance

Figure 3-4 shows how the resistance varies for walking as walk time is increased compared to using a cyber car system with and without a fare of 60 Euro cents. The other design parameters for the cyber car system are assumed as follows :- average walking time from the origin to CC stop is assumed to be 1 minute, average CC vehicle speed 15 km/h, average waiting time for a CC vehicle 1 minute, and the average walking time from a CC-stop to the original PT stop is 1 minute. As we can see in this case the tipping point is around 6 minutes so that it is only sensible to implement this type of feeder system in zones where average access is graeter than 6 minutes. As well as showing where a feeder system is perhaps useful the tipping tool can also be used to show the effects of changes to the feeder design parameters and in finding the equivalent walk time which can be used directly within MARS to represent a given feeder design without the need to model the individual components (as will be shown in the case study). The next section demonstrates by case study the implementation and impacts of various schemes for Vienna.

5 CASE STUDY

5.1 PRT in the city centre

In 2001 the Viennese central business district “Innere Stadt” was home to 17,056 residents and 101,668 workplaces (Statistik Austria 2003; 2004). More or less the whole district is a protected cultural heritage. The central business district (CBD) covers about 3 km² (Magistratsabteilung 66- Statistisches Amt, 2001). The city centre is well currently connected by public transport. Within or very near to its boundaries there are 39 bus stops, 23 tramway stops and 14 metro stations. This gives a density of about 25 public transport stops per km². From almost every location in the CBD it is possible to get to the next PT stop within a 3 minute walk. Within a 5-6 minute walk a metro station can be reached from more or less any point of the CBD.

The proposal to be analysed within the CITYMOBIL case study of Vienna includes the following measures (see Figure 4-1):

- replace the existing feeder bus lines by a new PRT system and,
- make the whole CBD car free except on the ring roads “Ringstraße”, “Kai” and “frühere 2er Linie” and on the access roads to public garages.

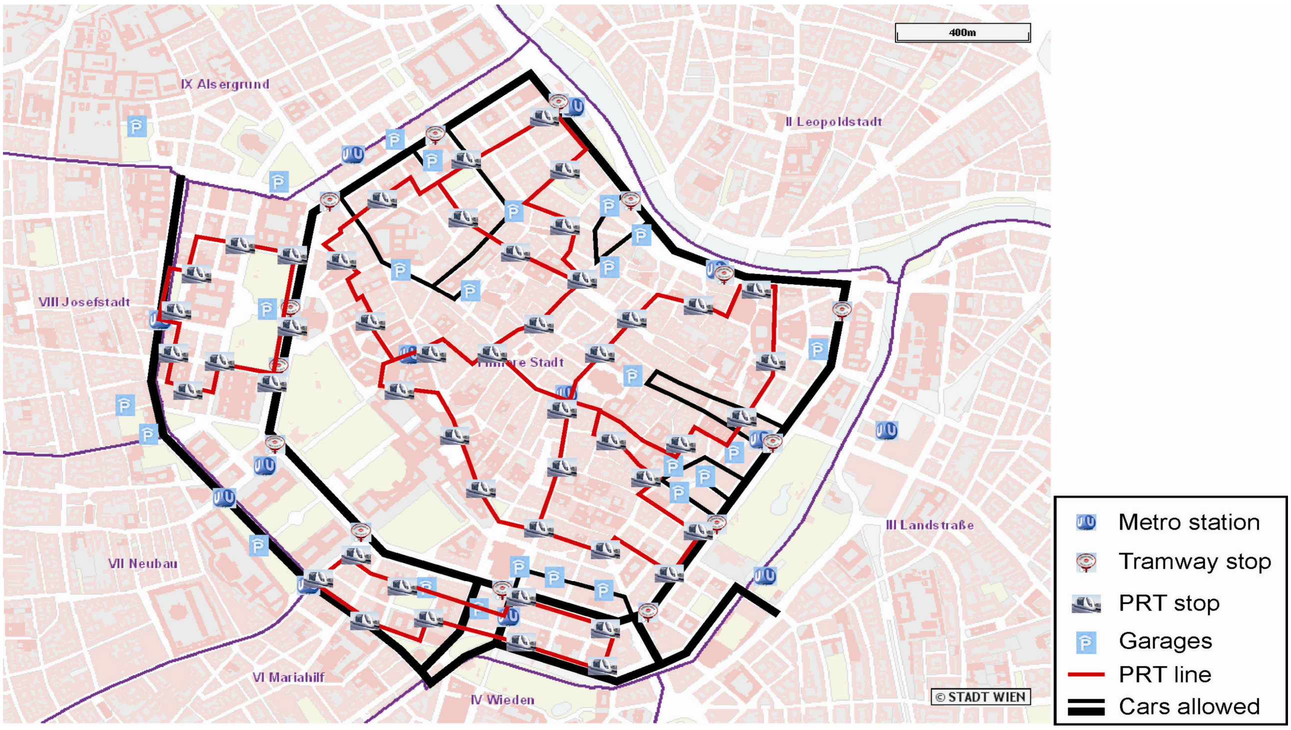

Figure 4-1 : Proposal for a PRT system in the Viennese central business district „Innere Stadt“

The suggested PRT system has 49 stops. The total length of the network is about 11 kilometres. As the city centre is an important cultural heritage it is impossible to create an elevated PRT system which is why the scheme also includes the reallocation of road space away from private car.

Concerning the MARS input data the proposed scheme has the following effects, it reduces

average walking time to and from a PT station from 2.3 to 1.5 minutes and the average PT headway time from 7.4 to 3 minutes (i.e. reduce the waiting time at the PT stop to 1.5 minutes). The scheme also increases the share of intra zonal PT trips which are separated from car traffic to 100% and increases the share of inter zonal PT trips with origin or destination in the CBD which are separated from car traffic by 10%. The friction factor for walking is reduced by 40% to account for the effect of the car free environment, (see Peperna 1982). For car users the access and egress time to and from a parking place is increased to 3 minutes and the number of parking spaces available is limited to 6,607 (the number available in the existing garages).

5.2 Cyber car feeder system in outer zones

The feeder system is implemented in zones 13, 14, 19, 21, 22 and 23 where current access times are between 4-6 minutes. For the feeder system we assme that there is a 1 minute walk to the cyber car with an average wait of 1.5 minutes and an average speed of 15km/h. Using the above tipping this equates to effective walk times between 2.6 – 2.85 minutes depending upon the zone considered.

6 RESULTS

This section presents initial results for the PRT and feeder system. In terms of area wide impacts the measures are not significant as they are applied to one zone or a few zones in the case of the feeder example. It does not make sense to look therefore at area wide indicators. Instead we concentrate on movements to or from the affected zones.

Table 1 shows the percentage change in the number of trips for each mode to and from the central area for the year after implementation of the PRT system and associated measures. It can be seen that car trips are reduced both in and out of the zone and that both slow and PT trips are increased. The slow modes are increased most for intra-zonal trips which come under the heading “from zone 1” as these benefit from the pedestrianised area and the reduced friction factor for walking in this area. In terms of Public Transport the most significant increases are for trips to the central area from other zones. This is mainly due to the fact that car access has been significantly reduced as part of the package of measures here.

Table 2 shows the mode share for three of the feeder zones for the average day. In all cases the feeder system has attracted users to public transport from both car and slow modes. It is noticeable that zone 14 is less successful than the other zones in shifting users to public transport as there already exists a relatively large share for slow modes.

	Peak		Off-peak		Total
	From zone1	To Zone 1	From Zone 1	To Zone1	
Slow	14.1%	8.3%	3.7%	4.6%	5.8%
PT	8.2%	41.7%	3.1%	18.3%	13.6%
Car	-14.3%	-22.6%	-13.5%	-12.4%	-14.1%

Table 1 : Percentage changes in number of trips by mode to and from the central zone 1 with PRT implemented.

	Zone 13	Zone 14	Zone 19
Slow Feeder	11.9%	21.6%	10.2%
Slow DN	13.1%	22.5%	10.8%
PT Feeder	33.8%	28.7%	34.8%
PT DN	29.5%	26.4%	32.3%
Car Feeder	54.3%	49.7%	55.0%
Car DN	57.3%	51.1%	56.9%

Table 2 : Mode share from three feeder zones

Many more detailed results are possible but space does not permit a full analysis. In general though we can see that for the PRT system the number of trips has been increased by around 9,000 per day. With the feeder system in place in 6 strategic zones the total PT trips increased by around 29,000 trips per day. This would suggest that investing in feeder systems is the way forward for Vienna. However this is a scheme and city specific result as the PRT system here has in fact replaced an existing service while the feeder system has enhanced an existing service.

7 CONCLUSIONS

This paper has described how a strategic system dynamic model MARS can be applied to investigate relatively new technologies at the scheme level. The tipping point tool allows the users to decide which zones could benefit from an improved feeder system and provides a quick and easy method for testing the sensitivity of the response to changes in the design of the scheme. It was also used to calculate the equivalent walk time which reduced the amount of data required to represent the system within the fuller model.

Regarding the PRT scheme it was shown that not only the impact of the improved service could be included but also the impacts on other modes such as reduced access for car users and improved walking conditions for pedestrians. From the initial analysis carried out here it appears that the feeder systems will have a greater impact than the PRT system – but that this is explained by the fact that the PRT was replacing an existing service rather than enhancing it.

Our future research will compare the systems with the dual mode vehicles and high-tech bus corridors for Vienna and for the full range of schemes being developed for Gateshead, Trondheim and Madrid.

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