AN ASSESSMENT OF CITY-WIDE APPLICATIONS OF NEW AUTOMATED TRANSPORT TECHNOLOGIES

Anthony D May, ITS, University of Leeds, England a.d.may@its.leeds.ac.uk

Simon P Shepherd, ITS, University of Leeds, England s.p.shepherd@its.leeds.ac.uk

Tomas Levin, SINTEF Transport Safety and Informatics tomas.levin@sintef.no

ABSTRACT

There is renewed interest in Europe in the potential role of new automated technologies for urban transport. This paper describes a significant element of a major European study, CityMobil, into novel public transport technologies, including cybercars, personal rapid transit and high tech buses. The model-based analysis presented here complemented a set of major, but site-specific, demonstrators, and was designed to assess the potential contribution of such technologies when applied on a larger scale in different types of European city. In the absence of empirical evidence on their performance, a common predictive modelling method has been used to predict the impacts of four comparable applications of these technologies in four case study cities. The design of the applications and the modelling assumptions were based on earlier research in the programme. The model results and a business case tool have been used to assess the contributions such systems make and their financial justification.

Personal rapid transit applications proved to be the most effective, particularly in city centres. Cybercars also performed well in city centres, and even better as feeders to line haul public transport. High tech buses were less effective, and only contributed positively on radial corridors in larger cities. Impacts on car use were often small, but were greater for city centre PRT schemes and cybercar feeder schemes. However, these schemes also attracted patronage from conventional public transport and from walking and cycling. Financial benefit cost ratios were often positive, reflecting the low costs of operation, and were particularly high in cities with high fare regimes and in areas with previously poorer levels of service. Performance was significantly affected by the pre-existing public transport service and, particularly, by fare levels. Road pricing complemented all new technologies, but had a greater impact on its own than did the new technologies.

It appears that each technology is likely to be most effective in certain niche markets, which will vary by city type. Cities are reluctant to experiment with new technologies, but are likely to be influenced by effective field trials. The model results suggest the applications which are likely to be most appropriate for such field trials.

Keywords: automated technologies; passenger transport; urban

INTRODUCTION

Automated transport systems are ones which require no driver or other on board personnel, thus reducing substantially their operating costs and enabling them to be applied more intensively than conventional public transport services. Some systems go further, and offer an on-demand service rather than a conventional timetabled service, thus substantially reducing waiting times. There has been interest for several decades in the development of such automated transport systems for urban areas, given their potential to improve public transport services, reduce their costs and encourage a switch away from private car use (Langdon, 1977).

Several new automated technologies for urban passenger transport are now being developed and tested as small scale demonstrations, but their site-specific application makes it difficult to generalise their results. It is likely to be some considerable time before cities are willing to take the risk of being the first to implement full scale applications. In the meantime, predictive modelling offers the most dependable way of assessing the likely contributions of such technologies to urban transport policy.

These recent technological advances have led the European Commission to finance a major investigation into the design and application of such technologies, CityMobil (van Dijke, 2008). A key element in CityMobil has been to bring together expertise in technology and in urban transport to assess the potential of such technologies when applied on a large scale in urban areas. Early work involved categorising the technologies available and identifying their most promising applications. Subsequently a research method was developed for assessing the performance and contribution of these technologies in such applications (Muir et al., 2009).

That method involved specifying in more detail four particularly promising applications; selecting four representative European cities in which to test them; determining the contexts in which they should be tested and the complementary policy instruments with which they might be tested; choosing a common modelling platform with which to test them; collecting data to understand behavioural responses to them; and creating a Business Case Tool to evaluate their impacts (Muir et al., 2009). In this paper we summarise the applications specified, the cities selected, the modelling platform chosen and the Business Case Tool developed. We then report the principal results in terms of peak mode shares and financial benefit cost ratios. This allows us to draw important comparisons between technologies and between cities. We then use these results to discuss implications for full scale field trials. Further results are available in the full project report (Shepherd and Muir, 2009).

THE TECHNOLOGIES AND APPLICATIONS

Within the context of the study the term automated transport technology is used to describe the vehicles and any associated infrastructure to enable vehicles to operate. The automated transport technologies modelled include cybercars, personal rapid transit (PRT) and high-tech buses. The specifications of these automated modes can vary between different types of system, so those reported here will not necessarily apply to all other similar modes but are used as the basis for the modelling work. The term application is used to describe the context in which the new automated transport technologies are used, and the design of the system within a particular location is referred to as the scheme. The types of application modelled are common across all four case study cities, though the individual schemes differ between cities due to variations in size, geography and existing road and transport networks.

The cybercar system specification is similar in concept to the ParkShuttle system operating in Rotterdam (2getthere, 2011). The vehicles run on a lane segregated from other traffic at a maximum speed of 25 km/h, with a maximum capacity of 20 passengers. The fully automated vehicles operate without a driver and have a battery powered energy supply. Two types of cybercar applications have been modelled: the first is an inner city network; the second includes several suburban feeder systems linking low density residential areas to existing high quality public transport systems. Both services are scheduled rather than on demand.

The PRT system specification is similar in concept to the ULTra system (ULTra PRT, 2011), operating on a segregated guideway at a maximum speed of 40km/h. The vehicles have a maximum capacity of four seats, 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. An inner city PRT network linking key facilities such as existing transport interchanges, universities and hospitals has been modelled.

High-tech buses are similar to regular buses in terms of appearance and specifications, but are able to run automatically, without a driver on guideways. The high-tech bus application includes services 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.

CITIES AND SCHEME DESIGNS

New automated transport technology schemes were modelled in four case study cities: Madrid, Trondheim, Tyne and Wear (a city region including Newcastle upon Tyne and Gateshead) and Vienna. Table 1 provides an overview of the scale of the case study cities, modal split and transport conditions.

Table 1 - Overview of case study cities

	Madrid	**Trondheim**	**Tyne and Wear**	**Vienna**
2005 population	5,846,473	150,000	1,451,872	2,755,000
2035 population (medium growth forecast)	8,502,867	192,000	1,400,438	2,859,000
Modal split 2005	55% public transport, 12% car, 33% walking and cycling	11% public transport, 58% car, 31% walking and cycling	23% public transport, 65% car, 12% walking and cycling	34% public transport, 36% car, 30% walking and cycling
Public transport provision	Bus, metro, LRT, rail	Bus, tram line	Bus, metro, limited intra-urban rail	Bus, metro, LRT, tram
Transport issues	Low levels of public transport provision in the suburbs which leads to high	Hills surrounding the city create challenges for transport provision,	River Tyne acts as a geographical barrier. High traffic flows	Good level of public transport provision throughout the city

	car usage compared to central areas	making it difficult to connect the east and west parts of the city	across the river create bottlenecks at crossing points	

The detailed application of each technology in each city is described below.

Cybercar city centre (M1)

This system is modelled as an enhancement to the local public transport system. Madrid's feed the local Metro, Tyne and Wear serves as a stand-alone system and feeds Metro and rail, Trondheim feeds the local bus service while Vienna feeds both Metro and tram lines. Vienna and Madrid implement the cyber car within the central zone only whereas Tyne and Wear and Trondheim consider routes which span more than one central zone. Table 2 shows the assumptions about the performance characteristics that are made when modelling this system for each city. The system modelled in Tyne and Wear used the network shown in Figure 2.

Table 2 – Assumptions in modelling city centre cybercars

Attributes	Tyne and Wear	Madrid	Trondheim	Vienna
Average wait time Peak	5 minutes	3 minutes	2 minutes	1.5 minutes
Average wait time off peak	3 minutes	3 minutes	2 minutes	1.5 minutes
Vehicle speed	15km/h	10km/h	15 km/h	15 km/h
Typical access/egress time	10 minutes	2-3 minutes	2 minutes	1.5 minutes
Inter-change time to other services	7 minutes	1 minute	2 minutes	1 minute
Fare	Same as Metro Average of €2.21	Same as existing system	0.5	Same as existing system
Capacity	20	20	20	20
Track/route length	20.7km	42km	7.2km	11km
Stops	30	84	17	49

Cybercar public transport feeder

This system is modelled as an enhancement to the existing rail/Metro/bus system. In all cities a number of suburban zones with relatively poor access to the public transport network were selected for the implementation of feeder systems. **Error! Reference source not found.** includes the assumptions about the performance characteristics that are made when modelling this system. Figure 1 shows the system modelled for Tyne and Wear.

Table 3 – Assumptions in modelling cybercar feeders

Attributes	Tyne and Wear	Madrid	Trondheim	Vienna
Average wait time Peak	5 minutes	3 minutes	2 minutes	1.5 minutes
Average wait time off peak	3 minutes	3 minutes	2 minutes	1.5 minutes
Vehicle speed	15km/h	10km/h	15 km/h	15 km/h
Typical access/egress time	10 minutes	2-3 minutes	2 minutes	1.5 minutes
Interchange time to other services	5 minutes	1 minute	2 minutes	1 minute

Fare	Same as Metro Average of €2.20	Same as existing system	0.5	Same as existing system
Capacity	20	20	20	20
Track/route length	22.2km	42km	22.78km	11km
Stops	36	84	36	49

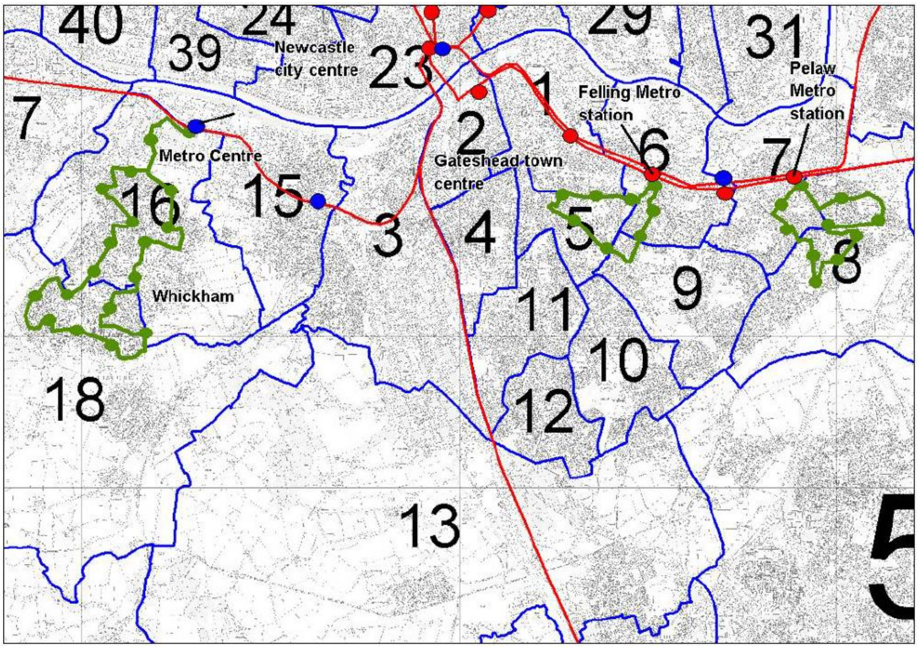

Figure 1 – Tyne and Wear cybercar feeder (in green) to line-haul services (in red)

Personal Rapid Transit city centre (M3)

In general the PRT network covers the same route and zones as the city centre cyber car but has the advantage of being personalised travel. The capacity of each car is 4 persons. Trondheim has a different route for PRT than for cyber cars in the city centre due to the small nature of the cyber car scheme and the specific requirements of the city. **Error! Reference source not found.** includes the assumptions about the performance characteristics that are made when modelling this system. Figure 2 shows the system modelled for Tyne and Wear.

Table 4 – Assumptions in modelling city centre PRT

Attributes	Tyne and Wear	Madrid	Trondheim	Vienna
Average wait time Peak	1 minute	1 minute	2 minutes	1.5 minutes
Average wait time off peak	0.5 minutes	1 minute	2 minutes	1.5 minutes
Vehicle speed	27.5 km/h	15km/h	15 km/h	15 km/h
Typical access/egress time	7 minutes	2-3 minutes	2 minutes	1.5 minutes
Inter-change time to other services	5 minutes	1 minute	0	2 minutes
Fare	Same as Metro Average of €2.21	Same as existing system	0.5	Same as existing system

Capacity	4	4	4	4
Track/route length	20.7km	42km	18.5km	11km
Stops	56	84	34	49

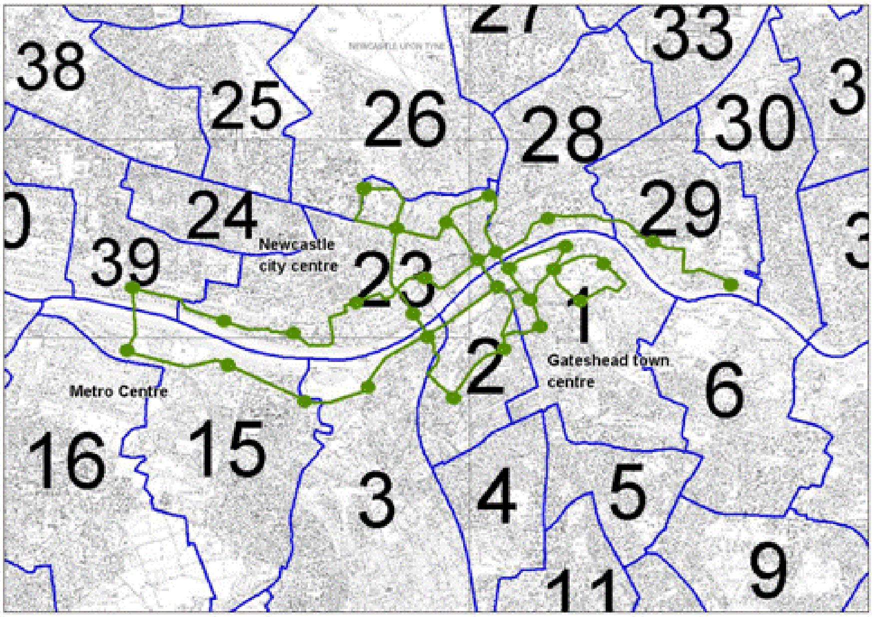

Figure 2 – Tyne and Wear PRT city centre network (in green)

High tech bus (M4)

This system is modelled as an enhancement to the existing bus system, and is assumed to replace the existing bus service on all high-tech bus corridors. Trips by high-tech bus are therefore included in the modal share for bus. The subjective value for in vehicle time is assumed to be 89% that of an existing bus trip based on stated preference surveys. The high-tech bus runs in lanes segregated from other traffic for the entire route. The headway time is assumed to be 50% that of existing bus services. The only attribute which varies by city is the location and length of routes selected: Tyne and Wear 51km, Madrid 143km, Trondheim 25km and Vienna 17km. Figure 3 shows the system modelled for Trondheim.

Scenarios modelled

Each scheme was modelled on its own, assuming a medium growth context for population growth, ageing, fuel price rises and urbanisation, and, in separate tests, a high growth context. A further set of tests in the medium growth context involved adding those complementary measures most likely to enhance the performance of the technologies; these included fare reductions of 20% and a road pricing cordon around the CBD of each city with a charge of €5 in the peak and €2 in the off-peak. The full range of tests undertaken in the project is reported in (Shepherd and Muir, 2009). The impacts of schemes were modelled over a total of 30 years, with 2005 as the base year. In all cases the new technologies were modelled as being introduced in 2010. Effects were predicted both at a city-wide level and for the local area. In the results that follow we present city-wide effects for medium and high growth and with complementary measures, and then focus on the medium growth context, without complementary measures, in presenting the local impacts.

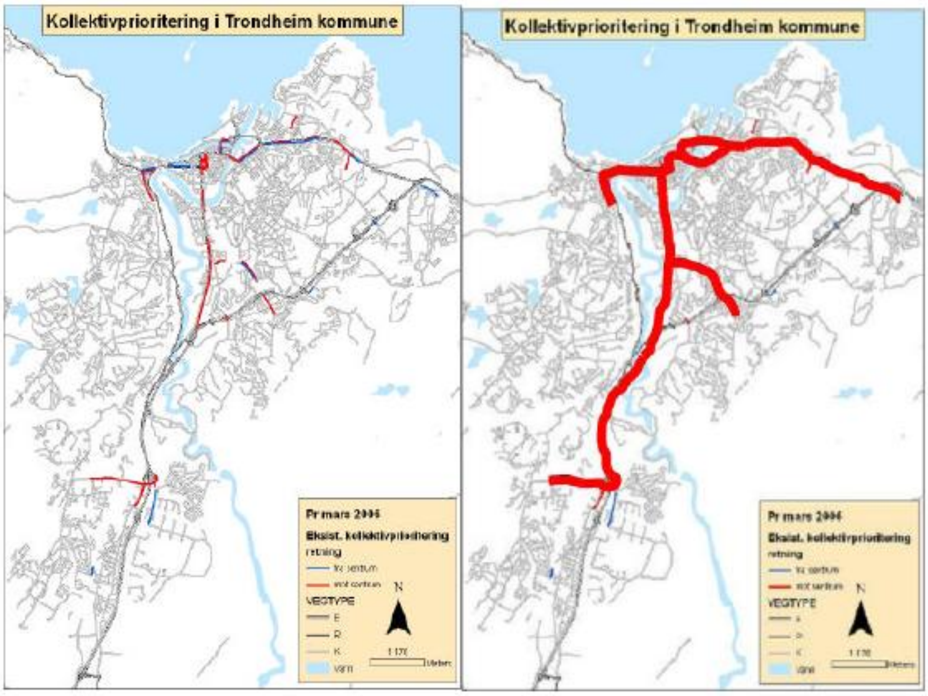

Figure 3 - Trondheim High Tech bus service

THE STRATEGIC TRANSPORT MODEL AND BUSINESS CASE TOOL

The strategic modelling of the new technologies transport schemes was undertaken using MARS (Pfaffenbichler, 2003), (Pfaffenbichler, Emberger and Shepherd, 2008), (Pfaffenbichler, Emberger and Shepherd, 2010). 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 present version of MARS is implemented in Vensim®, a System Dynamics programming environment and the model has been applied in 19 cities world-wide.

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 as shown in FIGURE 4. The sub-models are run iteratively over a 30 year time period. They are linked on the one hand by accessibility as an output of the transport model and input to the land use model, and on the other hand by the population and workplace distribution as an output of the land use model and input to the transport model.

MARS has two distinguishing characteristics that enable it to operate rapidly. Firstly it contains no detailed network, but instead represents the modes available between O-D pairs and the interaction between demand and supply for each. Secondly it assumes a constant travel budget so that if time is saved on commute trips then more time can be spent on “other” trips.

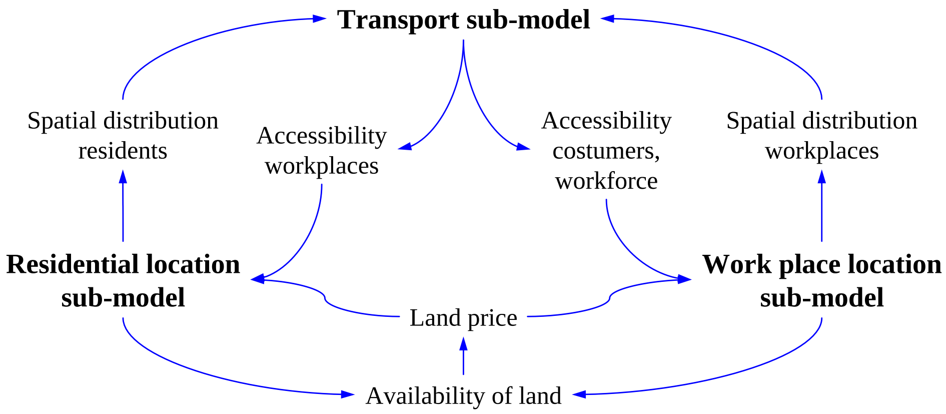

Figure 4 - Basic structure of the MARS sub-models

INCORPORATING NEW PUBLIC TRANSPORT TECHNOLOGIES

MARS models the mode choice between public transport, private car and slow modes (walking and cycling) 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 from origin
2. Average waiting time for the PT service
3. In vehicle time (OD)
4. Changing time (OD pair dependent)
5. Egress time to destination, and
6. Fare costs

Each of these parts is perceived and valued differently by the user. MARS uses perceived values derived by a previous study (Walther, Oetting and Vallée, 1997) that defines separate friction factors for the public transport modes bus, tram and rail, as well as for car. As will be seen later the use of these perceived values tended to favour schemes which reduce access/egress times over those which improve in-vehicle times. MARS makes a distinction as to whether public transport is separated from individual road traffic or not.

To include a new technology such as a PRT system, it is necessary to characterise the supply factors such as average speeds, access/egress times, headways, fares and changing times. The approach will depend on whether the new technology will be perceived as a completely new mode or as similar to an existing mode. This will determine which of the subjective valuation factors should be applied in the first instance.

We specifically chose to apply the same generic model within the four case studies so that we could evaluate the impact of the systems and their context in terms of city and existing infrastructure without worrying about differences in modelling approaches. However, some local calibration of the aggregate and OD-specific mode shares is possible by adjusting the relative subjective values between modes at the area level and for OD pairs.

The Madrid and Tyne and Wear models represent four modes: car, bus, rail and slow, with the new mode added to bus or rail as appropriate. Trondheim has no rail, and the Vienna model has a combined public transport mode.

Standard policy tests for fuel price and fare changes showed the output elasticities to be -0.1 for fuel price and -0.16 for fares which are in line with the mean value for fuel price elasticity reported in Goodwin et al (2004) and within the range for fare elasticities in urban areas, see TRL Report 593 (Balcombe, et al., 2004). The main response to the schemes was seen to be a change of mode, with very little relocation in response to the schemes tested.

A business case is the basis for the economic justification of any new scheme. The Business Case Tool (BCT) has been developed and is designed to provide a quick and simple means for assessing the economic case for a new transportation system. It is based on the results of a literature review from which a list of the relevant factors has been determined together with a preferred methodology for taking them into account. The BCT is a spreadsheet comprising a number of interlinked worksheets. When these are used in sequence, they take the user through a structured set of questions that are designed to elicit the information and data needed to build up the business cases for two alternative schemes, for example, a PRT versus a conventional bus scheme. The structure of these worksheets is described more fully in (Muir et al., 2009).

In the exercise reported here, the BCT has been applied to the MARS model outputs for the four proposed schemes in each of the four cities, under the medium growth context without complementary measures. In each case, the MARS model results have provided the length of the route, the number of stations/stops, the average fare, the peak and off-peak demand figures (passengers/hour) for a 16 hour/day operating period, the growth in demand over a 25 year period, and the number of buses needed in the HTB schemes. A sensitivity test was included to show the effects of a ‘worst case’ scenario made up from a 20% reduction in demand and a 20% increase in costs, and a ‘best case’ made up from a 20% increase in demand and a 20% decrease in costs. It should be noted that this sensitivity test was not intended to replicate the effects of the high growth or complementary measures contexts.

In order to accommodate the particular requirements of the exercise, and to facilitate cross-site comparisons, only a financial Benefit-Cost Ratio was calculated as:

$$BCR = (PVB - PVC)/PVC$$

where PVB and PVC are the Present Value of Benefits and the Present Value of Costs, on the assumptions that:

- scheme benefits derive from fare revenues only
- costs of systems are in 2008 prices
- costs and benefits are computed using a discounted cash flow analysis performed over a 30 year period starting in 2009, using a 3% discount rate
- scheme operation and fare collection starts in 2010
- generic costs, in 2008 prices are based on evidence from manufacturers and consultants.

CITY-WIDE IMPACTS

Table 5 and 6 shows changes in trips in relation to the base scheme in the year 2035. Table 5 shows the changes for the peak period and Table 6 those for the off peak trips. Changes are expressed as an index from the base values for each mode per city for each technology. In the case of Trondheim, there is no existing local rail system so the percentage change is shown for public transport as a whole. In the Vienna model, bus and rail are treated as a single mode as they are similar in terms of access times and have an integrated ticketing system. Values in bold indicate a change of greater than 2% which is deemed to be a significant change at the area wide level.

Table 5- Impacts of each technology in each city on the number of peak period trips by mode, represented as an index value where the base case, with no new technology, is 100

Tyne and Wear		**M1**	**M2**	**M3**	**M4**
	Car	99.9	99.4	99.6	99.9
	Bus	99.6	98.3	98.9	101.3
	Rail	**103.8**	**114.7**	**109.5**	99.6
	Total PT	100.7	102.6	101.7	100.9
	Slow	99.5	98.4	98.7	99.3
Madrid					
	Car	99.9	98.7	99.9	99
	Bus	99.8	98.8	99.6	111
	Rail	100.5	**107.7**	100.7	**96.2**
	Total PT	100.2	**104.2**	100.3	**102.0**
	Slow	99.7	**95.1**	99.6	98.9
Trondheim					
	Car	100.0	99.7	99.3	99.8
	Bus	100.0	**106.3**	**97.6**	**104.7**
	Rail	N/A	N/A	N/A	N/A
	Total PT	100.0	**106.3**	**114.2**	**104.7**
	Slow	100.0	98.1	**95.8**	98.6
Vienna					
	Car	99.9	99.3	99.6	99.9
	PT	100.1	100.9	100.4	100.2
	Slow	99.8	98.9	100.1	99.6

Key:
M1: City centre cybercar
M2: Cybercar feeder
M3: City centre PRT
M4: High tech bus

Table 6 - Impacts of each technology in each city on the number of off peak trips by mode, represented as an index value where the base case, with no new technology, is 100

Tyne and Wear		**M1**	**M2**	**M3**	**M4**
	Car	99.6	98.5	99.0	99.8
	Bus	98.8	**97.6**	**97.4**	101.7
	Rail	**106.7**	**112.9**	**128.0**	99.4
	Total PT	101.2	**102.3**	**106.7**	101.0
	Slow	98.3	**94.0**	**96.2**	99.0
Madrid					
	Car	99.9	98.7	99.8	99.6
	Bus	99.1	99.1	99.0	**121.6**
	Rail	**104.8**	**105.3**	**105.8**	**93.7**
	Total	101.4	101.6	101.8	**110.2**

	PT				
	Slow	99.5	**96.7**	99.5	**97.9**
Trondheim					
	Car	100.0	100.1	100.1	100.9
	Bus	100.0	100.1	**97.2**	**118.7**
	Rail	N/A	N/A	N/A	N/A
	Total PT	100.0	100.1	**170.6**	**118.7**
	Slow	100.0	100.0	**96.1**	99.6
Vienna					
	Car	100.1	100.5	99.9	100.0
	PT	101.2	**105.5**	101.3	**102.6**
	Slow	100.0	99.9	100.0	99.7

Key: M1: City centre cybercar
M2: Cybercar feeder
M3: City centre PRT
M4: High tech bus

In terms of area wide trips most changes are insignificant. This is due to the local nature of the schemes. In all cases the feeder system performs well compared to other systems. This shows the importance of reducing access times rather than reducing in-vehicle times. This is reflected in the MARS model by an exponential term on the subjective value of access/egress time compared to a linear term for in-vehicle times. The exception to this is the feeder system in Vienna which although still the best system did not produce a significant impact. This is due to the fact that most zones in Vienna are already extremely well served by an integrated public transport system and so the improvement in even the feeder zones is only marginal.

The other system which performs well in Madrid and Trondheim is the High tech bus which for Madrid impacts on 33 of the 88 zones, which goes some way to explaining the area wide impact. Similarly for Trondheim the High tech bus system covers a substantial proportion of zones.

The city centre PRT system always out-performs the city centre cybercar due to higher speeds and lower wait and access times. From the four cities only the Tyne and Wear and Trondheim PRT systems have an impact at the area wide level. Again this is explained by the number of zones covered compared to the total study area as Vienna and Madrid only implement PRT in the central zone. In Trondheim the PRT system was applied to an accessibility issue that is hard to solve with existing public transport technology, due to steep grades. For all public transport enhancements we see that the main effect is to transfer trips from competing public transport and slow modes rather than from car use. Again the feeder systems appear to be the best at reducing car use in all cities apart from Trondheim where PRT is better.

It was found that the change to a high growth context, and the addition of complementary measures, both had a largely additive effect to those of the technologies under medium growth which was independent of the type of technology (Shepherd and Muir, 2009). Tables 7 and 8 present these effects for each mode in each city.

Table 7 - Index of high growth trips to medium growth trips by mode in 2035 (medium = 100)

Peak		**Tyne and Wear**	**Madrid**	**Trondheim**	**Vienna**
	Car	107.0	107.0	105.9	108.1

	Bus	110.0	108.5	108.0	N/A
	Rail	112.6	104.3	N/A	112.4
	Slow	109.5	113.1	104.0	111.8
Off Peak					
	Car	106.9	105.1	102.9	104.7
	Bus	108.8	102.7	103.7	N/A
	Rail	107.8	101.2	N/A	105.9
	Slow	104.7	111.7	102.4	107.3

Table 8 - Index for 2035 trips per mode, in the medium growth scenarios with complementary measures (medium without measures = 100)

Peak		**Tyne and Wear**	**Madrid**	**Trondheim**	**Vienna**
	Car	98.3	97.3	98.4	94.1
	Bus	107.2	105.0	106.6	N/A
	Rail	100.6	103.6	N/A	105.8
	Slow	99.0	99.9	100.5	100.4
Off Peak					
	Car	98.8	99.3	99.0	97.2
	Bus	104.8	103.6	105.9	N/A
	Rail	100.4	104.0	N/A	105.1
	Slow	97.6	100.2	99.2	98.1

Table 7 shows the relative change in trips for each mode in 2035 in both peak and off peak for each city and mode when comparing high growth to high growth scenarios. It is noticeable that public transport and in some cases slow modes increase more than car use between medium and high growth scenarios. This is due to the higher fuel costs by 2035 and possibly due to greater congestion which affects car use and road based public transport.

Table 8 show the effect of complementary measures on the medium growth scenarios for the cities. The complementary measures were made up of a road user charging cordon and a 20% fare reduction. The effect of the complementary measures on car usage and public transport use is greater in the peak than for any of the technologies across all cities. The reduction in car usage in the peak ranges between 5.9% and 1.6% for Vienna and Trondheim respectively. While the combined effect of technologies and complementary measures was seen to be broadly additive, some synergies were found where cordon pricing reinforced the schemes (e.g. High tech bus in Madrid) but real synergies where the combined effect exceeded the sum of the individual measures were rare.

LOCAL IMPACTS

Cybercar city centre system (M1)

Table 9 shows the index for changes in trips in the peak within the implementation area when a cybercar feeder scheme (M1) is implemented in the city centre. First we notice that the Trondheim scheme has no impact even at the local level. This is due to the very small nature of the scheme. The inner city of Trondheim is quite small; the diameter for the inner city is just above 1km. The cybercar inner city scheme was set up to serve the zones just outside the city centre. One challenge here is that the zones surrounding the city centre have quite a good bus offering. All major bus routes either go into the city centre or pass through it. This gives the zones just outside the city centre quite high bus frequencies. The introduction of the cybercar system had very little effect in the inner city application. This is not unexpected as distances are short, bus frequencies are high, and walking is a very viable option.

For Tyne and Wear, Madrid and Vienna the reductions in car use are of similar magnitude and in all cases there is a reduction in competing public transport and slow mode use. The large increase for rail mode in Tyne and Wear can be explained by the fact that the cybercar network is implemented as an enhancement to rail and as the scheme is implemented through five central zones it adds new connections – which now count as rail.

Table 9 - Index of 2010 peak trips following cybercar city centre introduction (2005 = 100)

2010 peak	**Tyne and Wear**	**Madrid**	**Trondheim**	**Vienna**
Car	97.9	98.6	100.0	99.7
Bus	93.6	97.1	100.0	N/A
Rail	184.3	104.5	N/A	102.3
Total PT	124.5	101.6	100.0	102.3
Slow	95.6	92.2	100.0	98.7

Table 10 shows the resulting Business Case Tool results.

Table 10 - City centre cybercar Business Case Tool results

	Tyne and Wear	**Madrid**	**Vienna**
Capital costs (€M)	29.3	190	9.8
Base year op costs (€M)	2.9	22.8	1.4
PV cost (€M)	88	649	37.5
Base year benefits €M)	15.8	55.2	0.75
PV benefit (€M)	316	968	14.5
Business BCR	**2.58**	**0.49**	**-0.61**
BCR Sensitivity analysis:			
-20% demand, + 20% cost	1.67	0.25	-0.74
+20% demand, -20% cost	3.85	0.83	-0.42

Trondheim was not included as the system seemed to have no effect. It can be seen that the schemes differ substantially in size. That in Madrid has many more vehicles, and Vienna has far fewer vehicles. The Gateshead system was modelled as an addition to the relatively minor existing rail system, and thus had a major effect, with an 84% increase which contributed to the large positive BCR.

Cybercar feeder system

Table 11 shows the index for changes in trips in the peak within the implementation area when a cybercar feeder scheme is implemented in a number of suburban zones in each city. With the exception of Trondheim, where the scheme feeds the bus service, all schemes feed tram, light rail or rail systems. Cybercar trips are included within the rail mode, except in Trondheim, where they are added to the bus mode.

Table 11 - Index of 2010 peak trips following cybercar feeder introduction (2005 = 100)

2010 peak	**Tyne and Wear**	**Madrid**	**Trondheim**	**Vienna**
Car	91.7	91.9	99.6	98.1
Bus	74.2	88.1	111.7	N/A
Rail	290.6	149.6	N/A	103.8
Total PT	111.8	129.7	111.7	103.8
Slow	78.3	55.1	97.4	95.5

Both the Tyne and Wear and Madrid feeder systems have a significant impact in terms of reducing car use on their respective public transport corridors. For Tyne and Wear this is due to the relatively large reduction in access/egress times; for Madrid the results are due to improved access but also because the system is developed in high growth areas. However it should be noted that within the feeder zones there is also a high transfer from bus and from slow modes. The high increase in rail share for Tyne and Wear is explained by the relatively low mode share in the base.

For Trondheim and Vienna the impacts are more modest. In Trondheim the bus services which are fed have relatively low patronage. In Vienna the high level of service for public transport makes it difficult to find zones with poor access. In summary the feeder system works well in Tyne and Wear and Madrid where initial access times were poor and there was an opportunity to link to a good main line service.

Table 12 shows the resulting Business Case Tool results.

Table 12 - Cybercar feeder scheme Business Case Tool results

	Tyne and Wear	**Madrid**	**Trondheim**	**Vienna**
Capital costs (€M)	34.6	195	17.2	94.6
Base year op costs (€M)	3.3	17	1.8	6.4
PV cost (€M)	102	539	53.6	224
Base year benefits €M)	16.8	33.1	0.45	4.05
PV benefit (€M)	354	743	9.4	78.8
Business BCR	**2.48**	**0.38**	**-0.82**	**-0.65**
BCR Sensitivity analysis:				
-20% demand, + 20% cost	1.6	0.08	-0.88	-0.75
+20% demand, -20% cost	3.66	0.81	-0.74	-0.5

It can be seen that the schemes differ substantially in size and patronage. That in Madrid has many more vehicles, reflecting the size of the area covered. Vienna, despite its size, has far fewer vehicles, while the Trondheim system is too small to be viable.

The Tyne and Wear system produces a very respectable BCR suggesting the fare revenues should substantially cover the costs. The Madrid system has a small positive BCR, while those for Trondheim and Vienna are negative. The low fares in Vienna make it difficult to make a financial case for the scheme. Further tests showed that a fare of around €2 would provide a better than break even case in Vienna.

PRT system

Table 13 shows the index for changes in trips in the peak within the implementation area when a PRT scheme is implemented in each city. Vienna and Madrid are contained within large central zones but act as feeders to the main transport systems. The Tyne and Wear PRT network covers a few central zones and acts as a feeder to rail/METRO and also as a stand-alone system. PRT trips are included within the rail mode, except in Trondheim, where they are added to the bus mode.

Table 13 - Index of 2010 peak trips following PRT introduction (2005 = 100)

2010 peak	**Tyne and Wear**	**Madrid**	**Trondheim**	**Vienna**
Car	95.8	98.3	98.7	91.9
Bus	88.9	96.4	95.4	N/A
Rail	258.8	106.6	N/A	102.7
Total PT	146.9	102.6	126.1	102.7
Slow	91.4	90.6	92.5	99.8

The Tyne and Wear and Vienna schemes have a significant impact on car use. It should be noted however that the Vienna scheme also included some additional measures to remove cars from the central zone in order to reallocate capacity for the PRT track. Cars were effectively restricted to the use of ring-roads within the zone and only allowed to park at certain parking locations. For Madrid and Trondheim reductions in car use are smaller. Except in Vienna there is a notable reduction in bus and slow mode trips. The significant reduction in slow mode trips is due to the new opportunities to replace short within zone walk trips with short PRT trips. This should be taken into account when considering the design of such systems.

Table 14 shows the resulting Business Case Tool results.

Table 14 - PRT scheme Business Case Tool results

	Tyne and Wear	**Madrid**	**Trondheim**	**Vienna**
Capital costs (€M)	123	351	75.4	47.7
Base year op costs (€M)	6.9	25.8	2.7	2.3
PV cost (€M)	263	872	130	95

Base year benefits €M)	54.6	57.2	20.1	0.96
PV benefit (€M)	1062	1001	429	18.5
Business BCR	**3.04**	**0.15**	**2.3**	**-0.81**
BCR Sensitivity analysis:				
-20% demand, + 20% cost	2	-0.11	1.24	-0.86
+20% demand, -20% cost	4.51	0.51	3.83	-0.72

The schemes differ substantially in size and patronage. That in Madrid has many more vehicles, reflecting the size of the area covered. The Tyne and Wear scheme also justifies a substantial vehicle fleet, resulting from its success in attracting patronage from all other modes. The Trondheim and Vienna schemes are much smaller.

The Tyne and Wear and Trondheim systems produce very respectable BCRs suggesting the fare revenues should substantially cover the costs. The Madrid system has a small positive BCR, but is susceptible to becoming negative under certain assumptions, while that for Vienna is negative. The low fares in Vienna make it difficult to make a financial case for the scheme.

High Tech Bus

Table 15 shows the index for changes in trips in the peak within the implementation area when a High Tech Bus scheme is implemented on a number of corridors in each city.

Table 15 - Index of 2010 peak trips following High Tech Bus introduction (2005 = 100)

2010 peak	**Tyne and Wear**	**Madrid**	**Trondheim**	**Vienna**
Car	99.3	98.4	99.7	99.4
Bus	145.2	126.4	106.1	101
Rail	97.9	94.8	N/A	N/A
Total PT	128.4	105.8	106.1	101
Slow	96.3	97.8	98.3	98.4

These High Tech Bus schemes have little impact on car use in any of the four cities. Impacts on the slow modes are also typically small, as might be expected for longer distance services. The main impact is to transfer trips between public transport services.

Table 16 shows the resulting Business Case Tool results.

Table 16 - Assumed characteristics of the high-tech bus schemes and BCT results

	Tyne and Wear	**Madrid**	**Trondheim**	**Vienna**
Capital costs (€M)	453	3622	255	381
Base year op costs (€M)	9,9	481	9,9	20,4
PV cost (€M)	652	13329	455	792

Base year benefits €M)	27,9	443	38,5	1,56
PV benefit (€M)	549	7813	783	30,1
Business BCR	**-0,16**	**-0,41**	**0,72**	**-0,96**
BCR Sensitivity analysis:				
-20% demand, + 20% cost	-0,4	-0,52	0,28	-0,97
+20% demand, -20% cost	0,19	-0,25	1,33	-0,95

The Madrid scheme is very much larger than the others, reflecting the route length and the intensity of demand in the chosen corridors. Only Trondheim generates a positive BCR, and even this is small.

COMMENTARY

Whilst every attempt was made to ensure comparability of scheme design and model implementation between cities, this was not always feasible. Scheme designs were adjusted to local circumstances, for example speeds were lower in the dense streets of the centre of Madrid for cyber cars; cyber car and PRT coverage was allowed to differ in Trondheim and the relative scale of schemes was by definition difficult to control across cities. In addition to this there were differences in the basic MARS models. Madrid and Tyne and Wear have four modes modelled including separate rail/Metro and bus. Trondheim had no significant rail mode and so PRT could be modelled as a new mode rather than as an enhancement to existing modes. Finally for Vienna which has an integrated public transport system with high service levels a combined public transport mode with integrated tickets was modelled. Despite these differences we can draw some general and some more city specific conclusions from this cross comparison of the schemes.

Most schemes have little impact on area wide indicators in the peak. Those which do are the cybercar feeder schemes in Tyne and Wear, Madrid and Trondheim, PRT in Tyne and Wear and Trondheim and High Tech bus in Madrid and Trondheim. The feeder systems have an impact due to the relatively large reduction in access/egress times which is valued with an exponentially increasing subjective value in the MARS model. The Vienna feeder system does not have such a large impact as the initial service levels and access/egress times are already very good in Vienna.

None of the technologies reverses the declining share of public transport or increasing car use over time. These trends continue and other measures will be required to break them. The high growth scenarios resulted in similar relative changes in trips and mode shares. Thus the higher population scenarios only affect the absolute numbers travelling by the new technologies, which of course may be vital when considering the financial viability of the system.

The complementary measures tested consisted of a road user charging cordon and a 20% reduction in public transport fares. In all four cities and applications, these had a greater impact on reducing overall car use than did the technologies themselves. This is not so surprising given the area wide coverage of the fare schemes compared to the localised nature of the technologies. Although the complementary measures reinforced the mode shift for the technologies, evidence of true synergy was hard to find. One case where synergy was detected was for the High Tech Bus scheme in Madrid.

The local impacts were as expected more significant as described above. Rather than summarise by technology here we summarise the implications for each city in turn.

For **Tyne and Wear** the most successful scheme is the feeder scheme which was explained by the reduction in access times. The PRT system is next best and out-performs the cyber car in the city centre due to lower access and wait times. The high tech bus is successful along the selected corridors but does not have an impact at the study area level. It should be noted that all public transport schemes reduce the share of slow modes which may not contribute to sustainability.

For **Madrid** the best schemes are those which tackle the suburban zones where there was previously a lower level of public transport service which had resulted in a growth in car use in these areas. Thus it is not surprising that the High Tech Bus and feeder schemes in the growth areas perform best.

For **Trondheim** implementation of a PRT system results in the largest changes in the mode share. The PRT system establishes a new link from residential areas to work areas which historically have had poor connections. In the peak the PRT system has a significant impact. Bus passengers mainly move to the PRT system. In the off peak there is a reduction in car usage and slow modes and a resulting increase in the PRT share. Other systems have little impact in Trondheim.

For **Vienna** the introduction of cyber car as a feeder system results in the greatest increase in PT share in both the peak and off peak though this is limited compared to other cities. The greatest decrease in car share also results from the introduction of cyber car as a feeder system. Vienna has a well developed dense public transport network with high levels of service. Hence it was expected that the effect of the new technologies would be limited.

In general, feeder systems will have a significant impact when implemented in zones with initially poor access/egress to main line public transport. PRT will out-perform the use of cyber cars in central areas due to lower access and wait times but these systems will no doubt have higher barriers both financially and culturally to overcome compared to cyber cars which will be cheaper and less intrusive. High Tech bus systems rely on quality, comfort and segregation from other traffic to increase patronage and have been seen to be successful when implemented along corridors with previously lower levels of service from public transport.

CONCLUSIONS

Several new automated technologies for urban passenger transport are now being developed and tested as small scale demonstrations. However, it is likely to be some considerable time before cities are willing to take the risk of being the first to implement full scale applications. In the meantime, predictive modelling offers the most dependable way of assessing the likely contributions of such technologies to urban transport policy.

In this paper, we have presented some results from a comparative study of three technologies as used in three applications in four European cities. The study has used a common modelling and appraisal framework, building on assumptions described fully in an earlier paper (Muir et al., 2009). While the common framework will have avoided some of the differences which arise when trying to compare predictive results in different cities, it is important to bear in mind that the schemes tested are those which were agreed with the city authorities in each case study, and may well not represent the optimal application of a given technology. Moreover, lack of space has precluded the presentation of results for these technologies when combined with other policy instruments or tested in the context of high economic growth. These fuller results are available in (Shepherd and Muir, 2009). Bearing in mind these caveats, a number of conclusions can be drawn from the results presented above.

The impacts of all the technologies tested arise principally in terms of modal change; relocation impacts were typically small. Even so, the impact of many of the schemes on car use, even within the areas in which they are applied, are modest. Those in Trondheim, a small city where walking and travelling by bus are attractive, and in Vienna, which has a well developed public transport network and low fares, are particularly small. Moreover, the new technologies will extract patronage from conventional public transport and from walking and cycling as well as from the car, and this needs to be borne in mind in considering their contribution to sustainability.

Despite this rather negative overview, some applications have proved more successful in influencing car modal shares in some cities. On this criterion, the cybercar feeder service in Madrid and Tyne and Wear and the city centre PRT scheme in Vienna and Tyne and Wear were particularly effective, although it should be noted that the Vienna application of PRT included some reduction in road capacity to accommodate the segregated track. The city centre cybercar in Madrid and Tyne and Wear (not presented in detail in this paper), the cybercar feeder in Vienna, the city centre PRT in Madrid and Trondheim, and the High Tech Bus in Madrid also had a useful impact on car use.

This paper has only presented a financial benefit cost ratio (BCR). Even so, many of the tested schemes have generated positive BCR values. In the case of the city centre cybercar, cybercar feeder and city centre PRT in Tyne and Wear and the city centre PRT in Trondheim, the present cost of revenues was more than double the present value of costs, reflecting the high fares in both cities, and the substantial cost savings accruing from the use of driverless systems. Conversely, no scheme in Vienna, which has a particularly low fare regime, generated a positive BCR.

Overall, the city centre PRT system and the cybercar feeder system performed best in terms of impacts on car use and financial return. The success of PRT can be attributed to its high operating speed and the avoidance of waiting time. The success of the feeder systems arises from the improved access time to high speed modes, and improvements in their patronage. As mentioned previously this is partly because access time carries with it a higher value of time than in-vehicle time and so any scheme which reduces access time is expected to perform well. It may well be that a PRT system applied to these feeder services would have proved even more effective. The principal messages from this study are that new technologies do have a role to play in an urban transport strategy, both because they can attract users from the car and because they offer a much lower cost means of operating public transport services. However, they are clearly not a panacea. Rather, they will have a role to play in certain niche markets in a city, and those niches will differ from city to city.

The next and most important step in their development will be the funding and facilitation of a full scale trial, which will help cities to assess the risks which they will be taking in pursuing such technologies, and enable the public and business to gain objective experience of their performance. The results of this study help indicate the types of context in which such trials might take place. Feeder services to conventional high speed public transport routes, using cybercar or PRT, in cities with high fare regimes and in areas with relatively poor levels of public transport service, offer a particularly promising test bed.

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REFERENCES

2getthere (2011) Sustainable Mobility Solutions - Rivium GRT application. http://www.new.2getthere.eu/?page_id=12. Accesses 17th July 2011

Balcombe, R., Mackett, R., Paulley, N., Preston, J., Shires, J., Titheridge, H., Wardman, M. and White, P. (2004) The Demand for Public Transport: A Practical Guide, TRL Report 593, Transport Research Laboratory

van Dijke, J. P. (2008) CityMobil, Advanced Transport for the Urban Environment. TRA Conference proceedings, Ljubljana, April 2008.

Goodwin, P. Dargay, J. and Hanly, M.(2004) Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review, *Transport Reviews*, 24: 3, 275 — 292

Haken, H. (1983). *Advanced Synergetics - Instability Hierarchies of Self-Organizing Systems and Devices*, Springer-Verlag.

Langdon, M. G. (1977) A comparative cost/benefit assessment of Minitram and other urban transport systems. LR 747. Crowthorne, TRL.

Muir, H., Jeffery, D., May, A. D., Tripodi, A., Shepherd, S. & Vaa, T. (2009) Assessing the contribution and feasibility of a city wide personal rapid transit system. *Transportation Research Record* 2110 (1), pp163-170

Pfaffenbichler, P., Emberger, G. and Shepherd, S.P. (2010): A system dynamics approach to land use transport interaction modelling: the strategic model MARS and its application. *System Dynamics Review* vol 26, No 3: 262–282

Pfaffenbichler, P., Emberger, G. and Shepherd, S.P. (2008): The Integrated Dynamic Land Use And Transport Model MARS. *Networks and Spatial Economics* Volume 8 Numbers 2-3 pp 183-200

Pfaffenbichler, P. (2003). The strategic, dynamic and integrated urban land use and transport model MARS (Metropolitan Activity Relocation Simulator) - Development, testing and application, Beiträge zu einer ökologisch und sozial verträglichen Verkehrsplanung Nr. 1/2003, Vienna University of Technology, Vienna.

Shepherd, S. P. and Muir, H. (2009) City Mobil: Deliverable 2.3.2 Strategic Modelling Results. Summary of results across four cities. www.citymobil-project.eu

Sterman, J. D. (2000). *Business Dynamics - Systems Thinking and Modelling for a Complex World*, McGraw-Hill Higher Education.

ULTra PRT (2011) ULTra Personal Rapid Transit System. http://www.ultraprt.com/prt/. Accessed 17th July 2011

Walther, K., Oetting, A., and Vallée, D. (1997). Simultane Modellstruktur für die Personenverkehrsplanung auf der Basis eines neuen Verkehrswiderstands, Aachen